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TRANSNATIONAL HANDBOOK FOR ENERGY-EFFICIENT PUBLIC TRANSPORT INFRASTRUCTURE TECHNOLOGIES DEPLOYMENT

(2) Multipurpose public transport infrastructure use

IMPRINT

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About the EfficienCE project

EfficienCE was a cooperation project funded by the Interreg CENTRAL EUROPE programme that aimed at reducing the carbon footprint in the region. Most central European cities have extensive public transport systems, which can form the basis of low-carbon mobility services. More than 63% of commuters in the region are using public transport. Measures to increase the energy efficiency and share of renewables in public transport infrastructure can thus have a particularly high impact on reducing CO2.

This was achieved by supporting local authorities, public transport authorities and operators by developing planning strategies and action plans, implementing pilot actions, developing tools and trainings to plan and operate low-carbon infrastructure, and by transferring knowledge and best practices on energy-efficient measures across Central European regions.

Twelve partners, including seven public transport authorities/companies from seven countries were working together for three years to exploit the untapped potentials in this sector and to contribute to the EU's 'White Paper' goals to cut transport emissions by 60 percent by 2050 and to halve the use of 'conventionally fuelled' cars in urban transport by 2030.

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Executive Summary

Photo by City of Leipzig

Transportation systems are facing challenges due to increasing urbanization. Aging transportation infrastructure is struggling to meet today's demands, while personal choices about urban transportation have evolved in ways that the car-oriented transportation policies of the past are no longer adequate.

This handbook presents a primer on the multipurpose use of public transportation infrastructure for cities where public transportation infrastructure is not a planning priority and for cities with an advanced public transportation infrastructure planning culture.

Multipurpose use of public transport infrastructure integrates energy, mobility, and logistics aspects to minimize CO_2 emissions and make transport operations more energy efficient through various technologies.

Energy-efficient multi-purpose infrastructure technologies for public transport are generally structured into solutions for multi-modal use, multi-functional use, and innovative approaches to IMC charging technologies under development.

Each of the technologies have several advantages and benefits. These may be technical, financial, or safety related.

However, each of the technologies presented also have technical and regulatory barriers, e.g., lack of technical standards, compatibility between different manufacturers, safety limitations, low energy efficiency, additional costs, standardization of infrastructure and systems.

An overview of current practices related to different solutions for multimodal use of infrastructure PT and a case study from the EfficienCE pilot project present new technologies in operation with their benefits, experiences, and transfer possibilities.

1. Multipurpose use of public transport infrastructure

Electromobility has become an increasingly important topic for public transport (PT) in cities. Electricity is the energy source for powering various electric vehicles.

The main difference between the technologies for the use of multipurpose PT infrastructure is that they are used according to:

- The modalities for which the multipurpose use is relevant (based on the existing PT infrastructure) and
- The functionality of energy transfer between energy source, PT infrastructure and electric PT vehicles.

1.1 Summary of relevant technologies

The classification of multipurpose PT infrastructure technologies is based on the existing multimodal and multifunctional use of infrastructure PT.

Technology A - Multimodal use of existing PT infrastructure such as metro, tram, railroad or cable car, where additional charging takes place for: E-buses, (hybrid) trolley buses and other E-models (E-cars, E-bikes, E-deliveries).

Technology B - Multifunctional use of PT infrastructure, using existing PT infrastructure for more efficient use of recuperated braking, bidirectional charging (smart grid) and locally generated energy from RES (PV, wind).

Technology C - Innovative road-based multi-modal and multi-functional IMC (In Motion Charging): Inductive ground charging, conductive surface charging on highways, and conductive ground charging.

1.1.1 Technology A - Multimodal use of PT infrastructure

Technology A refers to the concept of charging different electric vehicle modes from the existing PT network such as metro, tram, railroad or cable car.

Solution 1 - Electricity from existing PT grids to power E-bus charging points

Technology refers to the concept of charging electric buses with energy from existing PT networks such as the metro, tram, trolley bus, railroad, or cable car networks.

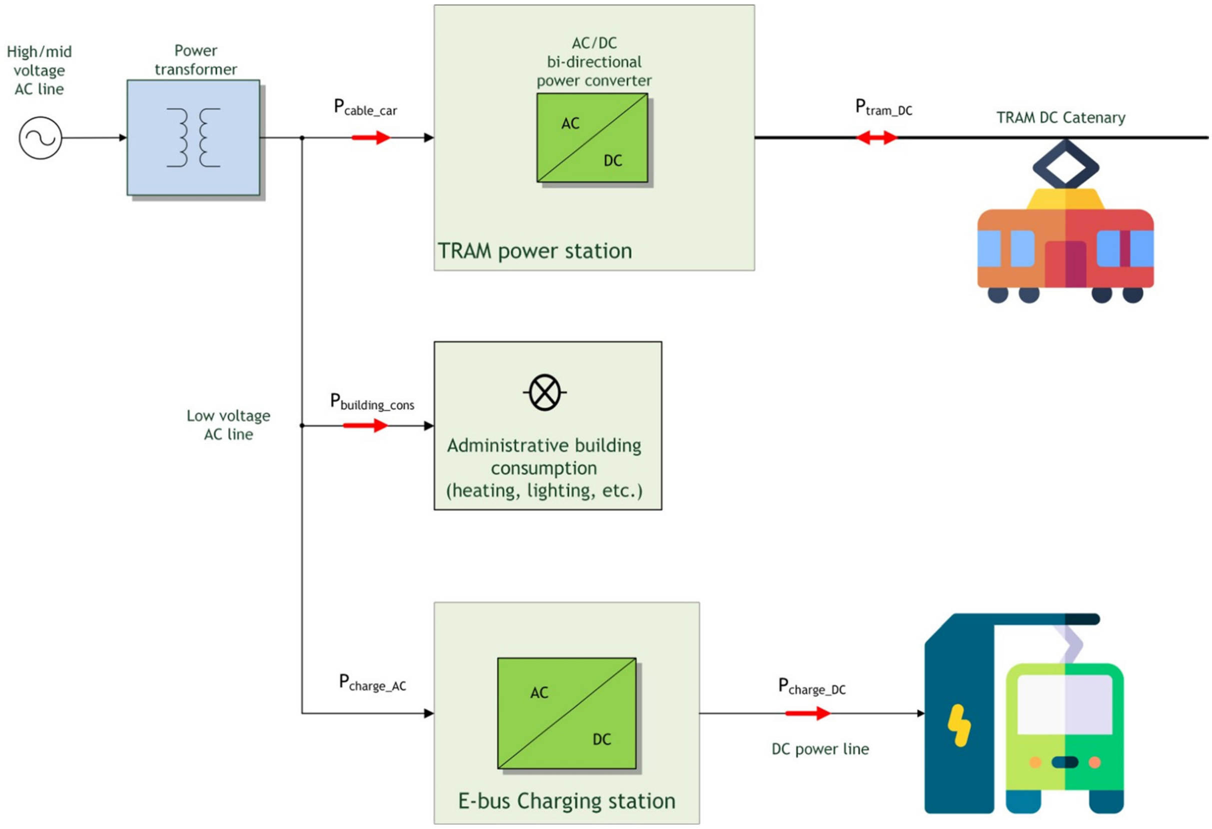


Figure 1: Connecting e-vehicle charging stations to the existing public transport infrastructure

Expected Benefits:

The primary benefit of this technology concept is to support the fast, efficient, and cost-effective electrification of public bus transportation by providing an infrastructure foundation.

By integrating the robust infrastructure (network) of the tram/metro with the electrification of e-bus fleets, there is an opportunity to accelerate the electrification of e-bus fleets. The tram/metro grid provides a feasible alternative to the public power distribution grid, with no need for additional substations to supply power to e-buses.

The main technical advantages are in the areas of:

- Location and time responsibility, reliability in case of power interruptions,
- Efficient and balanced distribution of power

The main financial advantage is:

- Achieving a lower energy purchase price (shared volume of metro/tram and e-bus).

Solution 2 - Electricity from existing PT grid (Tram or Metro) to power EV, Hybrid Trolleybus

Connections between existing rail, tram, or metro network with trolleybus network could be upgraded equipping trolleybuses with an additional traction battery, allowing an operation under catenary as well as without connection to the catenary (autonomous). The main objective of this cluster is to extend inner-city and regional electric bus lines, thus substituting current Diesel bus lines without the necessity to build additional overhead infrastructure. To lower the cost of implementation, the (Hybrid) trolleybus grid might be combined with a rail system.

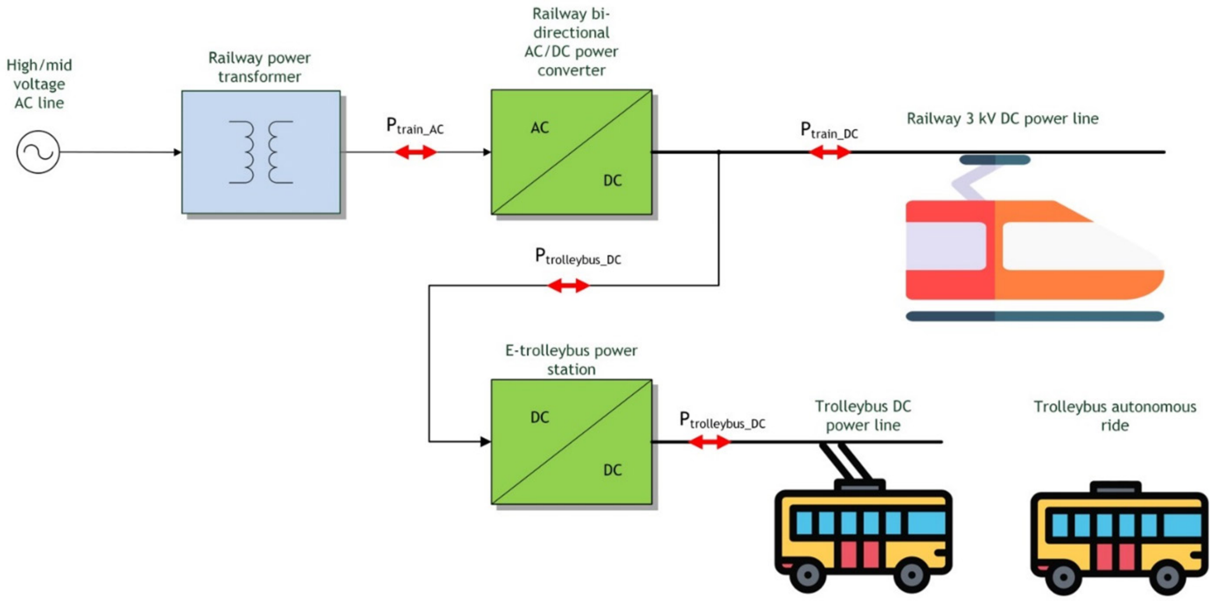


Figure 2: Combining In Motion Charging trolleybuses with a rail system

Expected Benefits:

Hybrid trolleybus technology is mature enough and commercially available to be used. In addition, electric vehicles are equal or superior to Diesel vehicles in terms of availability, efficiency, and reliability, while requiring less maintenance. Minor weaknesses have been identified in the management, sizing, and compatibility of lithium-ion batteries in older vehicles, but these could be addressed soon as battery technology evolves.

Solution 3 - Electricity from existing PT grid (Tram or Metro) to power multimodal charging hub

Refers to a technological concept that enables the multi-purpose use of electric PT networks (metro, tram or trolley bus) to power other types of electric vehicles, including, for example, commercial vehicles, passenger cars, and taxis. The electric vehicles considered in this solution vary depending on the use case and include electric cars, bicycles, and vans.

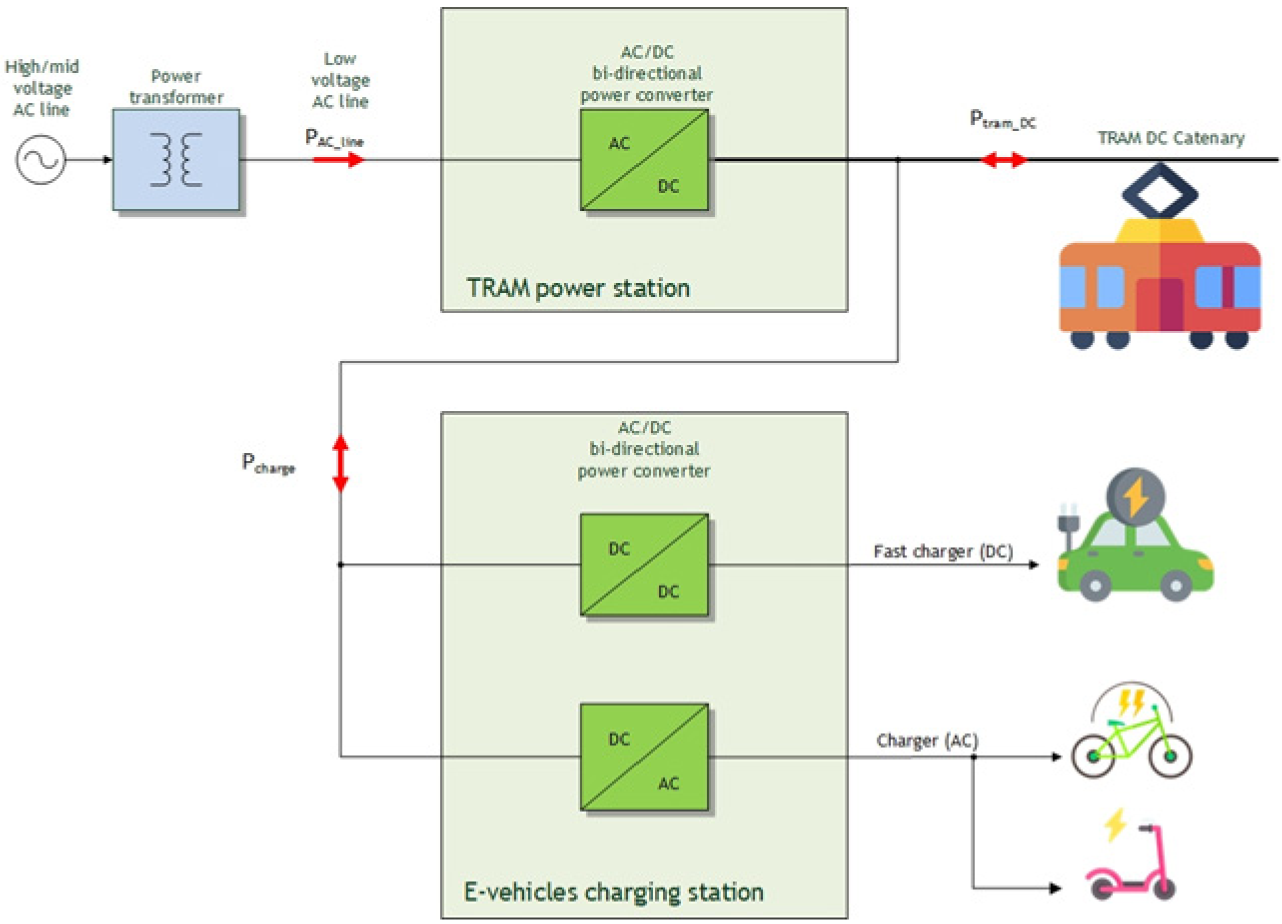


Figure 3: Fast charging of e-vehicles from tram catenary

Expected Benefits:

First, it must be clarified whether it is possible to use the power grid to meet the electricity needs of the charging infrastructure, especially at locations that are connected to the regular power grid.

Technology A	Technical barriers	Legal barriers
Multimodal use	▪ Lack of technical standards for opportunity charging. ▪ Compatibility between different manufacturers. ▪ Changes needed in the current timetable. ▪ Load on the grid - limited charging possibilities.	▪ Sale or distribution of energy to third party (bus) operators. ▪ Use of environmental benefits for extension of catenary lines (not simple).

1.1.2 Technology B – Multifunctional use of PT infrastructure

Technology refers to the more efficient use of charging infrastructure of the existing PT network such as metro, tram, trolley bus, railroad or cable car.

Solution 4 - Integrated recuperated braking energy

Technology groups the different measures and technical systems that increase the use of recuperated braking energy in rail vehicles (metro, tram) and buses (trolleybus). The main objective of this cluster is to increase the energy efficiency of the public transport system by more efficiently using the recuperated braking energy of its vehicles.

Three types of applications can be defined:

- Mobile storage applications
- Stationary storage applications
- Stationary "back-to-the-grid" applications.

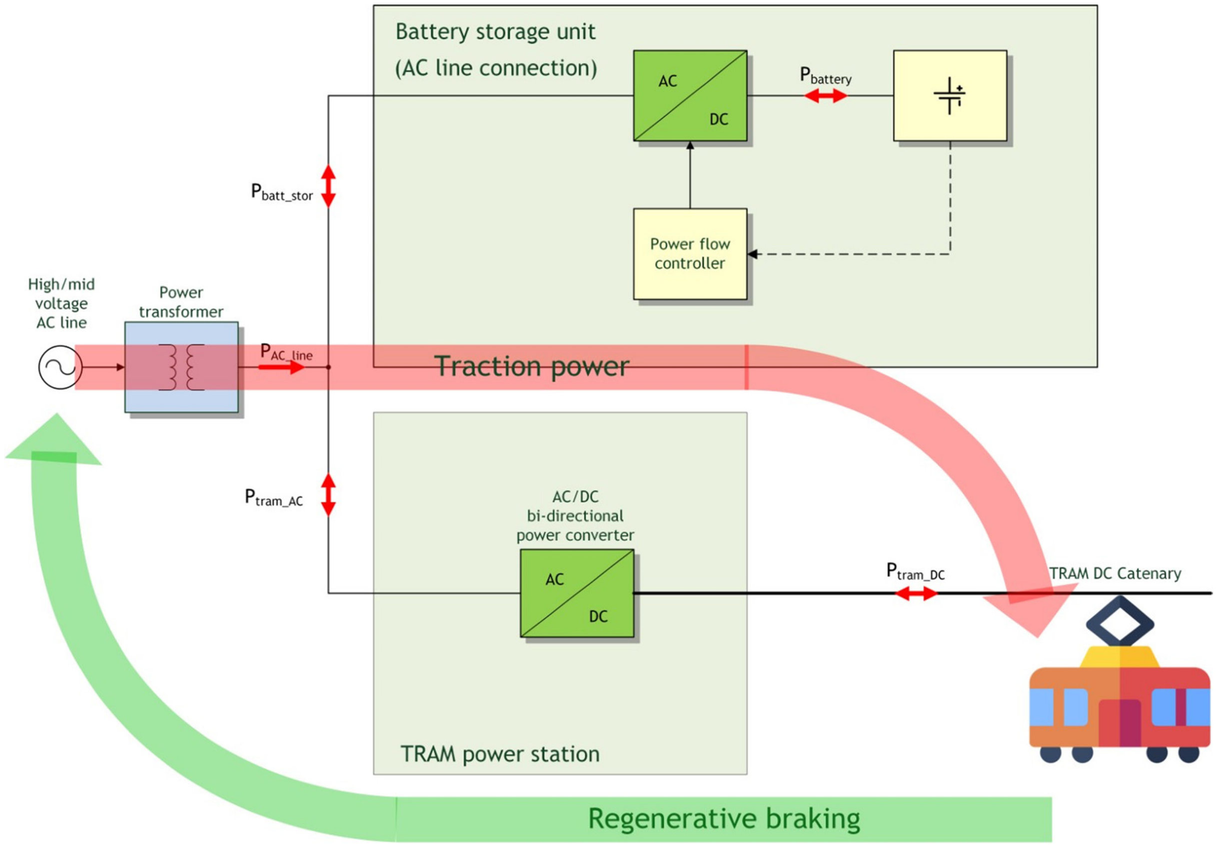


Figure 4: Stationary storage applications

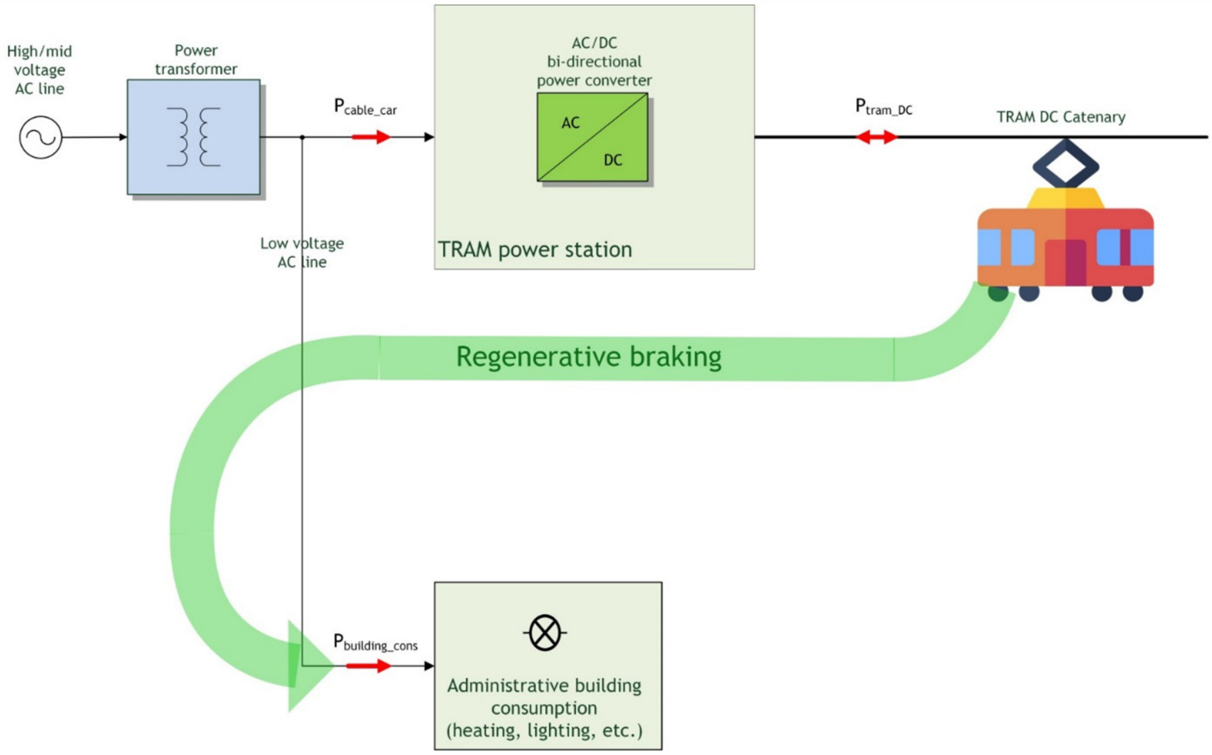


Figure 5: Stationary "back-to-the-grid" applications

Expected Benefits:

The benefits expected from the applications can be highlighted in the following points (François-Olivier Devaux (STIB), March 2011):

Mobile storage:

- High efficiency due to reduced overhead losses as storage is on the vehicle.
- Possibility to operate the vehicle without overhead lines on certain sections of the line.
- Voltage stabilization by mitigating voltage dips.
- Reduction of peak power demand by averaging loads over a period.
- Possible reduction of braking resistances in the vehicle.

Stationary storage applications:

- Can be used by all vehicles operating on the line, voltage stabilization by mitigating voltage dips.
- Reduction of peak power demand by averaging loads over a period.
- Reducing the number of traction substations or allowing vehicles to be added without upgrading the power system.
- Reduction in waste heat, avoiding heating of tunnels and stations.
- Possible reduction in trackside braking resistances.
- Reduced safety constraints compared to on-board systems.
- Implementation, maintenance, and repair do not affect operations (shutdown mode).

Stationary "back-to-the-grid" applications:

- Can be used by all vehicles on the line.
- Very energy efficient due to fewer transformation losses than storage applications.
- Compared to storage applications, reduction of waste heat (avoidance of heat tunnels...).
- Possible reduction of trackside braking resistances.
- Lower safety requirements compared to onboard systems.
- Implementation, maintenance and repair do not affect operation (shutdown mode).

Solution 5 – Smart Grid (PV, RES, Mobility 2 Grid, Vehicle 2 Grid)

Renewable energy and electromobility for a smart urban environment. With the help of increasing electromobility, there is an opportunity to develop an integrated energy and transport system. Developing and implementing innovative solutions to ensure an affordable and secure supply of electricity, heat and transport based entirely on renewable energy.

Expected Benefits (Massink, January 14, 2019):

- Reducing total cost of ownership of fleets, batteries, PV, ...
- Car OEMs (manufacturers) are able to sell vehicles with added value.
- Energy market parties can trade and optimize their balance sheet.
- Grid operators can optimize investments and stabilize the grid.

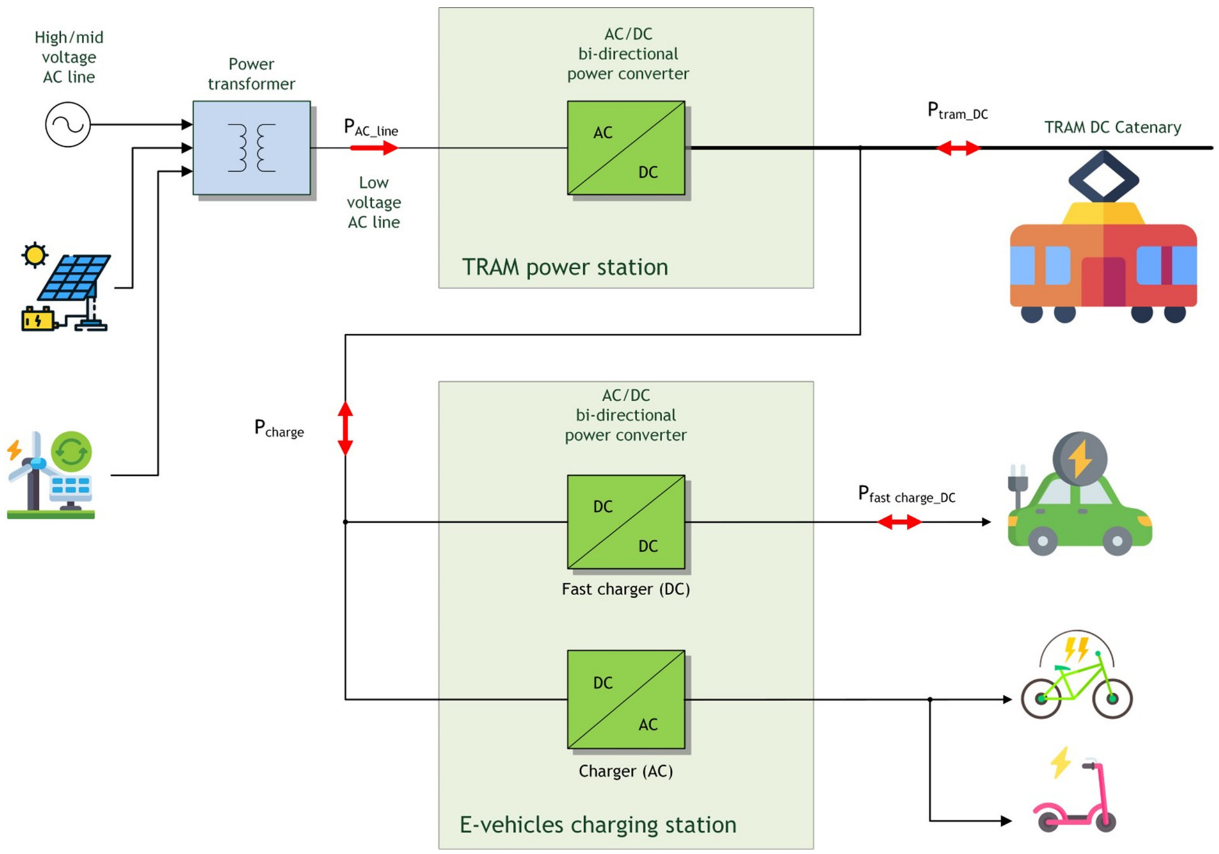


Figure 6: Connecting e-vehicle charging stations to the existing public transport infrastructure

Technology B	Technical barriers	Legal barriers
Multimodal use	▪ High safety constraints for mobile storage application (passengers on board); ▪ Overhead line loses (due to big distances between vehicles/stations); ▪ No voltage stabilization for back to grid systems.	▪ Stricter rules and enforcement may result in higher costs or abandoning the project; ▪ Bidirectional power transfer standards between different modes using ISO 15118-20 standard.

1.1.3 Technology C – Innovative in-motion charging for PT

Technology refers to the concept of charging PT vehicles while driving on the road (in-motion), with new innovative solutions possible to enable multimodal and versatile use in the future PT.

Solution 6 - Inductive Ground in-motion charging (OLEV)

There are several methods for building electrified roads. In inductive technology, magnetic energy is transmitted.

It is noted that all OLEV concepts developed appear to operate at a frequency of 20 kHz.

It is noted that a 6th generation of the technology is currently being developed. The main objective is to ensure compliance with the new standard SAE J2954 for stationary inductive charging of electric vehicles. Thus, it is pointed out that a 6th generation of OLEV technology will be based on coreless rails without rigid magnetic structure in the road.

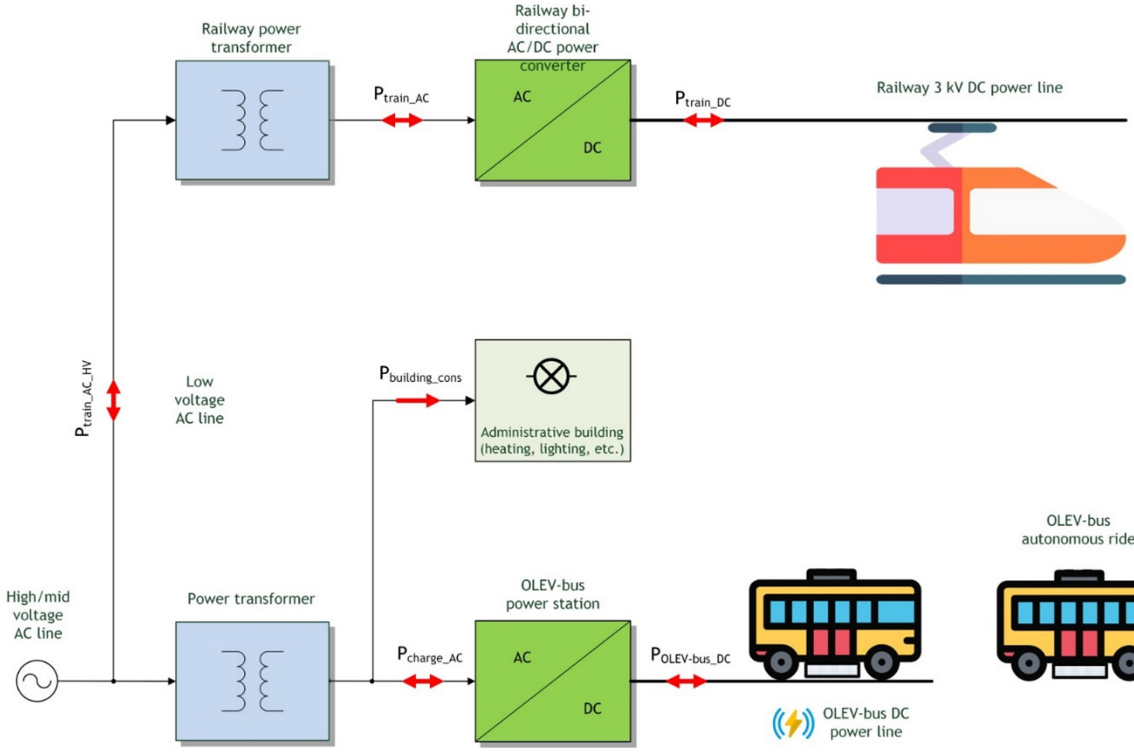


Figure 7: Inductive Ground in-motion charging

Expected Benefits:

It is expected that the systems for stationary and dynamic inductive power transfer to electric road vehicles will be compatible. The standard for stationary inductive charging calls for an operating frequency of 85 kHz, which also requires difficult considerations and compromises compared to existing OLEV systems operating at 20 kHz.

Solution 7 – Conductive Overhead in-motion charging on highways (e-highways)

The technology based on overhead lines can be considered the most mature, as it is based on the experience gained from operating overhead lines to supply power to trains, trams or trolley buses.

The main difference between road vehicle infrastructure compared to trains or trams, is that rail systems require only one conductor with sliding contact, as the rails are usually the return path for the current, while dynamic conductive power transfer to road vehicles requires two separate conductors. The key component of the system is the newly developed pantograph. It ensures safety during coupling and uncoupling with the overhead contact line in the speed range from 0 to 90 km/h (Akerman, 2015).

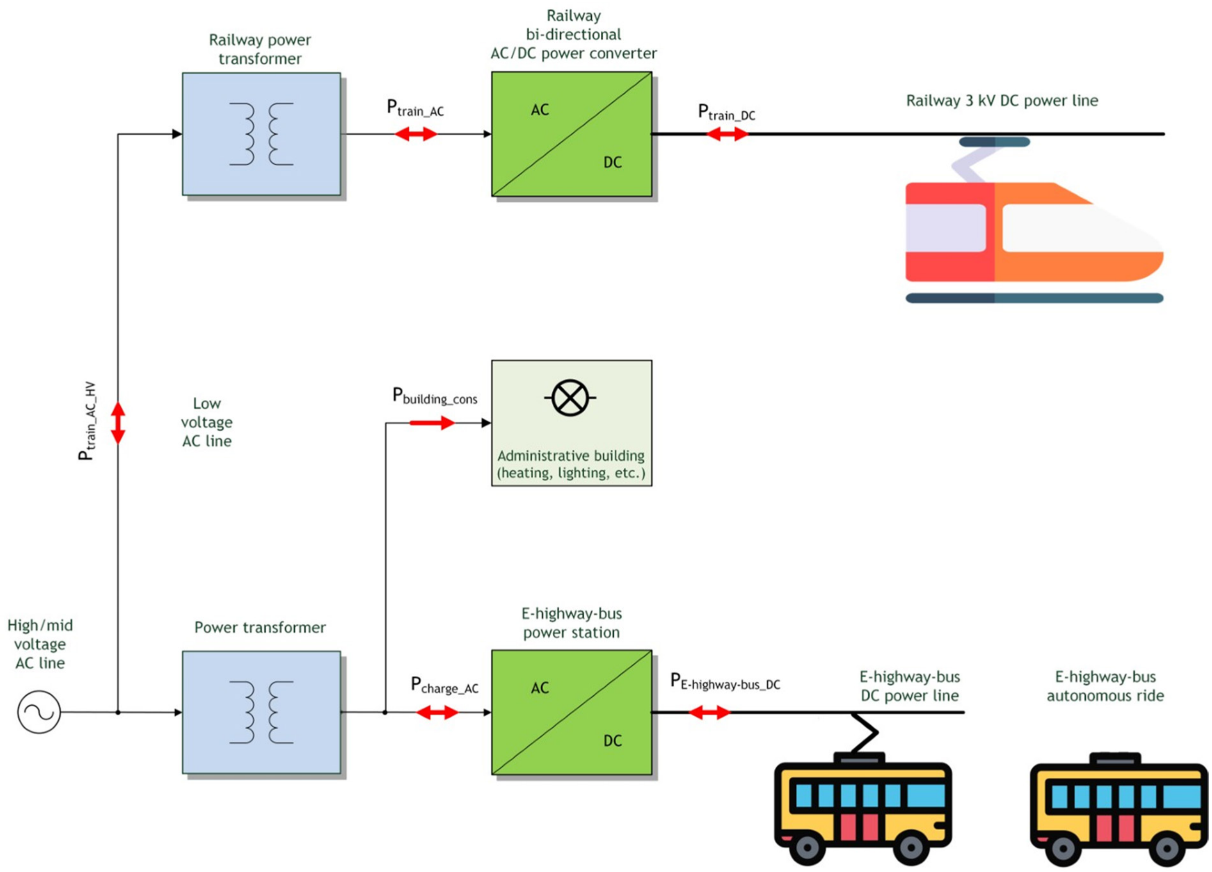


Figure 8: Conductive overhead in-motion charging on highways

Expected Benefits:

It is expected that trucks and possibly busses using overhead lines will have very similar interfaces between the pantograph system and the on-board propulsion system, although with some manufacturer-dependent adaptations. It is expected that the vehicles will have on-board battery storage with a nominal voltage between 400 and 900 V. Most likely, a DC-to-DC converter will be the interface to the propulsion system, providing voltage adjustment and control of the current from the overhead lines.

Solution 8 - Conductive Ground in-motion charging (multimodal)

The second conductive technology allows power to be supplied from below via wires in the street. Such systems have already been implemented for city trams, to avoid the visual impact of poles and overhead wires required for catenary systems. One of the concepts under development is based on adapting the technology for trams, while other systems are being developed specifically for road vehicles.

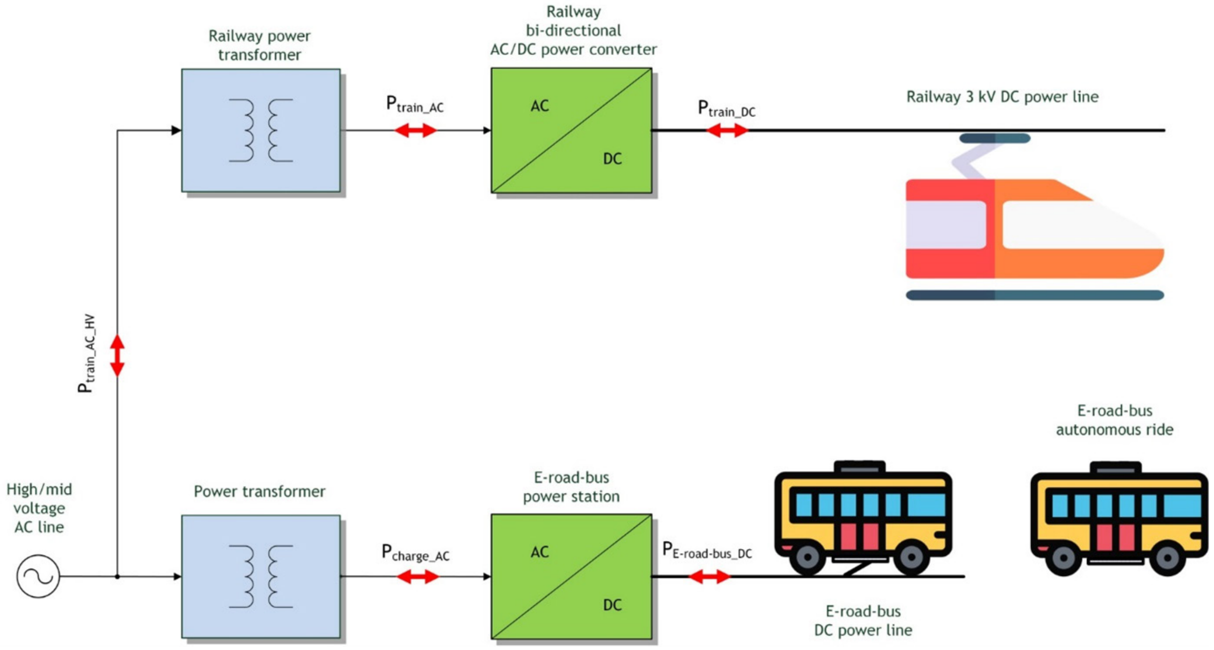


Figure 9: Conductive Ground in-motion charging

Expected Benefits:

- Possibility for vehicles of various sizes to use infrastructure.
- Avoidance of the laying of overhead power lines and the associated visual impact.

Technology C	Technical barriers	Legal barriers
Innovative in - motion charging	▪ Poor power transfer efficiency under real-world conditions; ▪ Wireless charging requires an additional charger to be integrated into the vehicle (additional cost); ▪ Power distribution system design, operation, and cost; ▪ No clear vision of multimodality.	▪ Standardization of on-board infrastructure and systems; ▪ Interoperability between different concepts.

1.2 Multipurpose public transport infrastructure use around the world

Oberhausen: Technology A (Solution 1) - Use of Tram for e-bus fast charging

Diesel vehicles were used primarily in urban bus systems. Electric buses have been introduced in the city to reduce dependence on fossil fuels and to reduce nitrogen oxide, particulate matter and noise pollution in the urban area. Charging energy is converted from the trams overhead line at the bus stop or taken from the substation at the bus stop so that the electric buses do not need to be recharged at the bus depot during regular operation.

Leipzig: Technology A (Solution 1) - Use of tram for full city e-bus charging

Power from existing PT (Tram or Metro) networks to supply the multimodal charging hub. Use of tram network to (re)charge e-vehicles. The main objective was to identify the legal barriers and legal background related to the multi-purpose use of the existing tram infrastructure for selling energy from the tram network to third parties.

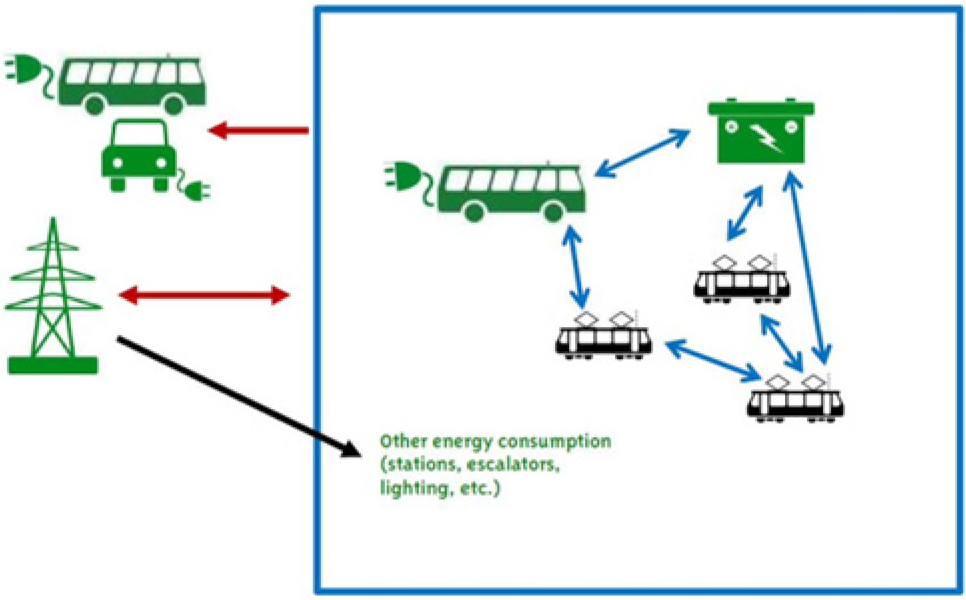


Figure 10: Pillar A Opportunity (re)charging of e-buses using tram infrastructure

Barcelona: Technology A (Solution 1) – Use of metro for fast charging of 18 m e-buses

Fast opportunity charging station in Barcelona - two electric buses perform their service with this operating model. These vehicles have a battery capacity of 125 kWh and are 18 m long. Basic fact - less capacity means less time and energy in each recharge, but more recharges.

Figure 11: Pantograph charging in Barcelona as part of ambitious electrification plan. Source: TMB.

Szeged: Technology A (Solution 2) – Electricity from existing PT grid to power hybrid trolleybuses

- Recharging e-buses "en route".
- Upgrading trolleybus network with battery buses.
- Automatic wiring/de-wiring.
- Benefits also for citizen.
- Financial and legal feasibilitiy.
- Not relavant technology for low density / peripheral traffic (articulated e-buses).

Eberswalde: Technology A (Solution 2) – Use of hybrid trolleybuses

Recharge the energy storage while the buses are travelling under the overhead wires. Once the buses leave the overhead network, all electrical energy and power is provided only by the vehicles' energy storage devices. This results in the need to minimise energy storage and avoid losses in passenger capacity.

Oberhausen: Technology A (Solution 3) – Multimodal hubs

Electricity from existing PT (Tram or Metro) grids to power multimodal charging hub. The existing DC tram infrastructure can also be used for fast-charging of other electric vehicles like private e-cars and LEVs.

- Electricity from existing PT grids to power multimodal charging hubs.
- Tram catenary used for e-bus fast charging and e-cars (Oberhausen).
- Electric power from 750 V DC tram catanery is transformed for fast charging station with 50 kW usable by cars and LEVs.
- With overvoltage protection system.

- Unclear legal framework and risks for business case.

Barcelona: Technology A (Solution 3) - Use railway for multimodal charging

The energy delivered from the electric network of the railway installations that is not consumed by electrical traction can be used for charging Barcelona EV fleet.

- Identification of time slots, available parking lots and electrical network of rail infrastructure (tram, metro) to deploy recharging points.
- Usage of not consumed energy delivered to electrical network.
- Stakeholders involved: PT operator, Parking operator anf final user.
- Different charging management schemes for private vehicles and public fleet:
- PTO to Parking Operator (PO) public fleet, PTO to EV private user, PTO to PO to public/private fleet.
- Legal barriers.

Rotterdam: Technology B (Solution 4) - PT infrastructure with integrated recuperated braking energy

All the metro trains used on the Rotterdam network had the ability to brake electrically using regenerative braking techniques. Braking energy recovery can be as a great opportunity to reduce the energy used by its metro system.

- Recovered kinetic energy from braking to power vehicle auxiliaries, remaining energy is sent to the electrical network for accelerating of nearby trains.
- If that is not the case the network voltage increases due to energy surplus, this extra energy is dissipated in braking resistors.
- Tested solutions: super-capacitator storage systems along tram network – no significant benefits, flywheels?
- No storage needed, just inverters.
- Simulation for optimal location (at 2 substations).

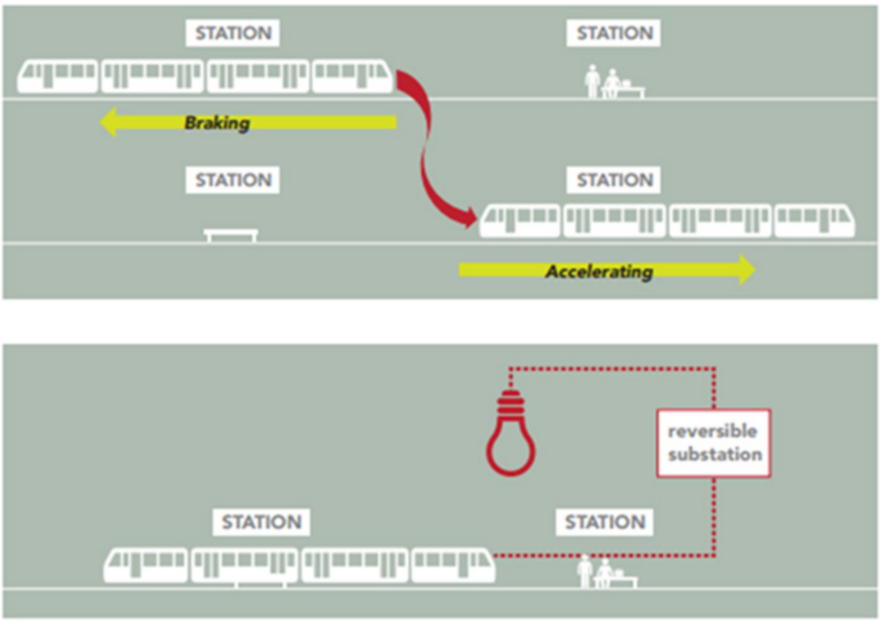


Figure 12: Braking recovery system on the metro network Rotterdam (Source: Virgil Grot, Regie & Ontwikkeling, 2014)

Torino: Technology B (Solution 5) - "Vehicle 2 Grid" technology with integrated RES

Bidirectional technology – which both charges the car and returns power to the grid.

- Car industry (FCA) + E-mobility and technology providers (ENGIE EPS) and grid operator (TERNA).
- Bidirectional technology – which both charges the car and returns power to the grid.
- Use of batteries to provide grid stabilization – optimize operating costs of car users.
- Installation of 32 V2G columns capable of connecting 64 vehicles. (goal 700 vehicles).
- 5 MW solar panel capacity (for 8500 homes).

Arnhem: Technology B (Solution 5) – Multipurpose use of smart trolley grids

The multi-purpose charging of other electric vehicles from your trolley grid:

- Infrastructure of trolleybus traction grids could provide a cost-effective solution.
- A flexible on-demand service to complement and extend regular public transport services.
- The installed vehicle fast-charger is operated through the DC trolley-tram network. Because the system is DC-DC, it has less energy loss than conventional charging systems.
- The charging station does not require connection to the conventional power grid when connected to the trolley-tram- network.

▪ The trolley tram network can have a positive impact on the use of renewable energy sources by creating a base load for the renewable energy source instead of feeding it into the grid.

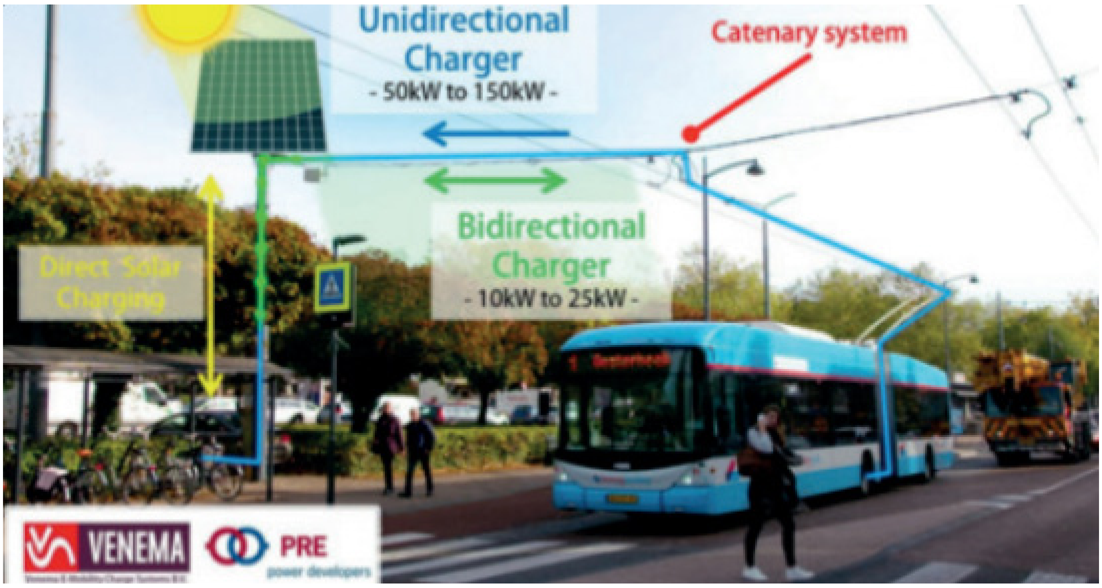


Figure 14: Concept drawing of multipurpose charger (Source: VENEMA/PRE Power; trolley:2.0)

Industry solution: Technology C (Solution 6)

The main applications have been for stationary opportunity charging of public transportation systems like trams, busses and trucks (800 m track in Augsburg by Bombardier).

- Transfering 200 kW to the vehicle.
- Airgap 6 cm (trams), 10 cm trucks.
- Possible integration with stationary (opportunity) charging of buses.

Figure 15: E-bus with inductive charging in Braunschweig. Source: Rupprecht Consult.

State of Hessen, Germany: Technology C (Solution 7) – Innovative PT infrastructure approach to power E-roads (highways)

The ELISA project aims to proactively support the vision of climate-neutral driving as part of logistical value chains while maintaining transport capacity. The aim of the project partners is the realization of an electric traffic system with overhead line infrastructure.

- The e-Highway Hessen was built over a distance of around ten kilometers on the A5 highway.
- It was approved and built within just two years. This demonstrated that this type of electric road can be erected in a short time, even on busy roads.
- Interoperability with PT?

Figure 16: E-highway test track ELISA 2020. Source: M. Werner (TU Dresden)

Sweden: Technology C (Solution 8) – e-Road ARLANDA-SE

Innovative IMC of PT; conductive ground sliding contacts. The innovative techniques are based on conductive technology that use an electric rail installed in roads to power and recharge vehicles during their journey. The system is designed with the capacity to feed heavier traffic, such as trucks, it also works for cars and buses. It can also provide help for uphill driving.

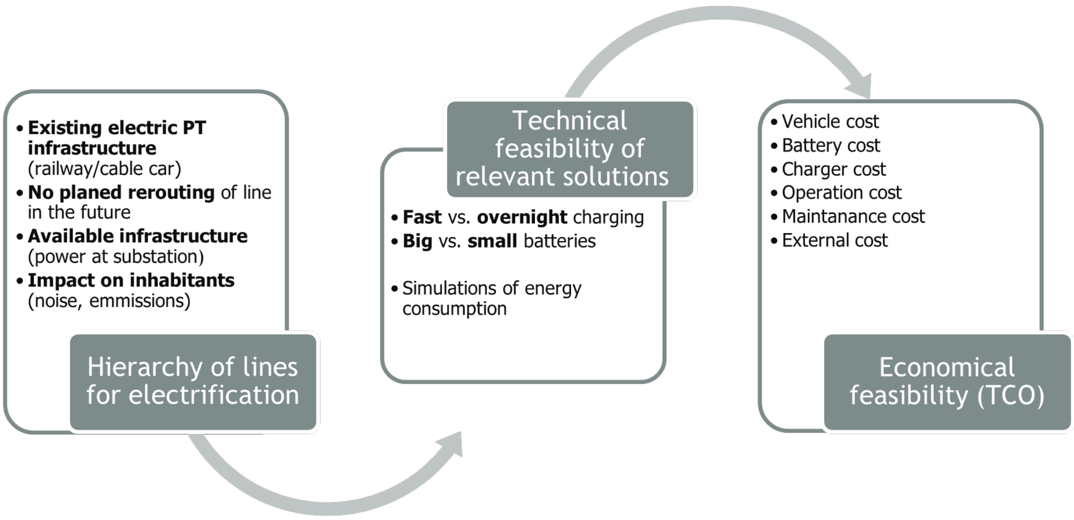
- Conductive technology using electric rail installed in roads to power and recharge vehicles during journey.
- Charging with "movable arm".
- 2030 Sweden goal on fossil free transport.
- Originaly built for trucks, but also relevant for cars and buses.
- 10 km test track -18 t trucks, 2 km electrified.

2. Use case Maribor - Adaptation of cable car station to multipurpose PT infrastructure

Technology A was used as part of the pilot project. The pilot focuses on multipurpose e-bus fast charging of e-busses, with the substation currently serving as a charging station for cable cars and e-car sharing. Since the electrification of bus line 6 is planned, the e-bus fast charger is located at the Vzpenjača station, where the cable car station is also located. The main challenge of the pilot project was to implement an e-bus fast charger for multipurpose use and to measure the grid stability under different circumstances. The measurements of grid stability before and after the implementation of the e-bus charger measured the energy consumption of the existing consumers (cable car station, e-car sharing), other occasional consumers (consumers during major events - e.g. campers during bike downhill and winter seasons) and the new innovative e-bus charger (according to the different daily charging situation).

A selection of the charging concept was prepared, which was done in three steps. First, we identified the route where electrification would have the greatest impact on noise and emission reduction for the population and which was adjacent to the already built public transport infrastructure and would not change significantly in the future. We then analysed various charging options for the selected route and determined which options were technically feasible. Based on the technical solutions, we then selected the charging concept based on the life cycle cost analysis.

Figure 17: Methodology for electrification of PT in Maribor



The implementation and installation of the metering device in the Vzpenjača substation was completed at the end of September 2020. The metering device is used to measure power, current, temperature and other parameters in the substation. It is configured to monitor the total consumption of the Pohorje cableway. After the fast charging station is put into operation, there will be two metres: one for the charging station and one for all other consumers together. However, the sum of their outputs will represent the total load of the substation. The local recording of consumption data will be transmitted via an LTE network to a server at the University of Maribor. The graph below shows the electricity consumption in VA between September 2020 and May 2022.

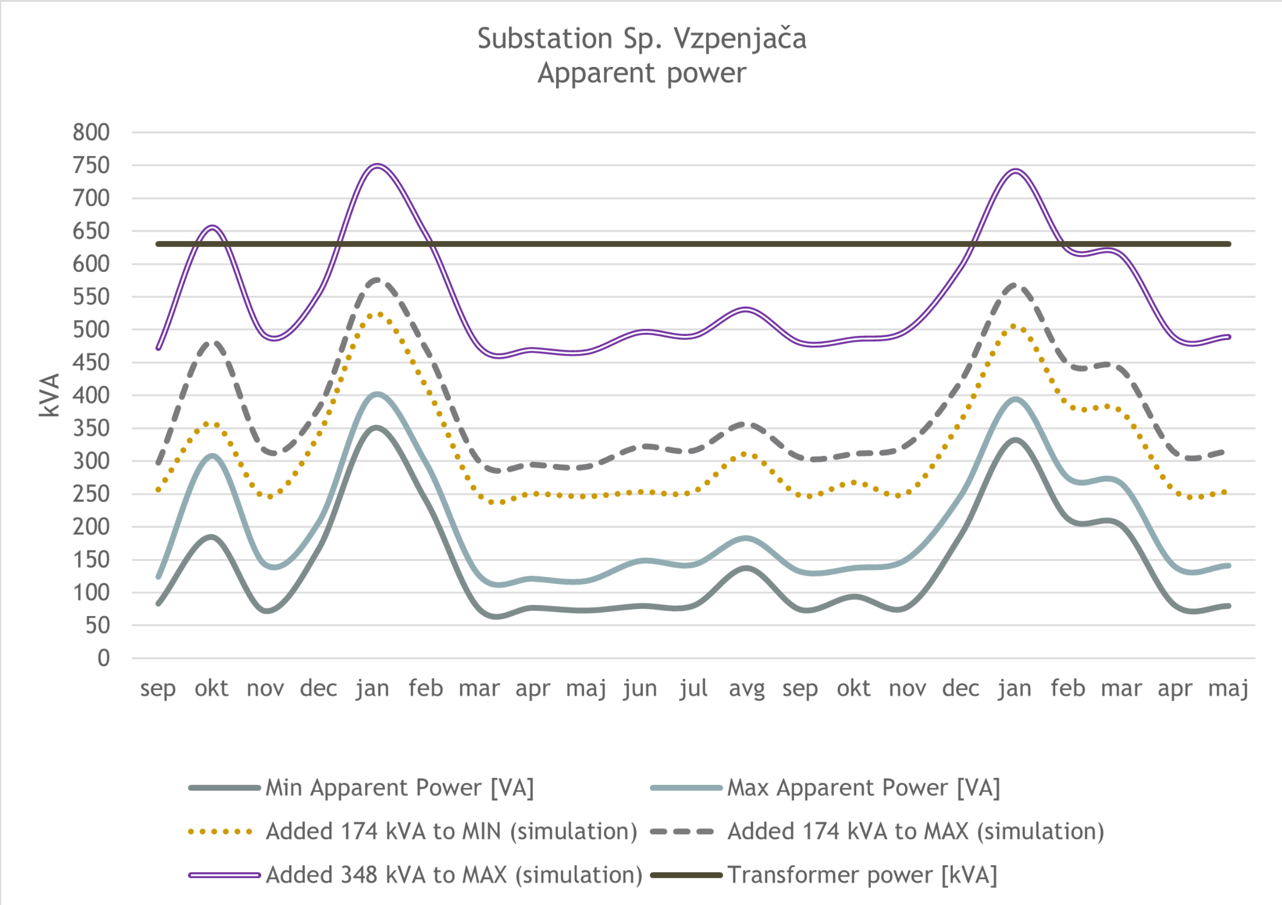


Figure 18: Apparent Power

The maximum peak load during this period was 399 kVA in January 2021 and a similar peak in January 2022. During this time (weekend) Pohorje Ski Center has started the snow cannons to be ready for the new winter season. Considering the maximum peak load based on the above diagram and the 150 kW charging station (174 kVA), the apparent power would be 573 kVA, which corresponds to the existing 630 kVA transformer. If the charging station capacity is to be increased by 300 kW, i.e., to the maximum apparent charging station capacity of 348 kVA, the peak load could be 747 kVA. The existing 630 kVA transformer would be inadequate and would need to be replaced with a new 1000 kVA transformer.

Considering the technical solutions available on the market, the municipality opted for two fast chargers and a set of LTO batteries. Municipality of Maribor held a public tender for the preparation of project documentation for fast charging stations under the "Pohorje cableway", at the main bus station and at the Marprom workshop in Maribor. A coordination meeting with the selected bidder was held in September 2020. Representatives of the Municipality of Maribor and the University of Maribor presented the EfficienCE project and the project conditions for the preparation of professional documentation in detail.

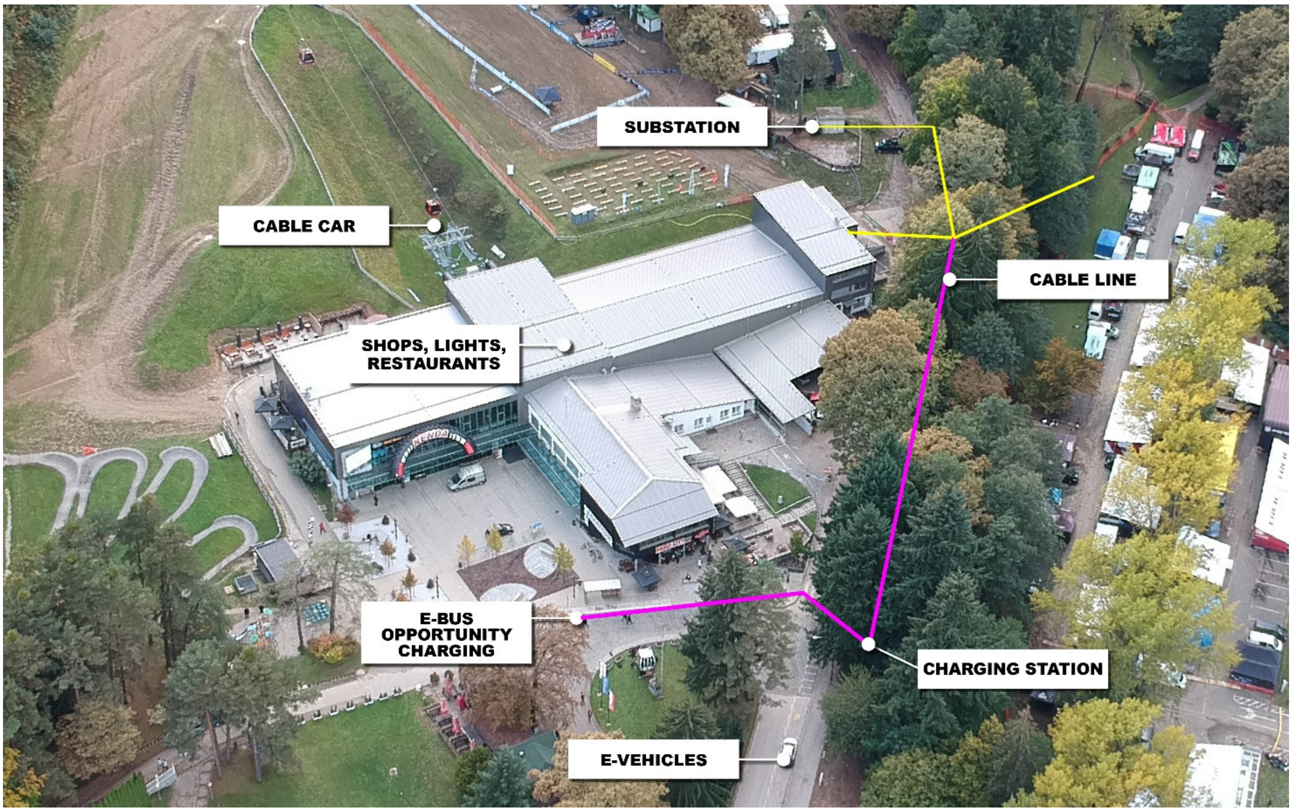


Figure 19: Areal view of a fast charger at Vzpenjača station

At the beginning of February 2022, the first pantograph for fast charging of electric buses in Maribor with a power of 300 kW was successfully installed at the main bus station. The second pantograph with a power of 150 kW was installed in mid-February 2022 at the cable car station, where the integration of charging for other e-vehicles and cable cars was implemented.

Figure 20: Installation of pantograph with a fast charger at cable car station in Maribor

Figure 21: Installed pantograph being tested with the purchased bus

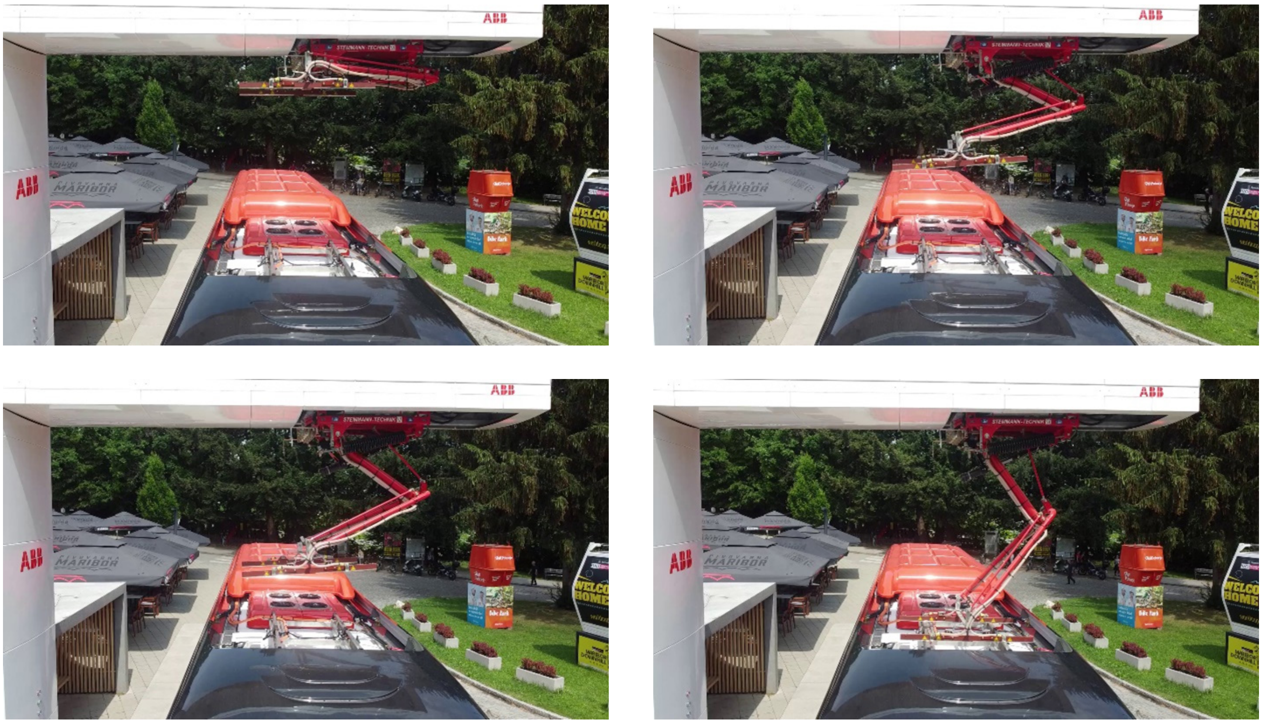


Figure 22: Demonstration of the operation of the pantograph

3. Conclusions

Technologies relevant to the use of multi-purpose infrastructure PT show a wide range of options and solutions that are available from suppliers and deployed in different cities. As the technologies evolve, the impacts are still in the early stages (especially dynamic/moving multipurpose use PT). In a first step, the 8 technical solutions were presented, with a description for each technology, followed by key benefits, general investments, and technical and legal barriers. In a second step, best practices were presented for each technology, where after the description of the state of the art, the implementation status was presented, followed by a potential for expansion of use. Each technology has both disadvantages and advantages, with implementation tailored to local conditions. Based on the report, we can see that cities and suppliers are upgrading existing local PT infrastructure for multipurpose use, while new (especially) mobile charging technologies are in the early stages.

Regarding the integration of energy, mobility, and logistics in the multi-purpose use of PT infrastructure, we can conclude that integration is related to demand and available locations and energy, while mobility and logistics hubs usually do not have integrated locations of their distribution networks from a spatial point of view and therefore integration is difficult but should be considered in the future.

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