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TRANSNATIONAL HANDBOOK FOR ENERGY-EFFICIENT PUBLIC TRANSPORT INFRASTRUCTURE TECHNOLOGIES DEPLOYMENT

(4) Pilots

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

The EfficenCE project focused on energy efficiency in public transport infrastructure in Central Europe and conducted research to identify contributions to an efficient public transport (PT) infrastructure. The focus was on the following topics:

Pilot focus topics
Energy storage in PT infrastructure
Photovoltaic system integration (PV)
Multi-purpose use of public transport infrastructure
Energy audit tools (EAT)
E-bus fast charger
In motion charging (IMC)

The project implemented and tested solutions to improve the energy efficiency of PT's infrastructure and integrate RES into PT's systems to reduce PT's dependency on fossil fuels and ensure that PT remains affordable and efficient in CE countries.

Four pilot investments in the EfficienCE project address the above topics.

Wiener Linien implemented a metro-station integrated PV-system to power building auxiliaries with RES.

Gdynia Trolleybus Transport Company (PKT) researched all three topics of the EfficienCE project in the recent years. However, the EfficienCE project presents the results of the investments in the use of recuperated braking energy and RES for the power supply of the trolleybus depot.

Municipality of Maribor upgraded an existing cable car substation and integrating an e-bus fast charger.

Lastly, PMDP municipal transport company from Pilsen demonstrated the integration of a buffer storage system into the trolley network. The research work focused on increasing energy efficiency.

1. Pilot projects

Pilot project 1 - Implementation of PV integration at the metro station:

- PV-system installation on the roof of metro station in Vienna.
- Integration and testing of the PV-produced energy supply into the station's energy system to supply auxiliary power units.

Pilot project 2 - Implementation of integration of braking energy and RES to power trolley depot:

- Deployment of energy inverter system to feed recuperated energy from catenaries into depot building energy system in Gdynia.

Pilot project 3 - Implementation of e-bus fast charger:

- Upgrade of multi-purpose substation and installation of the fast charger using energy from the multi-purpose substation in Maribor.
- The energy will be provided for charging e-buses, e-cars, and cable cars.

Pilot project 4 - Implementation of buffer storage integration into the trolleybus network:

- Installation of buffer storage station for excess energy storage in Pilsen.
- Provision of additional on-demand capacity for the catenary network.

1.1 Implementing a metro-station integrated PV system to power building auxiliaries with RES (Vienna)

Short description of pilot investment

As a public transportation company, Wiener Linien operates many properties in Vienna that could potentially be used to generate solar power. The potential is estimated at 100,000 square meters. Until now, however, it has not been possible to install conventional photovoltaic systems there due to the statics. The new product, photovoltaic foil, is significantly lighter than conventional systems and meets the special requirements for electrical grounding in a subway building.

The pilot project manages the establishment of a Pivot PV (photovoltaic) plant and the development of an energy monitoring tool (EMT) for the underground station as well as the monitoring and evaluation of the operation of this novel PV system.

Resources needed

For the first time, PV foils were bonded to the roof of a subway station. These PV foils are five times lighter than conventional PV systems. Another special feature is that a direct current railway and PV power generation are operated together.

The main challenges are the integration of this new technology into existing systems. Since the metro system is powered by direct current (DC), the risk of a stray current is present. Therefore, the PV system must have a special insulating layer. Another requirement is the weight. Regarding the design, there are no special requirements that go beyond the normal requirements for a PV system.

Figure 1: Aerial picture of Photovoltaic system (05-2020), © Wien Energie GmbH

Evidence of success

The photovoltaic plant has a size of 360 square meters and an annual output of 60,3 kW at peak. It produces around 62.000 kWh of solar power. This saves more than 21 tons of CO2 every year.

The plant's performance is highly characterized by the electric power output. As measuring equipment, the Siemens PAC 3200 is used, and the obtained data is automatically transferred to the energy control system. The yearly energy output is higher than expected in the forecast before the start of the project.

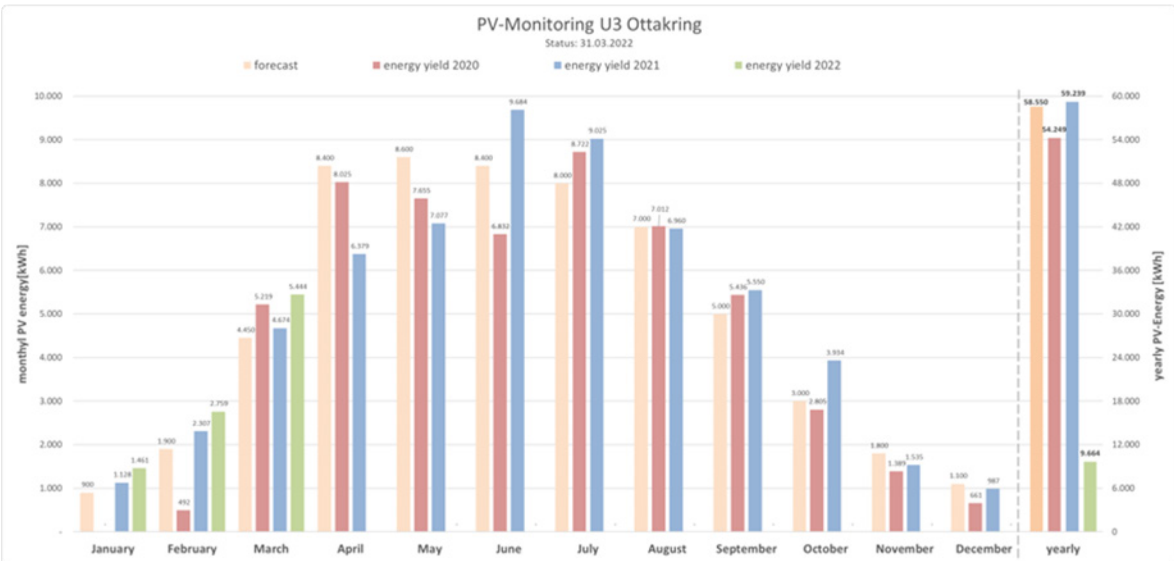

Figure 2: Energy yield of the PV-System

Difficulties encountered

One of the main challenges was to place the technical equipment such as a frequency converter. Since it was not possible to install the converter on the station's roof (due to its din), it was allocated in a spot within the station. The cable routing needed a precise plan to shorten the distance between the technical room and the low voltage main distributor room.

After connecting the low-voltage main distribution board to the technical room, the metering components were installed at the circuit breaker. Since the existing collectors were used, only minor additional costs were incurred for the consumption measurements. The adjustments regarding the cable routing were as expected.

Since this product and its application are a novelty, it was necessary to test and evaluate its performance. A measurement system was included. Both the environmental conditions (solar radiation, humidity, and air temperature) and the system performance (current and voltage at 2 locations: next to the panels on the roof and in the electrical installation room next to the inverter AC / DC) were measured.

Potential for learning and transfer

In terms of feasibility, the pilot project covered all the obstacles (e.g., weight, electrical grounding) faced by other potential mobility provider sites. The findings and outlook for potential future PV installations are that the realization of a PV installation on a railway building is possible without any problems. From an electrotechnical point of view, it can be said that there are no negative effects of the PV system on the traction and not in the other direction. In summary, the PV foils are a very good option for older buildings with static challenges, but if it is possible for static reasons, standard modules should be used for economic reasons.

1.2 Using recuperated braking energy and RES to power the trolley depot building (Gdynia)

Short description of pilot investment

Unused recuperated backing energy of trolleybuses has prompted Gdynia Trolleybus Transport Company (PKT) to implement energy optimization solutions. The investment will limit energy losses within the trolleybus traction network by utilizing unused recuperated braking energy. The recuperated braking energy disappears as heat in the braking resistors is placed on the network. By investing in a solution, the recuperated unused braking energy is transferred to the trolleybus depot grid to power the building (depot lighting, escalators, ...).

Resources needed

This is achieved using an innovative energy inverter that allows otherwise wasted energy to be fed directly into the building's energy system. It is necessary to place a specially designed DC / AC inverter in the depot to connect the DC traction network and the AC network of the building. The importance of the DC /AC inverter allows unused braking energy to be recovered and fed into the depot building, control the level of energy consumption in the traction network, detect the occurrence of unused energy, and thoroughly control the energy consumption of the depot building by further developing the energy monitoring system (EMS).

Evidence of success

The energy storage system was implemented in PKT Gdynia depot and connected to the trolleybus overhead lines as a power source for the electric car charging station. The availability of the charging power and the output values of the voltage AC were measured. In addition, the possibility of recovery of absorption braking energy were tested.

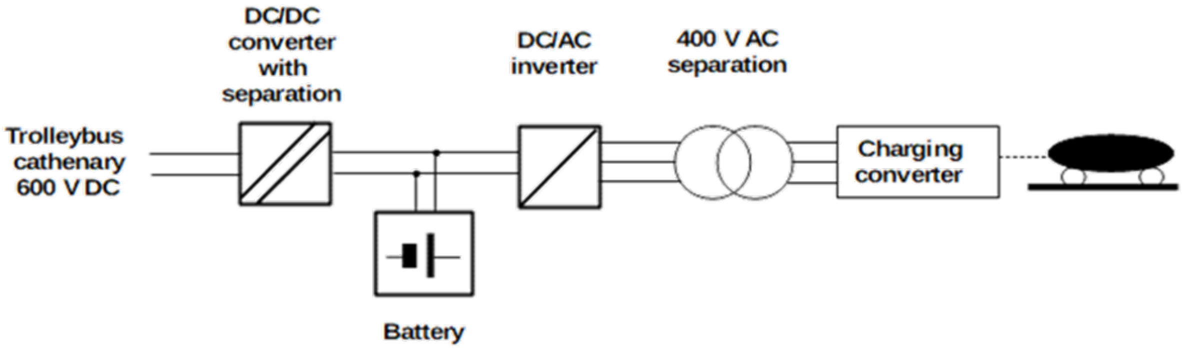

Figure 3: The innovative system scheme

Difficulties encountered

The device has been tested as a power source for charging stations for electric cars. In the first stages of testing, the cooperation of the charging stations was tested under different conditions, at different times of the day, and with different types of vehicles. Subsequently, the operation of the charging station was tested with high charging intensity, which allowed the verification of design assumptions and the determination of practical applications.

The availability of the charging power and the output values of the voltage AC were measured. The test of the possibility of recovery of absorption braking energy was performed.

The problem was that the station was overloaded by a 400 V receiver AC (charging station for electric cars). The inverter was not sufficiently protected against overloads, and the occurrence of such a situation led to its shutdown. It should be connected to the overhead contact line by a disconnector with a remote control that can be controlled from the substation control center. This facilitates the reconfiguration of the power supply system in emergencies as well as disconnecting the charging station during maintenance works on the catenary. To prevent the device from turning off in the event of a power failure in the overhead line (lack of the 600 V DC supply), the batteries in the inverter station were used.

Potential for learning and transfer

The advantage of the device is that this type of charger is not fixed to the ground and can be placed anywhere there is a traction network. The connection of the station does not require additional installation costs and no building permits shorten the investment period.

The advantage of the traction network is its large spatial extension in many cities and thus its wide accessibility. As a result, it can be used to supply power to vehicle charging stations where connection to the power line AC is problematic, for example, due to construction work.

An energy storage inverter was designed and built to handle excess braking and traction energy. It allows this excess energy, generated by braking trolleybuses, to be "captured" from the grid and managed. The inverter uses a used battery that will serve as an energy storage device. This opens up another potential, namely the "second life" of used traction batteries.

After implementation, the model of linking individual transport and public transport was tested on a larger scale by parking cars in buffer parking lots connected to the city center by a trolley bus or streetcar network and driving them home in a car charged with "green energy".

Figure 4: Battery-based electric energy storage; usage of a second-life traction battery from a trolleybus (Source: PKT Gdynia)

1.3 Upgrade of an existing cable car substation and integration of an e-bus fast charger (Maribor)

Short description of pilot investment

The Municipality of Maribor (MOM) invested in the modernization of an existing cable car station and integrate a fast-charging station for e-buses at the Vzpenjača station in Maribor (end of bus line 6). This will allow a multi-purpose use of existing public transport infrastructure (PT) by using the electricity from the cable car station both for operating the cable car and for charging an e-bus. Other preparatory measures within the scope of the corresponding pilot activity included a technical feasibility study. The technical documentation included the preparation of the tender procedure for the e-bus fast charger. Subsequently, the fast charger was installed and connected.

Resources needed

The pilot project focused on the multi-purpose e-bus fast-charging station, which was used to charge cable car stations and e-car sharing. An e-bus was also needed to test the e-bus charger.

The main challenge of the pilot was to implement an e-bus fast charger for multipurpose use and to measure grid stability under different circumstances before (cable car station, e-car sharing, other occasional consumers during bigger events) and after the implementation.

The graph below shows the estimated share of the various works for the electricity infrastructure for the charging station 150 kW (174 kVA) excluding the price for the supply and construction of the charging station.

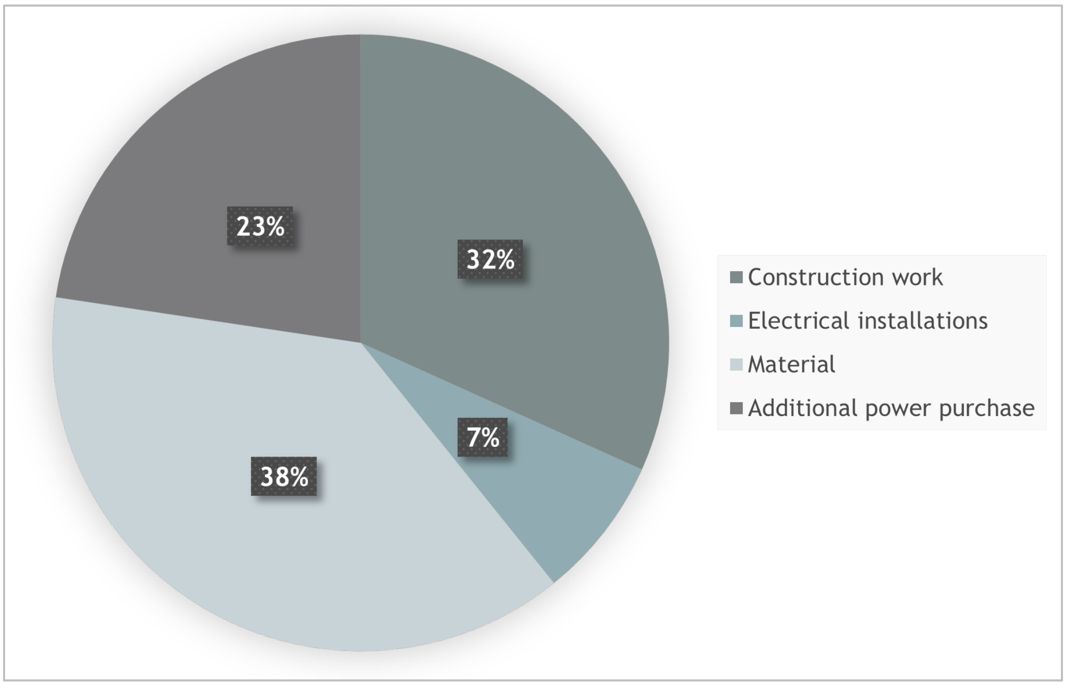

Figure 5: Share of various works for implementing a charging station

38% of all costs were material costs, followed by the construction work (32%) and the additional electricity purchase for 150 kW of power.

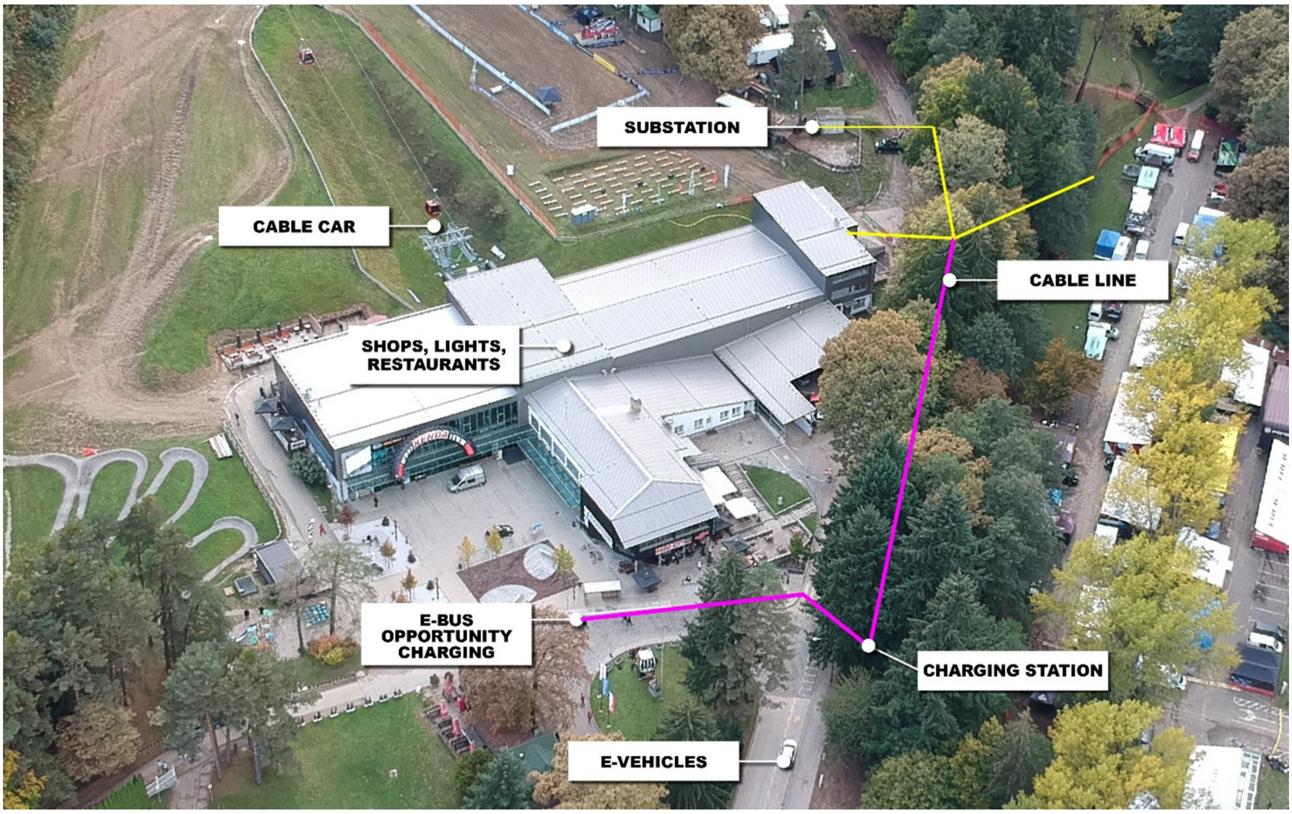

Figure 6: Aerial picture of an e-bus fast (opportunity) charging at Vzpenjača station (Source: City of Maribor)

Evidence of success

The fast-charging station was put into operation on Thursday, June 16, 2022. During this time, the buses were charged with 835.63 kWh of energy. The charger was used 102 times and the average charging time was 4 minutes.

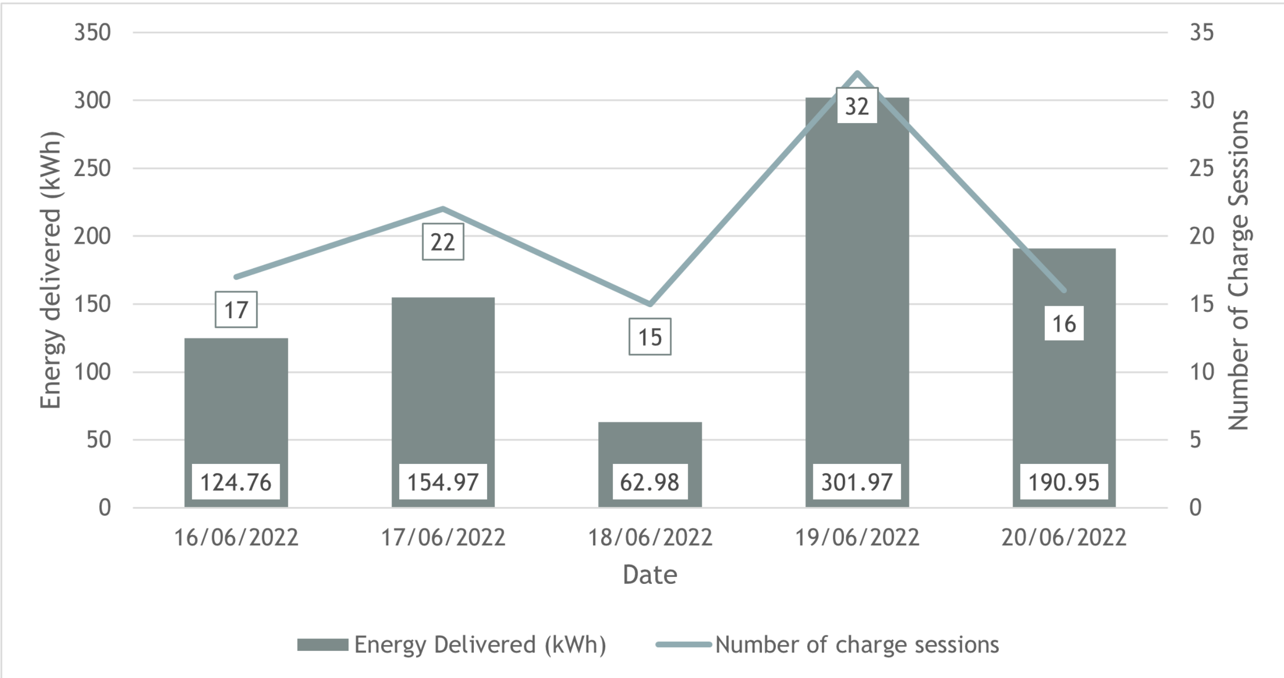

Figure 7: Charge sessions and energy delivered on the fast-charging station Sp. Vzpenjača

Real-time charging time without pantograph manipulation was also measured. This time is important for the calculation of the real charging power of the fast charging station and for a better optimization of the bus schedules.

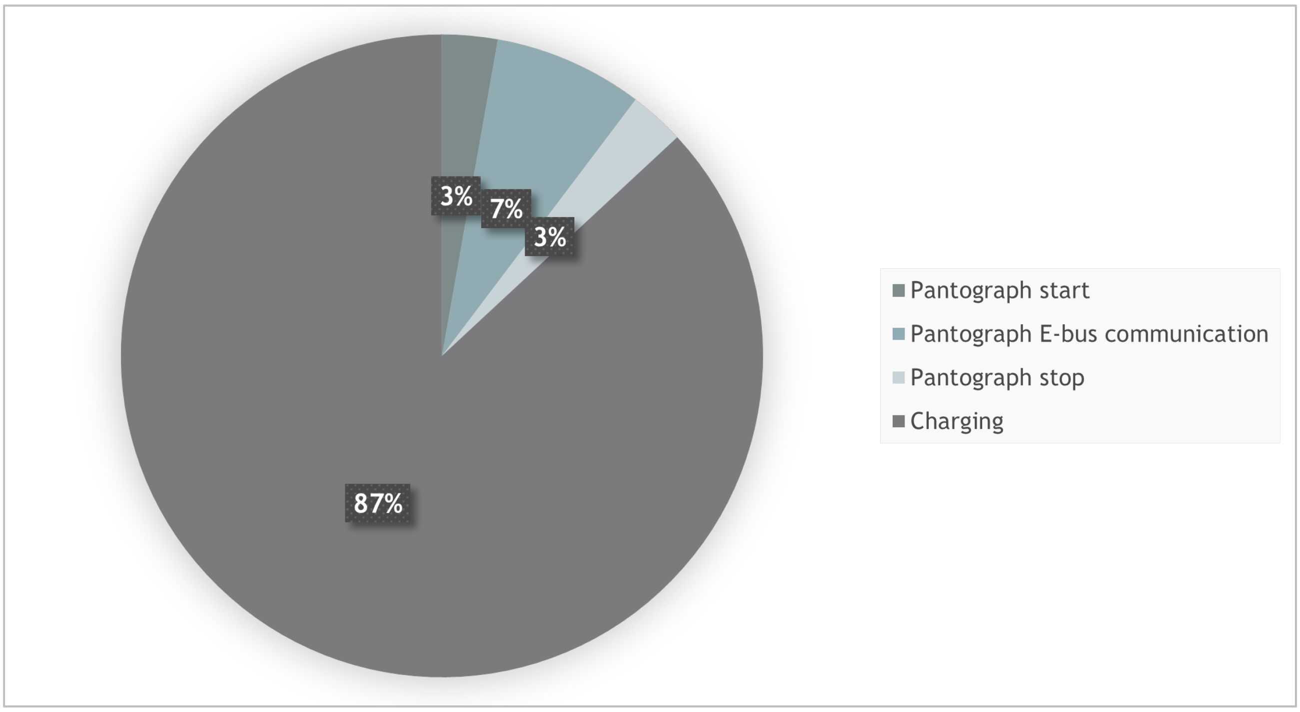

Figure 8: Charging session duration

Photo by City of Leipzig

The table below shows the charging time when the E-bus is charged for one minute. 87% of the time is spent charging, 7% is spent establishing communication between the fast charger and the bus, and 6% is spent moving the pantograph up and down.

Event	Share	Duration (mm:ss)
Pantograph moving	6%	00:04
Pantograph E-bus communication	8%	00:05
Charging	87%	00:51

When testing the fast charger, many errors were found during the charging process. Only 73% of all completed operations were successful, the rest were errors. In 14% of the unsuccessful completions, the position of the E-bus was incorrect. In further tests, this error will be able to be corrected, as the reason for this is the turning radius of the Sp. cable cars.

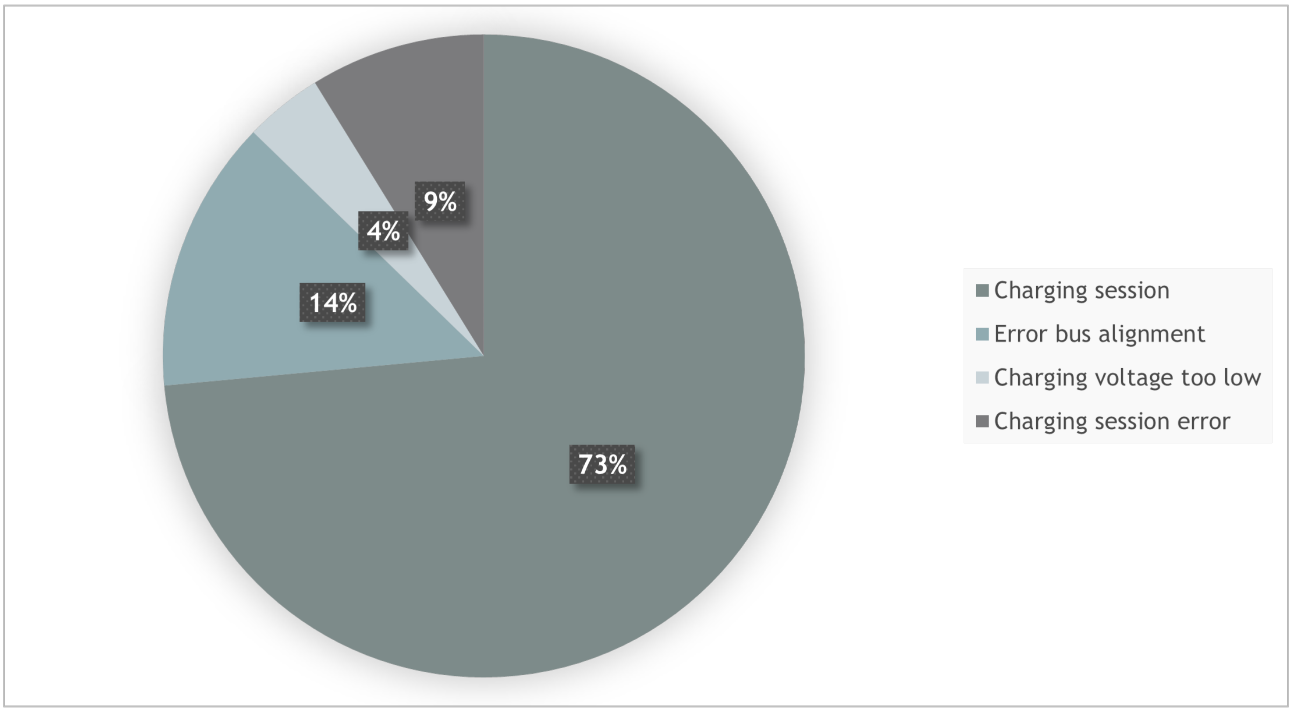

Figure 9: Overview of stop reasons by charging with the fast-charging station Sp. Vzpenjača

Difficulties encountered

For the power supply, a new conduit had to be built from the transformer to the charging station (power box), into which a new low-voltage cable line is pulled in. From the power box to the pantograph, a new pipe cable duct was provided, into which DC and communication cables for the power supply to the pantograph were pulled in.

A comprehensive energy analysis of the existing power transformer to which an electrical bus charging station is to be connected is planned. The measurements of the transformer load are carried out in two steps. The first set of measurements evaluates the current load of the substation before the charging station was connected. The second is performed after the charging station was connected.

The maximum peak load during the measurement between 2020 and 2022 was 399 kVA. Considering the maximum peak load-based 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 charging station's maximum apparent connected load of 348 kVA, the peak load could be 698 kVA. The existing 630 kVA transformer would be inadequate and would need to be replaced with a new 1000 kVA transformer.

Potential for learning and transfer

Figure 10: Demonstration of the operation of the pantograph (Source: City of Maribor)

The investment will serve as a showcase for a multi-purpose PT infrastructure for charging e-buses, e-cars, and cable cars not only in Maribor but throughout Central Europe. The experience and lessons learned from EfficienCE will enable MOM to expand the PT multi-purpose infrastructure in the city, as there is a high replication potential for cost-effective substation upgrades in its network.

1.4 Integrating a buffer storage station into the trolley network to increase energy efficiency (Pilsen)

Short description of pilot investment

The innovative solution is the use of a buffer storage station directly in the problematic overhead line section, which is based on high-performance batteries and intelligent computer control and requires neither an external power supply nor extensive construction work. The technical basis of the buffer station is a galvanically isolated traction drive (DC 600 V / DC 600 V), which ensures safe and reliable power transmission to and from the traction drive. The main station controller controls the traction of the drive. An air conditioning unit was installed in the buffer station to provide temperature equalization, which is critical to the health and longevity of the batteries. The technology and all components of the buffer station fit into the self-supporting steel frame, allowing for easy and quick installation or relocation. The main limitation of this solution is the short-term support of the overhead system and battery life.

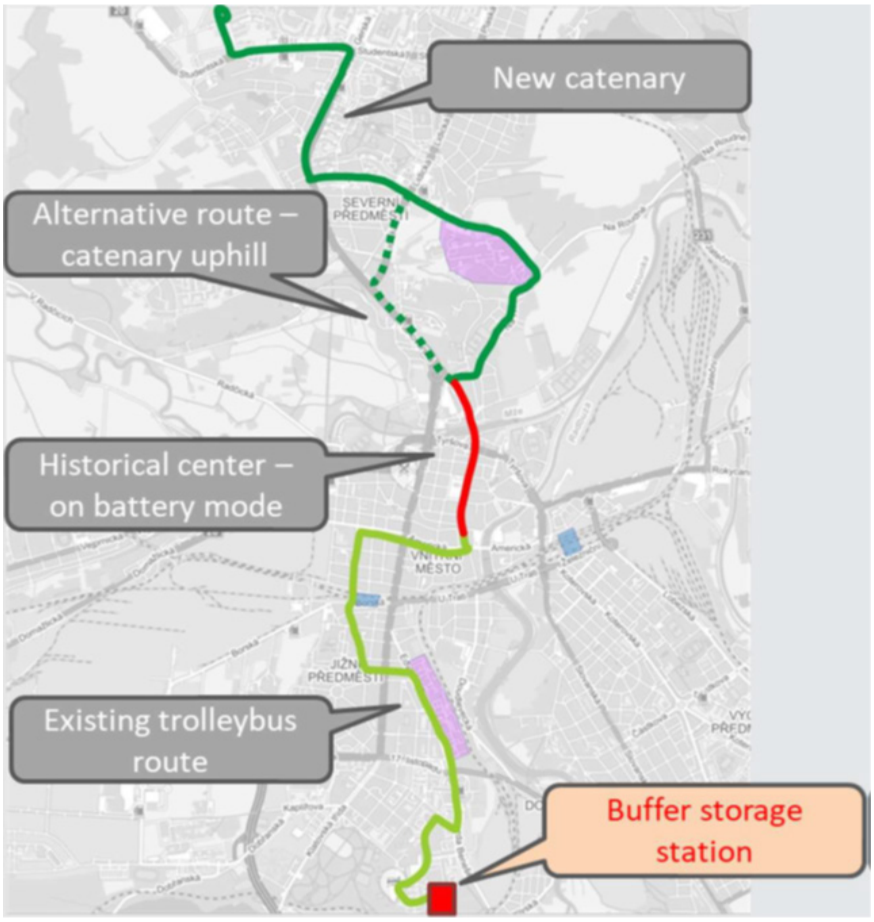

Figure 11: Trolleybus project to the hospital and Northern Suburb

Resources needed

The increase in trolleybuses and battery-powered trolleybuses also means an increase in overhead power consumption. Some sections of the overhead line have already reached the limit of the power supply. In these sections, there is a reduction in voltage on the overhead line when the load is higher. This voltage drop leads to short-term main failures. The innovative solution with the implementation of buffer storage directly at the location of the weak overhead line section is the answer to the conventional solutions. The innovative buffer storage station consists of a high-performance battery and an intelligent computer control system. All components, together with the air conditioning system (to ensure an appropriate temperature climate in the battery depot), fit perfectly into a self-supporting steel frame. This solution ensures flexibility in terms of easy and quick installation or relocation, if necessary. No external power supply is required to operate the buffer storage station.

Evidence of success

The solution is suitable where it is necessary to strengthen the power supply network and prevent voltage drops at higher loads. It can be used in combination with a renewable energy source, such as PV panels. It is important to correctly determine the required parameters (capacity, efficiency, peak current load).

Difficulties encountered

The use of a larger number of trolleybuses that are charged while in motion means higher electricity consumption in the sections where these vehicles are running and charging. In some sections, the existing power grid reaches its capacity limit, which is reflected in a reduction of the voltage in the trolley bus at higher loads. These voltage dips can lead to momentary power outages or immediate failures of the trolleybus drive units, which pre-emptively stop operating when the voltage is too low.

The first challenge in implementing leased battery stations to support trolley traction was the fact that only prototypes of such stations were available on the market. Therefore, it was necessary to specify the required parameters before a tender for the purchase could be carried out. It was also necessary to be innovative in the field of costs (economic challenge), exceeding the expected and prepared budget. The lease price increased due to the RFP and included requirements for testing the prototype battery station. In addition to these two challenges, the technical challenge of placing the battery station with the disconnect switch and insulation in the trolleybus turning circle area had to be overcome.

Potential for learning and transfer

Pilot tests were focusing on gathering data in case of outage/reconstruction of the loading converter station, supporting the network at the final section, and in the case supporting the network at increased consumption. The first impression of the installed investment is positive. The solution is transferable to any operators of trolleybus or tram PT with the needed support to strengthen the power supply network by preventing voltage drops at high loads. It is also suitable in combination with a renewable energy source (PV panels)

Figure 12: Buffer storage (Source: PMDP)

2. Conclusions

EfficienCE aimed to increase energy efficiency and the use of renewable energy in public transport infrastructures to achieve local, regional and also EU energy targets. To this end, 12 partners, including 7 PT authorities/companies from 7 different CE countries, worked together to test novel energy saving technologies in PT infrastructures, which are the first of their kind in CE. From RE integration in metro stations (Vienna) and trolley depots (Gdynia) to upgrading a substation for multipurpose use of existing PT infrastructure (Maribor) and new buffer storage technologies (Pilsen).

All pilot projects were implemented and successfully tested as part of the project, but are also integral part of municipal strategies and/or SUMPs to increase energy-efficiency. The implementation of a PV system integrated into the subway station has shown that it is possible to use the roof surfaces of public infrastructures to supply electricity to users and buildings. Recuperated braking energy is transferred to the trolleybus depot grid to power the building. Connecting the station requires no additional installation costs and no building permit, which shortens the investment period. Upgrading an existing cable car substation and integrating an E-bus fast charger allows to expand the PT multi-purpose infrastructure in the city, as there is a high replication potential for cost-effective substation upgrades in its network. Integrating a buffer storage station into the trolley bus network to increase energy efficiency and an innovative solution is the direct deployment of a buffer storage station. The technology and all components of the buffer station fit into the self-supporting steel frame, which allows for easy and quick installation or relocation.

The project results have a high degree of transferability and the projects become a nucleus for leveraging investments and multiplier effects for EE PT infrastructures.

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