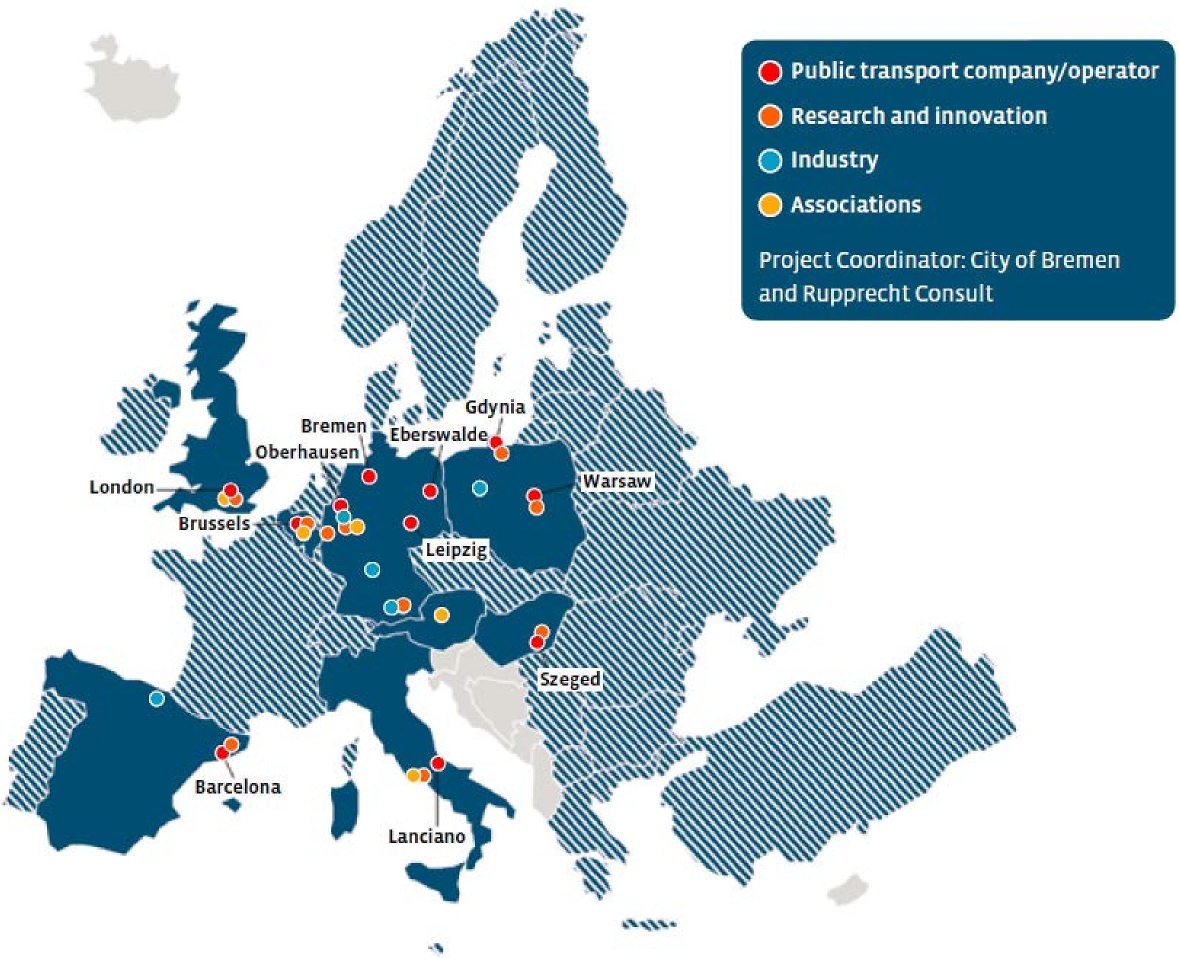
Foreword

ELIPTIC – electrification of public transport in cities was a three-years Horizon 2020 research and innovation project and a member of the CIVITAS initiative for clean urban transport running between 2015 and 2018. The consortium consisted of 33 partners from 8 different EU countries representing different sectors such as cities, manufacturers, research institutes, associations and public transport companies.

ELIPTIC evaluated various approaches and technologies for electrifying public transport and demonstrated that the further take-up of electric vehicles can be done in a cost-efficient way by integrating multi-purpose charging into existing public transport infrastructures. ELIPTIC received funding of 5.9 million € through which it was able to realize 20 different use cases in the form of both practical operation and feasibility studies.

The goal of the ELIPTIC policy recommendations is to share the insights our use cases have made with regard to the electrification of bus fleets in their cities and how existing electric public transport systems can be used for the charging of other electric vehicles.



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1. *Why do we need to talk about electric buses?*

In the ELIPTIC project, partners from different sectors - bus manufacturers, cities, public transport operators, associations and research institutes - worked together to test and analyse e-Bus integration in existing infrastructure (depots, tram or metro power grids), seeking a higher efficiency and use of recuperated energy in trolley and tram/metro networks and explored the possibility to charge other electric passenger and utility vehicles with these existing energy networks. Therefore, ELIPTIC gained insights and hereby presents recommendations for the electrification of the whole transport sector.

Transport has become one of the major issues affecting the sustainability of European cities. Road transport is the largest contributor to total NOx emissions and urban road traffic is responsible for 40 percent of total CO_2 emissions and 70 percent of emissions of other pollutants. Since more than 72 percent of Europe's population lives in urban areas, this poses a major health risk to European communities. Transport is a common and complex challenge for the entire EU, however, there are already now many dense urban areas in Europe that have highly developed public transport systems. These can already offer excellent means of motorised collective transportation services and fulfil all preconditions to become even better and cleaner cities.

Public transport is a backbone of sustainable mobility strategies and plays a major role for further increasing accessibility, tackling climate change as well as reducing local noise and air pollutant emissions. Public transport has the potential to further electrify the whole transportation system.

Furthermore, there is a need to reduce energy consumption, emissions and congestion and to solve space problems at the local level while at the same time tackling increasing transport volumes.

The dependence on, mostly, imported oil and limitations of road space, led to a general re-thinking of transport, from simply building more road infrastructure to smarter and more efficient use of existing infrastructure.

Nowadays, buses in urban areas are in operation for 13-14 hours per day, whereas cars are used less than one hour per day. On average, urban buses depend to 89% on Diesel engines, whereas cars depend "only" to about 50% on this technology (overall in Europe). An 18m bus consumes about 40,000 litres of Diesel per year in urban operation, which is equivalent to approximately 110 tons of CO_2, but uses less space and reduces congestion compared to individual motorised transport means.

Car		18-metre bus
< 1 hour	daily operation time	12 – 16 hours
small (- medium)	engine size	large
50 – 60 % diesel	fuel	95 – 98 % diesel
Diesel: PM10 + NO2 petrol: low	related local pollution	diesel: PM10 + NO2
500 l fuel	annual fuel consumption	40,000 l diesel
	overall impacts	**savings equivalent to 100 e-cars**

Figure 1: ELIPTIC Factor 100 campaign

However, despite the fact that public transport has significantly longer operating hours per day and higher annual fuel consumptions there is a much stronger support of electric cars in many European countries. Along with incentives such as free or reserved parking, access to bus lanes and limited taxation, purchasers of an electric car can receive direct funding of up to 7.000€. By comparison, the financial support for electric buses in Europe is weak. This low level of support for electric buses does not reflect their significantly higher positive impacts.[1] If financial support for the purchase of electric buses reflected their factor 100 impact, each 18-metre electric bus would be subsidised by €500,000 and each 12-metre e-bus by €400,000. With this, European cities could quickly achieve a substantial reduction in local and global emissions and improve overall traffic conditions.

Factor 100 led to a €100 million national funding programme for electric buses

Together with standard leaflets and roll-up banners, ELIPTIC also produced, somewhat unconventional for a transport research project, Factor 100 coasters. The intention was to reduce the core message to few enough words to fit on a coaster: *"Did you know that it takes 100 electric cars to achieve the impacts of one electric bus (18m) (but there is not 100 times the funding for electric buses)".*

The Factor 100 campaign was presented at various national events and events of the Commission – including at a workshop with Transport Commissioner Violeta Bulc in October 2016 on procurement of e-buses.

The city state of Bremen took the ELIPTIC Factor 100 to the Conference of the Ministers

[1] The ELIPTIC partners believe that clean Diesel buses will still have an important role to play in the transition period towards full zero-emission public transport. In contrast to passenger cars, Diesel Euro VI motors for heavy duty vehicles, such as buses, have to fulfil the emission limits in real drive emission test and procedures since 2013. By using Diesel particulate filters, selective catalytic reduction systems (SCR) and Diesel oxidation catalyst converter technologies the emission goals are being fulfilled.

for Transport and the Conference of the Ministers for Environment – both representing the 16 states of Germany.

Addressing the diesel-related air quality problems and the increase of transport-related CO2 emissions, Bremen started an initiative for appropriate national funding of electric buses. In May 2017, all 16 German State Ministers for Environment agreed on the "factor 100" proposal for a national funding programme, proposing €100 million in annual funding covering 80% of the additional costs for an electric bus. Such a programme could fund 400-500 e-buses annually. In the context of its Diesel Summit on 2 August 2017, the German government announced exactly such a programme with €100 million annual funding for electric buses.

The ELIPTIC project shows how research and technological development can be linked with ongoing political processes. It also underscores the value and relevance of involving municipalities and practitioners directly in European RTD projects.

The public transport sector should enhance its environmental leadership by shifting further to low and zero emission vehicles. This is crucial as the debate about low-emission zones and banning Diesel vehicles becomes more immanent.

The European Union has set the target of reducing the CO_2 emissions by 80% by 2050 against the 1990 level, whereas the transport-related CO_2 emissions have to decrease by 60%. So far, the EU member states have in total about 25% more transport-related CO_2 emissions than compared to 1990, and this is also the sector which achieved the least reduction.

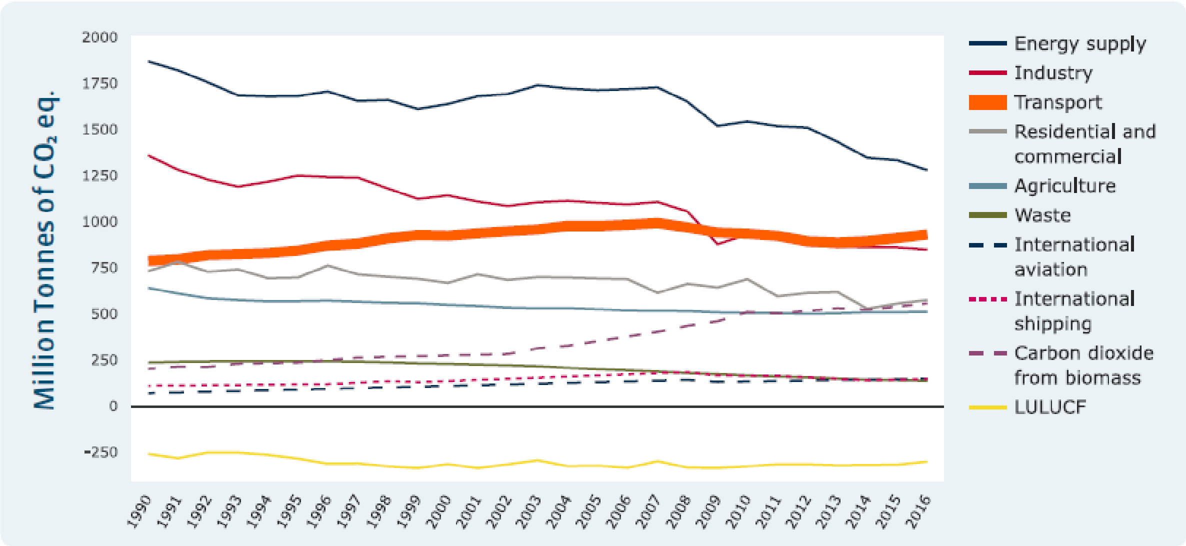

Figure 2: Development of emissions by sector in Europe since 1990[2]

[2] https://ec.europa.eu/clima/policies/transport_en

2. State of play – current (e-)bus technology

The main difficulty for operators who have the intention to introduce electric mobility into their public transport fleets is to identify the most suitable solution(s) to their local context conditions and operational requirements. Public transport operators need to find the most convenient solutions that neither change dramatically the daily operation of their buses nor exceed the personal, investment and operational boundaries. The existing bus lines and the planning of networks for bus operation and energy flows are the result of decades of experience and are already highly optimised. The main goal of all operators is to deliver efficient, comfortable and reliable service to all of their customers and to bring them from point A to B.

ELIPTIC Recommendation I: Finding the right resources saves time and money!
Public transport operators do not need to reinvent the wheel anymore when introducing electric buses into their fleet but can build upon the many experiences made and lessons learnt by other European cities. There are many good resources available, not only from the ELIPTIC project but also from other European research projects like ZeEUS and EBSF_2, which can help to avoid making the same mistakes. The European Alternative Fuels Observatory provides a useful knowledge centre as well as infrastructure and vehicle statistics related to alternatively-fuelled vehicles. Also, in 2017 the Clean Bus Initiative was launched by the European Commission which functions as a deployment platform to bring together public authorities, manufacturers, financial organisations, and public transport operators. The aim of this platform is to better coordinate relevant actors, provide recommendations on relevant policies and inform about investment opportunities.

Although getting closer, battery e-buses have not yet reached an equally high maturity level nor a similar driving range when compared to Diesel buses which have an 98% reliability These are two of the most important challenges and cost drivers. By contrast, battery-hybrid-trolley buses have already gained a high maturity level and within the ELIPTIC project it was analysed and tested if and how existing trolleybus routes can be modified and extended with trolley-battery-hybrid buses which are able to operate partially without being connected to overhead wires and charge when wiring back onto the overhead catenaries (in-motion charging).

“The hybrid trolley system is the most sustainable solution for public transport. Existing trolley systems can be extended to the outskirts of cities, providing fully electric public transport.”

- Frank Wruck, Managing Director of the Barnimer Busgesellschaft mbH (BBG) -

Within ELIPTIC, public transport operators like TMB (Barcelona), BSAG (Bremen), MZA (Warsaw) and SZKT (Szeged) tested and analysed different e-bus charging approaches. These were comprised of depot charging with large batteries on board, charging at the end of lines (also called opportunity charging), charging through already existing infrastructure by taking the power from the tram or metro networks and in-motion charging with trolley-battery-hybrid buses.

Charging concept / Battery concept	Opportunity Charging			Overnight Depot Charging (AC)	Charging On-Route (DC)
	Public Grid (AC)	Local tram/metro grid AC	Local tram/metro grid DC		
Small Capacity / High power	Barcelona				Szeged Gdynia Eberswalde
Medium Capacity / Medium Power	Brussels	London	Oberhausen Leipzig Warsaw		
Large Capacity / Low Power				Bremen	

Figure 3: ELIPTIC E-Bus integration use case approaches

Additionally, public transport operators face a situation with multiple ways and technologies of heating and cooling, diverse procurement and warranty approaches of the manufacturers as well as charging systems. This can be either realised with a plug-in cable or a pantograph (located at the front / back of the bus or integrated in the pole infrastructure). Therefore, a lot of different technology approaches have been developed and the decision for a certain solution always comes with the risk of vendor and technology lock-in.

Zero-emissions versus practicable operation of e-buses: the heating and cooling dilemma

Today's usage of fossil fuels like Diesel in E-bus heating systems is being perceived as a pragmatic and interim solution, a necessary evil on the way to achieve full electrification of bus systems. A Diesel heater consumes in wintertime on average 4 litres on 100km, while at the same time the electric bus saves approximately 40-50 litres of Diesel per 100km in comparison to a Diesel combustion engine.

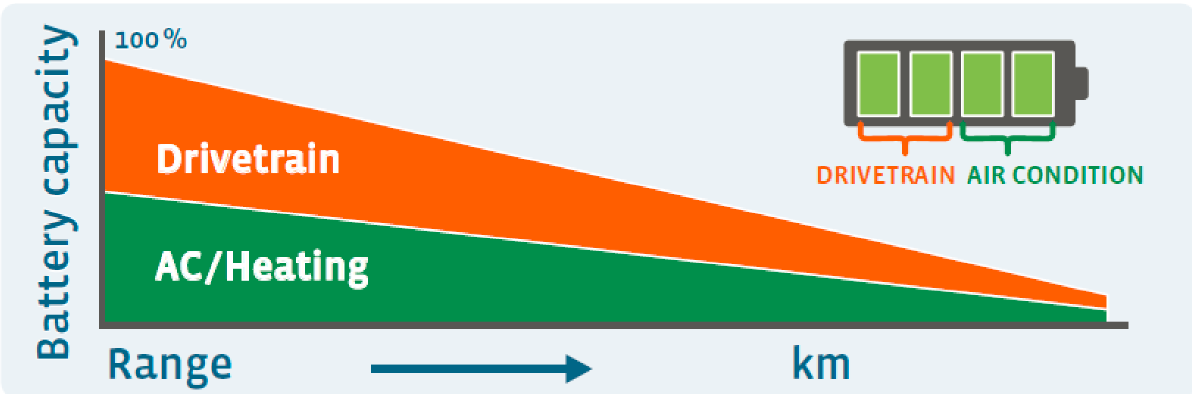

Figure 4: The air conditioning/ heating dilemma of E-buses

To reduce risks and minimise battery weights, Diesel heaters in electric buses will still be necessary until alternative fuels for the heaters like bioethanol or advanced technologies such as heating pumps become as marketable, affordable and reliable as Diesel heaters. This is expected to become a solution to reduce the fossil fuel consumption of heaters just for winter times with low ambient temperatures.

ELIPTIC Recommendation II: When it comes to heating and cooling, operable e-buses with some emissions are better than non-operational zero-emission e-buses!

As using the battery energy for electric heating significantly reduces the driving range (up to 50% in harsh winter conditions), it is recommended to continue using Diesel heaters as an interim solution for the transition period when electrifying bus fleets. However, more sustainable technologies such as heating pumps are currently being developed and will become more available as zero-emission buses are politically demanded. These developments should be taken into consideration in future procurement and electrification strategies.

High upfront costs

Financing of electric buses is one of the highest challenges for public transport operators who see themselves confronted with approximately twice as much upfront procurement and investment costs when compared to Diesel buses. Furthermore, costs incur for purchasing charging infrastructure and for further training of the staff.

ELIPTIC Recommendation III: Take all costs into consideration!

Introducing e-buses in your fleets does not only mean replacing the engine of a bus but rather to replace a whole system that is comprised of bus, battery, charging infrastructure, relevant depot equipment and existing practices. In addition, competencies and staff training are crucial cost factors that should not be underestimated. All these factors need to be taken into consideration when planning to electrify e-bus systems and calculating the associated costs.

These higher upfront costs result from high battery costs and the necessary charging infrastructure, depot equipment, new operations (schedules and strategies) and new ways to procure (lifecycle, maintenance). Also, standardisation and interoperability aspects as well as the closer cooperation between energy and bus sectors require operators to build up new capacities and knowledge. Against this background, the issues that arise include, among others, how to e.g.: identify suitable technology solutions for the specific local operational context, tackle technical barriers such as available capacity, grid connection, voltage stability, availability of charging technology manufacturers, lack of interoperable charging systems and standardised metering systems etc.

Standardisation and interoperability

The experience from the ELIPTIC use cases as well as from the other available data shows that the charging infrastructure is technically not mature when used in daily operation. Because of the recurring problem of inoperability for charging electric buses, Diesel buses were often kept in ELIPTIC use cases as back-up solutions, thereby increasing the operator's TCO.

To reduce investment costs and the risks related to interoperability of charging infrastructure, operators should ask in tenders for common charging systems and/or for specific compatibility with their existing infrastructure. This risk will be reduced when standardisation processes are more advanced.

The selection of one technology provider today can be a risk, as new technologies (also larger and more cost-efficient batteries which would favor depot charging) may render the present technological concept obsolete.

ELIPTIC Recommendation IV: Interoperability and standards are key!

The ELIPTIC use case cities made the experience that there is a lack of common solutions for charging technologies and missing communication protocols on the market which can lead to vendor and technology lock-ins or expensive retrofitting measures. The ELIPTIC partners recommend to demand interoperable solutions with open standards and the exact specification of technical details when procuring charging systems.

The CEN (European Committee for Standardization) and CENELEC (European Committee for Electrotechnical Standardization) both received the mandate from the European Commission to develop recommendations for the standardization of charging systems. A final recommendation will be presented already to the EU Commission in June 2018. The standard for inductive and wireless charging of electric buses should be completed by 12/2019.

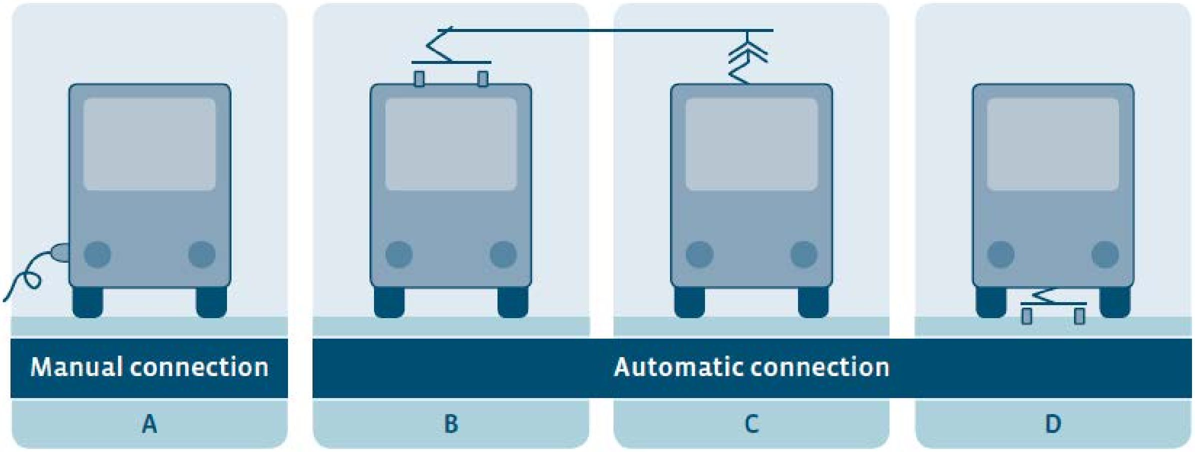

Figure 5: Overview of different technical charging solutions A (plug in), B (pantograph going down), C (pantograph going up) and D (pantograph below vehicle), (Source UITP, April 2018)

More challenging operation

Operating e-buses requires a good analysis of the operational needs**.** A technology only performs well when it is put in its best operational conditions. Therefore, the choice of the technology solution depends heavily on the local situation and can influence greatly the total cost of ownership.

ELIPTIC Recommendation V: Make use of simulation tools to find the best vehicle, battery and charging technology configuration!

Simulation tools help public authorities in the planning of e-bus systems and electrification of their fleets for real operation. The ELIPTIC research partners Vrije Universiteit Brussel, RWTH Aachen and Fraunhofer IVI have developed tools that can help finding the optimal technical configuration, design and charging strategy for the use of e-buses on a given line. The ELIPTIC E-Bus Decision Support Tool has been developed as a resource that allows operators to learn from projects in which bus lines with similar parameters, e.g. based on line length, line type and topography, have been realised in order to get a first understanding of necessary driving range and battery capacities.

The integration of charging infrastructure into an existing public (transport) power network potentially requires an upgrade or the first installation/ connection to the DC grid, if the operator cannot build infrastructure components upon an existing network used for the metro or tram operation. If the goal of the operator is the full electrification of the fleet, the overall demand should be calculated for a fully electric fleet, taking the electricity consumption during day and night and at peak times into account. Key stakeholders are the operators of medium-high voltage grids, which should be part of the planning process for the fleet and charging transition project.

ELIPTIC Recommendation VI: Get a good understanding of your own tram, metro or trolleybus grid's resources and potentials!

In order to gauge the potential of integrating charging infrastructure for e-buses into existing power networks, it is necessary to perform a point-by-point analysis to get a better understanding of energy capacities and underused potentials. Based on this, it can be seen whether charging points can be easily connected and integrated or upgrades/ new installations to the grid are necessary.

Synergies can be found with metro and/or tram operators when it comes to maintenance and operation skills of the electric bus charging equipment. Another important stakeholder to consult is the city/ municipality and the respective planning authorities as public spaces are needed for the power grid development as well as for the on-route / opportunity charging infrastructure installation. This is particularly important in dense cities in which public space is a scarce resource.

While energy supply is usually sufficiently available for the integration of electric buses, the cost of electricity and the monopolisation of energy distribution are important barriers. These conditions can limit the access to the city's energy supply significantly. Renewable energy sources are increasingly integrated into charging infrastructure, as many cities are taking further steps to reduce their ecological footprints. For instance, cities can start installing decentral power plants, such as PV panels, on parking/bus garage spaces.

Overall, each operator, together with the city/regional authorities, has to analyse the individual risks and opportunities. Most ELIPTIC partners expect that the implementation of electric bus systems will create positive impacts on both the energy and mobility sides. Examples are the improvement of the existing know-how on electric vehicles, the possible enhancements of the public transport electric grid, lower energy costs and a more efficient use of the network.

Procurement and warranty

When procuring e-buses, operators are not only procuring e-buses, but e-bus concepts, as operation, line / net planning has to go hand in hand with the planning of when and how to charge the buses. Such concepts have strong impacts on the charging concept and battery usage.

As battery buses still need to be considered as products relatively new on the market, the experience on both sides, procurers as well as providers, is limited with regards to mid-term to long term usage and battery aging.

In general, operators procure buses and charging infrastructure. They should also have guarantees from the providers for:

- Aspects related to the interoperability of charging infrastructure:
    - Is the pantograph going up or coming down?
    - Is the pantograph placed at the front or rear of the vehicle?
    - Are there additional plug-in solutions for depot charging and opportunity charging concepts?
- Defined and agreed measures on battery testing in case of warranty issues:
    - Definition of the line(s) for testing, definition of the conditions – and in particular in comparison with roller dynamometer test benches;
    - Timing (frequency, e.g. once a year);
    - Responsibilities (operator, provider, independent office)

Furthermore, elements that were usually not considered for tendering Diesel vehicles should now be taken into account when tendering an e-bus. These elements include lifecycle costs, operation range, reliability (share of the risks) / maintenance responsibility, safety limitation (legal conditions), and also positive externalities: air quality & noise cost reductions. This can eventually lead to better performance indicators for the transport service contract with the transport authority but requires negotiations.

E-Buses on the market

The biggest challenge at this moment (mid 2018) is the adequate availability of original equipment manufacturers in Europe to provide enough vehicles. This is a concern shared by ELIPTIC partners after having tested different bus, battery and charging technologies.

Before the current European e-bus projects, there were mostly prototypes available, whereas now – also thanks to research projects like ELIPTIC, ZeEUS and EBSF_2 – there are fully-commercial vehicles on the market. The efforts of the European Commission for e-bus deployment have been helpful to push for bus deployment, however, a good balance between cost-effective operations and procurement should be ensured. Local decisions for bus deployment could relieve cities and operators of great challenges such as high costs and rapid retrofitting of infrastructures.

E-bus manufacturers are currently growing rapidly, with higher e-bus productions each year. This is made possible thanks to the good cooperation with operators and cities that are open for new solutions and willing to take risks.

Still, many more bus manufacturers – particularly the bigger European manufacturers - are needed to fulfil European market requirements and the increasingly growing demand for e-buses. Many European cities have already announced ambitious plans to electrify their bus fleets, which requires much more production capacity by the manufacturers than is currently available.

3. Public transport as the backbone of an electro-mobile future: using the public transport grid for the charging of non-rail bound electric vehicles

The lack of city-wide charging infrastructure and the limited driving range of electric vehicles are barriers for the wider deployment of electromobility solutions. Being often much more cost-effective than building a standalone charging infrastructure or using the public electricity grid, ELIPTIC's use cases have shown how the existing electric public transport infrastructure (trolleybus, metro and tram sub-stations and catenaries) can be used as charging infrastructure for other electric vehicles such as e-buses, e-cars/ taxis, e-vans, e-bikes and e-utility trucks.

The multi-purpose use of infrastructure poses an especially interesting business case for public transport operators as the grids are usually overdimensioned and energy surpluses exist. Against the background of the expected larger uptake of electromobility in the coming years, these grids are valuable assets that public transport operators can use to also become energy providers for non-railbound electric vehicles. As other European cities are also currently looking into the possibilities of charging electric buses and other e-vehicles with existing public transport infrastructures, it can be expected that this topic will become increasingly important.

"Existing electric infrastructure for public transport can facilitate the next wave of electrification, public and private, in cities. ELIPTIC has provided practical knowledge about how electric buses can be integrated into an existing electric public transport grids, complementary to the ZeEUS project."
- Umberto Guida, Director of Research & Innovation, UITP -

Using existing DC rail grids to supply power to charge electric vehicles also has a high potential for the further integration of e-mobility related applications. In the future, these grids could be fed directly from a higher-level medium-voltage DC grid, which is supplied by the medium-voltage AC grid as well as by renewable energy sources such as solar and wind. The advantage is that energy flows can be better controlled, which allows, for the more effienct use of braking energy. Recuperated braking energy could be transported to more distant locations due to the higher voltage level where it could then be used for the charging of other electric vehicles. Furthermore, there are no conversion and rectifier losses since no (50 Hz) AC voltage is required in the system which will even further increase the overall efficiency of the system. To make the most use of these medium-voltage DC grids, intelligent power electronics (DC/DC converters) are necessary.

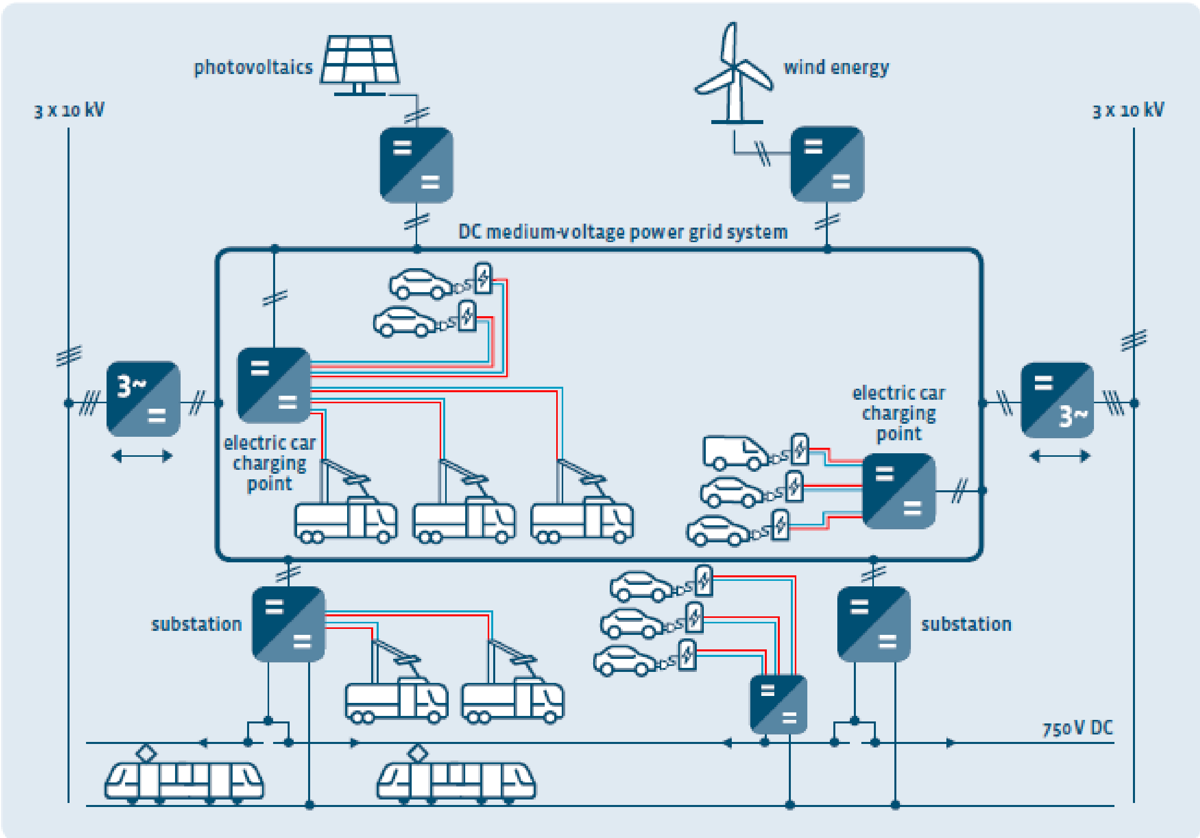

Figure 6: Connecting e-vehicle charging stations to the existing public transport infrastructure

Table 1: Possible advantages of the multi-purpose use of public transport infrastructure for the charging of other electric vehicles

Advantage	Explanation
Potential for high power charging	When using the existing DC grid, it is possible to draw relatively high power due to available capacities in the usually over-dimensioned systems enabling the application of DC fast charging stations (>=50kW). Therefore, vehicles can be charged in a relatively small amount of time.
More efficient use of public transport grids	In case of over-dimensioned grid capacities or times of low energy demand of rail-bound traction energy (e.g. at night), surpluses can be used to charge other electric vehicles without requiring new

	infrastructure and costly grid extensions. Thus, additional consumers can increase receptivity and thereby increase the efficiency of the grid.
Higher cost efficiency	In a lot of cases using the public transport grid can be more cost-effective than using the public distribution network to charge electric vehicles
Less additional space requirements	Existing switchgears, converter transformers and rectifiers of public transport sub-stations can be used. Chargers can be placed in sub-stations with weather-proof conditions
Less bureaucratic installation of charging points	Data (regarding grid connection etc.) can be accessed in-house and do not necessarily have to be requested elsewhere. Building permissions are unnecessary when land is owned by the public transport operator and determining sites for charging points can be done completely independent. This can highly reduce the regulatory burden for public transport operators.
Competencies are available in-house	For the introduction of electric buses, it is a great advantage to already have and operate electrical infrastructure. This provides sufficient experience in the design, operation and maintenance of electrical systems. For pure (diesel) bus operators this lack of in-house competence means a much more difficult entry to electric mobility. Therefore, the main technical and operational competencies are already available within the tram/ metro/ trolleybus own operating staff regarding electric infrastructures.
Potential to integrate different e-mobility services	Possibility to offer various e-mobility services in multimodal e-mobility hubs in order to also allow for e-mobile trip chains including energy provision for these e-vehicles.
Enhancing image of public transport	Enhanced image of public transport operator as providers of clean mobility solutions

For the safe operation of this multi-purpose infrastructure, it is necessary to look at infrastructure aspects and vehicle types as well as local context conditions, such as energy capacities of the grid, the institutional set-up in cities and regulatory frameworks. Within the ELIPTIC project partners have made valuable experiences and encountered several obstacles that currently pose a barrier to public transport operators which are interested in using their grid to charge other, non-railbound electric vehicles. The ELIPTIC project partners would like to share these experiences and see a necessity for the following barriers to be tackled in order to have a level playing field and fair conditions and requirements for the multi-purpose use of public transport infrastructure.

A. Technical constraints and obstacles

Many European cities have available capacities in the often overdimensioned systems of their public transport grids that can be tapped into and used more efficiently for the charging of other electric vehicles. In order to identify these capacities, it is necessary to analyse the technical possibilities to connect charging infrastructure to the existing rail grids.

However, this requires major changes in the policies and engineering standards that often govern the use of the existing rail grids which, in many cases, have been developed decades ago with the sole purpose of delivering a very highly reliable (e.g. in London several times the redundancy of public distribution networks) supply of current to metro and tram trains.

Overlapping the public transport network map with the map of on and off-street parking lot locations allows to identify the most economically feasible parking spaces that could be connected to the public transport energy system.

It was ELIPTIC's objective to better understand what the restrictions of connecting both systems and narrowing down the possible locations to the ones that are feasible in terms of connectivity are. There are many places around existing grids with spare capacities that could deliver sufficient power to support significant EV charging infrastructure. However, this is only one part of the story as the viability of the supply is equally dependent on geographic and accessibility factors. Spare capacities in the grid need to be determined on a site-by-site basis and are only a viable energy source for EV charging infrastructure when being close enough to the charging facility.

Special attention needs to be given to the trouble-free operation of the chargers for non-rail bound electric vehicles. These must not cause any perturbations and thereby become dangerous for the operation of the public transport network, which, certainly, still has the highest priority for public transport operators. When introducing measures that allow for the charging of other electric vehicles from the public transport grid, it is recommended to perform power quality measurements at the charging points that are connected to the grid. In doing so, it can be ensured that there are no harmful effects on the grid.

ELIPTIC Recommendation VII: Extensive testing will increase acceptance among electrical engineers!

In order to increase the acceptance for multi-purpose charging measures within one's own staff, a comprehensive programme of testing should be designed and carried out in collaboration with the electrical engineers. Prior to commencing the connection of vehicles to the chargers a programme of baseline measurements should be conducted to determine the state of the power system. Following on from this a testing programme of different demand recharging schedules should be implemented building from a single vehicle trickle charging to a higher number of vehicles drawing full power simultaneously.

Even though the actual costs highly depend on the city's population density, generally speaking, installing cabling in streets is a very expensive undertaking. In London, roadway excavations to install new cabling cost approximately £300 per linear meter of excavation. While many of the substations, switch rooms and other easier connection points to the grid can often be found at or close to the surface, many other seemingly viable connections can be inaccessible, for example when being buried in underground rail tunnels (e.g. in London).

The accessibility of necessary technical equipment is a crucial factor to bear in mind which can significantly limit the availability of potential places for charging places. For example, in the ELIPTIC partner city Barcelona the local partners found that 300 meters is the maximum recommended distance between the rail network and the charging point[3]. In London, it was determined that to be viable to charge electric buses through the metro a suitable bus depot would need to be located within 100m of a connection point to the London Underground grid.[4]

The question whether it is economically feasible to connect charging points to the rail-network therefore highly depends on many local factors and technical context conditions. Some of the questions that need to be investigated are:

- What is the proximity to the public transport grid?
- What is the availability of energy capacity to deliver charging from the rail grid?
- Is there enough space available to install charging infrastructure?
- What power source should the charging facility be connected to? Charging stations can be connected to the DC side (catenaries), or to the high (with new transformer) or low voltage side of the city's AC distribution grid (auxiliary station services).

The technical challenges differ significantly with regard to the selected grid connection (DC or AC).

Connection to the DC grid

ELIPTIC City	Use Case Description
Oberhausen	Use of tram infrastructure (catenary and sub-station) for (re)charging e-buses
Leipzig	(Re)charging of e-buses using tram infrastructure
Warsaw	Use of tram infrastructure for recharging e-buses

Where the electric power is taken directly from 750 V DC tram catenaries and transformed for the (fast)-charging stations for other electric vehicles, the technical difficulty lies in the use of the highly fluctuating DC input voltage (750 V +20%/-30%). Furthermore, the charger must be galvanically isolated, as normal electric cars (and also buses) do not have double insulation. A (dual or single) active bridge is used as the basic circuit to provide the required isolation by means of a transformer.

One of the biggest problems is the currently very small market and the corresponding lack of availability of manufacturers. This experience was made, for example, in Warsaw, where only one supplier bid on the tender and delivery was greatly delayed. In addition, some of the offered solutions have not yet reached their final technical maturity, which holds the risk of disruptive effects and outages. Furthermore, in Leipzig it occurred that the charging station failed when vehicles passed by because the voltage drop across the connecting cable was too high.

These experiences should be taken into account in the planning process by the operators

[3] See Barcelona Final Use Case Report
[4] See London Final Use Case Report

and manufacturers in order to be able to present a successful operation in the future with this concept.

Connection to the AC grid

ELIPTIC City	Use Case Description
Barcelona	Opportunity (re)charging of electric buses based on metro infrastructure
Brussels	Progressive electrification of hybrid bus network, using existing tram and underground electric Infrastructure
London	Opportunity (re)charging of e-buses and/or plug-in hybrid buses (using metro infrastructure)

No special technical issues have been encountered within the project when connecting charging stations to the AC grid. There is a bigger market for suitable charging stations and the technology is more reliable when compared to DC systems.

For the demonstration in London 3 double-headed 7kW chargers were procured with the intention on delivering a twofold proof of concept. Firstly, that EV charging infrastructure could draw current from the LU grid without any adverse effect on either the power network or underground rail operations. Also, secondly that the charging equipment could operate effectively and reliably while connected to the highly reliable but potentially low-quality supply in terms of voltage stability (due to DC traction current). As a result of the ELIPTIC trial, charging infrastructure connected to the London Underground grid has been accepted for long term use and the vehicles that collectively use these charge points will significantly reduce tailpipe CO_2 emissions of the Transport for London support fleet.

A special focus was placed on the topic of network perturbations, as the network of the London Underground must not be disturbed under any circumstances. A schedule of electric vehicle charging was undertaken complimented by a full monitoring of the power quality. Baseline measurements of power quality were also taken in the three weeks before testing of the e-vehicle charge commenced:

- Stage 1: 1 car trickle-charging with its battery almost full
- Stage 2: 1 car charging from flat battery
- Stage 3: 6 cars charging simultaneously from flat battery
- Stage 4: 6 vehicles charging as per usual (‘as is’) duty cycle

In this way risk to the London Underground AC power network was minimised by slowly increasing the amount of power required in each stage of the test. Following on from stages 1 and 2 which showed no impact of single electric vehicle charging on the London Underground power grid, stages 3 and 4 were combined into an 18-day measurement programme. Critical factors during the testing were voltage stability and the introduction of harmonics. The measurements showed that there were no breaches on any of the harmonic limits.

Complementary measures like demand control, electric separation, power storage and detailed real-time monitoring are opportunities that may help mitigate or altogether avoid potential negative effects on both metro/ tram operation and charging equipment (due to voltage spikes). Power management, together with careful scheduling of charging times can also help overcome the weakness of the technology concept having a secondary role before the metro/ tram operation by, e.g. optimizing off-peak charging possibilities.

Taking advantage of the complementary power demand patterns that have been observed in some ELIPTIC use cases (morning and afternoon peaks for metros and trams, electric vehicle charging at night), several apparent weaknesses may be turned into an asset, including charging speed (e.g. slow charging at 3.6 kW) and the second priority of vehicle charging to metro/tram operation. In this regard, smart meters, together with real-time monitoring of the metro/tram power grid and controlling the power supply can increase the operational availability both during and off-peak metro/tram operation hours, even without the use of storage media.

B. Cost comparison between using energy from the public distribution and public transport grid

A main advantage of using the public transport grid is the cost of electricity from the tramway transformer station in relation to the general grid when comparing the connection costs in the case of connection to traction-tram grid versus connection and fixed costs in the case of the general grid. The goal is to achieve a lower cost of 1 kWh of electricity consumed in relation to the price from the public electricity grid.

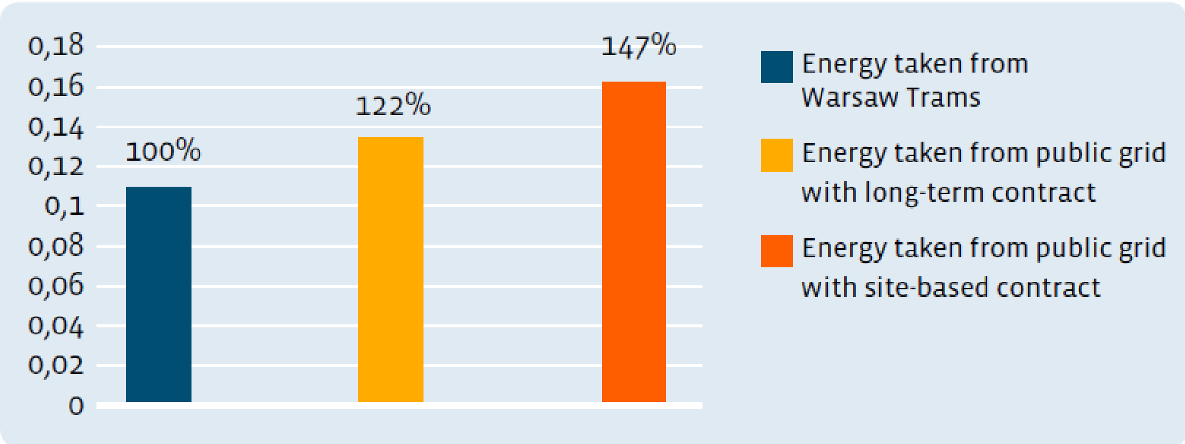

Figure 7: The cost of electricity per 1 vehicle/km compared by different supplies of energy in Warsaw[5]

- 0.1108 € / km for the charger on the TW “Włościańska” depot connected to the transformer substation of Warsaw Trams, powered by electricity based on the long-term contract between TW and the commercial energy supplier;
- 0.1354 € / km for chargers at the MZA "Woronicza" depot supplied with electricity based on a multi-annual agreement between MZA and commercial energy supplier;
- 0.1631 € / km for a pantograph charger placed on “Spartańska” bus terminus powered by electricity based on an individual contract between MZA and commercial energy supplier

[5] See for in-depth calculation Warsaw Final use case report

> *“Each innovative solution is worth considering, because it is a challenge and helps create the future. The ELIPTIC Project demonstrated that we are able to diversify the sources of electricity for our e-buses”*
>
> - Jan Kuźmiński, President of the Board, Miejskie Zakłady Autobusowe (MZA Warsaw) -

It is estimated that electrifying the entire London bus fleet will place a demand on the electricity network within the city approximately equivalent to the traction current used by the Underground of 1TWh per year. There is already considerable pressure on the distribution system from the demands of the non-transport economy in certain areas. This is why Transport for London is currently investigating the extent to which its own private AC high and low voltage electricity infrastructure could be used to support the electrification of surface transport such as buses. Transport for London is working with the Distribution Network Operators to analyse power supply options and costs for bus garages across London, supplied by (and connected to) the national grid. However, past experience has shown that in some cases high capital costs may render connections to the public grid harder to justify and/or make a viable business/investment case.

Results from the ELIPTIC project, here provided through the example of Warsaw and London, show that using the public transport grid as a source of electricity to charge other electric vehicles can be the most economic option being often significantly cheaper than using electricity from the public grid.

C. Unclear organisational roles for public transport operators

The management of large electric fleets, both on fixed (metro, tram, trolleybus) lines, as well as flexible bus routes will require a comprehensive control and management of charging points distributed throughout the service area. Given the rigid and limited availability of connection points to the public transport grid, connecting to the public distribution grid is thus inevitable and potentially also beneficial. This calls for the role of the public transport operator to be further developed to that of an energy manager.

Becoming an energy manager through the installation of multi-purpose charging stations implies a greater planning and technical challenge for public transport operators as when compared to using conventional connections to the public distribution grid where the installation burden is carried by the electricity operator. A cooperation with other authorities and operators is therefore a necessity because of complementary strenths and resources as well as joint operations. This is for instance the case when bus lines are operated together with other public transport operators and aspects like contracting, accounting and maintenance need to be dealt with jointly.

ELIPTIC Recommendation VIII: Identify your role and the necessary partners you need to work with when becoming involved in the energy market!

It highly depends on national, regional and local regulations to what extent and in what form public authorities can play a role in the energy market. This role and the necessary partnerships are also highly dependent on the question what kind of service the public authority wants to offer (e.g. parking, charging time) and to whom (public fleets, private customers). Possible roles are, for instance, charging infrastructure manager, operator and/ or distributor.

If public transport operators are interested in using their grid for the charging of other, non-railbound electric vehicles they have to analyse what role they can play and in what organisational constellation they would like to appear. Possible roles for the public transport operator are charging infrastructure manager, operator and/ or distributor.

If, at least, two companies take care of the charging infrastructure, a definition of the relationship between the public transport operator and the charging point operator is necessary. Different constellations will have an impact on the role of each player and the maintenance and operational costs.[6]

Scenarios need to take into consideration the type of charging management and the final use of the energy provided, distinguishing between private vehicles and public fleet vehicles.

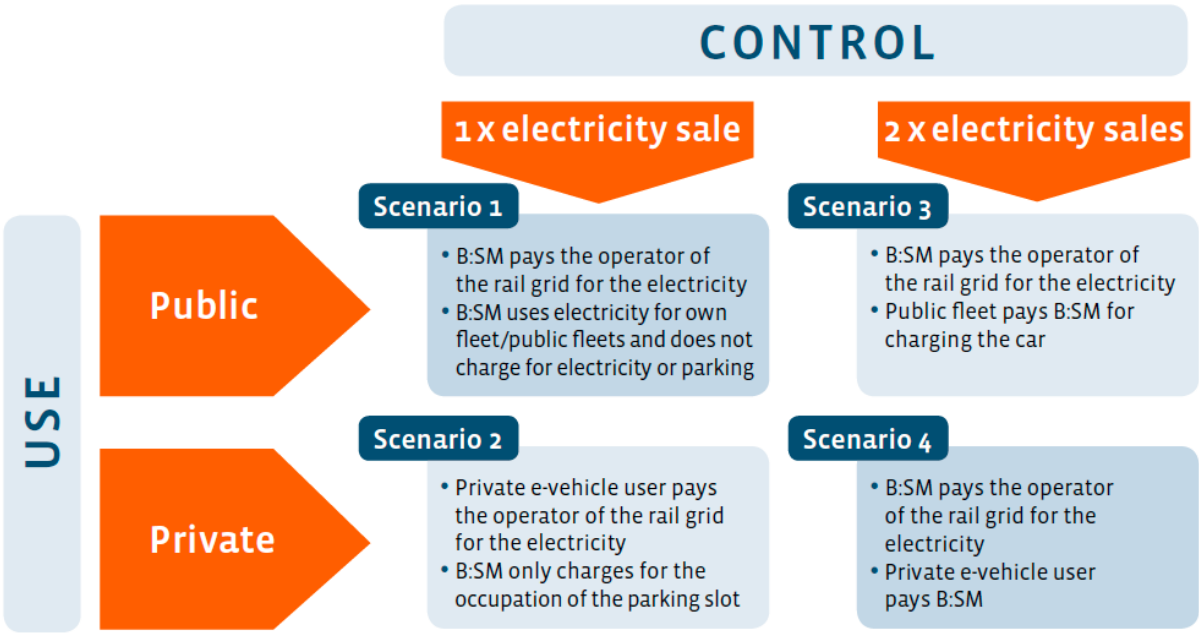

Figure 8: Different operational models for the management of charging points in Barcelona, B:SM

The charging manager is the only party that is allowed to sell energy. This role can be done

[6] See Barcelona Final Use Case Report

by the public transport operator or by the car park manager, this is not only important in financial terms but also has consequences on the maintenance responsibilities. Currently the most likely scenarios to be approved are the ones where there is only one charging manager (public transport operator to car park manager) and the end user is related to the public administration.

"On-street charging points supplied by the metro power grid offer energy efficiency advantages compared to those supplied by the public distribution grid."

- Josep Ariño, Infrastructure manager, Transports Municipals de Barcelona -

A crucial aspect encountered by the ELIPTIC project was also that official permits need to be obtained to access the power grid when grid operator and public transport operator are not within the same entitiy. Often approval also needs to be secured from national energy authorities regarding network usage and tariff conditions for the resale of energy. As these procedures are often completely unknown and only entities with a concession for selling the electricity are allowed to do this, obtaining permits can be time-consuming and need to be started early on.

D. Procurement and market situation: lack of standards and suppliers

Tram, metro and trolleybus networks are DC-powered infrastructures whereas most of the chargers on the market produce for AC. There is only a small market of suppliers and within the ELIPTIC project partners often encountered problems to explore the market and collect offers by manufacturers. Thus, within ELIPTIC project partners had to face a market situation in which chargers were either not available at all (e.g. charging station with input voltages of 600/750 volts DC (+ 20%/ ‐ 30%), allowing for the immediate use of the existing DC tram infrastructure for the fast-charging of other electric vehicles in Oberhausen[7]) or only as prototypes (e.g. multi-purpose trolleybus and e-car charger in Szeged[8]).

"The use of the existing tram power system to charge our electric buses is an innovative solution. It contributes to support the aspirations of the City of Oberhausen for a clean environment in a sustainable way."

- Werner Overkamp, Managing Director STOAG Stadtwerke Oberhausen GmbH -

Also, the interoperability of different charging systems must be significantly improved. There is still a lack of standardization, both in terms of the connections and the charging protocols used. Thus, it is crucial that a greater number of suppliers offer more varied charging products and services and that common and interoperable solutions, e.g. for data communication, are available on the market.

E. Regulatory challenges

[7] See Oberhausen Final Use Case Report
[8] See Szeged Final Use Case Report

The exact billing of charging processes is an important factor for both infrastructure operators and customers in order to ensure the wide take-up of e-mobility services. Drivers of conventional vehicles know the current fuel price and are used to being able to calculate prices in a certain unit of volume. They refuel, pay and can be sure to have received the correct quantity of fuel for their money because the fuel pumps are regularly checked by the responsible calibration authorities. This transparent and reliable solution is also a must for charging stations for electric vehicles.

All systems currently on the market are subject to measuring and calibration regulations and must therefore be designed in accordance with these. The charging station has to be either subjected to a conformity assessment, which could result in a positive assessment, or, in order to remain in conformity with calibration law, charging processes are only billed at a flat rate or supplied free of charge.

The ELIPTIC project partners encountered quite a few regulatory challenges. The legal unclarity of the sale of electricity was the most prominent issue for all use cases. In several countries, the legality of energy and fiscal issues concerning the use of electric transport infrastructure are not clearly defined. In some use cases, the sale of electricity was tolerated temporarily, despite being only partially legal. In other cases, new laws on this issue were in the process of being formulated, however this is a lengthy and ongoing procedure, which led to further uncertainties and delays in the implementation of use cases. For one use case, however, the sale of electricity did not pose a legal problem. In this particular city, the sale of electricity works through a licensing system, with which the use case partners were already experienced.

Other unclarities for ELIPTIC use cases were caused by the lack of billing regulations for pricing of energy and service, as well as for the measurement of energy input into electric vehicles. Further difficulties were the determination of charging sites due to restricting infrastructure regulations, and the lack of available devices that allowed the use of existing PT networks for charging purposes.

The current lack of calibrated DC current meters makes it impossible to resell the energy to an end customer with legal security. In order to guarantee smooth operation of the charging infrastructure it is crucial to get a full permission from the verification authority for certified DC counters. As a temporary solution within the ELIPTIC project customers were offered vouchers through which a full battery charge, regardless of the amount of energy, was offered at a fixed price. Not being able to charge customers based on kWh or time of charging does, however, not allow public transport operators to launch services with a solid business case. Also it can be expected that customers will not accept solutions that do not allow for transparent and exact billing of the charging process.

ELIPTIC Recommendation IX: The internal use of multi-purpose charging is much easier than selling energy to 3rd parties!

Due to current regulatory barriers, it is currently very difficult in most European countries for public transport operators to resell energy to 3rd parties. Therefore, it is recommended to start with the charging of one's own fleet such as service cars and vans as this does not involve any complicated metering and billing processes. Also due to the clear prisonisation of metro and tram operation, the charging of other electric vehicles will always be second priority. Thus, charging one's own fleet allows for the easier scheduling of charging times (e.g. at night) and power management and has therefore proven to be a much more viable business case.

F. Shortcomings of the existing legal framework

If the potentials of electrified urban rail systems can be used more efficiently by also charging non-railbound vehicles, it needs to be clarified whether and to which extent this new "interface" between the mobility and the energy system has been sufficiently considered by the current law. Also it needs to be seen what new challenges emerge and what obstacles the present legal and regulatory frameworks impose on such concepts.

Until now, the energy law has mainly ruled the generation, consumption and transport of energy. However, the requirements of the current and future energy sector, i.e. a high percentage of renewable energy sources as well as efficient and environmentally-friendly technologies, have not been adequately considered yet. Temporaray storage of energy such as in batteries or flywheels and the recuperation of braking energy are examples of such a disregard of the current energy law. So far, the legal framework of the energy system is based on the assumption that energy can only be generated and consumed once. The energy legislator then puts various duties on the parties generating or consuming energy.

So far, the traction power supply system has more or less been regarded as a "black box" in the sense of the energy law, but this might change as soon as the multi-purpose use of traction power supply systems become more common. This does not mean that the multi-purpose use of a traction power supply system would be illegal per se. However, it does mean that public transport companies that take on one (or several) new market role(s) are confronted with certain legal requirements, which often imply administrative, personnel and sometimes even economic challenges.

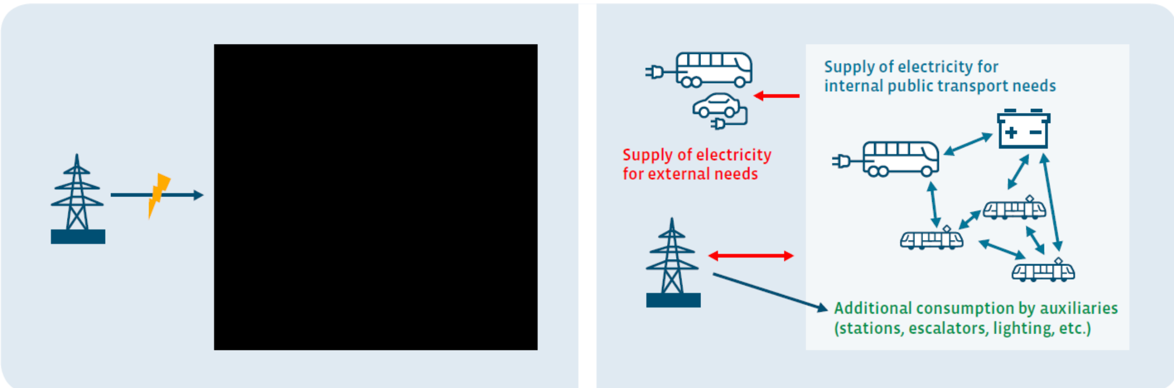

Figure 9: Opening up the public transport grids black box

As a result of this unclear legal situation public transport operators face the following challenges:

Classification of the activities of public transport companies in accordance with the energy law
If public transport companies begin to "open" their traction power supply systems to third

parties, questions may arise that have not been asked so far and could imply practical difficulties for public transport operators in their daily operation. This might imply for public transport operators to specify requirements for the measurement of the electrical energy generated and consumed as well as duties to report and inform, which would probably hardly be realisable in practice.

New market role for public transport companies as generators and sellers of electrical energy
If public transport companies enter the market for non-railbound electric vehicles, further administrative duties might have to be observed if energy is sold to third parties (e.g. duties to report to the grid operators or to authorities, to set up contracts and invoices and to delimitate energy flows).

Privileges for public transport companies versus sale of non-privileged electrical energy and feeding energy back to the public electrical grid
Public transport companies' main business task, i.e. 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 "open" their traction power supply systems to third parties, i.e. if they change from being pure power consumers to being active participants in the energy system, they are often confronted with requirements for complex delimitations and measurements.

In Hungary, for example, the regulation of the energy market currently does not allow for a simple way to sell electricity at a public e-car charger, making this possible only for major electricity suppliers, who operate charging stations mainly for advertisement purposes. Therefore, the current energy regulations do not allow the commercialization of energy from the trolley grid, further complicating a successful implementation of the concept.

To summarise, the currently unfavorable legal framework and the contractual difficulty of commercializing electricity to third parties partially block the feasibility of the concept. As a technical note on this issue, the nature of the current (AC or DC) currently present an added difficulty. As gauged DC meters are not yet available, measuring energy withdrawn from such grids (Szeged, Leipzig, Oberhausen) is not possible, which inhibits the operator's capacity of quantifying (and eventually commercializing) their outputs. This problem does not exist in AC grids, which, given favorable regulations, could go ahead with market available components.

4. The ELIPTIC policy recommendations

Cities in Europe are increasingly concerned in reducing emissions from transportation, and are focusing their incentives away from fossil fuels (with diesel in the crosshair) and towards electric solutions free of (local) emissions. While the wider take-up if electric mobility solutions seems within reach, however, key issues must be sorted out to ensure its viability, from which energy infrastructure, power availability, energy storage solutions, and economic incentives are just a few.

The seed that ELIPTIC has planted will undoubtedly lay the groundwork for many initiatives to come, and its fruit will be part of the electric landscape of tomorrow. The experiences gathered from its numerous use-cases elucidate the common ground most cities may encounter in their development of electromobility. This will allow them to plug into their potential by exploiting their electric systems and exploring solutions to power their growing electric fleets. One of the central lessons of ELIPTIC is that existing electric infrastructure for public transport can facilitate the next wave of electrification, public and private, in cities. While it is likely that full electrification will require the integration of a variety of power networks, a necessary first impulse can be provided from the installed capacity already in place.

Public transport operators can facilitate the next wave of electrification in our cities!

Increasingly, the symbiosis of a public transport operator's power grid and its operation of an ever-wider range of electric vehicles will see them managing not only the provision of public transportation, but also the energy systems that will drive it. Just as cities are looking for smart answers to their mobility problems, public operators will need to find smart solutions to efficiently provide their electric fleets with power. Smarter grids and effective energy storage options are some of the innovative items that will become central in designing future power systems for public transport. Innovative solutions that constantly monitor performance will allow operators to manage more than one grid, incorporating, e.g., the public distribution grid as an addition to their own.

Operators of electric public transport modes are increasingly becoming managers of their electric grid and their energy systems. As electric vehicles take a larger share of public transport trips, operator's role in providing access to its grid will require its specialization as such, and the permission to do so. Regulation actions aim at changing or adapting the existing legal and regulatory frameworks to take advantage of opportunities to operate the technology concepts.

Examples from the use cases include the restriction of distributing (commercially or otherwise) energy from the public transport grid (often itself subsidized) to third parties. As such, most cities are restricted from providing access to this grid to bus operation concessionaries, taxis, utility vehicles (supervision, maintenance, etc.) and, eventually, private individuals or commercial fleet operators. Relaxing some regulations could help operators implement several technology concepts for the benefit of their own electric vehicle operation, as well as the optimization of their power demand.

Shifting landscapes: what needs to happen if public transport operators increasingly also become involved as charging point operators and energy managers?

To support the development of future technologies in the field of renewable energies, energy storage and electric mobility, it is absolutely essential that a coherent regulatory framework is provided for the interface between the mobility and the energy sector. A coherent and administratively "leaner" legal framework for the decentral generation and sale of energy would be needed as the numerous uncertainties and inconsistencies restrain public transport companies from developing innovative electric mobility concepts such as being able to re-sell energy to third parties.

"Before a rail company provides its DC network for the charging of e-buses or other e-vehicles, it is essential to check whether the charging energy can be reliably and accrued.

Otherwise, there are currently considerable risks of insufficiently implementing provisions of energy and electricity tax law. This can lead to legal violations or the loss of privileges in the energy sector with considerable economic consequences. The legislator should simplify the implementation of e-mobility for businesses through consistent adjustments."

- Eberhard Nickel, Leipziger Verkehrsbetriebe (LVB) GmbH -

The regulations have to be elaborated in a way that existence-ensuring 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. This would impose a massive barrier to political goals set by the EU, i.e. the shift from private to electric collective transport, as the legal risks for the public transport companies would be too high.

Links

- **ELIPTIC Website**: http://www.eliptic-project.eu/
- **ELIPTIC Final use case reports:** http://www.eliptic-project.eu/results
- **ELIPTIC E-Bus Decision Support Tool:** https://www.mobility-academy.eu/course/index.php?categoryid=26

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If sources are not named directly, this brochure is based upon the work of the partners within the ELIPTIC project. Further information on the deliverables and outcomes of the project can be found on the website: http://www.eliptic-project.eu/

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