DELIVERABLE T1.1.2

Managerial Approach for integration of RES into PT infrastructure

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Executive Summary

The trend for public transport electrification presents a great opportunity to at the same time increase the share of RES. Many cities already have strategies or targets for the integration of renewable energies. This deliverable provides an overview of the integrated planning processes that took place in EfficienCE to guide other cities in their development of an action plan and the implementation of measures towards the integration of renewable energies in the public transport system. It shows the steps partners took in their strategic as well as operational approaches and elaborates on barriers the partners encountered during their planning and implementation phase. As result of the action plan and pilot implementations, it provides some lessons learned for measures towards the integration of renewable energy sources into PT infrastructures.

Why is the integration of RES important?

Burning fossil fuels to generate electricity and heat contributes to a large part to the production of greenhouse gases and favors climate change. Renewable energy sources (RES), on the other hand, present a clean, inexhaustible, and highly competitive source of energy. During the conversion no greenhouse gas (GHG) or other polluting emissions are generated, and their sources[1] cannot be used up or depleted. To reach the European Commission's Climate Action goal to become climate-neutral

[1] Renewable energy sources to generate green energy are sun, wind, biomass, or the recollected braking energy from, e.g., buses or trains.

by 2050, RES presents a viable option to meet energy needs. However, with currently less than 5%, transport is the sector with the lowest share of RES while at the same time producing almost 1/3 of the European GHG emissions[2]. It relies heavily on fossil fuels, not only as a fuel supply for private and public vehicles but also on the generated electricity to operate depots, stations (light, elevators, escalators, heating, etc.) and electric fleets, among other things. To achieve carbon neutrality strong changes in the current system are required to drastically cut emissions and to keep up with the increasing mobility- and thus energy-demand in a sustainable way.

The trend for public transport electrification presents a great opportunity to at the same time increase the share of RES. Many cities already have strategies or targets for the integration of renewable energies.[3] A good starting point is the european rail transport as its main lines are already mostly electrified. Especially in cities where rail bound PT almost exclusively runs on electricity, the change to RES is the logical next step. In the Netherlands wind energy is the main provider of renewable energy and every electric train runs entirely on this energy source since 2017. However, use cases for the implementation of renewable energy and its sources need to be chosen according to local context, resources and operating conditions. In other countries solar energy might provide better energy outputs than wind energy and/or the electric bus fleet proves more suitable for the integration than the rail system. The main barriers do not lie in the technology but are more often political and financial. The capacities and the knowledge need to be there to ensure a strong planning framework and the correct operational execution. While energy presents one of the largest operating costs for PT and prices for energy are rising the costs to generate renewable energy are declining and the business opportunities to source cleaner and cheaper energy is increasing. The strategy for upgrading the existing PT infrastructure with RES and the expected carbon and cost reduction need to be considered on a case by case basis, embeded in a wider framework of action for the urban mobility system.

What did the EfficienCE partners do?

In EfficienCE, several partners worked on the topic of integrating renewables into the local public transport system. They developed an action plan and demonstrated in two pilots how RES can be integrated into public transport infrastructure.

In Bergamo, an ambitious local action plan was developed, building on several municipal and regional plans and studies. The plan represents a strategic instrument for electrification and integration of RES in local PT infrastructures. Starting from an analysis of the reference context, the

[2] Greenhouse gas emissions from transport in Europe (europa.eu)

[3] REN21, Renewables in Cities 2019 Global Status Report

plan examines the European, national and local regulatory framework for energy and mobility, existing local plans and studies for mobility & energy including SUMP, and their interrelation. Based on a participatory design, strategic scenarios were developed, as well as use cases and measures that can be implemented in the coming years. Developed measures aim at increasing the share of RES and energy-efficiency through instalment of photovoltaic (PV) systems, and stationary energy storage at ATB depot and the mobility hub Porta Sud in the context of a large urban renovation project. Charging infrastructure is linked with new BRT and tram lines, and with redeveloping a railway connecting 5 cities. Additional measures refer to renewal of ATB fleet with e-buses and smart charging infrastructure, and possible investments for energy storage technologies (e.g. 2nd life).

In Gdynia and Vienna, two pilot demonstrations to feed renewable energy into the local public transport system were tested: a photovoltaic foil on the roof of a metro station (Vienna) and an inverter to charge e-cars with recuperated braking energy from trolleybuses (Gdynia).

PT company Wiener Linien in Austria tested a PV-system on the roof of a metro station (Ottakring) in Vienna. For the first time, PV foils were bonded to the roof of a subway station, which otherwise – for static reasons – would not be able to carry a normal and heavier PV plant. The PV-produced energy supply was integrated into the station's energy system to supply auxiliary power units. As main result, the yearly energy output of the PV plant is higher than expected with 62.000 kWh of solar power, covering 50 % of the station's energy needs on a sunny summer day. This energy generation leads to an energy share of the whole metro station (also including a parking hall for metro trains) of 6% of the yearly energy consumption, reducing CO2 emissions by more than 21 tons and saving more than 6.000€ every year. In the next years, Vienna plans to install 20 PV plants on metro stations, of which 2 are PV foils.

Trolleybus company Przedsiebior stwo Komunikacji Trolejbusow PKT Gdynia (PL) tested an energy inverter to feed the otherwise wasted braking energy into the building's energy system or to the charger. A specifically designed DC/AC inverter was placed in the depot to connect the DC traction grid and the charging station or building's AC grid. To increase reliability of the power supply (e.g., in the event of excessive drops of converter input voltage) and the flexibility of accumulation of regenerative braking energy, the station was equipped with a second-life traction trolleybus battery. This type of charger is not fixed to the ground, and can be moved. The connection of the station does not require additional installation costs and no building permits shorten the investment period. After implementation, the model of linking individual transport and public transport was tested by charging electric cars. In the future, PKT wants to link a PV plant to the inverter and storage device to either store or directly feed the generated energy into the trolleybus grid.

SUMP as framework for integrated energy and mobility planning

The processes described here serve as exemplary actions and might differ depending on local conditions. The SUMP (Sustainable Urban Mobility Planning) framework is used as an orientation to structure the integrated planning process. The framework provides a strategic and integrated approach to deal with the complexity of urban transport. Starting with a thorough assessment of the current situation and through "the involvement of citizens and stakeholders as well as the coordination of policies between sectors and broad cooperation across different layers of government and with private actors"[4], the framework supports decision makers and other mobility stakeholders in the development of a plan with a long-term vision for sustainability. As the SUMP framework is a simplified representation of a complex planning process, it can be adapted to various topics in the context of sustainable urban mobility, e.g. the integration of RES in the PT system. For further information there are numerous (mostly) free tools and know-how available on the Eltis platform (www.eltis.eu).

Traditionally, energy and mobility planning processes take place in silos. It requires political commitment, a high degree of horizontal and vertical integration, business models, insight based on data and KPI, and a participatory approach to raise the share of renewables in the public transport sector, and thus, to achieve a significant decrease of GHG emissions coming from public transport. By going through the SUMP cycle, we make sure to consider all relevant steps of the planning process while building on the experiences of the EfficienCE pilot demonstrations.

[4] Rupprecht Consult (editor), Guidelines for Developing and Implementing a Sustainable Urban Mobility Plan, Second Edition, 2019.

Assess Planning Practices

Cooperation and Resources

Cooperation throughout such a cross-cutting topic like the integration of RES, also across organizational and institutional boundaries, is an important factor in the success of an action plan or pilot action. Relevant know-how and sufficient resources should be present to set up effective working structures and drive the process forward. In Bergamo a core team of internal expertise (the municipal administration and the PT provider of Bergamo, ATB mobilita) with the technical support of external partners (consulting company STEER DAVIES & GLEAVE responsible for the e-plan and Redmint impresa sociale Scrl) worked together to ensure the multiple skills necessary for management and guidance of the action plan development in coherence with the SUMP. To start the whole process in Vienna, a company internal team of experts from different departments (buildings, energy and sustainability experts) covering all relevant skills was created. As the two companies Wiener Linien and Wien Energie already cover the stakeholders of the public transport and energy sector and are owned by the municipal stakeholder, no other stakeholders were involved in the preparation phase. Later on, some legal requirements regarding the railway law required the involvement of additional stakeholders.

Political Ownership

By building on existing strategies and objectives, the political mandate already existed for the City of Bergamo, Wiener Linien, and PKT. This enabled e.g., the City of Bergamo with their Public Transport Operator ATB, to carry out three main studies (e-plan, e-brt and porta sud) and to further develop the joint action plan, as the political and institutional ownership of the action plan was very strong from the beginning on.

Stakeholder Engagement and Citizen involvement

As stated above, the integration of RES requires specific (and technical) know-how which can be achieved through cooperation with various stakeholders. Keeping the process open for valuable input from the outside, but at the same time preventing the focus on the topic from being lost by too much input is a tightrope walk. To ensure a participatory process, a wide range of stakeholders was already involved in the SUMP process in Bergamo and various meetings with citizens and interviews with thematic focus groups were conducted since 2018, including a large survey with 1.200 participants. Focused specifically on the topic of the integration of RES, technical round tables were part of the local action plan development process. As part of the EfficienCE project, the midterm conference, held in Bergamo, presented another moment of stakeholder engagement with a chance to analyse good practices related to the action plan and receive valuable input from external participants and the EfficienCE partners. In 2022 certain participants that were involved in the three main studies (e-plan, e-brt and porta sud) came together online for a last workshop to define the measures which are ultimately included in the action plan. This was an important step in the action plan development. The stakeholders were chosen based on the collaboration they already have with ATB and their technical knowledge on the electrification of PT infrastructure.

Lessons learned:

In Vienna a project of this kind would not have received a lot of support without the EU funding. The PV foil is more expensive than conventional PV installations and many uncertainties, e.g., whether the desired energy results are achieved and if the cost estimate was correct, arise. The EfficienCE project was mainly used to test an innovative solution and to demonstrate that it is possible to solve problems related to statics that prevented Wiener Linien from using PV systems on metro stations in the past.

It can prove hard to narrow down the high level of engagement that a general topic like energy efficiency in PT generates to the very specific aspect of integrating RES into PT infrastructures. Throughout the participation process there is a need to focus on a restrictive group of stakeholders – experts – to receive the right input.

Building on existing strategies increases the political support and helps to manage the complex coordination and high internal personnel expenditure. A good way to gain support and visibility for a (innovative) project on the local level is to collect EU funding and prove the feasibility before rolling it out on a big scale.

Since already electrified systems, such as trolleybus systems or tramways, allow for rapid decarbonization, some partners experimented with the integration of RES in form of PV-installations or the collection of recuperated braking energy. This allowed for less cost intensive measures and at the same time increased the know-how of planners, preparing them to drive the decarbonization of not yet electrified systems forward.

Some cities have their own energy providers who can contribute to action plans and pilot projects, others need to find external partners to gain their expertise.

Determine the planning framework

Link related planning processes and strategies

The planning framework can be characterized by different projects and limitations set through existing studies and other plans which all work towards an effective and efficient PT system. The objective is to analyse the planning context of different projects to define knowledge gaps and common areas of action for the integration of RES into infrastructure measures. The Bergamo action plan for energy efficient PT infrastructure deployment evolved from the SUMP. Certain studies were consulted and further developed to build on the measures and resources already identified during the SUMP development, including three main studies: An electric mobility plan (E-Plan), both for private and public transport; A feasibility study for an electric bus rapid transit (e-brt) service between

Dalmine and Bergamo; and the study for the redevelopment of intermodal node porta sud, a complex intermodal node project close to the city center that involves a lot of stakeholders, like national railways, public and private buildings, urban planning amongst others. In addition to the three main studies, some minor studies, e.g. on city logistics and low/ultra-low emission zones, were also considered, to help build the vision towards the integration of RES. In Vienna, Wiener Linien as the major public transport operator is also owned by the city of Vienna. The RES strategy of Wiener Linien is therefore largely entangled with the city policies and frameworks. In its major strategy, the "Smart City Wien Framework Strategy 2019-2050", the city of Vienna depicts the objective of doubling renewable energy production within the municipal boundaries by 2030. To contribute to that goal, Wiener Linien plans to install PV-systems on as many metro stations as possible (currently 20 are identified as suitable and will be equipped by 2025)[5].

Align energy efficiency measures with (existing) PT infrastructure

The feasibility of integrating new elements into existing PT infrastructure heavily depends on the given prerequisites. Changing the energy supply of an already electrified PT system to renewable energy sources certainly proves less difficult as the energy grid is already aligned with the infrastructure grid (depots, charging stations, etc.). Even though it might still be challenging to align an optimal and energy efficient plan with the existing PT infrastructure, like depots, bus lines and tramway stations. As a lot of new infrastructure is currently being built in Bergamo, integrated planning of the action plan measures with these infrastructure measures creates a great opportunity, and new infrastructure, like the e-brt line and new tramway line, can more easily be aligned with the energy network and be more energy efficient than the existing ones. In case of the Vienna pilot, the tramway system is already an electrified mode of transport, but certain circumstances prevented the use of a conventional PV-installation in the past, one of them being the static limitations of the metro building's flat roof. Funding through the EfficienCE project enabled Wiener Linien to test a novel but more expensive PV foil, to overcome these limitations.

Define the work plan

The work plan is strongly influenced by different projects that are already taking place and sets the milestones and tasks for the different actors involved in the development. In the case of Bergamo, the timing between the action plan development and ongoing infrastructure interventions is a crucial point and an effort was made to harmonize the work plan with the different technical and political decisions. By following the three main studies in Bergamo, the actors involved have tried to break down the complex planning structure and reconcile the three basic themes of environment, energy sustainability and socio-economic sustainability. By focussing first on the SUMP and secondly on the need to integrate energy efficiency measures with other major plans and strategies, potential application areas to integrate RES into PT infrastructure are identified. In Vienna the pilot action was already defined during the application phase of the EfficienCE project. The work plan followed three

[5] Nächster Halt CO2-Neutralität - Greener Linien und Wien Energie zünden Sonnenkraft-Turbo - www.wienerlinien.at

simple steps. First: Identification of a metro building where the installation of the novel PV foil to power the building auxiliaries is possible and reasonable. This includes basic requirements like a flat roof with a maximum pitch of 7%, no shadowing through neighbouring houses or trees, minimal road traffic next to the installation to reduce the influence through pollution, etc. Second: Prove of the technical feasibility, like the static load capacity. Third: Cooperation between Wiener Linien and Wien Energie for the construction of the PV system and all electric measures. In accordance with all European and national directives and regulations the conditions for an in-house subcontracting were fulfilled and Wien Energie GmbH, controlled by Wiener Stadtwerke GmbH, which is controlled by the city of Vienna, was contracted through a direct award with the installation of the PV system. This vastly eased the procedures and accelerated the implementation process of the pilot.

Lessons learned:

One major problem in the development of the Bergamo action plan was the timing of different projects and plans that are usually not running in parallel. Through certain planning efforts and foresight of the municipality the electric mobility plan was aligned with the time frame of the EfficienCE project but e.g. the porta sud study follows a different timeline than the local action plan development. In addition, the study focuses on many aspects of urban and mobility planning and energy efficient PT infrastructure is only one of them. Therefore, it is especially complicated to steer the planning in the right direction.

In regard to the installation of PV systems on metro buildings in Vienna the problem of the age of the buildings arises. Many metro buildings are very old and therefore protected monuments. The installation of a PV-System is considered a massive change in the appearance of the building and can not be implemented so easily. For now, the selection of suitable buildings concentrated on the “easy” buildings that are fairly new and present no problem in modifying and the problem will be revisited in a few years.

When planning for existing PT infrastructures, the match of the energy and the infrastructure network layout may pose a problem, which can lead to higher costs for the whole project or in the worst case even that the project is not feasible. Furthermore, the identification of suitable renewable energy sources and the contracting and agreements for the procurement of clean energy to be used in PT presents planning and economic challenges.

Improving energy efficiency and integrating RES in PT infrastructure must be seen as a process. There is a need to create a work method and set it into the agenda of urban and transport planning by raising the awareness of planers and open the possibility for energy efficient measures that will affect the whole process from infrastructure planning to the procurement of buses.

Define strategic direction

Analyze the current situation

After assessing the planning framework and identifying existing resources and stakeholders, relevant data needs to be identified and collected to conduct a thorough analysis of the current situation and develop a baseline for the strategy development. As part of the e-plan in Bergamo not only the status quo but also future plans for the infrastructure, bus fleet, depots and some technical data like energy consumption were already analyzed. An overview of the mobility situation based on surveys conducted by ATB was published in October 2019 and used as basis for the SUMP development. In addition, data on the company internal resources like usage plans for the bus fleet, depot layout, etc. were used to define starting points for energy efficiency measures and RES integration. As the data was collected and is owned by ATB and the municipality, the data ownership did not pose any problems.

Define and discuss potential future scenarios

The scenario development is an important step to better understand the effects of future measures. Here it is especially important to involve stakeholders early on, to discuss the various scenarios and their impacts with the aim of identifying which scenario or element can become part of a common vision. In the end a strategic decision can be made, based on the thorough assessment of different possible future scenarios. After the baseline for the Bergamo action plan was determined and relevant plans and data for the development were identified and analyzed, two main strategic scenarios where defined, based on the actions planned in the near future related to local PT electrification. As a central element throughout the action plan development, a participatory process with relevant stakeholders took place in this step as well in the form of an online workshop. The aim was to gather input on the prefigured plan scenarios, stimulate discussion on strategic alternatives and their potential impact and develop a collective learning process on the topic of energy efficient PT infrastructure. The following participants were invited to the workshop:

- political and technical representatives of the main municipal offices involved (Department of Mobility and Environment, Mobility Office and European Planning Office)
- main local public transport operators of Bergamo (ATB and TEB companies)
- representatives of the companies awarded the various sector-specific studies of the SUMP including:
    - REDAS company as extender of the study for the identification of a model of urban logistics aimed at optimizing the regulation of access and management of freight transport
    - URBANTRAFFIC/LEM TTA as authors of the study of the impacts deriving from the implementation of Low Emission Zone (LEZ) and Ultra Low Emission Zone (ULEZ) and interchange parking system

- ETS/SYSTEMATICA as authors of the preliminary study for the drafting of the technical and economic feasibility project for the implementation of an E-BRT system between the municipalities of Bergamo and Dalmine
- company TRT as supervisor of the study aimed at defining scenarios of the intermodal hub of the Porta Sud area
- company STEER DAVIES & GLEAVE as extender of the development plan of electric mobility in the Municipality of Bergamo (E-Plan).[6]

The active involvement of the stakeholders allowed for the drafting of an action plan, adhering to their expressed needs.

Develop vision and agree on objectives

A common vision and objectives are important steps in integrating renewable energy in the PT infrastructure and as in previous steps also here, the collaboration of different stakeholders and departments is crucial for a successful implementation. The fundamental objective of the Local Action Plan of Bergamo is the decarbonization of the public transport system through coordination and in accordance with the SUMP. At the same time, it acts as a strategic planning and programming tool for interventions related to the integration of renewable resources in the Local Public Transport infrastructure. The municipality set for itself the goal, that all energy of PT will come from renewable sources. The Action Plan aims to identify possible strategic scenarios of development, deepening the interconnections with the decision-making, planning and financial aspects, in order to find points of balance between constraints and planning and to reach a really effective, realistic and feasible strategy in the near future. The agreed upon objectives of the action plan include:

- a feasibility check of new infrastructures planned by the SUMP and analyzed in detail by specific sector studies
- the outline of energy efficiency measures to support infrastructural and urban transformations
- correct and conscious planning of new projects and development scenarios related to infrastructure and public transport services
- the detailed analysis of the specific monitoring data of the Electric Circular Line called C, in order to prefigure hypotheses of improvement and possible transpositions of this experience in other city lines[6]

In its major strategy, the “Smart City Wien Framework Strategy 2019-2050”, the city of Vienna depicts the objective of doubling renewable energy production within the municipal boundaries by 2030. Wiener Linien provides its share in achieving this goal. As a public transport company, they operate a large number of properties in Vienna that could potentially also be used as base for a PV installation to generate solar power. The potential is estimated at 100.000 sqm. Up to now, however, it has not been possible to install conventional photovoltaic systems on many of these properties, due to the

[6] See also D.T1.2.3 Development of Action Plans for energy-efficient PT infrastructure deployment

statics and electrotechnical concerns, a PV-system could negatively affect the traction of the metro. This has now changed with the EfficienCE project which tested photovoltaic foil, that is significantly lighter than conventional systems and also meets the special requirements for electrical earthing in a subway building due to the absence of metal parts. The EfficienCE pilot confirmed a high potential to increase RES by using the roofs of metro stations for PV installations and Wiener Linien started a cooperation with sister company Wien Energie to build more PV-Systems on metro stations throughout Vienna. As a first step, 20 sites are identified to build PV systems in the next 4 years.

Lessons learned:

Depending on what data is needed and who is the owner of that data, the analysis of the current situation might prove more or less difficult and time intensive. By including the right stakeholders early in the process different points of view can be taken into consideration to correctly define the main problems and opportunities.

Good dialogue between the municipality and stakeholders is elementary. A good example is the Bergamo workshop with relevant stakeholders taking place online in April 2022. The municipality and ATB presented a range of ideas on how the objectives of the action plan can match the development of the existing studies and together common objectives and technical knowledge gaps were defined that will be considered in the executive planning of the new measures (e-brt, e-plan and porta sud).

A stakeholder workshop should not be seen as a problem-solving exercise, but rather to increase understanding of certain problems and to draw attention to them in future planning and to test possible solutions.

Strategy (vision) and objectives are crucial to plan for integration of RES into the local PT infrastructure.

Finding a compromise between an ideal and realistic vision for future plans might need a few rounds of discussions with stakeholders.

To increase acceptance for RES generation, a transparent and participatory approach from planning to operation of new facilities is recommended. Strategies and action plans should be developed in a participatory way. Also, marketing and communication measures can facilitate a greater understanding of the economic and social benefits of RES integration.

Set targets and indicators

Both vision and objectives define the outline of the desired future, but to monitor how and when this future is reached, indicators and targets need to be set to make possible changes measurable. A selection of reference indicators for actions and pilots developed in the EfficienCE project is shown in the table below.

D.T2.4.1 - Definition of evaluation framework

COD	DOMAIN	KPI	Description	Measurement Unit
T1	Technical	Degree of energetic self-supply by RES	Ratio of locally produced energy from RES and the energy consumption over a period of time (e.g. month, year); the quantity of locally produced energy is interpreted as by renewable energy sources (RES) produced energy	%
T6	Technical	Energy savings	Reduction of the energy consumption due to the implementation	kWh, %
T7	Technical	Storage Capacity	Energy storage technologies installed capacity	kWh
T8	Technical	Battery Degradation Rate	Capacity losses of the batteries, through use (some cycles) and through time (some years); The KPI concerns the effectiveness of technology, the need for maintenance, providing useful data concerning the financial feasibility of its integration	kW, %
T9	Technical	Storage Energy Losses	Losses generated by battery storage, including the added voltage transformations	kWh, %
[illegible]	Technical	Improved interoperability	Interoperability is the ability of a system (or product) to work with other systems (or products) by providing services to and accepting services from other systems and to use the services so exchanged to enable them to operate effectively together (ISO/TS 37151). The indicator assesses the improvement in interoperability in a qualitative manner without going into details.	Qualitative scale
[illegible]	Technical	Energy consumption data aggregated by sector fuel	Energy consumption of the mobility sector; it should be assessed for public transport (before and after) as well as for private vehicles (before and after)	GJ
[illegible]	Technical	e-car sharing subscribers	Number of subscribers of elettric car sharing services (station based, free floating)	Number
[illegible]	Technical	e-car sharing kilometers	Number of kilometres done using the car-sharing service	Km*year
T15	Technical	Efficient vehicles deployed	Number of efficient vehicles (electric/hybrid buses/trolleybuses) deployed, and percentage on total fleet	N, %
T16	Technical	EVs charging stations, solar powered, V2G enabled	Number of EV charging stations installed (rapid-ultrarapid, fast <22kW, slow <10kW) and density	N, N*Km2
E1	Environmental	Increase in Local Renewable Energy Generation	Renewable Energy generated by the project	kWh*year, %
E2	Environmental	Carbon dioxide Emission Reduction	CO2 emissions reduction achieved by the measure, and percentage on the relevant context	Tonnes*year, %
E3	Environmental	Decreased emissions of Particulate matter	PM10 and PM2.5 emissions reductions achieved by the project	Tonnes*year, %
E4	Environmental	Decreased emission of oxides (NOx)	Percentage reduction in NOx emissions (NO and MO2) achieved by the project	Tonnes*year, %
[illegible]	Environmental	Energy Return on Energy Investment	Energy delivered on primary energy required for a specific technology/measure	%
[illegible]	Environmental	Noise pollution reduction	Percentage reduction in NOx emissions (NO and MO2) achieved by the project	dB level, %
EC1	Economic	Reduction of energy expenditure	Economic benefits of the intervention in terms of reduced cost of the consumed energy	€*kWh, €*year
EC2	Economic	Return on Investment (ROI)	Ratio between the total incomes/net profit and the total investment of the project	%
EC3	Economic	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
EC4	Economic	Carbon dioxide Emission Reduction cost efficiency	External costs saved per year	€
EC5	Economic	Particulate matter reduction cost efficiency	External costs saved per year	€
EC6	Economic	Oxides (NOx) reduction cost efficiency	External costs saved per year	€
EC7	Economic	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
EC8	Economic	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
EC9	Economic	Financial benefit for users	Cost savings for users	€/ user/ year
EC10	Economic	Stimulating an innovative environment	The extent to which the project is part of or stimulates an innovative environment. A project can stimulate an environment that enhances innovations, either by being part of it or by contributing to it	Qualitative scale
EC11	Economic	Awareness of economic benefits of reduced energy consumption	User and stakeholders awareness of economic benefits of reduced energy consumption	%
SO1	Social	User engagement	Number of users involved in implementing/monitoring measures/solutions	N
SO2	Social	Stakeholder involvement	Number of stakeholders involved in planning/implementing/executing	N
SO3	Social	Social compatibility	Extent to which measures/solutions fit with people's 'frame of mind'	Qualitative scale
SO4	Social	Ease of use	User friendliness of measures/ solutions	Qualitative scale
SO5	Social	Advantages for users	Advantages generated by the measures/solutions for users	Qualitative scale
SO6	Social	People reached	Number of users benefitting from the measures/solutions	N
SO7	Social	Advantages for stakeholders	Advantages generated by the measures/solutions for stakeholders	Qualitative scale
SO8	Social	Increased environmental awareness	Level of environmental awareness generated by the measures/solutions	Qualitative scale
SO9	Social	Increased participation of vulnerable groups	Level of participation of vulnerable groups as users	Qualitative scale
SO10	Social	Local job creation	Number of jobs created	N
I01	ICT	Peak load reduction	Reduction of peak load thanks to the measure/ solution	%
L01	Legal	Self-consumption legal framework compatibility	Level of suitability of the legal framework for the integration of self-consumption RES generation	Qualitative scale
L02	Legal	Flexibility legal framework compatibility	Level of suitability of the legal framework for the integration of energy flexibility policies such as incentives for peak-shaving	Qualitative scale
L03	Legal	V2G legal framework compatibility	Level of suitability of the legal framework for the integration of V2G solutions	Qualitative scale

Lessons Learned:

Not all indicators are measurable (quantitative) and hard to transform into numbers, to see what kind of impact they have. Also, not all measures are easily comparable. Some might not show immediate impact but ensure positive effects in the long-run.

Measure planning

With the preparation phase and strategy development done, the process moves on to the planning of concrete measures, which are needed to achieve the defined objectives and targets. The measures contained in the Bergamo Action Plan were shared with the stakeholders previously identified and subject to validation by the City of Bergamo and ATB. They focus on the three studies already mentioned earlier. First, the e-plan, including the renewal of the local bus fleet towards full electrification and the subject of energy efficiency in depots by implementing smart charging solutions, exploring storage solutions and integrating RES. Second, the porta sud intelligent node project, where a new multi-modal hub is planned, including a photovoltaic system, new charging and storage systems on board of the bus lines that serve the node, a stationary energy storage to use the potential of RES to the fullest and multipurpose use of the infrastructure at the node. And third the new e-brt line, where actions take place on the topics of charging infrastructure, system and energy storage.[7] The action plan with its measures has been officially adopted by the city of Bergamo and the financial resources are also already planned. The whole process was very complex due to the difficult alignment of energy and mobility topics, stakeholder process in determine planning framework, analysis, scenario development, vision and strategy development, targets and indicators setting, so the measures planned are on a more general level and still need to be refined into an executive action plan in a follow-up project.

Lessons Learned:

The set-up of working structures, planning framework definition, analysis, vision and strategy building requires a lot of coordination and effort, and more in-depth studies are needed to define concrete measures to be implemented to align RES integration, spatial planning, and energy-efficiency needs.

The question of funding poses a barrier to the integration of RES and ensuring political support of the selected measures and at the same time, if not backed up by a (national) strategy, it becomes hard for a city to acquire (national) funding for local integration of RES into PT infrastructure.

[7] See also D.T1.2.3 Development of Action Plans for energy-efficient PT infrastructure deployment

Manage implementation

A good action plan does not automatically lead to good results. The successful implementation of measures depends not only on an effective coordination during the implementation phase on the responsible departments side, but also on a detailed handover from the core planning team to ensure the continuity between process development and implementation. In Vienna the company internal energy management team, put together of experts from different departments (buildings, energy and sustainability experts) managed the implementation of the pilot. A new type of PV system, PV foils that are five times lighter than conventional PV systems, was tested on one of Wiener Linien metro stations (Ottakring). The foils were glued to the roof and the cables fixed in duct.

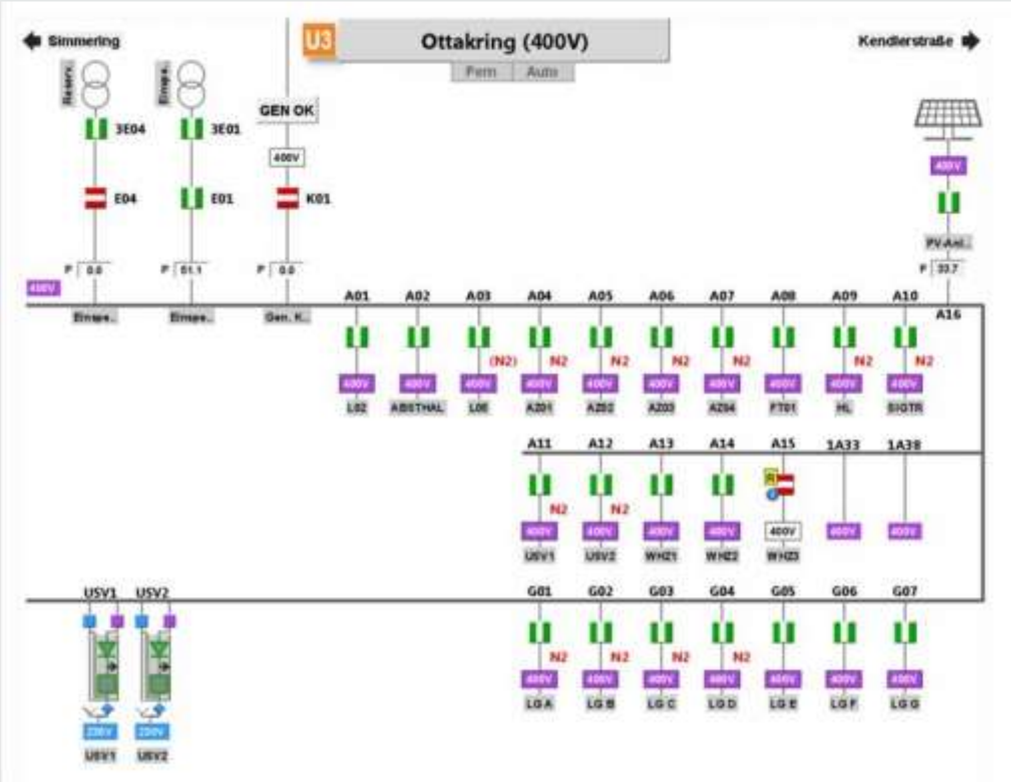

Figure 1: Electrical wiring scheme (05-2020), Copyright Wiener Linien GmbH & Co KG

During the implementation, the railway law posed an obstacle as a PV system on top of a metro station roof is not foreseen and some meetings were necessary to sort out the legal requirements. After that, the main challenge was where to place the technical equipment such as the frequency converter. Since it was not possible to install the converter on the station's roof (due to its din), it had to be allocated in a spot within the station itself. Once the right position was found, the cable routing needed a precise plan to shorten the distance between the technical room and low voltage main distributor room, to keep the costs and material low. Thanks to a well-structured work plan and preparation phase, all the project's technical specifications could be implemented as planned and the estimated costs were met. Regarding the timetable, all contractors executed their work as planned. In the end, only the complex coordination and high internal personnel expenditure delayed the acceptance tests marginally. The handover, accompanied by an inspection of electroluminescence by the Austrian Institute Of Technology AIT, slightly shifted back to January 9th. Wien Energie GmbH finally handed the plant over to Wiener Linien GmbH & Co KG End of February.

The City of Gdynia and PT operator PKT have already participated in many European projects on the topic of PT infrastructure grid development and more specific on the development of the Gdynia trolleybus grid, since 2005. Their expertise in experimenting with new technologies and measures to increase the energy efficiency of PT derived during these projects. Therefore, the internal team of experts was already existent and ready to implement the EfficienCE pilot. To limit the energy losses within the trolleybus network, PKT deployed an innovative and specifically designed energy inverter allowing them to feed the otherwise wasted braking energy of the trolleybuses entering the station directly from the DC traction grid into the building's AC grid, immediately powering the station or going into a battery for storage and later use.

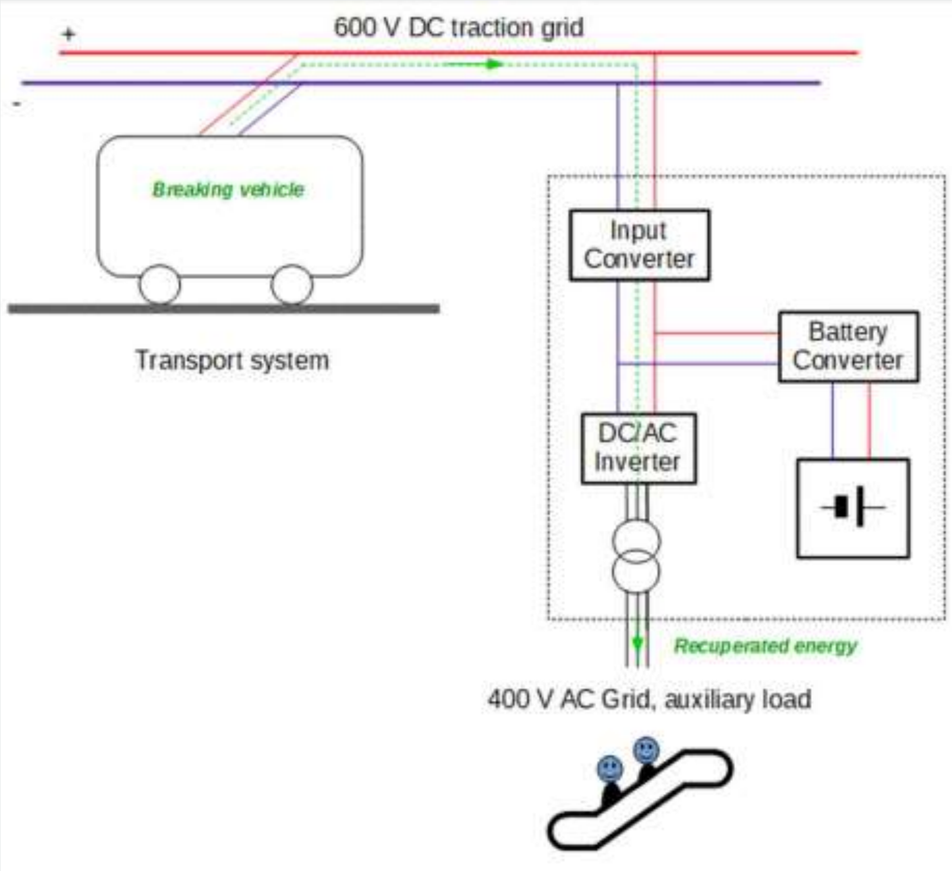

Figure 2: DC/AC inverter scheme, Copyright PKT (Trolleybus Transport Company)

The inverter could be installed very easily as it simply connects to the existing overhead contact line. Apart from the physical connection of the cables no additional calibration or modification was required. As the device is not permanently connected to the ground, it can be moved to wherever there is a traction network and the need for a charging station without additional installation costs or the need for construction permits. To store the collected energy, a used battery serves as an energy storage device in the inverter. It prevents the device from shutting down in the event of a power failure in the overhead line and opens up the potential for the “second life” of used traction batteries.

Monitor implementation

To reach a high implementation quality, continuous monitoring is an important aspect. With the predefined indicators, the progress towards achieving the set targets can be evaluated regularly. Problems can be identified early on and adaptations in the implementation can be made to prevent them from becoming risks for failure of the measure in total. Since the PV foil in Vienna and its application is a novum it was essential to test and evaluate the performance thoroughly. Both, the environment conditions (sun irritation, air humidity and air temperature) as well as the plant performance were monitored and compared. Wiener Linien GmbH & Co KG co-installed a measurement system to the consultant´s sensor to verify the data of the frequency converter. One month after the installation of the PV system, the energy monitoring started in February 2020. Every 15 minutes the electric current and voltage are measured automatically, both next to the panels on the roof, as well as in the electric installation room next to the inverter to consider transport losses. These measurements are transferred to the existing energy control system. Regarding evaluation, it can be confirmed that the data from the frequency converter is the same as the one of the sensor. To compare the plant to other plants, as well as different performances on different dates, these key performance indicators (KPI) are essential and monitored over the duration of the project:

- operating hours
- power (max. per month and area)
- amount of energy (kWh per month)
- Energy per area: consumed electrical energy divided by the conditioned area
- coefficient of performance: produced energy compared to total energy intake

In terms of electrotechnical concerns there were no negative effects from the PV-System to the traction and also not in the other direction. The PV-foils are a very good possibility for older buildings with static challenges but when it is possible, standard modules should be used because of economic reasons.

The energy inverter in Gdynia was connected to the trolleybus overhead line. It was tested as a power supply for an electric car charging station. Various conditions, different times of the day and types of vehicles were tested during the first stages and after that the intensity of the charging was increased, which allowed the verification of the design assumptions and the determination of practical application possibilities of such an inverter system. The following KPIs, which were measured on the traction network side (current, voltage), on the AC current side (current, voltage) and as operating parameters of the traction battery, were used to monitor and evaluate the energy efficiency:

- the amount of energy recovered from regenerative braking energy during converter operation
- average state of charge of storage unit
- output voltage stability
- the efficiency of the energy transformation

During the monitoring it turned out, that the inverter station was not sufficiently protected against overloads, which caused a shutdown of the system. In changing the connection to the overhead line and inserting a disconnector with a remote control that can be controlled from the control center, the power supply system can be reconfigured in an emergency and also disconnected during maintenance work on the overhead lines.

Problems and Considerations

Re-selling energy

Public transport companies' main business task, the operation of rolling stock, is often privileged in the form of subsidies, tax reliefs or exemption from levies. However, these privileges do not apply to the sale of energy to third parties via their traction power supply systems for other purposes, e.g. for the charging of the batteries of electric buses or cars. If public transport companies generate their own energy through renewable sources and "open" their traction power supply systems to third parties, they change from being pure power consumers to being active participants in the energy system and are often confronted with requirements for complex delimitations and measurements. Due to current regulatory barriers in most European countries, it is therefore recommended to start with charging one's own fleet such as service cars or buses, as this does not involve any complicated metering and billing processes. Still the regulations have to be elaborated in a way that important privileges granted to public transport companies (e.g. tax reliefs and subsidies) are not put at risk by the realisation of innovative electric mobility concepts. If the legal situation is harmonised in favour of electric vehicles within public transport, it is important to avoid that additional obstacles are created. Public transport companies should not face a situation in which they are overburdened with administrative tasks and legal uncertainties because the requirements for the delimitation of certain amounts of energy are exaggerated.[8]

Storage solutions

[8] See also ELIPTIC Policy Recommendations electrification of public transport in cities

To exploit the full potential of RES, energy generation measures, like the installation of a PV system or the use of recuperated braking energy, should always be planned in combination with storage solutions. The generation of most renewable energies varies throughout the day, depending on weather conditions with strong peaks, e.g. on sunny/windy days, making them seemingly unfitting to be used as a constant energy supply. Depending on the areas of operation in PT, the energy demand also doesn't follow a constant line but rather a wavy one with high peaks, e.g. during vehicle charging times. Usually these peaks are not conform with each other. Energy storage technologies provide different possibilities in order to optimise the consumption. Power purchase can be optimized to minimize demand charges by buffering needs between peak hours and low demand times for example in depots and stations or for charging infrastructure. Another possibility is the better 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. With the integration of renewable or breaking energy as well as fast charging stations, power quality becomes even more important, and storage technologies can provide grid stability for short-duration power loss or variations in frequency and voltage. Depending on the location (depot, station, onboard etc.), the voltage, energy and time for the storing, different technologies are suitable.

In Gdynia 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 the AC output. For this purpose, a used battery module from a trolleybus traction battery is used (second life application). These batteries usually wear out, due to an increase in charge and discharge cycles, and see efficiency drop below the utilization threshold, which is conventionally set at 80 %, before the vehicle has covered the mileage guaranteed for its life cycle. Second life bus batteries can then be used to store energy generated from renewable sources. For a thorough analysis of energy storage technologies see the EfficienCE Deliverable D.T2.3.2 Transnational Handbooks for Energy-Efficient PT Infrastructure Technologies Deployment.

Lessons learned from implementation and monitoring

The main residual is the unpredictable nature of PV energy generation: in the absence of solar radiation, full power supply from the energy system is necessary. Moreover, the greatest demand for electricity is in winter when the generation of solar energy is minimal.

A critical point for the integration of RES is the high energy demand that might arise at some nodes and during peak hours which is not consistent with the peak in the energy generation of RES and leads to the need to improve the energy grid and provide the right storage solutions.

A city and/or a PT operator has limited options for the generation of renewable energies. To reach carbon neutrality the deployment of RES needs a bigger scale than PT infrastructures. The used and gathered energy, e.g. of a PV-system on a depot or through collected braking energy may be sufficient to power a building on a sunny day but not to charge the whole bus fleet during peak charging times. Therefore, not only does the integration of RES into PT need to be advanced but also the integration into the whole urban context - PT buildings and public and private buildings. In this context, sharing of the costs of systems to generate renewable energies between private and public stakeholder might lead to a bigger percentage of RES in the urban energy supply.

The integration of RES into charging stations, like with the inverter in Gdynia, will make it viable for testing the model of linking individual and public transport on a larger scale, by leaving cars in buffer car parks connecting to the city center by a trolleybus or tram grid and coming back to pick up a car charged with "green energy".

Many new depots are already built for an eventually electrified bus fleet, so they are probably built with energy generation, e.g. through PV plants, in mind. Keeping current regulatory barriers in mind, the next step is to not only think about how PV plants can be used to power PT infrastructures and vehicles but also how they can be used to power neighbouring houses or other auxiliaries during peaks in the energy generation or when no buses are charging.

Despite unclear local and national strategies and timelines on implementing RES into PT infrastructure, it is worth to try out solutions within allowed legal frames as well as push legal frames ahead.

When there is already a national strategy with clear targets for the energy mix, finding funding for the integration of RES in PT infrastructures turns out to be much easier. Currently those strategies are still missing in some central European countries.

Try to link projects that complement each other, to build on what you already have but also be ahead of times even if the solution is not the standard at the moment.

To really implement a change, “eco” thinking is important at all times. If there is a choice, the environmentally sustainable option should be used. How to integrate and use renewable energies needs to become part of new infrastructure measure, making increasing the share of RES in the PT system a strategic objective within municipal and regional decarbonisation strategies and facilitating horizontal and vertical integration and cooperation between departments and external stakeholders to reach these objectives.

Annexes

List of references

D.T1.2.3 Development of Action Plans for energy-efficient PT infrastructure deployment

D.T1.3.1 Transnational guide on recommendations for policies, legal and institutional frameworks

D.T2.3.2 Transnational handbooks for energy-efficient PT infrastructure technologies deployment

D.T3.1.4 Evaluation report on pilot action 1

D.T3.2.3 Evaluation report on pilot action 2

D.T3.5.2 Transnational handbook on EfficienCE pilots & best practices for energy-efficient PT infrastructure