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TRANSNATIONAL HANDBOOK FOR ENERGY-EFFICIENT PUBLIC TRANSPORT INFRASTRUCTURE TECHNOLOGIES DEPLOYMENT

(3) Energy storage in public transport infrastructure

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 European Union is focusing on accelerating decarbonization of the transport sector based on renewable energy sources. Electric Vehicles (EVs), Fuel Cell Electric Vehicles (FCEVs). and energy storage can greatly foster this effort and at the same time foster also cost efficiency and grid stabilization for public transport infrastructure.

The role of public transport (PT) infrastructure strongly depends on its ability to foster the efficient use of electricity in the networks, as well as to enable the integration of Renewable Energy Sources (RES). In this process, storage technologies play a very important role, with applications in depots, stations and stops, and along the lines which form transport networks.

The EfficienCE handbook on energy storage in public transport infrastructure identifies the main enabled functionalities and technologies for energy storage that can be applied to public transport infrastructure, and investigates their application in both project pilot actions and international good practices. The results are summarized three use cases (energy efficient depot, smart node, linear infrastructure) describing the typical endowment to be developed in order to enhance the energy efficiency performance of PT infrastructure and covering the main exemplary applications enabling a higher energy efficiency, a higher integration of renewable sources and a more effective contribution to the grid by public transport infrastructure.

The use cases intend to highlight the main key elements, expected benefits, challenges and barriers to be considered when planning for integrating storage technologies in PT infrastructure, providing direct references to the pilots and good practices analyzed within the project for further guidance and benchmarking.

1. Introduction

The presence of electrified vehicles and infrastructure in public transport represents an important opportunity for the decarbonization process in transport, and at the same time sets relevant technical challenges related to the stability of the grid, in particular in presence of growing shares of renewable energy sources (RES) to be integrated and exploited.

Energy storage can have a variety of functionalities in public transport infrastructure depending on the respective frame conditions and needs.

Optimisation of consumption – Storage technologies can contribute to minimize demand charges by buffering needs between peak hours and low demand times, support the integration of renewable energies to maximise the own consumption, for example from PV power plants or to improve the energy efficiency by recovering and re-using breaking energy of vehicles, provide grid stability for short-duration power loss or variations in frequency and voltage.

System operation - Energy storage systems can provide ancillary services to the grid primary response to stabilise frequency and voltage changes in the network, secondary response to correct imbalances between load and generation, and peaker plants replacement to ensure sufficient generation capacity during peak demand periods

Prosumerism/Integration of renewable energies –Energy storage technologies can better integrate and maximise the share of renewables used; depending on the cost of the storage and proposed energy/cost savings it might be necessary to include other options as providing charging infrastructure also to external parties and to become an active player in local energy networks for mobility (connections with multipurpose use of infrastructure, etc.); As prosumer with available storage capacities also energy arbitrage is possible, and therefore gain from low-price energy purchases which can be sold in high price periods.

1.1 Relevant technologies

The most relevant storage technologies for the use in public transport have been selected in order to be analysed and considered for the use cases described in the handbook. Technologies vary depending on power capacity, energy density and discharge time (Fig. 1) and therefore have different levels of suitability, functions and fields of application in public transport.

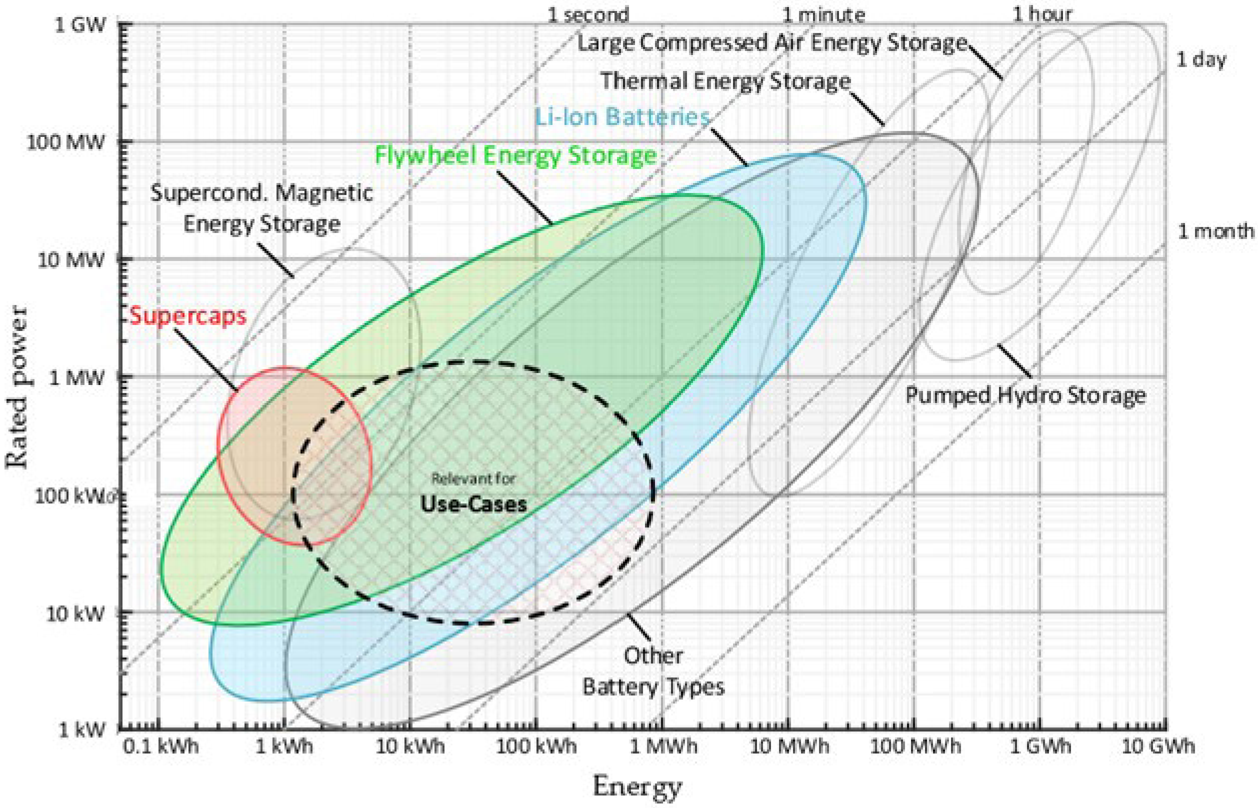

Figure 1: Power rating, energy capacity and discharge time of different energy storage systems for stationary and mobile transportation applications. (Haidl et al. 2019)

Batteries can be used either on vehicles for propulsion or other services within the vehicle (as auxiliaries, recuperation of breaking energy etc.) or as stationary storage. For stationary batteries requirements are lower for light weight and safety, they allow a wider range of battery technologies.

Among batteries, lithium-ion technologies allow high energy density, lower cost per energy capacity and low self-discharge but also less power density and high costs per power capacity, and are therefore mostly used in weight sensitive applications requiring more capacity, e.g. automotive and consumer electronics.

Second life battery storage systems can reduce peak power consumption and related costs from the grid for fast charging, enable charging in areas with grid limitations and support further services, for example the integration of renewable energies. The use of Second life batteries sounds promising to better support the grid, integrate renewables and add elements of circularity.

Supercapacitors can be produced in different sizes for various applications. Due to the very short recharge time supercapacitors allow to supply for high and frequent power demand peaks, main applications are connected to the reuse of breaking energy in railways and diverse vehicles, the integration of renewable energies and the replacement of batteries in electric vehicles.

Flywheel Energy Storage Systems (FESS) are mechanical devices to store kinetic energy for a short time. Small-sized flywheels can be used as storage devices in uninterruptible power supplies (UPS) as well as in vehicles. Main characteristics are long lifetime without capacity losses (very high number of charging and discharging cycles), high power quality, o temperature dependencies, Precise verification of state of charge / health, no deep discharge problems, minimal environmental impact.

The following table summarizes the main expected benefits and barriers of the reviewed technologies, to assess their opportunity of application according to the handbook use cases.

Technology	Expected benefits	Possible technical barriers	Possible regulatory barriers
Li-Ion-batteries	high energy density, low self-discharge	degradation, temperature sensitive, safety standards	related to second life reuse
Second life batteries	extension of the lifetime of batteries	missing standardisation, also for remaining capacity and charging	no regulatory framework, fiscal rules, energy taxes
Supercapacitor	no capacity loss, long lifetime, very low charging times, high voltage	high investment costs, low energy density, large and heavy systems for high power capacity	n.a.
Flywheels	no capacity loss, long lifetime, low charging times, high voltage, retrofitting	high investment costs, low energy density	possible safety regulations

Figure 2: Storage technologies, benefits and barriers (EffcienCE, 2021)

1.2 Energy storage and EfficienCE – the pilots and international good practices

In this section the EfficienCE pilots and good practices, distributed across different technological categories (batteries, flywheels, supercapacitors), and between stationary and onboard. The following table indicates the functionality category (consumption optimization vs system operation) as well as the main energy source involved.

	Battery	Flywheel	Supercapacitor	Stationary	On board	System operation	Consumption optimization	Integration of renewables	Brake recuperation
London (UK) Bus2Grid	V2G				x	x		x	
London (UK) Walworth depot	x			x		x	x		
Solingen (DE) Smart Trolleybus system	x			x	x		x	x	x
Hannover (DE) Rectifier substation	2ND LIFE			x			x		x
Hamburg (DE) goes electric	x				x		x	x	
Madrid (ES) eLobster project	x			x		x			x
Los Angeles (US) Metro WESS		x		x			x		x
Graz (AT) FlyGrid research project									
Huai'an, Jiangsu (CN) Supercapacitors for Public Transport			x		x		x		x
Warsaw (PL) Trams with supercapacitors			x		x	x	x		x
La Spezia (IT) Smartbus			x		x		x		x
Nice (FR) Dual-mode tramway			x		x		x		x
Gdynia (PL)*	2ND LIFE						x	x	x
Pilsen (CZ)*	x			x		x			
Vienna (AT)*				x			x	x	

Figure 3: Classification of pilots and good practices (EfficienCE, 2022)

1.2.1. The EfficienCE pilots

These examples, although focusing on different specific purposes (recuperation of breaking energy, multipurpose use of charging infrastructure, energy buffering in trolleybus networks), are all characterized by the use of storage technologies in depots, along lines, in stations.

Maribor (SI) – Multipurpose use of public infrastructure for e-Bus charging

The objective of the Maribor pilot action was to implement e-bus fast chargers in multipurpose charging facilities located by an existing cable car station and by the railway station. The infrastructures for multipurpose charging are placed at the termini of the bus line.

The solution identified for the analyzed route according to spatial planning, technical feasibility and economic viability analyses envisages the instattation of two fast chargers (150 kW and 300 kW), and the acquisition of two 12 meter e-buses with 73 kWh LTO batteries.

Figure 4: Fast charger for e-buses at the cable car station (Municipality of Maribor)

Focusing on the cable car station, the modernization involves the integration of a fast charger for multipurpose use of the existing public transport (PT) infrastructure. The power of the cable car substation used for the operation of the cable car can also be shared for the charging of an e-bus as well as e-cars. The substation has a capacity of 630 kVA, and given the current load and the capacity of one charging station, 230 kVA would be sufficient to build two charging stations.

Pilsen (CZ) – Buffer storage station in trolley network for energy efficiency

The deployment of a large number of in-motion charging trolleybuses results in higher electricity consumption in the sections where the vehicles move and charge (so far 8 articulated and 22 12 meter battery vehicles) which can generate a reduction in the voltage at higher loads and can therefore cause short-term mains failures or instantaneous failures of the trolleybus drive units.

To avoid high investment costs and long-term preparation required for the construction of a new substation or cables reinforcement the public transport operator identified the installation of a buffer storage station along the line as possible technical solution.

The chosen buffer storage station based on high power batteries and intelligent computer control and a galvanic separated traction drive unit (DC 600 V / DC 600 V) assures safe and reliable transfer of energy to and from the traction.

Figure 5: Battery buffer storage station in Pilsen(PMDP)

Possible future upgrades may include the use of high-capacity batteries (and second hand) and/or the integration of a small photovoltaic power plant for energy provision on site.

Gdynia (PL) - Recuperated braking energy and RES to power trolley depot building and application of a traction supply system for charging electric cars

The Gdynia pilot action focused on the optimization of energy resources within the trolleybus depot building, through a mix of technological applications.

The depot is equipped with a 0,5MW peak PV-power plant on the roof generating annually roughly 450MWh to be fed directly into the trolleybus grid (5% of total usage). Moreover, the braking energy from the buses is recuperated thanks to an energy inverter allowing to feed the otherwise wasted energy directly into the building's energy system.

The device also controls the level of energy consumption in the traction network, detects unused energy and thoroughly controls the energy consumption of the depot building, further enhancing its already existing energy monitoring system (EMS).

The inverter system is equipped with an innovative energy storage system, which can accumulate recovered unused recuperation energy in case there is no load on AC output. For this purpose, one battery module from a trolleybus traction battery is used (second life application).

A mobile charging station for electric cars set up as part of the project CAR (Creating Automotive Renewal – INTERREG South Baltic) by the city of Gdynia, allowing charging with different ranges of power and electric current, can be connected to the trolleybus traction network anywhere in the city and allows for synergies between the two projects.

Figure 6: Mobile charging station for electric cars powered by the trolleybus network (PKT)

Advantages of the combined system over traditional solutions are:

- connecting the station does not require additional installation costs and shortens the investment time
- no long formal process related to its construction,
- the traction network with its extensive spatial range and wide accessibility enables the charging station to be deployed where there is a problem of connecting to the AC power line, e.g. due to the need for construction works.

Within the Gdynia pilot a mobile charger for electric vehicles was connected to check how the charging of electric cars affects the stability of the network, its parameters or the regular line operation of trolleybuses.

Vienna (AT) - Metro-station integrated PV-system to power building auxiliaries with RES

Wiener Linien GmbH & Co KG tested on the Ottakring metro station a new type of foil photovoltaic system, which is five times lighter than conventional PV systems and made the installation possible on existing stations not withholding the extra weight of conventional PV systems.

Another special feature was the parallel operation of a DC (Direct Current) railway system and PV power generation for which the chosen PV modules had to meet special technical requirements (and additional

Figure 7: Opening event with local authorities, November 2019 (Wiener Linien)

Photo by City of Leipzig

costs). One of the main challenges was to place the technical equipment such as a frequency converter in a suitable place within the station and to plan the cable routing precisely to shorten the distance between the technical room and the low voltage main distributor room. The PV modules are glued to the roof and the cables are fixed in duct. Once the low voltage main distributor was connected to the technical room, the measurement components were finally installed at the power switch.


Figure 8: PV-foils on the roof of the metro station (Wiener Linien)

Technical details: The photovoltaic plant has a size of 360 sqm, a nominal power of 60,3 kWp and an annual output of approximately 60,000 kWh which covers an energy share of 6% of the yearly energy consumption of the whole metro station (also including a parking hall for metro trains). Maximum energy share per month reached was 13 % of consumption, on a sunny summer day up to 50 % of the stations power demand is covered by the PV-system. The measurements are carried out in intervals of 15 minutes. As measuring equipment, the Siemens PAC 3200 is used, and the obtained data automatically transferred to our energy control system.

1.2.2. Energy storage applications in PT infrastructure – good practices

In this section we propose a review of good practices on energy storage applications in public transport infrastructure, in some cases integrating the already reviewed approaches with functions such as vehicle to grid, wayside energy recovery systems, integration of renewable energies.

London - Bus2Grid

Bus2Grid refers to an ambitious project connecting 28 double decker buses to the grid to perform V2G tests. The buses equipped with 382kWh lithium iron phosphate batteries are charging overnight in low demand times and are capable of feeding back 1.1MW to London's grid when demand is high to provide balancing services.

The depot is equipped with AC charged with 2 x 40kW on-board-chargers, a mobile discharge facility. Very important: most V2G projects use DC (CHAdeMO) charging, therefore requiring only the ChargePoint and associated inverter - which does not move - to be certified rather than the vehicle. Of course, the cost of infrastructure is lower.

Abellio London, Walworth depot

Abellio planned to deploy 34 electric buses for TfL routes from their Walworth depot. They required battery financing and charging infrastructure services, as well as a solution to restricted grid import capacity and space constraints. Zenobē financed the 34 e-bus batteries with a managed service and installed a stationary battery to support the grid when charging the e-buses at peak periods. The battery, which provides services to National Grid during the day, generates additional income and reduces fees for Abellio. The charging infrastructure includes multiple DC chargers capable of charging vehicles at >80kW, with energy use monitored by Zenobē's proprietary software. From an economic point of view this is a unique approach which shows that battery storage connected to transport infrastructure could become an interesting business case when engaging with specialised third parties, such as Zenobē.

Figure 9: Abellio London Bus Depot (Zenobe)

Solingen - Project BOB

BOB is part of the Smart Trolleybus system and the further development of the existing catenary network into an intelligent infrastructure that is integrated into the city's electricity network. The overhead line network is coupled to the medium-voltage network, and braking energy can be fed back. Photovoltaic systems along the overhead line can feed directly into the grid without loss. Batteries installed in substations can store electricity and deliver it when required. Charging points for electric cars will be integrated.

Figure 10: https://www.bob-solingen.de/

Hannover – Rectifier substation with 2nd life batteries

In Hannover, twenty 2nd life bus battery systems are providing approximately 500kWh capacity connecting to the new rectifier substation to supply electric buses and trams operated by ÜSTRA Hannoversche Verkehrsbetriebe AG. The energy storage units serve as a buffer to enable the efficient use of recovered energy in tram operations, for grid stabilization, especially the compensation of load peaks, as well as support in case of a power cuts and the provision of electric energy for public charging infrastructure.

Figure 11: Sustainable Bus

Hamburg goes electric

In the Hamburg Alsterdorf depot, two of the six carports have been equipped with smart infrastructure for e-bus charging, consisting in 96 charging points and 240 parking spaces.

The charging concept is modular and therefore scalable, the electricity supply is connected to the Hamburg power grid via a substation. Modular standard transformers (1,600 KVA) supply power to up to 16 buses.

Figure 12: Source: © INIT I Ulrike Kabel

Buses will be charged overnight, with a maximum charging capacity of 150kW per bus and average charging times of 4-5 hours, using also excess of generated wind energy enhancing the integration of renewable sources in the grid.

Madrid - eLobster (H2020)

The eLobster project aims at improving the synergies between light railway infrastructure and electricity distribution networks, to reduce electricity losses and increase the grid stability especially in scenarios where a high integration of renewable energies is possible.

The solution is based on an integrated Railway and Grid Management System which starting from the real time analysis of energy losses will be able to optimize the interexchange of electricity between the networks maximizing local RES self-consumption.

Photo by City of Leipzig

The demonstrator site of E-LOBSTER is the Metro de Madrid as its underground railway is connected to a local power distribution network with a high penetration of RES.

Los Angeles, United States - Way Side Energy Storage System (WESS)

The project Way Side Energy Storage System (WESS), integrated the VYCON REGEN flywheel-based system into the Red and Purple Line Traction Power Substation (TPSS) at the Westlake/McArthur Park station.

The system collects the breaking energy of the metros in curves or when entering the passenger station near WESS TPSS, stores this energy and provides it to the next train that needs it. Therefore, it lowers the peak power demand and realizes a 10-18% reduction of the traction power energy. The system is running in daily full operation since August 2014. The annual savings are estimated at around 541 MWh which equals the energy supply for 100 average California homes.

Figure 13: Copyright © 2022 | Metro - Los Angeles County Metropolitan Transportation Authority; The Source, by Dave Sotero , October 3, 2014

Research project "FlyGrid", Austria

A FESS is developed for a fully automated EV charging station to allow in a low-voltage distribution grid to reach high charge-power while at the same time stabilizing the grid. The system is suitable to integrate local renewable sources contributing to increase the share of clean energy in the electricity mix. Superior cycle life of the energy storage device, the ability to feed high power back into the grid as well as easy transportability in the form of a mobile "fast-charging box" (for electric construction machinery or similar) are further characteristics of the FlyGrid concept. One module of this prototype will be used as the reference case and will deliver 5 kWh at 100 kW peak power. (Haidl et al. 2019).

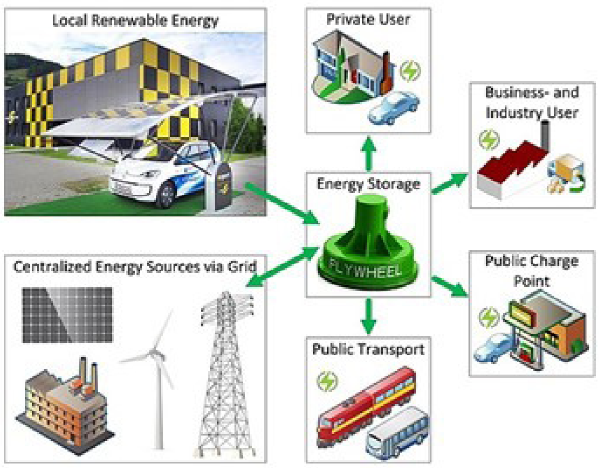

Figure 14: TU Graz

Huai'an, Jiangsu: Supercapacitor Technology Leading the Charge for Public Transport

The application of supercapacitors in public transport is mainly onboard vehicles.

With a 20 km long route and 23 stops, Huai'an has introduced the longest running electric tram using supercapacitors.

The supercapacitor technology with very short recharging times around 30 seconds and a long life time replacing 30% of private vehicles and carrying 7 million pax in a densely trafficked area, saves 4,900 tons of CO2 emissions annually.

Warsaw

Figure 15: sustainable-bus.com/

A similar approach was adopted in Warsaw, where ultracapacitor systems produced in Estonia by Skeleton Technologies recuperate braking energy and reuse it for acceleration, decreasing the total energy consumption significantly as well as shave power peaks stabilizing the grid infrastructure in Warsaw and therefore increase energy efficiency considerably. With 1 million charging cycles, supercapacitors represent a technically enhanced solution compared with li-ion batteries for specific applications.

La Spezia (IT) SmartBUS

Figure 16: sustainable bus

In La Spezia buses equipped with ultracapacitors (32 kWh) were tested in a 17-km long line with a AC/DC 150 kW charging station at the bus terminal. The charging time of the SmartBUS is 5 to 7 minutes. The innovation lies mostly in the reduced weight and size of the bus and the possibility of braking energy recovery up to 40 %.

The joint venture of E-CO, Chariot, Prometeon and Politecnico Milano showed that ultracapacitors of various capacities in SmartBUS models (8, 12 and 18-meter), used in place of batteries, can allow distances of over 40 km on a single charge.

2. The EfficienCE use cases on energy storage and integration of renewable energy

In this chapter, three relevant use cases are identified according to the analysis of functionalities and technologies and to the review of good practices carried out in the previous chapters. The cases consist in concepts for a) energy efficient depot, b) smart node, and c) linear infrastructure where the deployment of energy storage technologies enabling the integration of renewable energy sources and the support to system operations. The three use cases summarize the typical endowment to be developed in order to enhance the energy efficiency performance of PT infrastructure.

	Energy efficient depot	Smart node	Linear infrastructure
London (UK) Bus2Grid	x		
London (UK) Walworth depot	x		
Solingen (DE) Smart Trolleybus system			x
Hannover (DE) Rectifier substation			x
Hamburg (DE) goes electric	x		
Madrid (ES) eLobster project		x	
Los Angeles (US) Metro WESS		x	
Graz (AT) FlyGrid research project		x	
Huai'an, Jiangsu (CN) Supercapacitors for Public Transport			x
Warsaw (PL) Trams with supercapacitors			x
La Spezia (IT) Smartbus			x
Maribor (SI)* Multipurpose use of public infrastructure		x	
Gdynia (PL)* Recuperated braking energy and RES	x	x	x
Pilsen (CZ)* Buffer storage station in trolley network			x
Vienna (AT)* Metro-station integrated PV-system	x	x	

*EfficienCE Pilots

Figure 19: Pilots, international good practices and use cases (EfficienCE, 2022)

The framework blueprint is represented by the context of the City of Bergamo, where the SUMP implementation envisages the renovation of an important mobility node for the transport network, the construction of new light rail and eBRT lines, and the development of a multipurpose recharging network for electric vehicles.

The case of Bergamo, where an action plan for a better integration of renewable energies and storage systems in the public transport infrastructure is being developed within the EfficienCE project, represents a suitable framework representing a model context for the allocation of storage facilities for different purposes and to different types of infrastructure.

2.1 Energy efficient depot

The use case focuses on the enhancement of the energetic performance of a PT depot (refurbished or newly designed), through a better use of renewable sources where available (including braking) as well as a more efficient consumption, and on the contribution to energy autonomy and to the grid (e.g. Bus to Grid).

The planning of an energy efficient depot may involve a broad range of stakeholders such as the local authority, public transport operators and other providers (e.g. e-carsharing), energy TSOs and DSOs, as well as the citizens.

According to the use case background, the design and implementation of energy efficiency solutions for depots based on storage are mainly based on battery storage (new and second life), and investments include also PV systems and other renewable generation solutions, charging facilities (also V2G), monitoring systems, etc.

The main expected impacts are related to a higher energy efficiency through self generation and decrease of losses, a better integration of renewable sources, and the related environmental and economic benefits.

Challenges/barriers

The implementation of storage solutions for energy efficient depots can face different orders of challenges and in some cases barriers, in particular related to the regulatory context when talking about V2G and energy dispatching, and related to the evaluation of costs and benefits of investments needed. Moreover, social acceptance represents a relevant element to be taken into account when planning for new infrastructure in densely populated neighbourhood and the challenges related to storage and V2G can bring benefits to be considered.

References:

London (UK) Bus2Grid
London (UK) Walworth depot
Hamburg (DE) goes electric
Gdynia (PL)* Recuperated braking energy and RES
Pilsen (CZ)* Buffer storage station in trolley network
Vienna (AT)* Metro-station integrated PV-system

2.2 Linear infrastructure

This use case analyses possible applications of storage technologies to the linear infrastructure, mainly with the purpose of supporting and balancing the grid, taking into account both stationary and in motion approaches.

Applications like stationary and in motion batteries, as well as flywheels and supercapacitors shall be considered in order to investigate the range of benefits that can be generated for the grid by the use of storage technologies, and their benefits and limitations.

The engagement of stakeholders shall focus in particular to the technical side both concerning mobility (public transport operators and other providers), and energy (TSOs and DSOs).

The main expected impacts are related to the support to the grid, in order to improve operational efficiency and therefore enhance the environmental and economic performance of the infrastructure through economically viable solutions. The range of application varies according to the type of infrastructure existing or to be developed: for this reason, the references include trolleybus, bus and tram examples.

Challenges/barriers

The implementation of storage solutions for linear infrastructure may face in particular economic challenges related to the investments needed, but at the same time can represent opportunities for deferring relevant investments on the grid and to fine more flexible solutions for the stabilization of the grid. In some case specific regulatory barriers might be in place for different technological applications (e.g. safety regulations on flywheels).

References:

Solingen (DE) Smart Trolleybus system
Hannover (DE) Rectifier substation
Huai'an, Jiangsu (CN) Supercapacitors for Public Transport
Warsaw (PL) Trams with supercapacitors
La Spezia (IT) Smartbus
Gdynia (PL)* Recuperated braking energy and RES
Pilsen (CZ)* Buffer storage station in trolley network

2.3 Smart node

The last use case focuses on the design of a smart node, as a station, stop or multimodal hub where storage can be adopted to enable the efficient use of renewable sources as well as well as the multipurpose use of charging infrastructure. Different approaches can be considered, from the pure improvement of the energy efficiency and performance of the infrastructure to the active contribution of vehicles and generation to the stability of the grid.

The engagement of stakeholders shall focus in particular to the technical side both concerning mobility (public transport operators and other providers), and energy (TSOs and DSOs).

The selection of solutions for smart nodes based on storage will consider a variety of technological options including batteries, flywheels and supercapacitors and assessing their potential according to the characteristics of the nodes and systems.

The main expected impacts are related to the integration of renewable sources, the support to the grid and energy efficiency, in order to improve operational efficiency and therefore enhance the environmental and economic performance of the infrastructure. The identification of an optimal scale for the integration of storage and renewable energy technologies at node level, considering the coexistence and interactions among different (linear and node) infrastructures is crucial to guarantee the effectiveness and economic sustainability of the applications.

Challenges/barriers

The implementation of storage solutions for smart nodes may face in particular challenges and technical barriers due to the complexity and interactions among different systems. In particular, the implementation of multipurpose charging systems and the energy exchanges among different services may require in depth regulatory and business models analyses.

References:

Madrid (ES) eLobster project
Los Angeles (US) Metro WESS
Graz (AT) FlyGrid research project
Maribor (SI)* Multipurpose use of public infrastructure
Gdynia (PL)* Recuperated braking energy and RES
Vienna (AT)* Metro-station integrated PV-system

3. Lessons learned and conclusions

The combination of energy efficient depots, smart nodes and linear infrastructure for public transport highlights the potential of innovative solutions development in optimizing the relationship between mobility and the energy grid.

Concerning the efficient depot, one lesson learned from the analysis is that the scale of RES infrastructure is crucial in order to determine the opportunity for storage applications. It might be worth to consider for example the role of the PT grid as collector of different RES sources at neighborhood level, in order to make the reuse of energy flows efficient and economically viable.

Application of storage on linear infrastructure might be consider residual in terms of integration of RES, but provides good and flexible responses when dealing with ancillary functionalities e.g. voltage control. Moreover, in some cases the use of storage facility can be an opportunity for deferring relevant investments on the grid.

The main lesson learned on the smart node use case complements the previous ones: the planning process must take into account the complexity and interactions among different systems;in particular, the implementation of multipurpose charging systems and the energy exchanges among different services may require in depth regulatory and business models analyses.

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