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Accelerating bus fleet electrification

Key aspects for overnight
and opportunity charging

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Public transportation is becoming more sustainable and innovative. Ambitious electrification targets for bus fleets disrupt the business as usual for all stakeholders. This white paper supports decision makers from local governments, bus operators, public infrastructure providers and original equipment manufacturers in finding the right charging infrastructure to fulfill their project needs.



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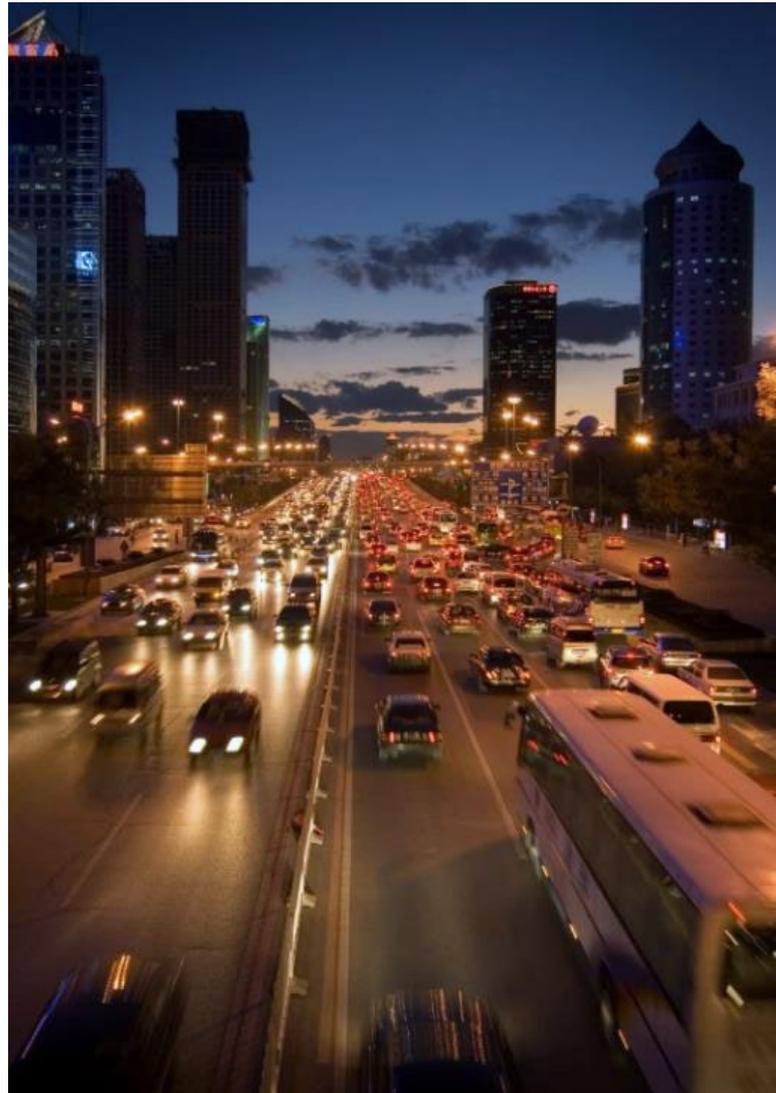
Introduction

The market requires individual solutions

Governmental support for electric mobility, the need to reduce emissions, and advancements in technology are driving worldwide eBus fleet growth. Public transport operators (PTOs), city managers and original equipment manufacturers (OEMs) must now take action to ensure a smooth transition towards clean and affordable transport choices. Finding the right charging strategy will be a key success factor but poses several challenges for decision makers.

A one-fits-all solution does not exist. Cities differ not only in their transport demand but also in structural conditions and financial capabilities. Two charging pathways have proven to be most promising – each serving different needs: overnight charging and opportunity charging.

This white paper provides support for city administrations, PTOs, and OEMs to identify which charging concept is most favorable based on individual requirements. It covers a comparison of overnight charging and opportunity charging for buses, their capabilities, advantages and limitations from a system's perspective.



“Overnight and opportunity charging will play a major role in future electric bus fleets.”

Prof. Dietmar Göhlich, TU Berlin

Drivers and Trends

Government

Legal regulations and funding initiatives boost the electrification of buses all over the world. In the EU, new minimum procurement targets require 27-45% electric buses in public tenders starting mids of 2021 [1]. With the Berlin Mobility Act [2], the city already decided to ban all conventional public buses until 2030.

The Chinese government invested \$1 billion dollars in 2016 to successfully electrify Shenzhen’s entire bus fleet of 16,000 vehicles. A project of this size has caused quite a stir internationally. Today, 10% of all municipal buses in China are electric [3].

To support clean public transport in the US, \$300 million have been provided since 2016 to states and local governments [4]. In 2019, funding for a total of 52 projects in 41 states was granted (\$85 million).

International initiatives such as C40 cities also continue to drive market growth for electric buses. 35 cities (Paris, London, Los Angeles, Copenhagen, and others) committed to only purchase zero-emission buses from 2025 by signing the Fossil Fuel Free Streets Declaration [5].

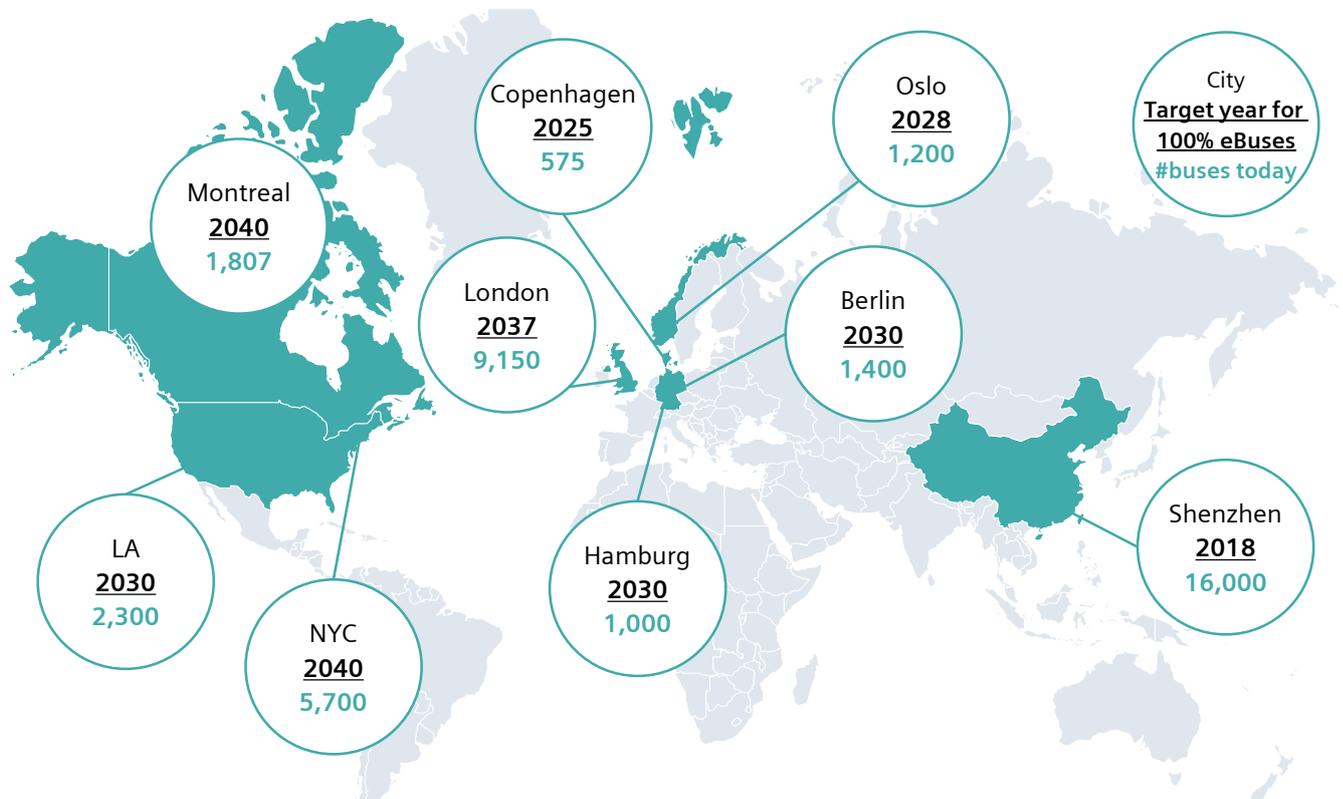


Figure 1: Selection of electrification targets worldwide. Number of buses reflects today’s fleet size.

Drivers and Trends

Public transport operators (PTOs)

Municipal PTOs were among the first actors to anticipate a growing interest in eBuses. Prototypes have been tested early, which helped them to be prepared for the upcoming mass rollout. Many cities worldwide have already defined targets to electrify their public bus fleets. Operators must now develop strategies to accelerate this shift.

Electrification goals range from Copenhagen in 2025 (total of 575 buses) to Berlin in 2030 (total of 1,400 buses) and New York City in 2040 (total of 5,700 buses). A selection of cities with a 100% bus electrification goal is shown in Figure 1.

Original equipment manufactures (OEMs)

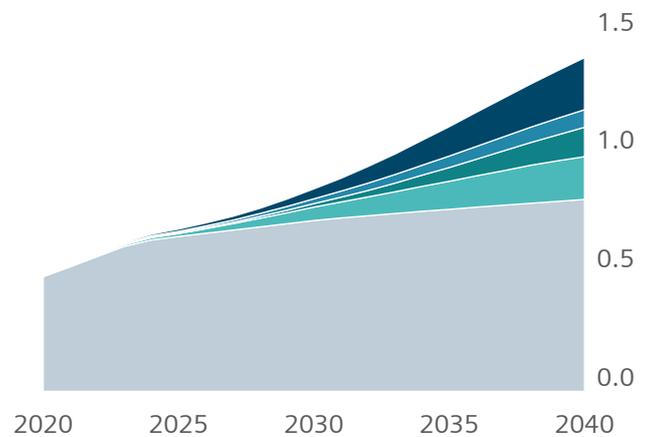
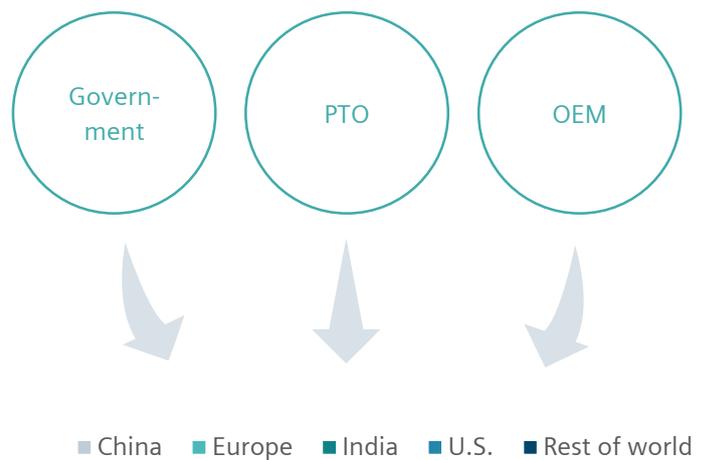
The major share of the global eBus market is held by a few key players in China (e.g., BYD, Yutong). The rest is fragmented among all other manufacturers, including Solaris, Volvo and EvoBus [6]. OEMs are still having challenges responding to a rising order intake. To drive forward the electrification urgently demanded by governments and PTOs, OEMs must now rapidly expand their business.

Huge growth potential for charging infrastructure

Fleet sizes of eBuses goes hand in hand with an increasing demand in charging infrastructure. The European bus charging station market is expected to increase at a compound annual growth rate (CAGR) of 22% in the forecasting period 2019 to 2025 [7]. By the end of 2025, revenues of approx. \$700 million may be generated in Europe alone [8].

The biggest share can be allocated to the two charging concepts discussed in this white paper:

- Overnight charging and
- Opportunity charging



Source: BloombergNEF "Electric vehicle outlook 2019" [9]

Figure 2: Global municipal eBus fleet (in million vehicles) and relevant stakeholders driving development.

Info box

Lower total costs of ownership, noise reduction as well as reduced downtime will further drive the development of eBuses. Industrial policy considerations such as local job creation potentials in new businesses will probably be an important factor impacting future funding decisions.

MindSphere

Serving Different Operational Needs of a Transport Provider

Range versus resilience to traffic conditions

Transport operators face an enormous paradigm shift. The electrification of entire fleets is associated with major challenges. Overcoming them requires removing existing obstacles in diesel bus operations first, before the additional dependencies of the fleet electrification increase complexity.

The decision on a charging strategy plays a central role. Overnight and opportunity charging both have their justification, as **Simone Torzynski** from Berlin's PTO BVG explains [10]. It is important to base the decision on operational conditions – these are different for every transport provider.

While overnight charging is exclusively charging in depots, opportunity charging buses also get power along the route. **Andreas Laske**, Senior sales manager eBus infrastructure for Germany at *Siemens*, states that both approaches have different advantages and disadvantages. They each perform well in different conditions [11]. These properties need to be included in operational, economic and environmental considerations [12].

Buses designed for opportunity charging, for example, have a smaller battery than buses designed for overnight charging only. This is why opportunity charging buses can carry more passengers. They have a higher range if operated properly and avoid large grid connections in depots.

However, opportunity buses depend on access and time at terminal stations, thus being more sensitive to incidents en route such as road blockings and unforeseeable delays (Figure 3).

The provider's point of view

Together with experts from the TU Berlin, parameters were identified that reflect a PTO's individual situation. These parameters can be taken to estimate whether to focus on overnight charging or on opportunity charging for a specific situation.

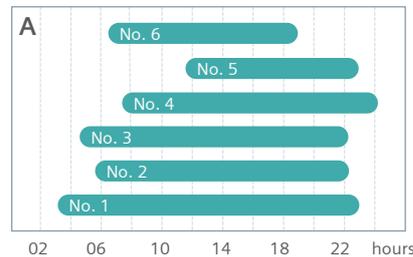


Figure 3:

Properties of overnight charging and opportunity charging are often opposite.

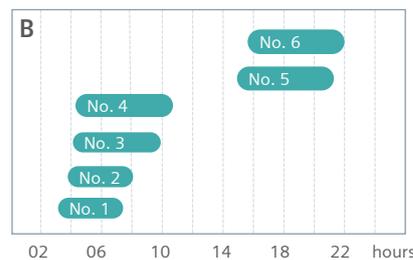


Figure 4:

Two bus lines with six circulations. Line A (top) would be suited for opportunity charging. Line B (bottom) would be suited for overnight charging.

	Overnight	Opportunity
Vehicle weight	↑	↓
Limited grid connection at depot	↑	↓
Resilience to traffic conditions	↑	↓
Range	↓	↑
Passenger capacity	↓	↑

A first hint can already be provided by looking at circulation plans (Figure 4). Many long circulations are often in favor of opportunity charging while short ones such as for student traffic can be operated by overnight charging.

Serving Different Operational Needs of a Transport Provider

The five characteristics

Five characteristic parameters should be considered when deciding on a charging strategy (Figure 5). Each one indicating whether to focus on overnight charging or opportunity charging. All figures are estimated based on expert interviews and simulation results. They are representative for the following conditions:

- Depot connection capacity is 10 MW
- Buses are standard 12 m eBuses
- One way travel distance of 1 bus is 10 km

(1) Length of bus rounds: To date, the typical range of an eBus is approx. 150 km. This is much less than an average bus round. Serving a round that exceeds this limit would not be feasible with overnight charging buses.

(2) Turning time: Opportunity charging buses require a certain amount of charging time along the route. At least 5 min should be available at the terminal station.

(3) Delays: Irregularities heavily impact available turning and charging time, respectively. PTOs that face severe delays

would be better advised to focus on overnight charging buses or change their operation routine.

(4) Connection capacity at terminal station: Modern high power charging stations (pantographs) usually operate from 300 kW to 600 kW (minimum 150 kW). This capacity is needed to sufficiently charge at low turning times.

(5) Depot bus capacity: Approx. 150 overnight buses can be supported at a depot with a load management system. Otherwise costs would increase drastically due to the need for a high voltage grid connection. Additionally spatial and construction restrictions may apply to depots especially when located in the city center.

The aim here is to make statements as generally valid as possible. An actual strategic decision has to be made based on specific simulations. A combination of both overnight and opportunity charging will most likely be the best solution for all depots and many lines as well.



Figure 5: Five characteristic parameters of a transport provider to decide whether to focus on overnight or opportunity charging.

Technical Fact Sheet: Overnight Charging



Description

eBuses operate from depots, just like diesel buses. When on the route, vehicles have very similar operational requirements as diesel buses, except for range limitations. They charge at night and may return to depot for charging once again during daytime. There is commonly a 1:1 ratio of buses to charging points (number of actual chargers can be lower).

Characteristics infrastructure

Bus depot

Grid connection medium voltage (10-12 MW)

Transformer (low voltage level 1.6 MW)

Distribution box (for 10 chargers)

DC charging station (80-150 kW)

Centralized/decentralized

Connector:

Front end based plug

Carport-based hanging plug / pull-up plug

Underfloor pull-up plug

Top-down pantograph

Bottom-up pantograph

Depot load-/charging management system

Disposition system

Optional: Battery storage for peak load

Characteristics Buses

- Large batteries with low C-rate
- Commonly 12 m buses

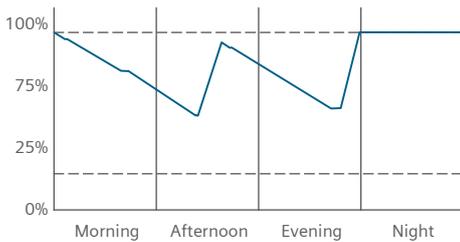


Figure 6:

Day profile of the state of charge (soc) of an overnight charging bus

The supporting infrastructure is therefore in one location. There is a larger variety of options to provide charging infrastructure and adapt it to local conditions of existing depots and operational requirements. These range from centralized to decentralized power electronics, ground or roof based and a large variety of vehicle connectors [13].



Technical Fact Sheet: Opportunity charging



Description

Buses run on lines that are equipped with opportunity chargers at one or both terminal stations only. Buses commonly connect to chargers via a pantograph in a few seconds when parked under the charger. There is no range limitation if operated with sufficient waiting times at terminus (commonly 5-10 minutes). They therefore draw the majority of their power on the route with a charger to bus ratio of approximately 1:5 to 1:7.

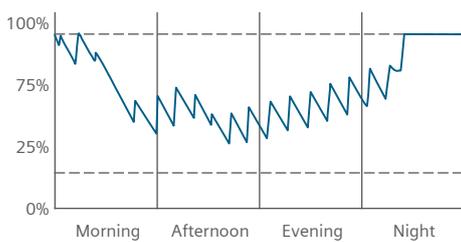


Figure 7:
Day profile of the state of charge (soc) of an opportunity charging bus

Chargers in depots are necessary for battery balancing and for preconditioning of the battery and the cabin shortly before service. Bus to depot charging point ratio is currently 1:1. In the future, bus to charging inverter ratios can be expected to drop to 2:1 or even 3:1 with operations maturing over time [11][17].

Characteristics infrastructure

En route

Grid connection (existing LV or MV connection)

DC charging station (commonly 300-450 kW)
Top-down pantograph
Bottom-up pantograph

Bus depot

Grid connection as for conventional overnight charging, but may be of smaller capacity

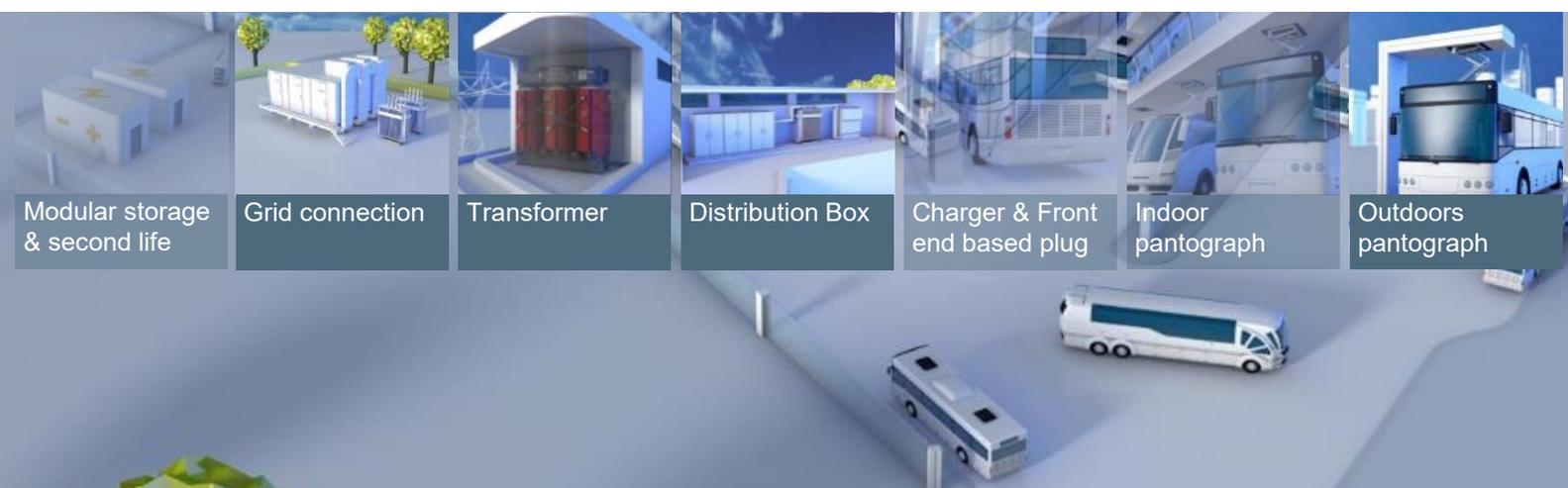
1:1 Low power DC charging station for balancing and conditioning (commonly 30-80 kW)
Plug-in connector or others

Depot load-/charging management system

Optional: 1:50-1:100 short-term high power pantograph chargers (300-600kW); AC chargers possible if onboard chargers on buses; Battery storage for peak load

Characteristics Buses

- Smaller batteries with high C-rate
- Commonly 12 m and 18 m/articulated buses



Key Operational Advantages

Bus electrification

Apart from lower emissions and a more comfortable riding experience, the electrification of buses has several operational advantages over diesel and other alternative drive trains:

- Lower fuel cost due to highest well to wheel efficiency
- Less mechanical maintenance due to fewer rotating parts and less mechanical braking
- Increased lifetime (less wear and vibrations), compared to 10-12 years for diesel buses [10].

For these advantages to facilitate in an actual increase in service quality or even cost savings [18], a smart operational setup and a best fit charging infrastructure is inevitable. Available charging time at depots or terminal stations and power availability in depots has to be managed to avoid additional demand for bus drivers, vehicles and space in depots.

Core preconditions for successful electrification:

- Good operational procedures and infrastructure such as dedicated bus lanes pay off. Delays or pile ups of vehicles at terminal stations result in range issues if not addressed (see the example simulation **Case study: delays**). During electrification, such insufficiencies have to be compensated by additional vehicles, space in depots and therefore costs. [10]
- The PTO has to accept that the diesel based circulation plans do not work for efficient electrification. Lines and depots need to be analyzed. New circulation plans need to be developed in an iterative process, matching different charging options with conditions on bus lines and in depots. [10][15]
- Additional funding

Case study: delays

Results of electric bus schedule planning and simulation for a real-world bus line. Created with eFLIPS [14] at MPM, TU Berlin.

Assumptions:

- Metro bus line with 18 m buses
- 10.5 km line length
- 6 minutes at terminal station
- Variable delay at terminal station from operator's records

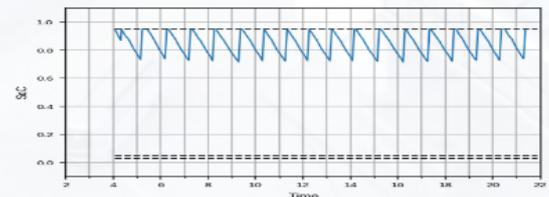


Figure 8: State of charge of a bus over the course of the day. Circulation plan optimized for no delays and full charge, run **without delays**.

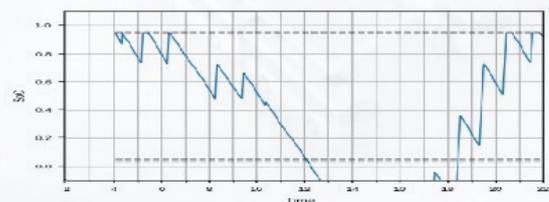


Figure 9: State of charge of a bus running the same circulation plan **with delay**. Bus runs **out of power** before 1pm.

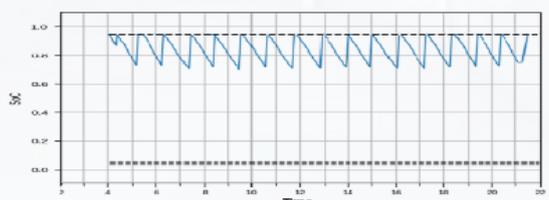


Figure 10: State of charge of a bus **with the same delay** as in figure 9, but with **adapted circulation plan** (one run less).

Delays have to be considered when preparing circulation plans to guarantee service quality.



Key Operational Advantages

Overnight Charging

Buses operating as overnight chargers currently cover the larger market share of all bus electrification projects. They have their core advantages for bus lines with short circulation plans and terminal stations close to the depot, small depots without severe grid limits, partial electrification of fleets, small buses (12 m) and routes with frequent incidents, limiting access to or time at terminal station.

Key advantages:

- Not depending on availability of opportunity chargers at terminal stations
- Infrastructure only in depots on private property (flexible routing)
- Less prone to traffic delays
- Larger availability of vehicles
- More manufacturers for charging infrastructure

Opportunity Charging

has a smaller market share. It has its core advantages for bus lines with long circulation plans, large depots with grid limits, a high share of eBuses in the fleet, large buses (≥ 12 m) and bus lines with few disruptions.

Key advantages:

- Higher range or even 24/7-service possible (see **Case study: possible eBus shares**)
- Grid relief at depot due to lower power demand at night and around noon. Drawing power distributed over the city in many locations makes use of existing grid capacities.
 - Complexity in depots is reduced
 - Less demand for complex charging management and disposition systems [10]
 - Saving high voltage (HV) grid connection in depots larger 150 buses (12 m). An HV grid connection is an eight digit € investment per depot [11]
- Higher passenger capacity buses due to a small battery
- Fewer empty runs from and to depots

Case study: possible eBus shares

The study [23] analyzes to what degree overnight- and opportunity charging can electrify the existing (diesel bus) circulation plans in Berlin. Evaluation criteria is for:

Evaluation criteria is for:

- Overnight charging:
 - range \geq length circulation plan
- Opportunity charging:
 - turning time \geq full charge time

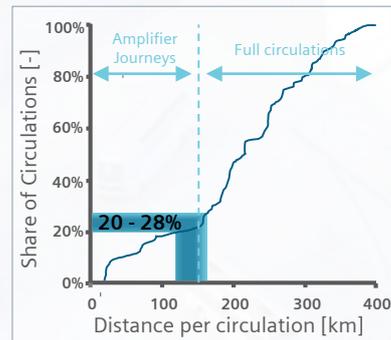


Figure 11:
Overnight charging: 18-28% of the current circulation plans can be electrified without adaptation (worst case assumptions)

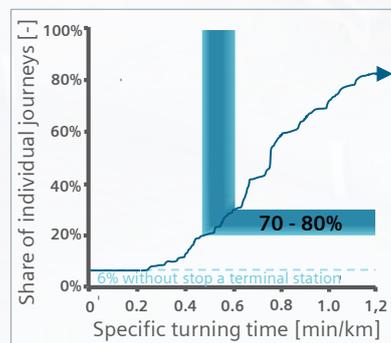


Figure 12:
Opportunity charging: 70-80% of the current circulation plans can be electrified without adaptation (worst case assumptions)

The results are indicative since circulation plans are adapted for major electrification projects. But they provide insight as to what degree each option results in operational changes or additional resource demand.

Key Economic Advantages

The break even point

Costs for bus fleet electrification are influenced by several factors. General statements should therefore be used with caution. Capital costs are mostly driven by the buses itself and the necessary charging infrastructure. Operating costs are driven by electricity prices and maintenance expenses [17], if well planned and executed.

The procurement of eBuses can currently be nearly twice as expensive as conventional (diesel) buses. Additional costs apply for the necessary infrastructure. A PTO's commitment to invest in charging infrastructure depends on contractual and legal aspects, as **Markus Vogelsang**, sales manager eBus infrastructure at *Siemens*, knows [16]. This can be a challenge, since the duration of concessions is usually shorter than the lifetime of a charging station.

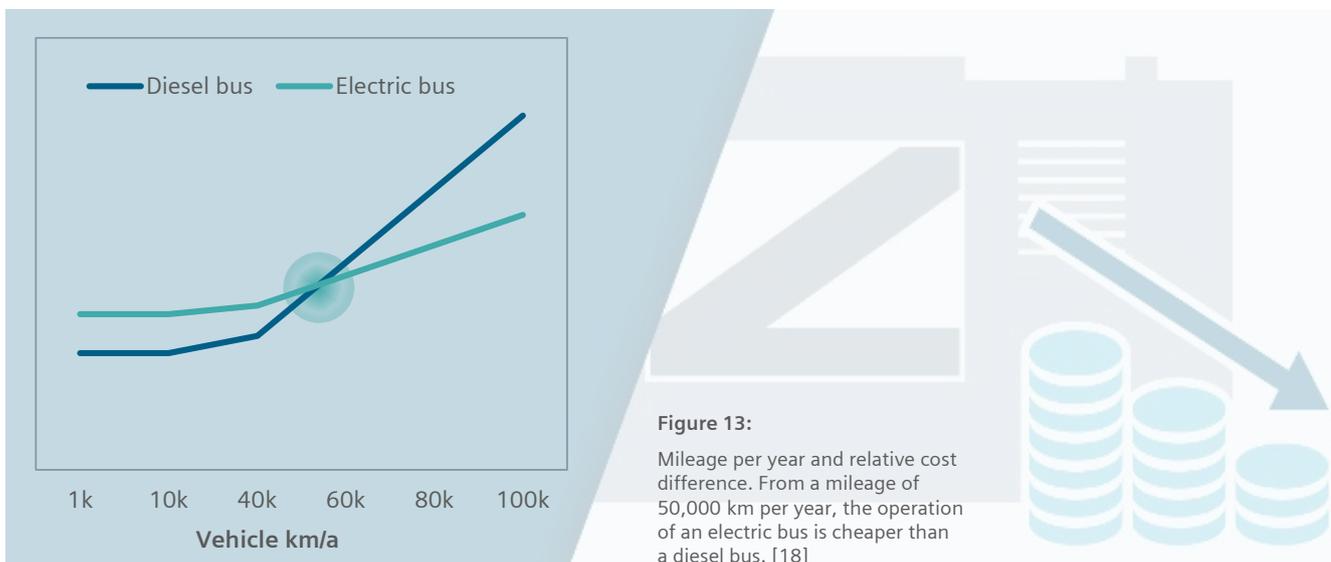
Due to low operating costs, conventional and electric buses can break even provided they reach a certain mileage per year. This point can be reached at 50.000 km/a already [18], which is less than most diesel buses currently run in larger cities (Figure 13).

It is to be expected that eBuses will get cheaper in the future [19].

As soon as externalities such as costs for health issues and climate change are taken into account, eBuses have a clear advantage over conventional buses [20].

So far, prices for opportunity charging buses tend to be lower than for overnight charging buses mainly due to their smaller battery. Compared to overnight charging buses, opportunity charging buses require investments for chargers on the route, but have lower cost for charging infrastructure in the depot. The overall cost per bus for infrastructure is comparable for depot charging and opportunity charging [11].

Literature suggest that the TCO of opportunity buses is slightly lower than that of depot buses [20].



Key Environmental Advantages



Driving towards a smaller carbon footprint

Compared to conventional vehicles, eBuses offer a number of ecological advantages [21]. Locally, they produce hardly any emissions and are extremely quiet.

If they are operated with an electricity mix with a high share of renewables, they also have clear advantages over a conventionally operated fleet over their entire life cycle (production, use, end of life) [22].

Because of their smaller battery, opportunity charging buses usually have a smaller environmental footprint [22]. Modern charging solutions also keep the impact of the overall system on the environment low and help to save CO₂.

Similar to the economic considerations, the ecological characteristics of the eBus system are very case specific and in particular depend on:

- Battery size
- Mileage of the fleet
- Passenger capacity utilization
- Outside temperature

Conclusion

Keeping up the speed of transition

The political will to electrify the transport sector continues to grow, so does the technological availability. Targets were set under a relatively short time frame. This challenges especially PTOs, but also manufacturers. It is now time for all stakeholders to collaborate more closely and share experience and knowledge in planning and designing charging infrastructure. In return, clean and affordable public transport will be of outstanding societal value.

The decision on charging solutions as an enabler for this transition is not trivial. **Prof. Dietmar Göhlich**, TU Berlin and chairman of Research Campus Mobility2Grid, states that overnight and opportunity charging have both advantages at multiple levels depending on the specific requirements and operational conditions. Both technologies will play a major role in future electric bus fleets.

Continued funding schemes are necessary to keep the required speed of transition. However, purchasing vehicles and infrastructure will not be enough to overcome some of the most inhibiting factors. An efficiency improvement of operational processes is necessary. Due to the additional dependencies of eBuses, these require digitalization. The development of digital management systems especially for depot operations is urgent and has great potentials.



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