DELIVERABLE T1.1.3

Managerial approach on multipurpose usage of PT infrastructure

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Executive Summary

This deliverable places energy efficiency in the public transport operations through shared use or multipurpose use of public transport infrastructure high on the agenda. As a pretext, the deliverable also captures the challenges leading to stressing the need to have energy efficiency measures such as the multi-purpose use of the energy and charging infrastructure. Furthermore, it outlines briefly the steps undertaken by EfficienCE partners to implement the pilot demonstrations showing both strategic and operational approaches to go about implementing and later on following it up with some lessons learned and action plans to pursue based on the result of the demonstrations. The planning process for implementing such pilots which provides a good base to prepare strategies and action plans is argued as one of the key aspects before embarking on achieving larger decarbonization goals as well as energy and mobility plans.

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1. EfficienCE action plans and pilots to increase multipurpose use of electric PT infrastructure

EfficienCE partners have committed themselves to replace diesel buses with clean buses by introducing electric mobility gradually, to decrease air and noise pollution as well as the public transportation system's dependence on fossil fuels. This is based on political decisions from higher levels. Thus, EU member states and their cities need to prepare for decarbonisation of public transport, as the Directive 2014/94/EU of the European Parliament and of the Council of 22 October 2014 on the deployment of alternative fuels infrastructure asks Member States to develop appropriate infrastructure of charging and filling stations (electricity, CNG, LNG and also hydrogen). Also, Directive 2009/33/EC on the promotion of clean and energy-efficient road transport vehicles (CVD) requires for member states in the period 2026 - 2030 certain shares of clean buses (e.g., for the Czech Republic, 60 %, of which 50 % must be fulfilled by procuring zero-emission buses 50 % by procuring other types of "clean" buses like alternative fuels powered vehicles).

While the electric drivetrain for buses are themselves more efficient than their conventional counterparts, the introduction of energy infrastructure within the system introduces the need to optimize the consumption and reduce the operational costs further. This is linked to the high-power requirements for charging of e-buses and the lack of availability thereof in many cities, also, energy providers are refusing to provide new connections, which is a driving force for multipurpose use of already supplied power using existing infrastructure. Thus, using and develop existing or new electric surface electric transport PT infrastructure with a built traction network (e.g., tram, metro or trolleybus) for many purposes, e.g., as an urban smart energy micro-grid, which integrates renewables, battery storage systems, car and e-bike chargers.

Multipurpose use of PT infrastructure introduces many advantages, but also makes high demands on the planning process. In terms of advantages: space is used more efficiently through shared charging hubs with consolidated energy demand, a circular economy perspective is introduced through intensifying infrastructure use, clear economic advantages are linked to lower investment costs, as not every vehicle type needs its own charging infrastructure, new operational and business models are possible for energy distribution system operators, as they benefit from surplus energy in the network that can charge buses,cars and other vehicles within the concept of charging hubs. The challenge, however, is that many different factors, plans, and stakeholders need to be considered in the planning process.

The EfficienCE project approached this challenge by developing three action plans and testing four pilots (integrated in local strategies). The action plans are used within ongoing strategy processes or to update existing strategies. Doing so, the project partners used the SUMP[1] (sustainable urban mobility planning) concept as framework for planning.

In the following chapters, the managerial approach of the partners, as well as their lessons learned from planning, implementing and evaluating multipurpose use of PT infrastructure, are described[2].

[1] https://www.eltis.org/mobility-plans/sump-online-guidelines

[2] EfficienCE D.T1.2.3 Action plans for energy-efficient PT infrastructure deployment from Pilsen, Maribor, Budapest, and EfficienCE pilot implementation and evaluation reports on pilot actions D.T3.2.3 (PKT Gdynia), D.T3.3.3 (Maribor), D.T3.4.3 (PMDP Pilsen) describe the results in more detail, and can be found on the EfficienCE website: https://www.interreg-central.eu/Content.Node/EfficienCE.html.

2. Integration of EfficienCE results into local strategies

This chapter explains how the EfficienCE action plans and pilots related with multipurpose use of PT infrastructure are used to update or refine local strategies for PT decarbonisation. Thus, the PT company Plzeňské městské dopravní podniky (PMDP, CZ) and the City of Maribor (SL) tested pilots serving local SUMP goals and used the pilot results as a stakeholder inspiration to develop action plans based on extensive analysis of local challenges, potential for multipurpose use, and resulting investment needs. These action plans are included in the SUMP update for Pilsen and Maribor. The PT authority Budapesti Közlekedési KözpontBKK (BKK, HU) used the EfficienCE project developing an action plan in line with their new vehicle strategy, to understand challenges and future investment needs for a multipurpose PT infrastructure in Budapest. Przedsiębiorstwo Komunikacji Trolejbusowej Sp. z o.o. w Gdyni, the Gdynia trolleybus operator (PKT, PL) tested an inverter to charge e-cars from recuperated braking energy as part of the municipal strategy for electromobility as an exemplary measure that can be applied in planning documents for other trolleybus operators. Along with the recuperated braking energy which, if not used immediately to power vehicle auxiliaries is lost in the form of heat, PKT Gdynia also would like to combine the solar energy in the near future to power the trolley bus depots. Hence, investments made in EfficienCE to test the alternative usage of recuperated braking energy is an important element of the local strategy of PKT Gdynia which focuses on optimizing the existing available energy from different sustainable sources thereby limiting the losses within the trolleybus traction network.

In Pilsen, the strategy of sustainable mobility of the Pilsen agglomeration (SUMP PA) brings in its design part a total of 93 measures for the development of an integrated transport system. The PT company of Pilsen, PMDP’s strategic goals in EfficienCE and at large, in the field of public transport are several measures for the electrification of urban transport and increasing its energy efficiency. As part of the EfficienCE project, a battery storage station was tested in Pilsen. The battery storage station/charging station made it possible to limit voltage drops in the trolleybus traction network. Since local strategies of PMDP driven by SUMP prioritizes modernization of PT electric fleet, e-mobility development – using battery technologies in trolleybuses and buses, he results from buffer storage system tested in EfficienCE contributed to the strategic goals of PMDP. The other goal, solved together with the University of Gdańsk, was to determinate needs and possibilities for power supply by IMC trolleybus network expansion. This evaluation process and cooperation should design the possible use of buffer storage stations and set the parameters about quality or quantity of their elements for in-motion charging projects which is in line with the plan to develop SUMP ITI for Pilsner agglomeration, which will be a time (outlook 2040) and area extension of existing SUMP.

In Maribor strategic policies on Urban mobility (SUMP), Urban logistics (SULP) and energy concept represented the main framework for implementation of Strategy for Multipurpose use of PT infrastructure with the focus on e-bus fast charger. Driven by local strategies as outlined in the action plan of Maribor, the plan for multipurpose use of PT infrastructure includes also implementation of PV on main bus terminal, workshop and Cable car station, implementation of energy storage and usage of old batteries from e-buses. In relation to electrification of Public Transport, the trends in Multimodal aspect are considered through integrated technical measures on charging infrastructure for different modes (e.g. Cable car, buses, rail, e-cars, e-bikes, e-delivery vans, e-garbage trucks), while the trends in multifunctional aspect are related to integration of Renewable energy sources, smart monitoring/charging, Vehicle to Grid technology and using of regenerative braking of trains for charging e-vehicles or PT Stations/Workshops. The strategy also tackles the challenges of management, spatial and energy planning for public transport through different management measures (e.g. change management, supplier contracts, data management, innovative procurement processes), and environmental measures (local production of energy through RES (Photovoltaic).

SUMP update in Pilsen

At the city level, the main strategic document is the Sustainable Mobility Plan of Pilsen (PUMP), which supports decision-making on the implementation of both investment and non-investment measures in Pilsen's transport services for the period 2016 - 2025. It is declared SUMP goal to further electrify PT by extending the tram and trolleybus network, with the outlook to also cover the functional urban area (FUA), thereby replacing Diesel buses by battery trolleybuses. This leads to an increase in overhead power consumption, and partial limits of power supply. The result is a reduction in voltage on overhead lines when the load is higher, leading to failures.

To limit voltage drops on bus line #11 through introducing a battery trolley bus, PT operator PMDP tested a battery buffer storage station (BS), giving evidence to grid stabilization measures in the SUMP update (spring 2022) that support further fleet electrification through battery-technology in trolleybuses, extension of further trolleybus lines, and overall increase of travel comfort in trolleybuses.[3] The BS was used directly in the problematic overhead line section, is based on high-performance batteries and intelligent computer control, and requires neither an external power supply nor extensive construction work.

SUMP update in Maribor

The EfficienCE Action Plan for energy-efficient PT infrastructure deployment was developed as a supportive strategy for SUMP and other relevant strategic and investment documents adopted by the Municipality of Maribor in recent years:

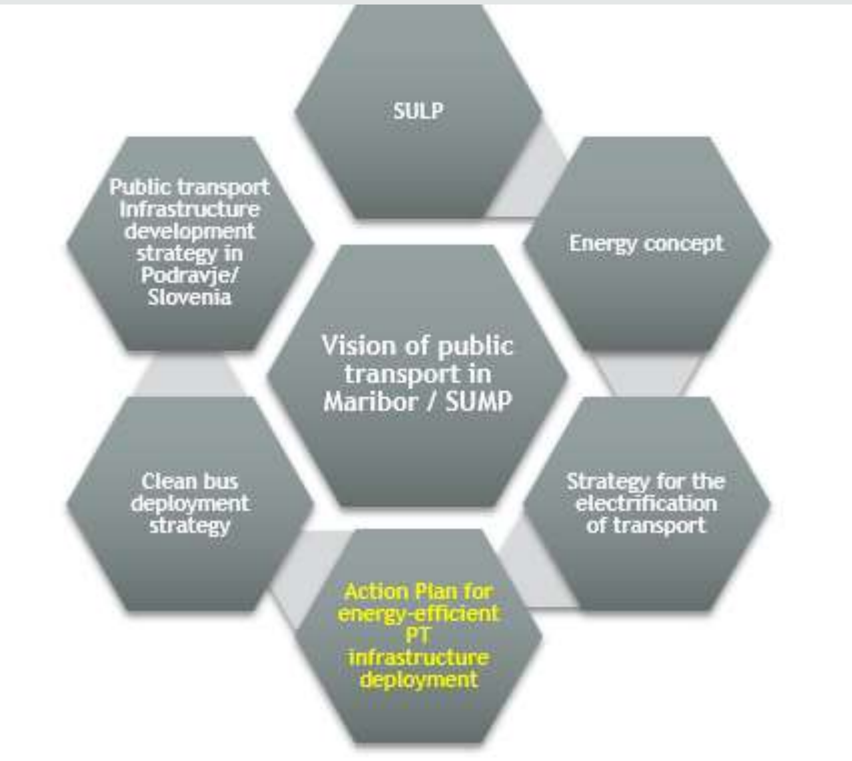

Figure 1: Schematic overview of the strategic documents of the Municipality of Maribor

The Municipality of Maribor developed an action plan for energy-efficient Public Transport (PT) infrastructure deployment as a long-term solution for energy-efficient public transport and fast charging of e-buses. It includes ways to invest in charging infrastructure for PT in Maribor in parallel with charging

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of other e-modes and integration of different novel functionalities of multipurpose hubs. Identified challenges represent the broad area of impact of electrification framework and the obstacles in the implementation process. Vision and long-term goals set the ways to introduce decarbonized PT and renewable energy solutions in the Public transport in Maribor and represent the basics for the developed measures in action plan.

The action plan supports the strategic objective to fully electrify its PT by 2030, as laid out in Maribor's SUMP, SULP, and the municipal energy concept. The action plan includes technical measures on infrastructure and vehicles investments, RES and management measures to improve the energy efficiency of PT in Maribor. Since rerouting the PT network affects the location and performance of the charging infrastructure, the selection of charging concepts must be based on the selected future PT network that is planned to be implemented. Multipurpose use of PT Infrastructure in Maribor refers to the multimodal and multifunctional use of infrastructure PT, which combines various solutions for the integration of PT networks (railroad, cable car, regional bus, city bus), mobility and logistics hubs with different modes of transport and RES. Main measures are based on the electrification of the urban PT service in conjunction with other modes of mobility and logistics. Implementation of detailed measures and investments will lead to 20 % less GHG emissions and noise, and 25 % less energy-costs by 2027.

As a pilot, Maribor tested a fast charger for e-buses, and used the preparation, implementation and evaluation process as inspiration for the action plan development.

Budapest – plan in alignment with vehicle strategy

BKK, the PT authority of Budapest, identified defined the technical and financial parameters of the infrastructure needed for electrification of its entire system based on multipurpose considerations to reach its goal to fully electrify local PT by 2050. The study area covered the administrative territory of Budapest, including buses, trolleybuses operated by BKK and the agglomeration bus service segment of Volánbus within city-limits. The action plan complements BKK's Vehicle Strategy, as it specifies the decarbonisation process of Budapest's public transport sector for the 2022-2050 timeframe. The action plan evaluates the timing of procurement activities, to reach the zero-emission goal for 2050, when all buses operating in Budapest should be local zero emission buses. It defines measures, such as acquisition of further zero-emission buses (battery operated trolleybuses or e-buses) and the implementation of the estimated 200-250 required charger infrastructure between 2026 and 2030, as well as transforming the external operator contracts with zero-emission requirements between 2030 and 2040 – from the remaining available amount, preparing terminals, terminus and bus and trolleybus depots for the growing electromobility challenge.

The action plan sets out the size and cost of the vehicle purchases and the main groups of lines to be served by electric buses or trolleys in the future. In the design of vehicle acquisitions and infrastructures, due consultation with stakeholders, not only from a vehicle but also from an accessibility perspective.

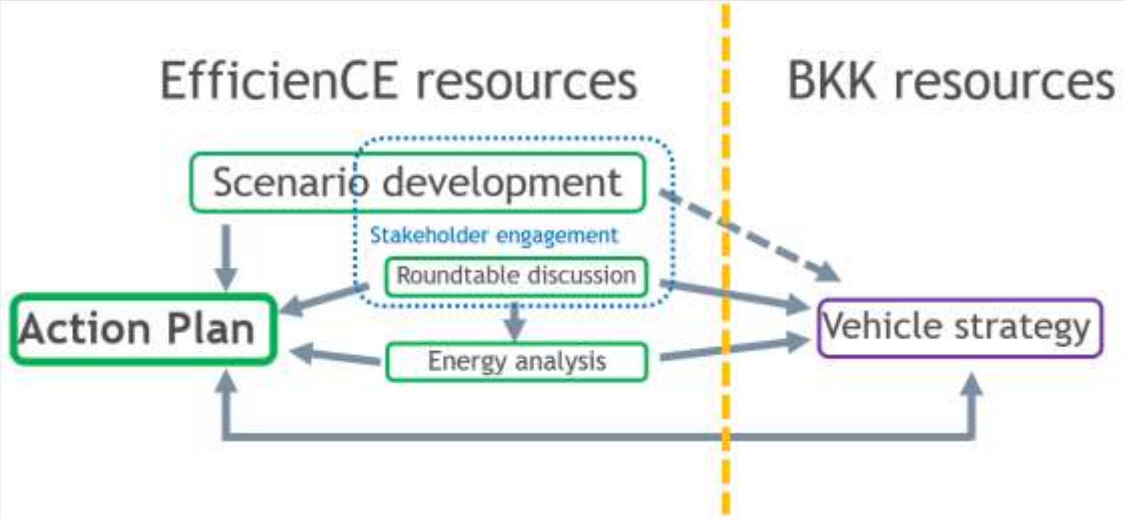

Figure 2: BKK action plan was supported by the vehicle strategy in Budapest

In a consultation process with local stakeholders, BKK identified trends, vehicle groups, costs, and planned additional studies to specifically plan for depots, charging points, and procurement.[4]

3. Preparation and analysis

Exploring the current situation is the first step in the electrification of diesel buses. To conduct needed feasibility studies and to identify and develop possible scenarios or pathways how to reach the given policy objectives, external expertise was organized by the partners.

In Maribor, the EfficienCE project partner university of Maribor was responsible for analysis of the status quo (age, energy-mix, energy consumption, share of RES) of the current PT system in Maribor, as well as for the scenario building process with the main goal of developing long-term solutions for energy-efficient public transport and fast charging of electric buses, such as a hierarchy of lines for electrification based on impacts of Diesel buses on inhabitants.

The focus of the scenario process was to develop a path for electrification of the entire PT fleet from a multi-purpose aspect with alternative scenarios and alternative strategies (see chapter 4).

[4] D.T1.2.3 Action Plan BKK, O.T1.2.1 Output factsheet BKK action plan, D.T1.1.3 Managerial approach on multipurpose PT infrastructure use

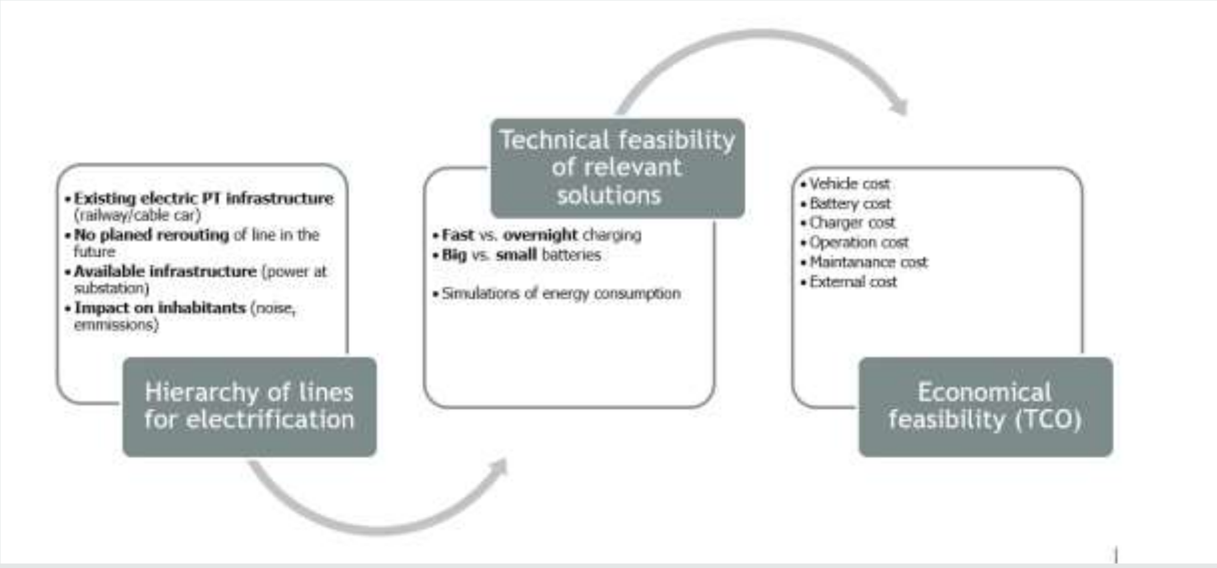

Figure 3: Methodology for scenario assessment in Maribor

Furthermore, University of Maribor carried out technical and economical studies to assess feasibility of solutions identified with stakeholders. Thus, the assessment methodology helped to identify basic conditions, resulting in defining a line electrification hierarchy of lines: available existing electric PT infrastructure, no planned rerouting of line in the future, available infrastructure (power at substation) and impact of replacement on inhabitants (less noise, emissions).

According to available infrastructure line 6 represents the most adequate solutions, due to the fact, that it is the only line operating near to local PT infrastructure (Cable car), Railway network is in national responsibility. Line 6 was suggested to be selected as first line to be electrified.

In addition to the positive effects on the modal split, urban bus transport in Maribor also has negative effects on the number of inhabitants. These negative impacts are emissions, noise and greenhouse gases, which largely depend on the type of propulsion system. Since electric propulsion is more environmentally friendly, produces less noise and fewer emissions, all bus lines in the municipality of Maribor are evaluated according to the number of inhabitants who are most exposed to the negative impacts of bus transport; the inhabitants live 100 m away from the line (example of line 18). Based on the timetable and the number of inhabitants along the line, a priority list for the electrification of the lines was created.

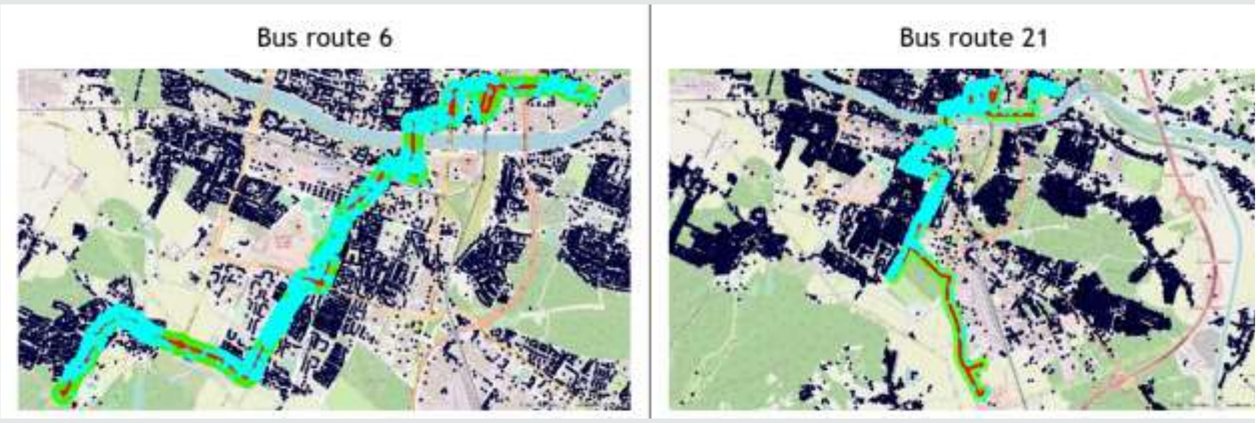

Figure 4: Bus routes examples to calculate impact of buses on inhabitants

For a selected line or group of lines a tool to determine the optimal battery size and charging power was developed. Main part of the tool represents the analysis/simulation of energy consumption of a single bus route with a mathematical model to calculate energy consumption based on infrastructure (Altitude change), vehicle characteristics, drive cycle data and timetable. It evaluates different scenarios of input data on recuperation, heating/cooling system, passenger load, battery size, charging power, dwell time, delays, etc.

For route 6 different technological solutions were identified according to batterie size (small batteries vs. big batteries) and charging concepts (overnight charging, charging with one fast charger and charging with two fast chargers at the end and at the beginning of the road).

For selected technical feasible solutions additional tool was developed to assess TCO (Total Cost of ownership. The tool for assessing the costs of different charging options is based on economic parameters (operating cost-energy consumption (€/kWh/km), infrastructure costs, vehicle costs, battery costs, external costs).

BKK, the PT authority in Budapest, investigated its future PT infrastructure and energy needs in parallel to developing the Budapest vehicle strategy (e.g., for trams, metros, e-buses incl. fuel-cell, trolley) against its assumed socioeconomic and spatial development. The study was done by the sub-contracted Budapest University of Technology and Economics with the Department of Transport Technology and Economics, preparing the Energy and Infrastructure Analysis for the Budapest Public Transport Vehicle Strategy and the Action Plan.

The BKK study's main scope was the examination of the location and ratio of overhead catenary length/vehicle batteries and charging points for the pre-defined BKK Public Transport route groups and possible use of electric buses in Budapest Public Transport network. The study considered temperature extremes on a probabilistic basis and energy needs (winter minimum and summer maximum for operating heat coefficients affecting battery capacity). It contained detailed energy assessment of bus and trolleybus garages in Budapest, definition of possible energy developments, examining connection of bus depots, station charging points to the electricity grid, assessment to meet electricity demand, assessment of needed financial resources and financing opportunities. The study covered the identification of the basic characteristics of the groups of lines for each one. The energy demand of the lines belonging to the groups of lines as well as the number of charging points at the terminus. For each sub-section, the length, the number of vehicles entering and leaving at the same time, the peak hours, the time spent on the section, the number of stops were determined based on the timetable of PT lines and also the type of vehicle (solo, articulated) analyzed. These data help to determine the energy demand of the PT lines at the group of lines. Based on the baseline data, the estimated energy demand and the energy demand per relationship were established in the study.

In addition to examining the electrification of the main public transport lines currently served by buses (electrically operated buses or trolleybuses), BKK also examined the vehicle requirements of other modes of transport (tram, metro) for the following period by 2040 in terms of purchase period and purchase price.

The study analyzed the electrification of the main bus lines at public transport network in Budapest.

Total cost of vehicle purchase and terminus infrastructure development: 486 526 000 EUR
(194 610 000 000 HUF)

- e-buses: 235 327 000 EUR (94 130 800 000 HUF),
- trolleybuses: 251 199 000 EUR (100 479 200 000 HUF)

Total cost of depot infrastructure development: 23 198 000 EUR (9 279 200 000 HUF)

- e-buses: 19 313 000 EUR (7 725 200 000 HUF),
- trolleybuses: 3 885 000 EUR (1 554 000 000 HUF)

The total cost: 509 724 000 EUR (203 889 200 000 HUF)

- e-buses: 254 640 000 EUR (101 856 000 000 HUF)
- trolleybuses: 255 084 000 EUR (102 033 200 000 HUF)

In Pilsen, cooperation with the supplier's development department and especially with experts from the University of Gdańsk was established for measurement planning, data processing design and detailed analysis. These skills already exceed the normal capabilities of the electricity public transport operator. The buffer station can also be used to supply charging stations for electric vehicles, e.g. electric cars. However, then an analysis of the legal conditions for the sale of electricity would be required.

Stakeholders involved

Stakeholder involvement was at the core of EfficienCE planning process to define the 1. challenges and opportunities, and to 2. discuss the scenarios or pathways how to reach the policy goals set out in the relevant strategy documents. To this end, the partners organized stakeholder workshops on the local level.

Stakeholders involved by BKK were Hungarian key actors, such as BKV (Budapest Transport Ltd), BME (Budapest University of Technology and Economics), Volánbusz (National bus company, operating buses at national, regional and city level) discussed the main issues of electrification and decarbonization of current bus fleets. BKK also involved an expert from EfficienCE partner Wiener Linien to give input.

As a take-away and based on the good results from stakeholder dialogue in EfficienCE, BKK plans to continue having regular round table discussions with stakeholders on the phasing out of diesel buses in Budapest, with the objective to update strategies being prepared, and also coordinate exchanges with other Hungarian cities and the relevant ministries on the electrification of diesel buses, to learn from relevant actors to learn about good practices from other European conties, possible directions and alternatives.

Stakeholders involved by Maribor were selected according to their influence on local and regional transport development. They are strategic decision makers in the fields of rail, road, cycling and mobility: from municipal departments, energy suppliers, the national Ministry of Infrastructure, Ministry of the Environment and Spatial Planning, the Regional Development Agency for Podravje – Maribor, Energap - Energy Agency for Podravje; Slovenian Railways, the PT operator Marprom, the e-car rental provider Avant2GO, road infrastructure maintenance Nigrad - road infrastructure maintenance, the regional PT provider Arriva, Maribor cycling network, professional associations in the field of traffic and transport; Universities of Maribor and Ljubljana; Large enterprises: Elektro Maribor – energy distributors.

Stakeholders involved in Pilsen were the Pilsen Department for Coordination of European Projects, the Traffic Department of Technical Authority of Pilsen City Magistrate, the Management of Public Property of Pilsen City, the Department for Conception and Development of Pilsen City, the Pilsen City Transport Company PMDP, Pilsen Region Organizer of Public Transport, Pilsen Region Regional Development Agency, Road Management and Maintenance in Pilsen Region, Road and Highway Directorate for Pilsen Region, Plzeňsko na kole (Pilsen Region by Bike, NGO), Mott Macdonald (Large enterprise), Atlas Copco(Large enterprise), Royal Haskoning DHV (Large enterprise), Czech Technical University.

Definition of main challenges and opportunities

Based on analysis of the current state of the PT systems in Budapest, Pilsen and Maribor, the stakeholders identified the main needs and challenges to be worked on.

In Budapest, the aging bus fleet, and need for interventions as well as for feasibility studies to understand available infrastructure characteristics and needs (basic infrastructure, weight/range ratio, battery needs, spatial planning conditions, heating and cooling effects, power needed, ideal distribution of chargers, battery lifetime considerations, vehicle capacities. Also, stakeholders stated that highly polluting buses make up a significant share of the bus fleet in Budapest, and that the most pollutive buses with a classification of EUR 5 or under should be phased out by 2026 – approximately 400 vehicles, and that Diesel-powered buses with an age of 15 or more years should not be operated. Furthermore, it was considered an advantage to rely on the existing trolleybus overhead network and operational experience. Considering the major route groups, the cost of developing an electric bus and trolleybus network was stated to be about the same.

In Maribor, discussed needs and challenges were structured:

Further needs discussed with stakeholders in Maribor

- Spatial planning / Infrastructure needs,
- Needs on vehicles, energy and consumption and
- Needs on economy, financing and image.

Main challenges identified at the workshop were

- Technical and operational challenges,
- Planning challenges and
- Financial/Economic challenges.

Planning, technical, and economic problems pose the greatest challenges for all partners. In addition, financing options pose the greatest challenge to future planning, as do legal constraints between the private and public sectors with respect to electricity sales. Contractual constraints and RES appear to be less difficult to resolve. For Maribor, in terms of technical and operational challenges, the main problem lies in the use of fast charging stations with the existing railway electrical infrastructure.

In Pilsen, a high share of electrified public transport, represented by the modern trolleybus system, including hybrid / battery trolleybuses, and excellent walking distance to public transport, are seen as most important assets. Further electrification of public transport and the growing number of electric vehicles are, however, a challenge for battery charging and electricity supply, that the current infrastructure can not catch up with. Stabilisation measures are needed.

4. Strategy development

To understand the risks and opportunities related to current trends and possible changes in circumstances, to inform about likely impacts of different, and to create a factual basis for developing a vision and objectives, the EfficienCE partners developed scenarios that were discussed with stakeholders.

Scenarios help to better understand the likely effects of external factors that affect urban mobility in combination with alternative approaches to react to them. By illustrating different possible future situations, they allow planners to assess the consequences of current trends, potential societal and local changes, as well as alternative strategic policy priorities independently of each other. Examining the effects of these different scenarios strengthens the factual basis for strategic decisions. It can inform and inspire the development of vision and objectives and helps to set realistic targets for strategic indicators[5].

Figure 3 Scenarios – definition from SUMP 2.0 guidelines

BKK developed scenarios of future PT vehicle developments in order to phase out diesel buses on long term and to manage zero-emission fleet from current state up to 2050. These scenarios were: (i) Do nothing scenario, (ii) Business as usual scenario, (iii) Trolleybus scenario, (iv) Electric bus scenario, (v) Mixed scenario. The following professional aspects have been considered in the scenarios: Serving long term vision, Base infrastructure, Weight/range ratio, City landscape aspect, Operational hours/range, Power needed, Distribution of chargers, Battery lifetime, Capacity of vehicles.

The scenarios have considered the modal split by 2030, which stated at the Budapest Mobility Plan, the SUMP (Sustainable Urban Mobility Plan) of Budapest.

Nearly 1,400 buses need to be replaced in Budapest by 2050, which will require a rethink of the entire Budapest bus transport system. The 5 scenarios provide different pathways how they could manage the level of decarbonization of diesel engine buses by 2050.

The outcome of stakeholder meetings was that the mixed trolleybus and electric bus option has the greatest value in Budapest and it is the most feasible to implement by 2050. The phasing out of diesel buses can only be achieved gradually, and the Action Plan should examine the steps to be taken in several scenarios (optimistic, realistic, pessimistic). A network of multiple systems responds to the spatial and historical context of Budapest. For this reason, the Mixed version of how to develop Budapest public transport is the most valuable, economically suitable of all.

In Maribor, 5 scenarios were assessed about synergies with their plans and strategies with stakeholders:

- Do nothing
- BAU (Business as usual), where electrification of modes (with focus on Public Transport) is done individually,
- Trend A, where electrification of modes (with focus on Public transport) is built on existed PT infrastructure (rail, cable car)
- Trend B, where electrification of modes (with focus on Public Transport) is considering multimodal and multipurpose aspects
- Trend C, where electrification of modes (with focus on Public Transport) is integrated with rail transport, regional bus and in-motion charging.

The scenario process provided a clear understanding, that changes in the field are necessary. Trend A was implemented for the bus route 6. Visualisations of scenarios for the next stakeholder workshop led to selection of Trend B and Trend C as most relevant to follow. The main difference is in implementing fast chargers for e-buses vs. building catenary for hybrid trolleybuses or other dynamic charging solution

[5] https://www.eltis.org/mobility-plans/activity-41-develop-scenarios-potential-futures

In Pilsen, three scenarios were discussed with stakeholders, as described in table 2.

Scenario	Description / Technology	Pro / Contra / Synergies / Risks (Negative effects)	Policy / Stakeholders
Maintain the current state	Maintenance of PT infrastructure and the continuous modernization of the vehicle fleet to maintain the current share of 65 % zero-emission PT	Pro: lower financial costs, certain operating costs Contra: development lag of PT, without improving the city environment Synergies: common tram and trolleybus service Risks: deepening of investment debt	Basic implementation of Clean Vehicle Directive Only financial coordination at the local level
Gradual development of e-mobility	Modernization of tram fleet and depot reconstruction. Trolleybus network development using in-motion charging (IMC) technology and construction of new overhead sections.	P: realistic financial costs, attainability C: zero-emission target achievable after 2045+ S: maximizing the use of existing infrastructure R: economic downturn, vehicle price trends and battery development	Zero-emission bus deployment strategy according to SUMP and Clean Vehicle Directive Coordination at the local level (PMDP, City of Pilsen)
Rapid shift to emission-free public transport	Two new tram extensions, depot and tram fleet modernization. Extensive trolleybus network development and use of IMC fleet. 2-pole static charging e-buses for supplementary bus routes.	P: maximal improving the city environment C: high investment costs, higher operational costs S: maximizing compatibility and joint use of network development for trams, t-buses & ebuses R: economic downturn, price and political instability	Zero-emission bus deployment strategy strenghtened in SUMP High level of coordination with developers, authorities and national subsidy policy

Table 1: Scenarios for upscaling of IMC trolleybus infrastructure in Pilsen, developed by PMDP

Vision and objectives

In Maribor, based on stakeholder discussion around scenarios, a vision of Multipurpose use of PT Infrastructure was elaborated:

"Create a competitive and sustainable public transport service by deploying alternative fuels to reduce transport emissions and improve air quality and noise levels in urban areas. Lower energy consumption of people's mobility and establish green environment accepted by society and end-users"

Among other key objectives, Maribor plan to make energy-efficient public transport a priority in urban planning, integrate cable car and PT energy management, integrate electrification of other urban e-transportation modes (e.g., e-car sharing, e-bike charging stations, e-van sharing, e-buses), including the legal process involving various stakeholders such as industry and private, Integrate 50% of e-delivery and e-waste collection vehicles into the charging infrastructure of e- PT and Establishment of near 100% grid stability in within the greater vision of multipurpose use of PT. Likewise in Pilsen, PMDP aims to achieve a long-term increase in the quality of life while not unnecessarily burdening traffic, environment or public resources and BKK aimed to increase the energy efficiency of public transport networks and to promote the use of renewable energy sources. Based on the vision, objectives as described in table 3 were defined.

No.	Indicator category	Indicator	Data availability and method	Current (2022)	Goal (2027)
1	Environmental	% Of clean vehicles	Counting - PT (Marprom) Vehicle register (all vehicles), Energy transport model	5 %	25 % 100 % in Friendly zone till 2030
2	Energy	Grid stability	Elektro, Marprom (city energy distributor and supplier)	99%	99,9%
3	Energy	Energy cost and consumption (€, kWh)	MOM, Marprom, Elektro, HEP, Petrol (city energy consumer and supplier)	1,4 mil €	Decrease for 25 %
4	Environmental	Noise and emissions	MOM (traffic noise and emmisions model)		Decrease the noise and emmissions of PT by 20 %
5	Environmental	% of RES used	Counting MOM. Marprom	18 %	25 %
6	Transport	Load Factor	Counting Marprom, MOM (PT transport model)		Increase for 20 %

Table 2: Main goals with indicators, Maribor

In Budapest stakeholders decided to adhere to the objective as defined in the Budapest SUMP, to enhance environment-friendly vehicle technologies through the encouragement of the diffusion of vehicle technology solutions supporting climate policy, in improving the energy efficiency of vehicles, supporting the introduction of sustainably produced fuels and promoting the introduction of new propulsion systems, which reduce harmful emissions by the transportation system.

In Pilsen, in terms of their efficiency, the SUMP updated based on PMDP's contribution defines that "electric drives are a clear choice for the future development of the construction of means of transport. Public transport can draw on the advantage of a large proportional use of vehicles and infrastructure, i.e. in the total volume of costs, the part intended for the establishment of (still) relatively expensive equipment for electric operation (especially infrastructure) does not appear to be dramatically higher compared to fossil fuel drives. The higher purchase price of vehicles and infrastructure is compensated by cheaper, significantly more efficient and environment-friendly operation."[6]

5. Measure planning

The City of Maribor developed a list of investments and priorities in the implementation of the multipurpose use of the infrastructure of PT for the next 5 years (2023 to 2028) with a view to the year 2030. It is not a binding document in terms of the city budget. The main responsible parties for the implementation are the Municipality of Maribor and Public Holding Maribor with PT operator Marprom and power supplier Energetika Maribor. Electricity distribution is to be provided by Elektro Maribor. By the planned measures, Maribor expects to halve the CO2 emissions of the bus PT. The measures include 1. additional fast charging infrastructure with charging stations serving multiple bus routes and close to the transformer station. On the other hand, route prioritization for electrification was planned by weighing factors like noise value, average age of the buses on the line, daily mileage and altitude

[6] D.T1.2.3 Action Plan PMDP

differently. Maribor then merged the charging station plan with route prioritization plan to incrementally introduce electric buses in operation. 2. Owing to the benefits like existing PT infrastructure, available excess capacity of the current grid, improved grid stability, lower operating costs due to lower energy price and dynamic management of other modes, Maribor prioritized multipurpose charging hubs. Planning of simple multipurpose charging hubs can integrate limited number of modes and functionalities. It depends on the importance of the hub and spatial conditions as depicted in figure 5.

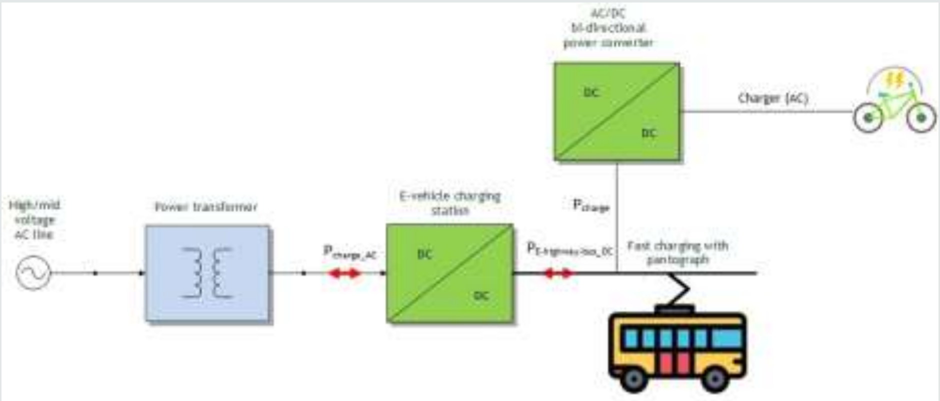

Figure 5: Example network connections in a multipurpose charging hub

BKK in its action plan outlined detailed measures to decarbonize the transport and act upon other Budapest’s sustainable goals. In public transport, among other measures trolleybus overhead line-network was planned to be expanded 2 times to its current length, the extension of a metro line and multipurpose hubs. In order to determine vehicle purchases (when to purchase which type of vehicle), it is important to consider several socio-economic variables. Within the framework of the vehicle strategy, BKK examined 3 socio-economic scenarios with low, medium and high growth prospects. In total, 20 criteria were assessed. Each criterion was associated with 1 low, 1 medium and 1 high growth future condition (scenario). Based on expert analysis, the most likely scenarios were then selected. In addition to the levels of development, minimum PT vehicle fleet requirements have been defined. The assessment criteria were the following: maximum age, target average age (optional), passenger comfort level and target electric powertrain ratio. The expectations given have an impact on the need for vehicle replacement

In Pilsen, the development of the integrated transport system follows the horizon of 2040. Therefore, the optics of the design part is focused on the "S-Bahn Pilsen" concept, which brings a transport service model for the Pilsen agglomeration based on frequent rail transport. In the horizon of 2030, five of the six railway lines starting from Pilsen will be electrified with an AC power supply system of 25 kV 50 Hz. according to economic and technological possibilities, to gradually replace diesel buses with electric buses optimally with the possibility of recharging during standstills or even while driving from a two-pole traction line. The evaluation of the proposed measures in SUMP ITI was carried out by members of the Working Group, or other experts nominated by one of the members. In any case, however, the evaluators are independent of the authors of the proposed measures, which guarantees a certain objectivity and a different view of the nature and expected benefits of individual projects. The number of nominated evaluators in each chapter varied from six to eight. Accordingly, the measures include, Extension trolleybus lines and transfers selected bus to trolleybus traction with use alternative battery drive. Supplementing the trolleybus infrastructure (trolleys, cables, power supply) o necessary sections for optimal combination traction and battery drive, especially sections of Slovanská alej, Francouzská, Částkova, Lobzy, Průmyslova intersection and others within reconstruction or new buildings (Masarykova, Samaritská). Checking the possibility of connection charging stations for the trolleybus infrastructure, addition of the catenary line with maximum use of the existing infrastructure and the power supply solution for the traction line and examination of the possibilities of electrification of bus public transport and regional bus transportation.

6. Implementation and monitoring - EfficienCE pilots

EfficienCE tested the solutions that improve energy efficiency including the multipurpose use of PT infrastructure in Pilsen, Gdynia, Maribor which aligned with the local strategies. Partners further elaborated the action plans based on the results, learnings. Implementation threw light on the challenges both technically, in governance and regulatorily. But also, gave lessons on the benefits of investing in improving energy efficiency through giving multipurpose use to new and existing PT infrastructure such as buffer storage station in Pilsen, charging hubs in Maribor, etc. In any projects where we have piloting new and innovative solutions, strong monitoring is an important element of the innovation cycle which shows the gaps between expectations and reality as well as gives an opportunity to tune the pilot implementation towards experiments that yield positive results. In EfficienCE, KPIs were carefully selected and monitored to determine the success (or some counter lessons thereof) of the pilots in each site. This indeed will serve as a basis to draw up further strategies and concrete action plans with the vision of putting energy efficiency at the center of PT operations.

In **Pilsen** already today, 74% of passengers are transported by emission-free modes, of which 46% use trams and 28% use trolleybuses. The tram network is complemented by backbone trolleybus lines, which represent a modern emission-free and quiet means. It is a declared SUMP goal to further electrify PT by extending the tram and trolleybus network, with the outlook to also cover the functional urban area (FUA), thereby replacing Diesel buses by battery trolleybuses. This leads to an increase in overhead power consumption, and partial limits of power supply. The result is a reduction in voltage on overhead lines when the load is higher, leading to failures. To limit voltage drops on bus line #11 through introducing a battery trolley bus, PMDP tested a battery buffer storage station (BS). The BS was used directly in the problematic overhead line section, is based on high-performance batteries and intelligent computer control, and requires neither an external power supply nor extensive construction work. Overall, the station helped equalizing the electric power demand by providing power in peak moments, while storing electric energy in off-peak minutes. It made the PMDP trolleybus power network smart and more stable, providing extra power supply for battery trolleybuses through mitigating the fluctuances in a trolleybus power network, when battery powered vehicle need to recharge itself. The pilot supported replacing 2 Diesel buses on the bus line, which would lead to an annual reduction of Diesel consumption by 112.000 l or 295 t of CO2, and to less noise and air pollution.

The battery storage station was purchased in the form of a lease agreement. The monthly price for the lease, operation and maintenance of the station, as well as the performance of tests and measurements during the EfficienCE project, amounted to CZK 113,000 (approx. 4,300 EUR / month). The tests also replaced the battery technology from lead to lithium. The operation of the station was financed by PMDP with the grant support of the Interreg program. The data results of all tests were collected by PMDP and were sent for analysis to the University of Gdańsk, which processed a complete evaluation of the project. As part of the EfficienCE project, the battery station was in operation from 1 April 2020 to 31 March 2022, ie exactly two years.

The charging station made it possible to limit voltage drops. It is visible in the charts below. Ubuff means the voltage level below which the buffer station supports the supply of the overhead line. As can be seen, with the buffer station connected, the voltage drops in the overhead contact line below Ubuff are significantly reduced. The table shows a comparison of voltage drop times before and after activation of the buffer station. The improvement factor means how many times the voltage drop time has decreased.

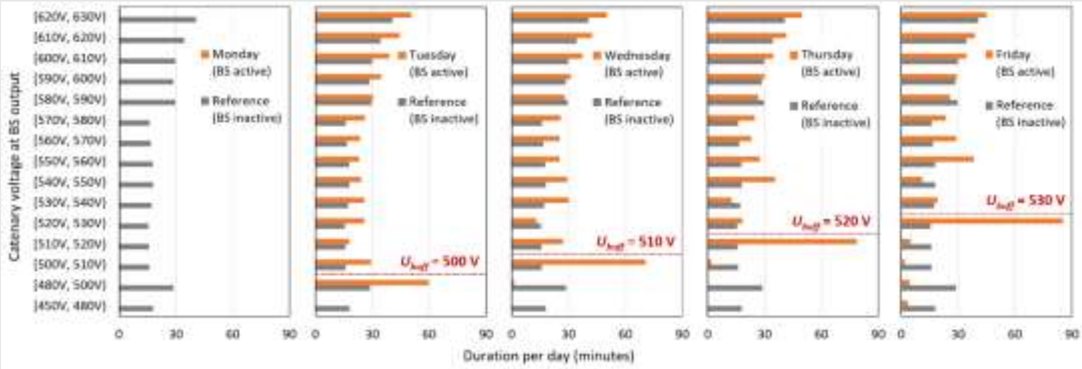

Fig 6: Performance measurement of buffer storage station

Indicator	Monday	Tuesday	Wednesday	Thursday	Friday
U_{buff} setting	520 V	530 V	540 V	550 V	560 V
t_{drop} for reference	397 s	548 s	722 s	932 s	1216 s
t_{drop} with active BS	7 s	12 s	14 s	37 s	40 s
Improvement factor k_t	56.7	45.7	51.6	25.2	30.4

Table 4: KPI v/s Measurements leading to conclusions

During the design works, the algorithm for controlling the battery charging of the buffer station was modified. The purpose of the modification was to improve the interception of energy recovery by the buffer station. After changing, the battery is charged mainly with energy from regenerative braking. The diagram below shows the voltage at which the buffer station is charged. As you can see, after modifying the control algorithm, charging occurs at higher voltages, which means that the regenerative braking energy is used.

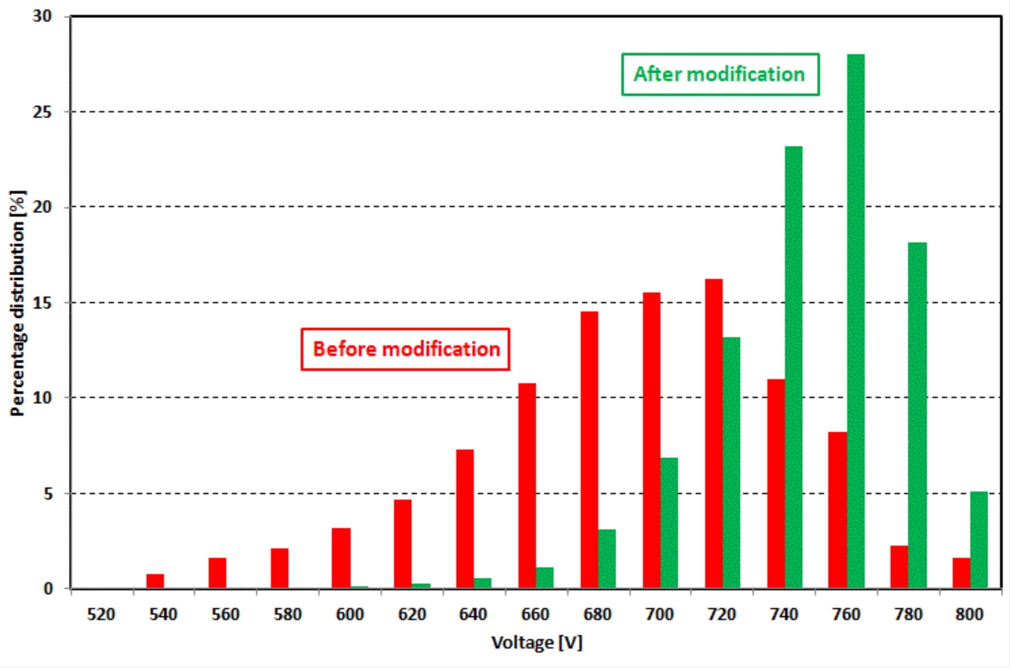

Fig 7: Indication of the effect of introduction of buffer storage station

By evaluating the data from the pilot operation, it is possible to determine the optimal way of using this technology. There is possible to suggest and design further upgrade like usage of high capacity batteries and/or supply small photovoltaic power plant.

An important part of this pilot was the cooperation with the University of Gdańsk. Evaluating pilot run outputs, designing potential new electric routes, design of power supply optimization, including the use of a buffer storage station, will be done in cooperation with PP University of Gdaňsk.

Buffer storage station does:

- help equalize the electric power demands during the whole day, by providing power in peak moments, while storing electric energy in off-peak minutes.
- make the trolleybus power network smart and more stable.
- also provide extra power supply for battery trolleybuses, mitigating the fluctuances in trolleybus power network, when battery powered vehicle needs to recharge itself from power network.
- The buffer station can be an alternative to the construction of classic traction rectifier substations
- A buffer station can be a place for the use of used batteries from electric vehicles - 2nd life of battery

The other goal, solved together with the University of Gdańsk, was to determinate needs and possibilities for power supply by IMC trolleybus network expansion. This evaluation process and cooperation should design the possible use of buffer storage stations and set the parameters about quality or quantity of their elements for in-motion charging projects.

In cities where the trolley network covers a large part of the city (e.g., Gdynia), a buffer storage station can be used to supply consumers with electricity, in particular where the availability of the public power grid is limited. The most predestined recipients are electric car charging stations.

The solution is transferable to any trolleybus or tram operator in need to strengthen their power supply network by preventing voltage drops at high loads. The buffer station can be the place of application of the "second life" battery. Used batteries (“second-life”) from electric vehicles (e.g. trolleybuses with auxiliary drive, electric buses or electric cars), which after several years of operation have a reduced capacity and are not suitable for use in a vehicle, but can still be used in stationary applications, can also be used in the buffer station.

Expertise needed for implementation

In Pilsen, in terms of expertise required, the operation of tram and / or trolleybus transport requires trained maintenance personnel, but also technical experts with a high level of knowledge in the field of electrical engineering. This condition is met in Pilsen and PMDP, so no further training of employees was necessary. Only routine operator training and driver information was provided.

Special emphasis must be placed on the correct assignment of technical parameters for the procurement procedure of the buffer storage station, which requires qualified personnel on the part of the contracting authority with long-term experience in the field of technology and transport. Not only knowledge of electrical systems, but also a good knowledge of operational needs in terms of transport, is a prerequisite for any successful innovation project in the field of emission-free urban transport.

Testing a fast charger

The Municipality of **Maribor** invested in the modernization of an existing cable car station and integrated a fast-charging station for e-buses. This allows using the electricity from the cable car station both for operating the cable car and for charging an e-bus. The investment will serve as a showcase for a multi-purpose PT infrastructure not only in Maribor but throughout Central Europe. By supporting the electrification of one bus line with e-busses, the pilot contributes to (annually) 190 t less C02 emissions, 40 % less noise, 80 % less energy costs, reduced maintenance, short charging time (5 minutes to charge with 12 kWh), and a return of investments within 8 years.

Charging e-cars with recuperated braking energy from trolleybuses (inverter)

PKT Gdynia implemented an innovative energy inverter allowing to feed the otherwise wasted energy directly into the building’s energy system or to the charger. For this it was necessary to have a specifically designed DC/AC inverter placed in the depot for connecting the DC traction grid and the charging station or building’s AC grid. In order to increase the reliability of the power supply (e.g., in the event of excessive drops of converter input voltage) and to increase the flexibility of accumulation of trolleybuses regenerative braking energy, the station was equipped with a battery-based electric energy storage. For this purpose, a second-life traction battery from a trolleybus was used.

Fig 8: DC/AC Inverter

The power conversion process is split into two stages. First, the system uses the DC/DC converter, which provides galvanic separation from the traction network voltage and regulates the battery charging current. Next, the DC/AC converter delivers the power to the charging station via an additional transformer used for insulation purposes. The output power is 50 kW. The charging station is supplied by 3 × 400 V AC, which is a commercial standard. Hence, a typical fast charger for electric cars was used.

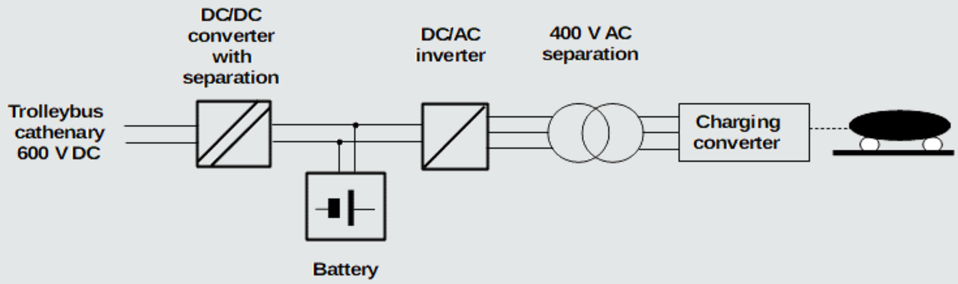

Fig 9: Thematic circuit of the multipurpose use of overhead traction network

The connection of vehicle charging stations and the urban transport energy system can be carried out in different manners, which is shown on the figure below.

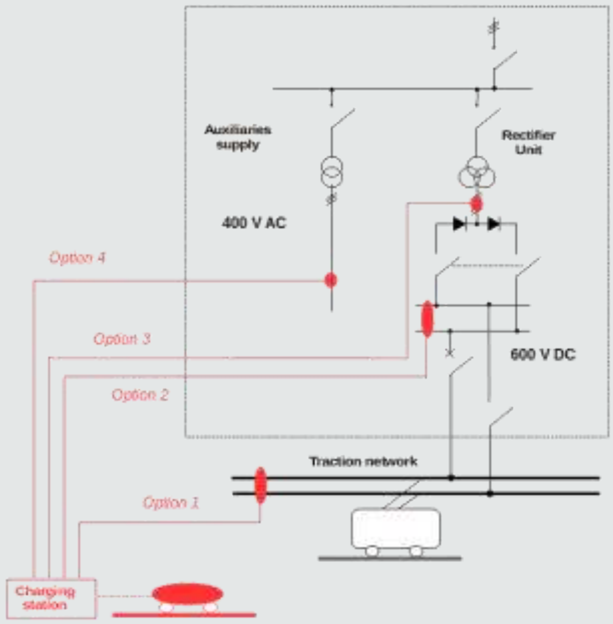

Fig 10: Options for multipurpose use of high voltage traction network from trolleybus

The charging station may be connected to the DC level, i.e., directly to the traction overhead line (option 1 in Fig. 3) or to the DC busbars in the substation (option 2). Such solutions allow the best synergy between the systems, mainly due to possibility of directing the trolleybuses regenerative braking energy to the charging stations. An additional advantage of drawing the power from the overhead contact line (option 1) is a large spatial accessibility of the overhead traction line. The power that can be drawn from the overhead line by the charging station depends on the distance from the traction substation and the design of the traction network. Under favorable conditions (close proximity to the substation and large cross-section of the overhead line) it can be at the level of 200-300 kW, but in most cases the available power is approximately 50-100 kW. Supplying the charging station from the DC part of the traction power system (both options 1 and 2) requires the use of a DC/DC power-electronic converter, which is not a typical solution, thus substantially increases the costs of the system. In turn, powering the charging stations from the AC voltage (options 3 and 4) uses standard solutions, which makes it inexpensive. However, the AC voltage is available only in traction substations. A detailed comparison of all the options is included in Table 5.

Option no	Supply method	Supply voltage	Advantages	Disadvantages
Option 1	Power supply from overhead traction line	600 V DC	1) Large spatial availability of the power source; 2) Synergy between traction power supply and vehicle chargers	1) Limitations related to the current load capacity of the traction network; 2) Voltage fluctuations; 3) Possible power outages; 4) Deterioration of the power supply parameters for vehicles; 5) Necessity to use a DC/DC converter
Option 2	Power supply from DC busbars of traction substation	600 V DC	1) High power available; 2) Synergy between traction power supply and vehicle chargers	1) Applicable only in the vicinity of substations; 2) Necessity to use a DC/DC converter
Option 3	Power supply from the secondary circuits of rectifier transformers	525 V AC	1) High power available	1) Applicable only in the vicinity of substations
Option 4	Power supply from auxiliary circuits of traction substations	400 V AC	1) Possibility of using typical chargers (without transformers or power converters)	1) Applicable only in the vicinity of substations; 2) Limited power available

Table 5: Detailed comparative analysis of options for multipurpose use

The exemplary electric vehicles charging system powered by the tram overhead line has been launched in Oberhausen, Germany. It consists of a DC/DC converter, three electric cars charging stations and one electric bus charging station. Charging station for electric bus and electric cars powered from tram overhead line in Oberhausen, Germany.

Fig 11: Charging station for electric bus and electric cars powered from tram overhead line in Oberhausen, Germany.

Monitoring Buffer Storage station

KPIs were develop in cooperation with PP, the University of Gdansk. The main KPIs describe:

- the ability of voltage level balancing (elimination of the number of undervoltage cases - elimination of voltage drops)
- the ability to deal with turn-off / power cut the supply from substation (temporary replacement of the supply point)
- the ability to cover peak power consumption from the substation (charging battery trolleybuses, air-conditioning...)
- the efficiency of the buffer storage station and possibilities of efficiency increase, for example, using another type of battery
- the possibility of increasing the number of operated trolleybuses and dynamic (IMC) trolleybuses (determination of needs and possibilities for IMC trolleybus expansion - to use more battery trolleybuses in Pilsner public transport instead of diesel buses)

Note: The battery technology of the battery station during the project was changed, the new lithium-based batteries show better performance parameter.

KPI	Description	Measurement Unit
Degree of energetic self-supply by RES	Ratio of locally produced energy from RES and the energy consumption over a period of time	%
Reduced energy curtailment of RES and DER	Reduction of energy curtailment due to technical and operational problems; the integration of ICT will have an impact on producers, as the time for curtailment will be reduced, and the operative range will be wider	%
Average number of electrical interruptions per customer per year	Average number of electrical interruptions per year	N* year
Average length of electrical interruptions	Sum of the duration of interruptions in hours (numerator) divided by the total number of interruptions (denominator); the result shall be expressed as the average length of electrical interruptions in hours	Hours
Energy savings	Reduction of the energy consumption due to the implementation	kWh, %
Storage Capacity	Energy storage technologies installed capacity	kWh
Battery Degradation Rate	Capacity losses of the batteries, through use (some cycles) and through time (some years); the conclusions of this KPI concern the effectiveness of this technology, the need for maintenance and thus, gives useful data	kW, %

	concerning the financial feasibility of its integration	
Storage Energy Losses	Losses generated by battery storage, including the added voltage transformations	kWh, %
Efficient vehicles deployed	Number of efficient vehicles (electric/hybrid buses/trolleybuses) deployed, and percentage on total fleet	N, %
Increase in Local Renewable Energy Generation	Renewable Energy generated by the project	kWh/year, %
Emission Reduction	Emissions (CO_2, PM10 and PM2,5, NO_x) reduction achieved by the project, and percentage on the relevant context	Tonnes/year, %
Reduction of energy expenditure	Economic benefits of the intervention in terms of reduced cost of the consumed energy	€/kWh, €/year
Return on Investment (ROI)	Ratio between the total incomes/net profit and the total investment of the project	%
Payback	Time needed to cover investment costs. Payback period is usually considered as an additional criterion to assess the investment, especially to assess the risks	N of years
Total Investments	Value of asset or item that is purchased or implemented with the aim to generate payments or savings over time	€/m2 or €/kW
Total Annual costs	Sum of capital-related annual costs (e.g. interests and repairs caused by the investment), requirement-related costs (e.g. power costs), operation related costs (e.g. costs of using the installation) and other costs (e.g. insurance)	€/year

9. Barriers and lessons learned

For the implementation of new solutions, often barriers are encountered on Societal, Technical/technological, Economic, Ecological, Political/Regulatory (STEEP/R) grounds. Similarly for EfficienCE pilot implementation, there were a few barriers encountered by partners as listed below.

Pilsen pilot

- The COVID-19 epidemic and the subsequent waves of restrictive pandemic measures significantly affected the implementation of the project, especially in terms of the dates and venues of the EfficienCE project.

- Tendering process of buffer storage station - limited number of supplier companies (narrow specialization in the field of rail urban transport), large differences in the bid price
- Structure and complexity of measured data, delays on data transfer and delays of analysis by University of Gdansk – time and effort need to modify measuring devices and evaluation software on substations, buffer storage station and vehicles; additional costs, postponed schedule
- Excessive energy consumption (own consumption, losses) of buffer storage station and limited ability to absorb recovered energy from the overhead contact line - we changed the battery technology of the battery station during the project, the new lithium-based batteries show better performance parameters, especially the ability to accumulate brake energy and thus reduce the overall consumption in the power grid. Another solution is to use of conventional solutions (construction of a new substation or cable reinforcement).
- The container solution of the battery station is ideal for testing and quick installation (assembly and recovery in a single day, possible exchange "piece by piece"), on the other hand, installation of battery technology in existing technical buildings can be more economical in terms of investment and operating costs.
- The buffer station only slightly influenced the use of energy braking recovery in vehicles. It is true that the modification of the control algorithm caused the BS to charge mainly the recovered braking energy, but it did not affect its total balance (energy recovery did not increase). This is due to the fact that the "Bory" substation supplies a large area of the trolleybus network and is also connected to the tram network, so that the generated energy for recovery can be used by other vehicles. To assess the increase in the use of energy recovery, the BS would have to be installed in another place of the trolleybus network.
- The small impact of BS station installation on braking energy recovery is also due to the fact that in most trolleybuses in Plzeň, braking energy recovery does not function properly, which was found during the data analysis. Therefore, in the first place, it is necessary to modify the energy recovery system in the existing trolleybuses.
- In this case, these are older vehicles (approximately 8-16 years), which have unsatisfactory recuperation values

Gdynia pilot:
The theoretical analysis carried out showed a great potential for the use of the traction energy system to supply external facilities. The practical implementation of UPNEiMT as part of the EffcienCE project showed the possibility of the practical implementation of this idea. The main problems identified were:

- low demand for this type of service, electric cars are still not very popular. Although there is an increase in their number, the demand for charging stations is relatively small and the currently available standard solutions are perfectly sufficient
- charging stations powered from the traction network are much more expensive than standard charging stations, this is due to the unitary nature of their production
- there are no business models that would make power supply to external recipients attractive to the bus/tram infrastructure operator
- questions on legal aspects of electricity resale from the PT organization to third parties

Gdynia pilot identified the gaps for the implementation of multipurpose use of PT infrastructure concept such as:

- mostly, legal expertise is needed to determine the legal conditions for the resale of energy to external entities.
- it would also be expected to develop business models of cooperation between the trolleybus network operator and external entities

<u>**Lessons learned**</u>

Systems thinking to plan efficiently and cost-effectively

- Find out whether the existing PT grid should be used – and extended - for multipurpose use, or whether the entire PT network should be newly planned for e-bus deployment or trolleybus, factoring multipurpose solutions. Planning should consider three different objectives: 1. achieving net zero transport, 2. increasing energy efficiency and 3. accommodating the growth of electric mobility at an affordable cost of infrastructure and energy, by keeping new investments at a minimum.
- In case of different owners of PT infrastructure, search for support within your national regulations, joining energy distributors to minimize energy costs (e.g. bigger operators and railways has normally lower energy costs, due to big consumption). If possible, seek for energy distributors which provide green energy.
- Identify problems such as energy loss (braking energy) or the need for additional power/reinforcements of the grid to power e-buses (massive problem to deploy e-buses in scale). Identify opportunities such as surplus energy in the trolley grid or cable car substation's capability of taking additional load in the form of a charging hub created with high power charging stations.
- Build scenarios, including pessimistic ones like grid companies not able to accommodate additional consumers including EVs, and optimistic ones like technology development to cost-effectively harness braking energy with innovative business models (key for decision-making).
- Rethink the functionalities and land-use that enable combining different mobility functions (such as logistics operations, heavy duty vehicles, PT-centered mobility hubs) in joint strategic locations to consolidate the energy demand as well as increase the potential for shared use of infrastructure.
- The recommendation is to perform independent verification (measurement) of real parameters of operated vehicles of all types in a given city - to avoid unexpected properties
- Make a detailed analysis of the tram and/or trolleybus infrastructure supply network.

PT: Develop new business models

- As the use of charging facilities can be optimized through multipurpose use, adequate business and management models must be elaborated to guarantee efficient use of the network and power supply. Identify revenue streams for financial sustainability and develop new business models for PT operators.

- Bring in the end users to leverage/market the benefits of cleaner air, to attract investments for expansion of the charging network.

Legal and regulatory actions needed

- Integrated tenders for design, supply and installation of the system - vehicles and charging infrastructure - would allow participants in public tenders to carry out an optimization of the entire system based on the performance required by the PT operator, transferring the design risk of the system to the suppliers.
- To better integrate electric vehicles and infrastructure within PT fleets, it seems necessary to review current methods of accessing funds by extending them to operating leases for integrated offerings of vehicles, infrastructure and energy, as well as allowing operators to also access funds through the adoption of Public Private Partnerships for bus line electrification projects.
- High electricity pricing for fast charging - needs a change of national electric energy regulations or continuous use of charging station (slower charging)

Industry: Support standardization to enable interoperability

- For innovative in-motion charging concepts, systems available for rail and e-buses miss standards & regulation that allow interoperability between them.

7. Conclusion

As a collective effort between the city authorities, PT organizations and energy sector entities, new innovative ways of improving the energy efficiency were targeted in EfficienCE, learnings of which translated into action plans. On wider sense, the advantages of making smaller changes which yields considerable results such as multipurpose use of existing and new PT infrastructure provided an evidence-base for future investments and projects. Pilsen, Maribor, Gdynia and Budapest made considerable plans for decarbonization led by PT energy efficiency measures. Given the uncertainty of future developments and driving forces that govern the market, all the action plans developed scenarios and analyzed the strategies that fit the scenarios. Since there is no "one size fits all" solutions, each city shared their own challenges, barriers for implementation, extrapolated by the disruption like COVID-19 pandemic. Based on the success of the Pilsen pilot, it can be said that the buffer station worked very reliably, with minimal maintenance. Modern SW enabled parameter changes and remote evaluation. All performed load tests have shown that the parameters meet the specified requirements. This was mainly to cover power outages, possible power supply failures, or increased vehicle consumption due to the use of more, electric heating in winter, air conditioning consumption in summer, even in combination with the need to charge traction batteries of trolleybuses operated in-motion charging mode. The battery station was also able to operate successfully as an opportunity charging station for static charging of trolleybuses (without moving), i.e., in the same mode as for the electric bus. The functionality of the buffer station can be developed by adding other elements of intelligent Smart Grid networks, e.g. a photovoltaic system or power supply for electric car charging stations. Accordingly, every two years, the development of the implementation of the measures will be reviewed according to the individual areas of the SUMP ITI and their guarantors. In Budapest it was concluded in the action plan that with an appropriate intervention strategy, the phasing out of diesel buses by 2050 can be achieved by fully electric public transport and also a regular review of the Decarbonization Action Plan is needed. The review involving the relevant stakeholders in round-table discussion. For Maribor more different multipurpose charging infrastructure are recommended in relation to justified reasons for implementation, spatial boundaries and regulative limits. Complex Multipurpose charging infrastructure can integrate Electric rail charging, e-bus fast charging, e-car and e-bike charging, e-delivery van charging and multifunctional elements like Photo-Voltaic, Recuperative braking, energy storage etc. Such technology can be adopted at Railway Triangle in Maribor. Last but not the least, in order to increase the share of renewable energy, environmental measures are foreseen in public transport including installation of PV panels on the bus depots and stations.

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