Roadmap for Electric Bus Systems

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SUMMARY SHEET

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Abstract	The ZeEUS Roadmap is aimed at providing comprehensive look into the evolution of e-bus deployment, starting from the ZeEUS project and its achievements and building on the current challenges and technology state to define the steps likely to follow in the next decade in order to achieve mature, fully developed e-bus systems across Europe and beyond.
Key words	

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CONTRIBUTING PARTNERS

#	Participant Partner Name	Short Name	Country
1	UITP	UITP	Belgium
All	Feedback from ZeEUS Partners		

ACRONYMS

3iBS: Intelligent, innovative, integrated Bus System. *http://www.3ibs.eu/en/home*

CAPIRE: Coordination Action on PPP Implementation for Road-transport Electrification. *http://www.capire.eu/public*

CCS: Combined Charging System

CEN-CENELEC: *http://www.cencenelec.eu*

COP21: 21st *conférence des parties*

EBSF: European Bus System of the Future (1 and 2). *http://ebsf2.eu/*

EPoSS: European Technology Platform on Smart Systems Integration. *http://www.smart-systems-integration.org/public*

ERTRAC: European Road Transport Research Advisory Council. *http://www.ertrac.org/*

ERRAC: European Rail Research Advisory Council. *http://www.errac.org/*

EV(s): Electric vehicle(s)

HVAC: Heating Ventilation and Air Conditioning

ICE: Internal Combustion Engine

ICT: Information and Communication Technologies

KPI: Key Performance Indicator

LIB: Lithium-ion battery

OEM: Original Equipment Manufacturer

PTA: Public Transport Authority

PTO: : Public Transport Operator

TCO: Total Cost of Ownership

SETRIS: Strengthening European Transport Research and Innovation Strategies. *http://newrail.org/setris/*

UN: United Nations

INDEX

INDEX OF FIGURES

INDEX OF TABLES

1. EXECUTIVE SUMMARY

Electric bus technologies have seen a growing interest among the urban mobility actors, especially operators and authorities. From a promising but uncertain future, e-buses and e-bus systems have experienced major technological and operational advances which have led to a slow but secure pace of positive development.

Back in 2013, e-buses represented only 1.2% of the European fleet share. Nevertheless, a significant 40 % of the operators and authorised surveyed expressed their wish to transition to electric powertrains, mainly hybrid and battery electric vehicles (3iBS project, 2013).

After five years of successful work, the ZeEUS project has proved that a series of electric solutions for high capacity buses are a reliable and economically and environmentally feasible option ready to play a major role in the urban public transport.

Today, the deployment of electric bus systems is politically-driven as a strategic decision to meet the needs and expectations of cities and citizens.

The present report "Fully Electric E-bus Systems Roadmap" is aimed at supporting the introduction of e-bus systems in urban environments. It provides a comprehensive look into the evolution of e-bus deployment, starting from the ZeEUS project and its achievements, and building on the current challenges and technology state to identify the steps milestones likely to follow in the next decade in order to achieve mature, fully developed e-bus systems across Europe and beyond.

The roadmap identifies key topics of e-bus systems such as the main phases to achieve the objectives, considering R&D, demonstration as well as the establishment of regulatory frameworks and market introduction. Suggestions and priorities are given about topics that can be developed in the framework of research and demonstration projects capitalising the ZeEUS knowledge on the e-bus systems to a maximum extend, and about mature concepts and technologies suitable for harmonisation, standardisation and legislation.

We wish you a pleasant read!

1. INTRODUCTION

1.1 The ZeEUS project

The ZeEUS project gathers 48 partners representing the entire value chain of e-buses: cities, operators, industries, charging solution suppliers, energy providers, researchers and more. Together, they fully embrace the challenge to extend the fully-electric solution to the core of the bus network.

With the goal to provide decision makers with the necessary tools to evaluate the economic, environmental, operational and societal feasibility of urban e-bus systems, ZeEUS has carried out live operational tests in 10 European cities (Barcelona, Bonn, Cagliari, Eindhoven, London, Muenster, Paris, Plzen, Stockholm and Warsaw). With a total fleet of 110 vehicles, the buses run in full revenue operation in a range of different geographical, climatic, environmental and operational conditions.

Aimed at facilitating the market uptake of e-buses, the methodology and analysis proposed within ZeEUS facilitated the creation of guidelines and tools to support decision makers in determining "if", "how" and "when" to introduce e-buses.

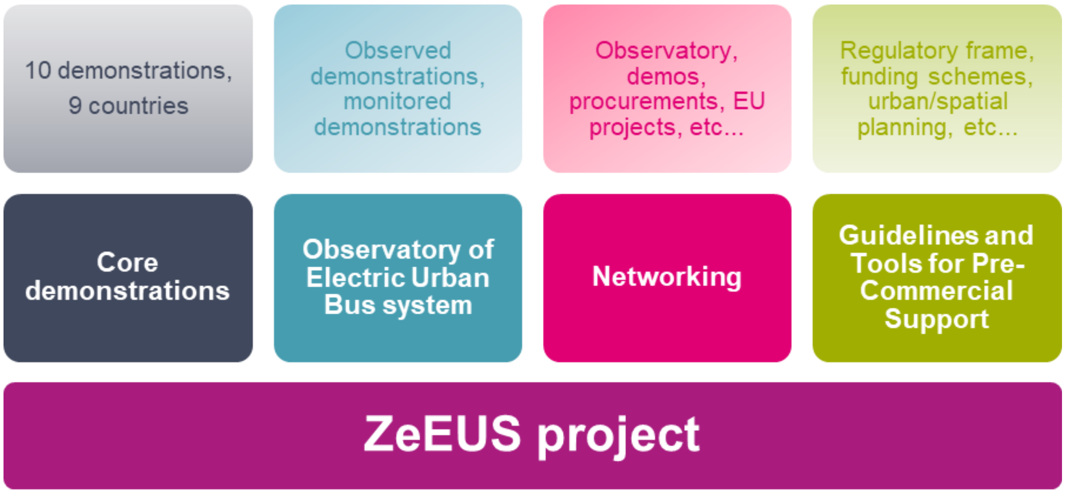


Figure 1. The ZeEUS work plan
Source: ZeEUS project

After almost five years of project, ZeEUS has demonstrated the feasibility of several electric solutions for high capacity urban buses, contributing to increasing confidence in e-bus technology and consolidating e-bus deployment as one of the trends in clean urban mobility.

We are confident that the knowledge basis elicited and the experience gathered within the ZeEUS project will contribute to making the electrification of the European urban bus systems a reality in the next future.

1.2 Vision

"Driving together towards the fully electrification of the bus system in Europe"

Research and technological development in the field of alternative fuels are shedding more light into the opportunities and potential of cleaner transport in Europe. By supplying electricity from alternative fuels rather than from fossil fuels, we have the knowledge and capacity to:

- Instead of using the energy consumed during 1 year of services in a biogas bus, **driving an e-bus for 3 years**;
- Instead of using the energy consumed during 1 year of services in an ethanol based bus, **driving an e-bus for 2 years**;
- Instead of using the energy consumed during 1 year of services in a biodiesel bus, **driving an e-bus for 2 years;**
- Instead of using the energy consumed during 1 year of services in a diesel bus, **driving an e-bus for 2 years.**

Already in 2013 and in the frame of the 3iBS project[1], UITP recorded a high interest of the urban mobility actors towards e-buses. In addition, electric powertrains seem to be much more energy-efficient than other technologies. Still, the e-bus has not conquered yet its place as the backbone of the European bus system. Why?

The ZeEUS project aimed to address this question by testing different technologies and solutions in a series of European cities with the overall goal of bringing electric buses to the core of public transport.

International efforts like the Paris Agreement[2] set the policy framework and show the commitment of the global community to abandon carbon emission this century, and stop global warming "well below" 2° Celsius (if possible, even below 1.5°). Reducing the carbon emissions involves undoubtedly a wider proliferation of public transport, as officially recognised by the UN during the climate summit. In particular, e-buses have a great potential to tackle climate change as they operate emission-free at a local level[3]. If we ensure the energy supply is coming from alternative energy sources we can consider the e-bus technology as one of the most promising to tackle local emissions and pollution and global climate change.

This ZeEUS Partners and the project goals fully support this vision.

1.3 Scope

Electric buses can be seen today in fully operation in many cities. We have achieved a state of development where the number of e-buses evolved from very little (1 or 2 buses per scheme) to the growth of entire lines and even fleets. In order to understand what are the challenges ahead and the progresses achieved within ZeEUS in the last 5 years, it is necessary to define the scope of the project and the barriers associated to it.

The deployment of e-bus systems imply a paradigm shift from considering the vehicle in isolation to design a new whole ecosystem, which includes the vehicle, the infrastructure, and the operational context. This poses one of the biggest challenges, as e-buses require the design and development

[1] 3iBS: Intelligent, innovative, integrated Bus System. *http://www.3ibs.eu/en/home*
[2] On 11th December 2015, 195 nations participating in the COP21 (21st Conférence des Parties) meeting of the UN Framework Convention on Climate Change adopted by consensus a legally binding plan to fight climate change, named the Paris Agreement.
[3] http://www.eliptic-project.eu/news/zeeus-and-eliptic-projects-support-efforts-reduce-carbon-emissions

of the charging infrastructure and a tailored charging strategy, which is subsequently related to the type of e-bus technology.

While e-buses come in different types, the name always refers to a motor road vehicle that is mostly emission free at the point of operation. Because they are battery-driven and have a lower environmental impact than an internal combustion engine bus, they are usually viewed as ‘clean’ and ‘green’, particularly when charged with electricity derived from renewable energy sources.

In line with the ZeEUS project scope, the current report focuses on the following categories of e-buses. However, we acknowledge that other categories are in operation with different propulsion schemes (hybrids, or fuel cells) and/or capacity (mini and midi buses).

The e-bus technologies considered in the ZeEUS project are:

1. **Plug-in hybrid buses** (PHEVs) are hybrid electric vehicles that use rechargeable batteries or other energy storage devices that can be recharged by connecting them to an external electric power source. PHEVs share the characteristics of both a conventional hybrid electric vehicle, with an electric motor and an internal combustion engine (ICE) and an all-electric vehicle equipped with a plug or other device to connect to the electrical grid. Diesel hybrids (as they exist in the current bus market) are excluded from the scope of the project and from this publication.
2. **Full battery electric buses** (BEVs) are all-electric or purely electric vehicles with an electric propulsion system that uses chemical energy stored in rechargeable battery packs. BEVs use electric motors and motor controllers for propulsion in place of internal combustion engines (ICEs). They have no internal combustion engine, fuel cell or fuel tank and derive all their power from their battery packs. Battery buses are charged statically using mechanical and electrical equipment.
3. **Battery trolleybuses**: also referred to as dual-mode trolleybuses (China) or hybrid trolleybuses (Germany). These are bus-type vehicles propelled by an electric motor, drawing power from overhead wires via connecting poles called trolleys. Power is supplied either from a central power source that is not on-board the vehicle or via on-board rechargeable batteries. This enables the vehicles to run electrically while independent of the overhead wires for part of their route while maintaining full operational capability. Battery trolleybuses are charged dynamically using the existing trolleybus catenary, or in when static with a device for connecting to the electrical grid. Trolleybuses with auxiliary-only batteries are considered proven technology and are therefore excluded from the scope of the project.

As indicated previously, the charging infrastructure and strategy are directly related to the type of e-bus technology:

a) **Overnight charging** at depot for the day entire operation. The main contras are the need of bigger batteries and thus heavier vehicles, which imply less passenger capacity.

b) **Opportunity charging or ultrafast charging**. The term “opportunity charging” comes down to the charging of the battery pack at strategic locations, whenever time in bus route is available, mostly at the end of the bus line.

c) **Continuous charging**, meaning that the e-bus can charge dynamically along the whole route. The main contras are the expensive infrastructure and the flexibility loss in the route definition (e.g. in case of incidents).

d) **Inductive charging** (based on inductive systems) The main contras are the up-front cost of vehicle and infrastructure, the safety concerns on the magnetic shielding, low energy transfer efficiency.

e) **Conductive charging** (based on conductive systems). The main contras are also expensive infrastructure, potential loss of operational flexibility.

Each of these systems carries a completely specific infrastructure, thus a specific technology and maintenance. The following figure is just intended to show the complexity and diversity of the current charging technology options.

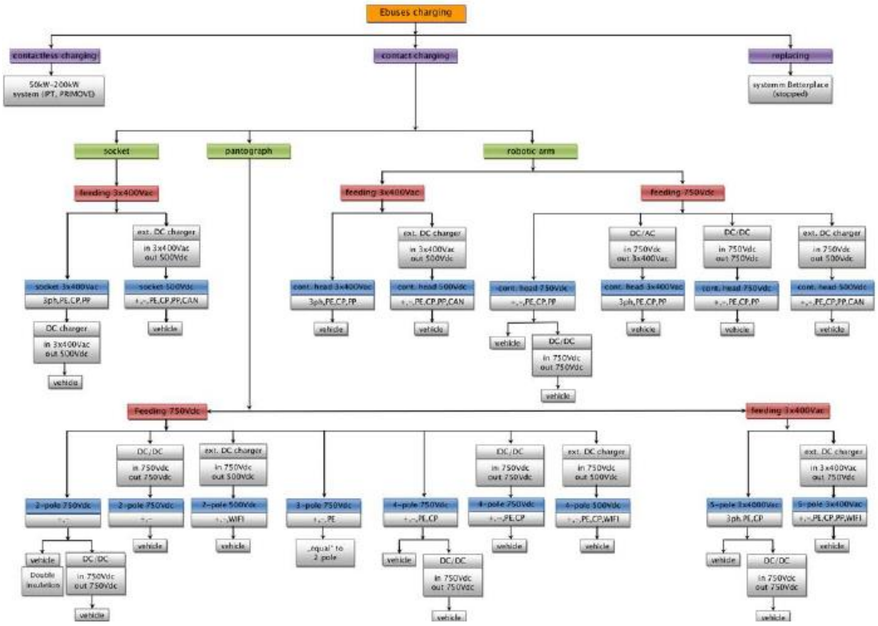


Figure 2. The complexity of the current ways of charging an e-bus
Source: ZeEUS challenges, presentation (UITP).

In this regard, it is important to understand how the infrastructure contributes to the success of an e-bus system within a specific environment and urban/spatial planning.

ZeEUS, the Zero Emissions Urban Bus System, has become the flagship EU project to extend the fully-electric solution to the core part of the urban bus network. It follows on recommendations from fellow UITP European bus system projects (EBSF, EBSF2, 3iBS, ELIPTIC) to apply the electric solution to urban bus systems.

Not only European industries, but also European cities play an important role as living labs and implementation areas for new digital services. The 2016 European Roadmap “Towards an integrated Urban Mobility Roadmap” delivered by the joint Urban Mobility Working Group of ERTRAC and ERRAC, also in close cooperation with ALICE, is confident about the contribution of cities in this regard. Overall, Europe is deemed to be the leader in sustainable transport and mobility. Many European cities have worldwide reputation in terms of innovation, sustainability and clean technologies for urban mobility and smart cities. Introducing their experiences to other cities would be beneficial. So far, international cooperation with emerging markets often focuses on big cities. However, since European cities are comparably small, their experiences need to be properly considered if addressing different urban sizes, e.g. mega cities in emerging market countries.

This vision fits within the context of the European Commission's objective to create a competitive and sustainable transport system by deploying alternative fuels to reduce transport emissions and improve air quality and noise levels in urban areas.

To support this mission, ZeEUS has tested a wide range of different e-bus technologies and charging infrastructure solutions in ten demonstration sites with diverse operational conditions in order to validate their economic, environmental and social viability. The ZeEUS demonstrations were selected from 45 candidate demos. They tested series or pre-series vehicles in different geographical, climatic, environmental and operational conditions represented in the demonstrations, which allowed the collection of relevant and sufficient data to perform a meaningful and statistically valid evaluation of the real impact of the solution on the operations.

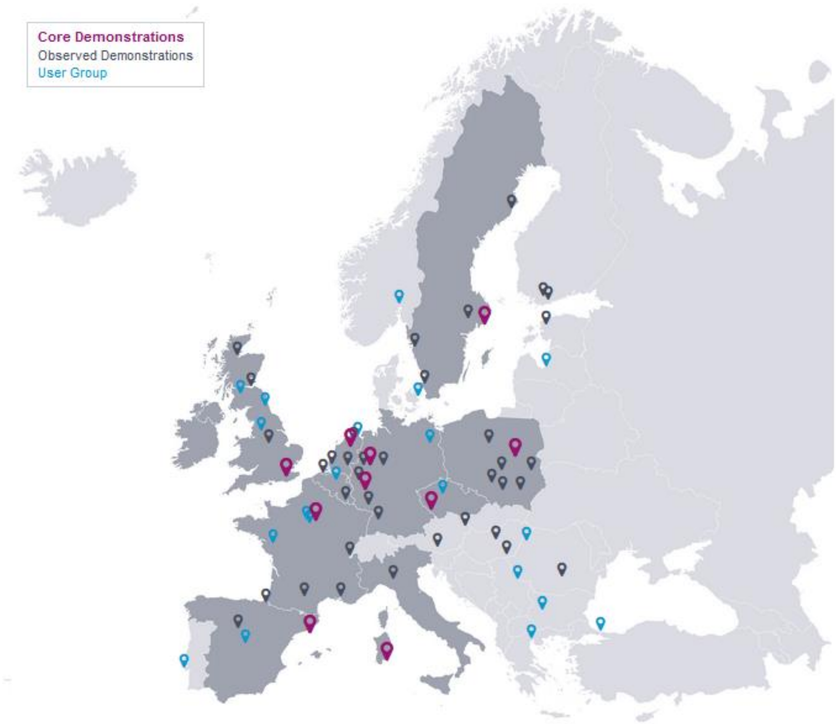


Figure 3: Demonstrations and activities within ZeEUS.
Source: ZeEUS website

The present report **"Fully Electric E-bus Systems Roadmap"** is aimed at supporting the introduction of e-bus systems in urban environments by providing the project's view on the needed steps and milestones to achieve it. After discussions, the horizon for this total introduction is proposed to be 2030.

This roadmap identifies key topics of e-bus systems such as the main phases to achieve the objectives, considering research & development, demonstration as well as the establishment of regulatory frameworks and market introduction. Suggestions and priorities were given about topics that can be developed in the framework of research and demonstration projects capitalising the knowledge developed about the e-bus Systems within ZeEUS to a maximum extend, and about mature concepts and technologies suitable for harmonisation, standardisation and legislation.

1.4 Process

1.4.1 PARTICIPANTS

The ZeEUS Consortium represents the complete value chain of electric bus systems. It is made of the whole stakeholder spectrum representing the key actors and decision maker categories who will facilitate the process of extending the e-bus technology to the core urban bus network. The 43 partners, led by UITP, are Public Transport Authorities, Public Transport Operators, Industry and Vehicle Manufacturers, Energy Providers, Universities and Research Centres, Engineering Firms, Consultancies and Associations.

- **PTAs and PTOs**: Transport de Barcelona (Spain), Stadtwerke Münster (Germany), Stadtwerke Bonn Verkehrs (Germany), Régie Autonome des Transports Parisiens (France), Île-de-France Mobilités (France), Transport for London (UK), Miejskie Zakłady Autobusowe s.p. (Poland), Hermes Groep (the Netherlands), Plzeňské městské dopravní podniky, a.s.(Czec republic)., Stockholms Laens Landsting (Sweden), CTM S.p.A (Italy).
- **Industry**: Solaris Bus&Coach, Skoda Electric a.s., Volvo Bus Corporation, VDL Bus&Coach BV, Irizar Coop, Alexander Dennis ltd,
- **Energy providers**: Endesa, Enide Solutions, Vattenfall AB, Plzeňská teplárenská, a.s.,
- **Engineering**: Idiada Automotive Technology SA, Grupo Mecanica del Vuelo Sistemas,
- **Consultancies**: Helmut Berends, Przemysłowy Instytut Motoryzacji, Thinkstep, D'Appolonia.
- **Research & Academia**: Universitat Politècnica de Catalunya, Università degli Studi di Roma "La Sapienza", Rheinisch-Westfälische Technische Hochschule Aachen, Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V., Západočeská univerzita v Plini, Fachhochschule Landshut, Viktoria Swedish ICT, TRL.
- **Associations**: UITP, ASSTRA, Polis, VDV, UTP, Eurelectric.

1.4.2 BACKGROUND

The drafting process has been performed by involving the members of the ZeEUS Consortium that have been responsible for the development of the main roadmaps impacting the electrification of bus systems and developed in specific projects. Indeed, a lot of roadmaps include the electrification of the transport system as part of the future landscape. Main EU-funded research projects that have been contributing to the development of these SRIAs show a clear continuous timeline during the last years. EU projects, such as ERTRAC II (2005), ERTRAC (2007), EBSF (2008), CAPIRE (2010), 3iBS (2012) and SETRIS (2015-2018) have contributed to these developments. First EU projects supported the update as a single-mode initiative (e.g. ERRAC Roadmap). Further steps intensified a multimodal approach covering all transport modes (SETRIS). However, the focus of the ZeEUS roadmap is e-bus systems, and includes the vehicle and the infrastructure perspective.

Previous roadmaps:

- "European Bus System of the Future". ERTRAC. June 2011;
- "Electrification of Road Transport". 2nd edition. ERTRAC, EPOSS, Smart Grids. June 2012;
  - ICT for the Fully Electric Vehicle. Annex;
- "Electric Vehicle Infrastructure Roadmap". CAPIRE project. May 2014;
- "Roadmap for the advanced bus systems". 3iBS project. July 2015.
- "Electrification of Road Transport". ERTRAC, EPOSS, Smart Grids. June 2017;

The ZeEUS roadmap is also based on the project's demonstrations and activities, as well as in the outputs of the consortium discussions.

1.4.3 STEPS FOLLOWED

The work started with the review and refinement of existing roadmaps that can affect in different ways the introduction of e-buses in cities. The general Bus Systems Roadmap was developed within the EBSF project, which includes a chapter dedicated to energy sustainability of bus systems, including electrification. This roadmap, which is the result of a joint work of more than 100 bus stakeholders, was further developed in terms of e.g. energy efficiency within the fellow project 3iBS (Innovative, Intelligent and Integrated Bus Systems). In the frame of ERTRAC and CAPIRE, further important roadmaps about electric mobility of road transport have been developed.

The ZeEUS project partners and European relevant forums and networks, e.g. EUCAR, POLIS, EUROCITIES, ERTRAC, EURELECTRIC, UITP Commissions, etc. were contacted to consolidate the main topics and define the priorities of the present roadmap. The consolidation of the existing roadmap material included the further development of its contents taking advantage of the indications collected during the execution and the evaluation of the demonstrations.

Lastly, additional content has been collected from a previous general description of sub-system block architecture with the identification of the key interfaces that are more suitable for standardisation (part of the ZeEUS project), to develop the roadmap for standardisation as input for the compilation of the "Fully Electric Bus Systems Roadmap".

2. CHALLENGES

2.1 New landscapes, new expectations

Why Electric Mobility?

According to the latest European Roadmap "Electrification of the road transport" (June 2017): "*Electrified mobility means different things to different people. Public authorities seek air quality improvement and climate action, as well as reduction of inner city traffic in general. Consumers expect no less flexibility or reliability; fleet operators need reliability and competitive running costs. (...) It is expected that urban and suburban transport will be the major application for the pure battery electric vehicle, at least within the short and medium term*"[4].

After five years of major developments and intense work in the field, it is possible to say that electric bus technology has entered the market and consolidated itself as the next main powertrain technology in urban transport in the next decades, as reflected in the bus orders in Europe (Fig.5).

However, the interest from urban mobility stakeholders in deploying clean buses was already high back in 2013 at the beginning of the ZeEUS project. In a survey carried out in the frame of the 3iBS project, over 40% of the operators and authorities surveyed indicated their wish to switch to electric traction options and, within that category, mainly to hybrid and fully electric with batteries. This clearly responded to the need of introducing cleaner vehicles to address environmental and social challenges. At that time, almost 50% of the European bus fleet was still EURO III or older, showing the urgency of fleet renewal in order to achieve EU climate and energy targets.

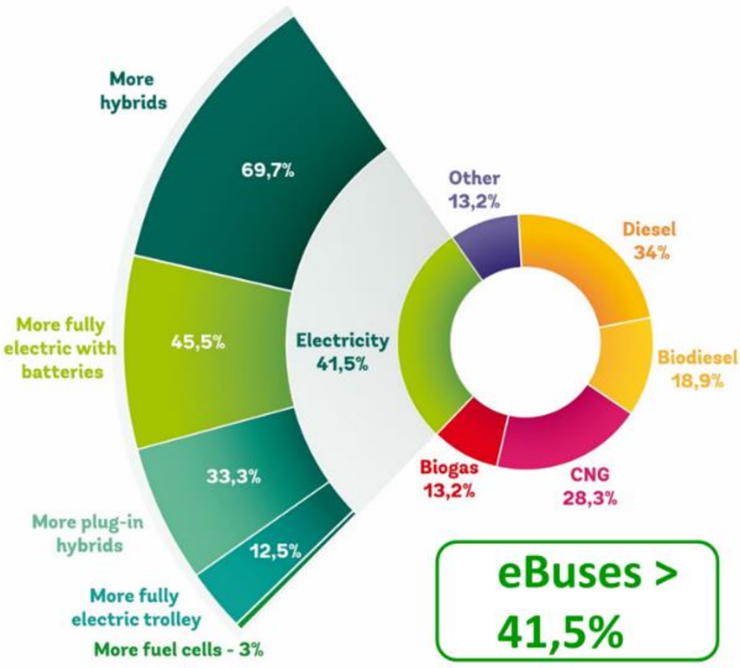


Figure 4. Respondents distribution according to future plans to change propulsion system ratio
Source: 3iBS Project (2013)

[4] European Roadmap Electrification of Road Transport "Electrification of the road transport", page 8.June 2017; ERTRAC, EPoSS and ETIP SNET.

Exploring this further, in 2017 ZeEUS and the UITP VEI Committee investigated scenarios to understand how the urban bus market would evolve in Europe by propulsion technology. The results showed an increasing trend for pure electric powertrains such as battery-electric and fuel cells, while clean diesel showed a marked decrease. Technologies such as diesel-hybrid and CNG and/or biogas retained a stable percentage of the market.

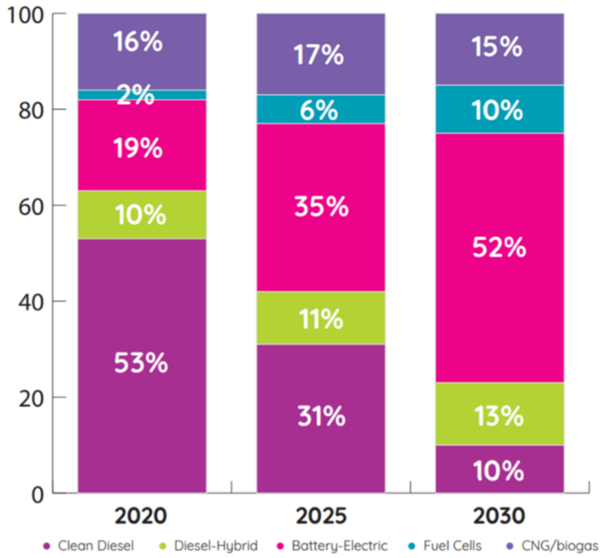


Figure 5. **Urban bus market share projections by propulsion technology in Europe**
Source: ZeEUS eBus Report#2

Electric mobility is already in the European market. Electric buses are a real trend, answering a high quantity of the European citizens' concerns as shown in Fig. 6, the distribution electric bus technology in the European bus fleet 2017 it appears to indicate a preference for battery-electric buses among operators and authorities, with 70% of the current e-bus stock powered by batteries alone.

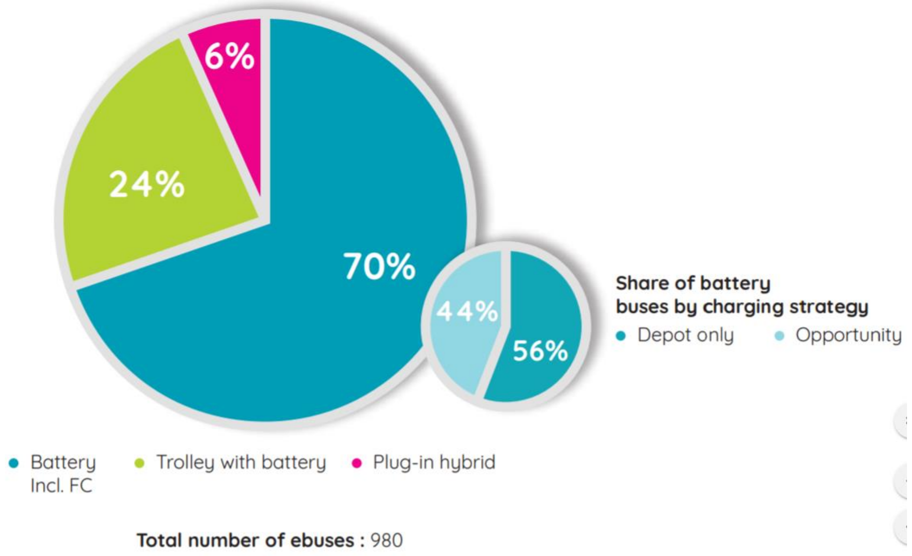


Figure 6. Distribution of the electric bus technology in the European bus fleet in 2017
Source: ZeEUS eBus Report#2

The outcomes of the activities carried out during the project, including informal consultations with key stakeholders beyond the project (e.g. the UITP Bus Committee), have shed some lights on the key expectations and interest to test and implement e-buses within European cities:

- Contributing to tackling the climate change challenges – e.g. contributing to setting on strategies for Zero Emissions at local level;
- Improving air quality conditions and air pollution, especially in cities;
- Supporting how to comply with regulations on CO_2 and other pollutant emissions;
- Reducing the dependence on fossil fuels, thus non-local (beyond EU in general) suppliers;
- Promoting the use of renewable energies;
- Reducing the noise level within the cities;
- Boosting the European technology leadership role around the world;
- And finally, collaborating to end the "*one vehicle fits all"* mentality, adapting vehicles from the scratch to specific needs and expectations.

Indeed electric buses offer great potential to reduce dramatically local air pollution, greenhouse gas emissions and resulting climate change impacts, and oil use from the transport sector. Additional benefits makes this sector more and more appealing along the technological development.

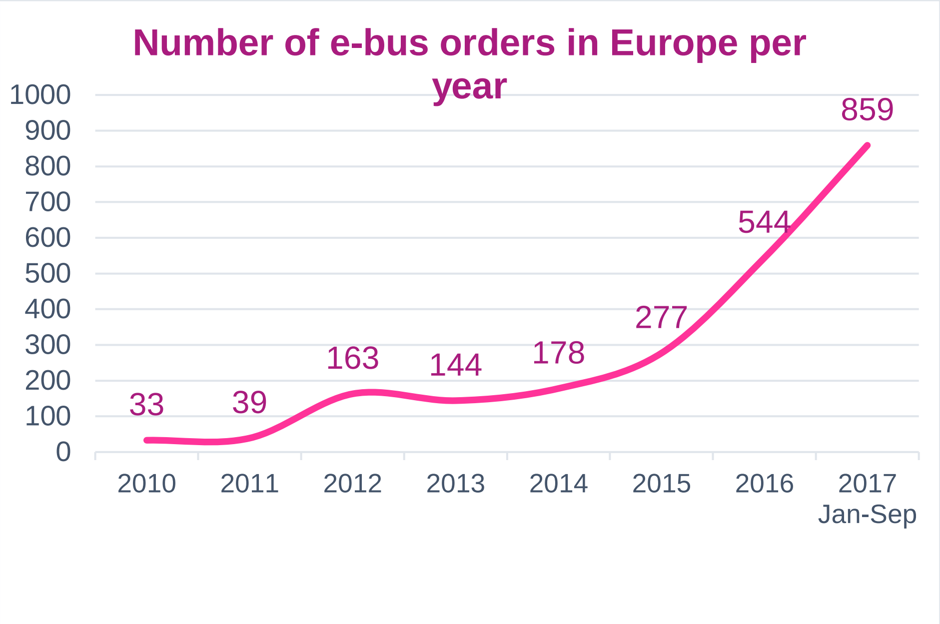


Figure 7. Fast growing of the e-bus orders in Europe
Source: ADL (2017)

However, even if there has been a notable increase on the numbers of e-buses ordered in Europe during the last years, there are still some barriers to a wider deployment of the e-bus technology. The ZeEUS project identified the top five key challenges, based on the contribution of PTOs and PTAs, and local administrations. The next section provides a comprehensive description of the challenges, including a reference for high-level key performance indicators (KPIs) to monitor their performance among a timeline.

2.2 The ZeEUS Top Five Challenges

2.2.1 Challenge 1: High up-front costs of the system

Despite the technology has achieved major developments in the last 3-5 years, the price of an e-bus is still higher than the price of conventional (diesel) buses mainly due to the battery price, which can represent almost 45% of the price of the vehicle. Moreover, the additional costs linked to the first implementation of an e-bus line, e.g. charging infrastructure and required adaptations in bus depot, imply higher up-front costs both at capital and at operations level and are a considerable concern for many operators. Some of the elements of a new e-bus system affecting the costs (both CAPEX and OPEX) are listed below.

1. Choosing the right technology: mostly linked to the selection of the right battery technology for the needed usage, the battery is a key concern not only because of the different available technologies but also in terms of global sustainability and their disposal;
2. Charging infrastructure: this is a new cost element to which traditionally, operators were not used.
3. Daily operating ranges (battery autonomy) and vehicle reliability: although there are examples of best practices and some systems have achieved significant cost reduction, today, the operation of the majority of e-buses systems is still more expensive than diesel buses.
4. New operations and maintenance: the new requirements for providing the service and adapting bus depot to the new bus technology are still unknown by most of the PTO, increasing their perception of risk linked to the new system.
5. Local depreciation rules: this factor plays a key role in lowering the TCO of e-bus system as so far, the tender specifications were mainly set up following up the specifications for conventional buses in terms of depreciation time.

The praxis is showing that it would be convenient to consider e-bus vehicle lifetime at least equal, if not longer, to conventional buses. There are considerations on the refurbishment of e-buses after the finalisation of the contract period (as it is done in the tram sector, for instance), battery replacement if needed.

Nevertheless, the entrance of private electric vehicles in the market has speed up the deployment of the market for bigger e-vehicles in Europe. The industry is positive about the improvement of battery technology and the cost reduction. Indeed, the increasing orders of e-vehicles (e-buses but also e-cars) are seen as a positive push to decrease the price per unit. This assumption is reflected in the following figure, which shows a decreasing trend (future costs estimated in different publications) with prices ranging from 150-500 USD/kWh by 2020, and 100-300 USD/kWh by 2025.

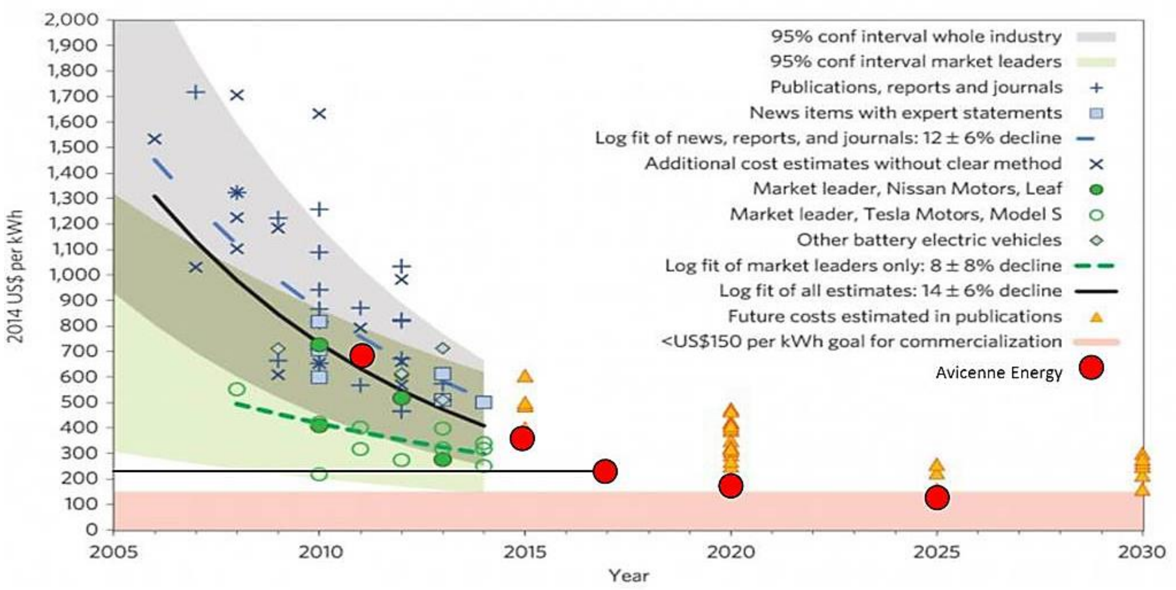


Figure 8. Lithium-Ion battery costs forecasts

Source: Nature Climate Change (March 2015); "Rapidly falling costs of battery packs for EVs"

This is supported by other American organisations, stating: *"If battery costs continue to decline as e-vehicles production increases, within several years they will reach the $125–$150 target that makes EVs competitive with conventional gasoline vehicles. (…) e-vehicles are forecast to cost the same or less than a comparable gasoline-powered vehicle when the price of battery packs falls to between $125 and $150 per kWh. Analysts have forecast that this price parity can be achieved as soon as 2020, while other studies have forecast the price of a lithium-ion battery pack to drop to as little as $73 / kWh by 2030".*[5]

High-level KPI

- Battery price (per kWh and battery type)
- e-Bus price (per unit)

KPIs units

- Qualitative measure: Price increasing/decreasing
- Quantitative measure: % price increasing/decreasing, € increasing/decreasing

The cost is the charging infrastructure is new one for the bus sector. In addition, the availability of e-charging infrastructure varies greatly at a local level and depends on the type of e-buses, mostly part of the global mobility strategy of the city. Currently this cost is zero for the diesel conventional buses. These new costs for equipment and installation are hampering a wider build-out of the charging network. Indeed, although electricity itself is ubiquitous, its transmission, distribution, and retail charging options for electric vehicles need to be designed and adapted to the needs of the new e-bus system, and in some cases as a tailored solution to the specific local context. Its complexity poses an additional barrier for the deployment of the new system, as the bus sector stakeholders are reluctant to this new expense.

[5] Union of Concerned Scientists; Electric Vehicle Battery: Materials, Cost, Lifespan; March 9, 2018: *https://www.ucsusa.org/clean-vehicles/electric-vehicles/electric-cars-battery-life-materials-cost#bf-toc-2*

In addition, the charging infrastructure is often linked to the market uptake of the e-vehicles (chicken-egg dilemma) and in particular, to the charging strategy chosen by the local authority and/or operator. So far, and despite the progressive consolidation of the electric technology, the required charging infrastructure still suffers from fragmentation and a lack of standards in most markets.

High-level KPI

- Charging infrastructure price (per bus type)

KPIs units

- Qualitative measure: Price increasing/decreasing
- Quantitative measure: % price increasing/decreasing, € increasing/decreasing

Today, the operation of e-buses is still more expensive than for conventional buses. An initial analysis of the operational needs for each line is key to understand the operational needs that will help determine which technology is the most convenient for the specific local and operational context. Factors such as the type of route, topography, traffic conditions, weather, etc. shall be analysed in order to assess the daily mileage vs battery range and vehicle reliability. This, together with the selected charging strategy (en-route opportunity charging, at depot) can help define the needed trade-offs and design a suitable e-bus system.

High-level Key performance Indicator

- Battery autonomy (per type and per network line)
- Energy composition per km (per type and per network)

KPIs units

- Qualitative measure: Autonomy increasing/decreasing; life-span increasing/decreasing
- Quantitative measure: % autonomy increasing/decreasing, hours of autonomy, €/km, kWh/km

The maintenance of an electric vehicle is completely different from a diesel engine and require new skills and knowledge, a fact that has diverse impacts:

- To fully enjoy the benefits of an e-bus it needs to operate at its maximum performance – in other words to fully utilise the battery potential;
- The maintenance models, schedules and cost are still unknown and raise some uncertainties that are not welcome in the sector, as the TCO shall include the maintenance cost;
- Safe and secure handling of the vehicles and charging process is required.

Today, there are significant differences of TCO models between the different manufacturers (this difference is also significant when comparing European and Chinese manufacturers, who tend to be less conservative). The practicalities of navigating around these different views difficult make the assessment of the market offers a complicated issue for a PTA.

However, there are considerations on the need of sharing the technological and project risk in a fair and transparent way. For example, the maintenance costs shall be shared among the e-bus sector stakeholders, in order to define a suitable project framework with a clear definition of roles and responsibilities. Still, it is not clear how to define the most appropriate constellation on who should pay what. Main questions addressing the ownership and maintenance of the rolling stock and/or infrastructure remain open.

High-level Key performance Indicator:

- Knowledge on Maintenance per type of e-bus
- Maintenance cost per type of e-bus per network line

KPIs units:

- Qualitative measure: Knowledge level increasing/decreasing; maintenance cost increasing/decreasing;
- Quantitative measure: % maintenance cost increasing/decreasing, € maintenance

Finally, regarding the local depreciation rules, the purpose of the depreciation is to recover the investment incrementally throughout the service life of the asset. However, the time scopes considered in tenders and the charging infrastructure for e-buses may have different lifespans. Though calculating a depreciation rate is simple "*in the papers*", the obscurity of the operator's future, and the need of assessing the risk in a measurable way makes this task very complex. The lack of knowledge on the depreciation rules is also a barrier. In addition, it seems highly affected by the local conditions of the area. Depreciation, contracts length and their extension are also consequently critical issues. Even if manufacturers remain in charge of the battery replacement, the e-bus lifetime shall be adapted accordingly to the new vehicle lifetime, and the consideration of measures as refurbishment of the vehicles shall be taken into account. Finally, the entrance of new battery technologies and regulations can also have a significant impact in the calculation of the TCO.

High-level Key performance Indicator

- Depreciation rules knowledge
- Depreciation rules economic impact

KPIs units

- Qualitative measure: Knowledge level increasing/decreasing; depreciation rules increasing/decreasing

2.2.2 CHALLENGE 2: NEW WAYS OF OPERATING

"A chosen technology performs well only if put on its best operational conditions"[6]

When an operator decides to invest in an e-bus, he will have to face some operational challenges, e.g. the battery capacity is very unpredictable due to external influences that constantly affect the energy usage and could only be assessed when the e-bus is tested in the real conditions that may change based on the drivers experience and skills.

As indicated previously, an analysis of the operational needs for each line is a first good step to understand which electric technology is the most convenient, following the system approach. The system approach developed within ZeEUS underlines the need of defining a proper project governance by involving all stakeholders related (local administration, transport authority, bus operator, grid owner, etc.) from early project stage. In addition, at the operational level it is essential to understand that designing e-bus systems requires taking into account the complete ecosystem: not only the vehicle, but also the infrastructure (bus stops, dedicated lanes, chargers, etc.) and the operational context (network design, information to passengers, traffic management, etc.).

[6] Source: EBSF project, DG-R&I; Study by VDV and Prof. Dr. Ralph Pütz from Landshut University.

High-level KPI

- Technology knowledge
- Technology deployment
- Operational monthly average cost (per type per network line)

KPIs units

- Qualitative measure: Knowledge level increasing/decreasing; deployment increasing/decreasing, average cost increasing/decreasing;
- Quantitative measure: % average cost increasing/decreasing, €

2.2.3 CHALLENGE 3: NEW WAYS OF TENDERING AND PROCURING

Despite major developments in terms of better knowledge on e-bus technology and operation and some operators are a reference in the field of e-bus tender and contracting, a large majority still lacks of the experience and knowledge on what are the main aspects to take into account when starting an e-bus project. Also, the willingness of deploying a new technology that is consolidating its position in the new public transport landscape requires that authorities and local administration are aware of the risks linked to new technology deployment when preparing a tender for e-bus systems. Some of the possible measures to mitigate the risks are: a) considering vehicle or technology leasing; b) considering the lifecycle guarantee/insurance of the vehicle; c) including the possibility of a back-buy condition. Other aspects to take into consideration when tendering an e-bus system are: a) the cost difference (vehicle, supply technology); b) the lifecycle (batteries, etc.); c) the operational condition (operational range) of the line; d) the vehicle reliability; and e) the legal conditions regarding safety limitations.

There are several models for the procurement and contracting of e-bus systems. In any case, in models where there is interaction between the authority and the operator during the development of an e-bus operation, it is essential to ensure a successful project that both actors work closely in the definition and implementation of a new e-bus system. Moreover, the new system shall be developed in a way that allows the operator (sometimes in cooperation with the bus manufacturer) to determine performances according to the technology available and the system needs. Imposing operational parameters without involving the operator in their definition can lead to unsuccessful systems. Independently from the model chosen, a feasibility study of the possibilities for implementing electric buses, including associated infrastructure should be carried out.[7]

Finally, social and environmental benefits should be also included in the tender frame. The public transport contractual framework shall start considering including positive externalities such as social, health and environmental benefits derived from the use of clean bus technologies into the procurement, e.g. emissions linked to air quality (NO_X, CO_2, PM_x) can be based on existing EU regulation, noise (interior, exterior, during opportunity charging), vibrations, etc.

High-level KPI

- PTO confident level regarding the e-bus tenders
- PTA confident level regarding the e-bus tenders

KPIs units

- Qualitative measure: Level of confident (PTO + PTA) increasing/decreasing

[7] For further information please consult the ZeEUS report on "Tender Structure for Urban Electric Bus Procurement" available on the website *www.zeeus.eu*

2.2.4 Challenge 4: Standardised and interoperable charging infrastructure

The standardisation of the charging infrastructure is key to ensure the efficient and flexible operation of the e-bus system.

The standardisation of the charging infrastructure is key to ensure the efficient and flexible operation of the e-bus system. Operators are not willing to lose the versatility and flexibility of bus operation, which represent a main advantage compared to other public transport modes, because of the need of a dedicated infrastructure (road system and charging infrastructure).

For this reason, from the operational point of view, any change derived from the introduction of e-buses must be able to ensure a safe and reliable operation, offering service excellence, i.e. bringing passengers efficiently and comfortably to their destinations, without compromising the level of service in any form.

Today, there are multiple charging solutions and suppliers, with different devices (plugs, sockets, pantographs) and their operational requirements. Currently there are two main charging strategies:

- Slow charging/overnight: based on the car protocol and the Combined Charging Standard (CCS), which is easy to adopt and requires minor modifications at the depot.
- Fast charging/opportunity: through a wide array of different charging solutions and different implementations of the same charging solution.

For this reason, a standardised interface between the vehicle and the charging infrastructure is key to enable a further deployment of e-bus technology and electric mobility in general. Moreover, cities need to access a fair level playing field market where different bus brands are compatible with different charging solutions (opportunity and overnight chargers).

To address this challenge, ZeEUS has worked closely with the Standardisation Working Group (with relevant project partners like VDV and the UITP Bus Committee) led by UITP and commissioned by CEN-CENELEC in a joint effort to advance this topic at the European level. Part of the results of this fruitful cooperation are a series of e-Bus Use Case documents for “opportunity charging”[8] and “charging in depots”[9]. Thanks to this crucial work, CEN-CENELEC will release officially the “Landscape report on e-bus charging standardisation” capturing the outcomes of two main workshops organised in 2016 and elaborated since then in 2017.

After this, the CEN-CENELEC ad hoc working group will continue working on a report (recommendation) for the European Commission on the e-bus charging interface standardisation. The standardisation covers many aspects (safety, mechanical and communication requirements), but not how a bus stop should be designed, which is considered very important. In order to address this important point, the working group is considering the elaboration of an “application note” or “good practice” document, most likely that will released by UITP in the coming future.

The progress achieved within ZeEUS through the CEN-CENELEC Working Group on Standardisation will be taken over by the ASSURED project (www.assured-project.eu), which will focus the next steps on the standardisation, and conformance and interoperability testing of e-buses. After the interface, the standardisation activities will focus on the test protocol for interoperability between different e-bus brands and chargers.

[8] Use Case for e-Bus opportunity charging: *https://www.uitp.org/sites/default/files/Newsmedia/News/Final%20-%20Standardisation%20-%20Opportunity%20Charging.pdf*.

[9] Use Case for e-Bus charging at depot: *https://www.uitp.org/sites/default/files/Newsmedia/News/Final%20-%20Standardisation%20-%20Depot%20charging.pdf*.

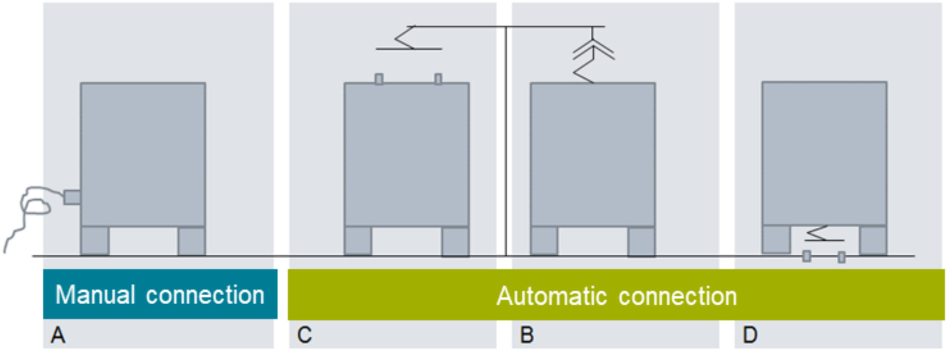


Figure 9. Different charging solutions (connector, ACD)
Source: ZeEUS presentation

High-level KPI
- Agreed standards for charging infrastructure
- Interoperable charging solutions

KPIs units
- Qualitative measure: Achieved standards.
- Interoperable solutions

2.2.5 CHALLENGE 5: REINFORCING THE COOPERATION BETWEEN THE ENERGY AND BUS SECTORS

To secure the suitable energy supply of the new e-bus system, the operator and the grid owner must engage in a close cooperation for the definition of the main aspects related to energy provision.

The quality of the electricity distribution network point (in terms of capacity, age of the cables, etc.) as well as the location of the charging points shall be discussed and agreed on to ensure the availability of connection points that meet the power needs of the system.

Likewise, operators and grid owners (given the case with the distribution system operator) shall agree on an index-based electricity pricing as well as the cost of the permits for the connection points in the planned locations.

These aspects are not trivial and shall be discussed in detail during the feasibility study of the line and system requirements, especially to assess the economic feasibility of the e-bus project.

Finally, there are considerations about sharing the charging infrastructure in place among different public transport modes, e.g. the use of the tramway and metro power network, as explored in the frame of the ELIPTIC project (*www.eliptic-project.eu*).

Today there are different markets and service models, e.g. the Stadtwerke (municipal/public utilities) in Germany, which can bring together under a single public entity the provision of different services (energy and transport). Other models have independent entities for energy and other services provision, most of them with a strong position of the energy provider.

High-level KPI
- Increased cooperation between PTO and DSO

KPIs units
- Qualitative measure: Level of cooperation (PTO-DSO) increasing/decreasing

TOP CHALLENGE		Type	Timing	Concept	Unit
1. HIGH UP-FRONT COST	**Battery / Vehicle cost**	QTT	Starting ZeEUS	Battery price/type	€
		QTT	Starting ZeEUS	e-bus price/unit	€
	Charging infrastructure cost	QTT	Starting ZeEUS	Price of charging Infrastructure/type	€
	Local depreciation rules	QLT	Starting ZeEUS	Knowledge	Increasing/decreasing
		QLT	Starting ZeEUS	Economic impact	Increasing/decreasing
		QTT	Starting ZeEUS	Appearance of reliable financial tools	€
	Daily operational range	QTT	Starting ZeEUS	Battery autonomy/type/line	Hours
		QTT	Starting ZeEUS	Energy consumption/km/type/line	€/km, kWh/km
	Maintenance	QLT	Starting ZeEUS	Knowledge	Increasing/decreasing
		QTT	Starting ZeEUS	Cost/type/line	€
2. NEW OPERATIONS		QLT	Starting ZeEUS	Knowledge	Increasing/decreasing
		QLT	Starting ZeEUS	Deployment	Increasing/decreasing
		QTT	Starting ZeEUS	Operational monthly average cost/type/line	€

TOP CHALLENGE	Type	Timing	Concept	Unit
3. TENDERS AND CONTRACTS	QLT	Starting ZeEUS	PTO confident level regarding the e-buses related tenders	Increasing/decreasing
	QLT	Starting ZeEUS	PTA confidence level regarding the e-buses tenders	Increasing/decreasing
4.- INTEROPERABILITY AND FLEXIBILITY	QLT	Starting ZeEUS	Agreed standards for charging infrastructure	Achieved standards
	QLT	Starting ZeEUS	Interoperable charging solutions	Existence of interoperable solutions
5.- REINFORCED COOPERATION ENERGY-BUS SECTORS	QLT	Starting ZeEUS	Level of cooperation PTO-DSO	Increasing/decreasing cooperation

Table 1. Briefing of KPIs per challenge.

Source: UITP, ZeEUS project (2018)

3. ROADMAP

This section collects the different actions that need to be carried out to achieve a fully electrification of bus systems in Europe (ZeEUS main aim). Indeed, ZeEUS worked closely with ERTRAC in the update of the “ERTRAC Electrification Roadmap Contribution for electric urban bus systems (3rd version, June 2017)”, enlarging its impact to a wider electric vehicles community. Therefore, this section takes into account the inputs from the ZeEUS partners, already collected in the named roadmap but not only. This sector-agreed information, together with the lessons learned in the project’s test fields and the recommendations produced thanks to the implementation and test of the ZeEUS solutions, led to a set of detailed recommendations.

The main objective of the present roadmap is to provide the stakeholders’ view on the development of fully e-bus systems in Europe. The roadmap proposes a timeline, starting at the end of the ZeEUS project and based on its latest achievements, and considers a listing of available technologies that may help stakeholders to overcome the different challenges encountered during the project lifetime. The roadmap provides short and sharp development paths, showing how to reach the proposed milestones. The ZeEUS partners recommend considering them as leading areas for the following research and development activities.

In addition, it is important to consider the development of the relevant regulation. Local authorities play a key role for the development of policy and regulatory support aimed at easing and speeding up the transition to the fully electrification of the public bus system.

Finally, it is important to underline that this roadmap is only applicable to fully electric bus systems. Private vehicles, coaches, or mixed bus systems are out of the scope of the present report.

Figure 10. ZeEUS Key milestones
Source: UITP, ZeEUS project (2018)

3.1 Present: Market penetration

This phase started in the period 2013-2016 (beginning/half of the ZeEUS project) and finishes in 2018 (end of the project) - 2020. Its duration is considered as parallel to the ZeEUS project followed by a consolidation period of two years until 2020. Whereas the market share of electric passenger cars is steady growing, the electrification of bus systems is still in an early stage.

The fast introduction of urban e-bus systems is acknowledged to be a powerful tool to improve air quality by policy-makers, and citizens appreciate the benefits of electric powertrains vs diesel engines, e.g. the smooth and silent driving. Different regulations are set in place in Europe, e.g. low emission zones (environmental zones) restricting the entrance of certain types of petrol vehicles in specific areas of the city (city centre). It's expected that in the future this regulation also paves the way to the introduction of e-bus fleets in the very same area.

Whereas the basic electric propulsion technology is available, fast charging and energy storage on board need to be addressed in upcoming research activities. Further, not only the component and system costs but also TCO has to be reduced significantly in order to be competitive. Finally, also energy efficient operation of these buses by means of connectivity shall contribute to optimise the TCO.

As it happens with other technologies, to effectively address the need to move quickly from laboratory research to actual innovation of the e-bus fleets in operation in Europe, the technologies to be tested have been selected according to their technological maturity (and not only because of their potential). In this regard, ZeEUS project has already undertook key steps through the implementation of a series of demo-tests in European cities. Moreover, ZeEUS brought together a large community of actors (operators, authorities, cities, bus manufacturers, charging solutions suppliers, energy providers, etc.), to jointly work for the wider implementation of e-bus systems, promoting and enabling knowledge and expertise exchange, and clearly contributed to speed up the market entrance of e-bus technology.

It's worth noting that the ZeEUS demos tested series or pre-series products and homologated for real operation. This allowed to obtain valid outcomes in real operation and be able to respond to the needs of the demo cities.

The key steps achieved are listed below:

- The first step for the deployment of e-bus systems is the development and the adaptation/ conversion of existing buses into plug-in hybrid and fully e-buses in small series production. This is made in parallel, allowing authorities and operators to better understand both technologies, comparing them in real situations;
- First demonstrations, field operational tests and initial purchases run in several European cities on single bus routes under the umbrella of ZeEUS. It is deemed fundamental as a necessary support with transitory subsidies and dedicated financial tools;
- Launching the "e-bus deployment community" means the initiation of a joint learning phase where different stakeholders discuss about the use of e-buses in real operation (OEMs, authorities, operators, energy providers). This discussion accelerates the knowledge transfer;
- At the same time, based both in the joint learning process but also on the demo test results, a major progress is reached in terms of the understanding of underlying technologies and principles;

- The demonstrations allow the public to understand the real impact (and benefits) of the e-buses, raising public awareness and acceptance. Air quality improvement and low noise perception are considered key for the citizens acceptance;
- One of the key concerns raised during this phase addresses the existence of different charging technologies available on the market, as there is a lack standardisation of charging systems (CEN-CENELEC).

Figure 11. Market introduction: key elements.
Source: UITP, ZeEUS project (2018)

This context has led to an increased awareness of the stakeholders in the sector. However, technical shortcomings of the vehicles and the infrastructure still require further research and development activities in the years to come. Before 2020 it is expected the development of the following research and innovation areas:

- It is expected that the base technologies for a dedicated 2nd generation of EVs providing efficiency gains of main components, advanced system integration and high performance energy storage systems will become available at the intermediate time scale;
- Mass production should likely be growing, with less need for subsidies;

- New modular bus platform adaptable to the different possibilities in terms of alternative fuels and electric charging modes will be also developed and introduced in the European market;
- The successful development of optimised auxiliaries to reduce energy consumption, improving the operation time of the fleets, stakeholders acceptance and therefore making e-buses more and more attractive;
- Pioneering operators prepare first bus depots and bus routes with standardised charging infrastructure, and extend the number of bus routes for e-bus deployment. The e-bus community benefits from the development and approval of charging standards (communication and, potentially, mechanical/electrical interface).
- As the e-buses are progressively and widely implemented in Europe, the necessary specialised skills for maintenance, safety and security are further developed, framed by different standards addressing each of the named areas;
- Data communication between vehicles, charging infrastructure and bus depots/operators are further developed.

3.2 2020-2025: Market wider implementation

Encompassed by the entrance of EVs market (private-owned and for shared use), it is expected to have larger series of e-buses in production, increased thanks to the successful experiences carried out during the previous period. Indeed, the development of new vehicle platforms adaptable to the different possibilities in terms of alternative fuels and charging modes are already available on the market and produced at medium-large scale.

Particularly, auxiliaries will be optimised to reduce energy consumption. However, it is not foreseen to reach their fully potential in energy composition reduction in the next future, but in the next decade with further research activities.

Various charging concepts are already demonstrated through the interactions between vehicle (OEM), infrastructure (charging solutions and energy suppliers) and bus depots (operators). Answering the request of the different stakeholders (operators, public authorities and others), the first standards of automatic charging and signal interfaces for charging services will be in place.

The new technology provides the opportunity to redefine bus systems in terms of vehicle and infrastructure (EBSF2 project). As a new element in the city landscape, e-buses and e-bus systems can greatly contribute to increase overall acceptance of public transport and bus systems. In this regard, authorities and operators will have the opportunity to adapt bus systems to the needs of cities and travellers, with bus depots and routes that meet the operational requirements and benefit from standardised charging infrastructure, thus leading to a wider e-bus deployment.

As it was done in the market penetration phase, demonstrations of various charging concepts of vehicle and infrastructure will continue taking place, resulting in draft standards of charging interface for automatic charging and signal interface for charging services (OppCharge).

The key aspects that may characterise the following years are listed below:

- Yet small, but growing numbers of e-bus fleets are positively running in Europe;
- Further development of new vehicle platforms, driving towards the adaptation of existing platforms;
- Auxiliaries' energy composition is optimised in a first step, indicating new areas of research in this topic but also demonstrating the potential positive impact of this activity in the e-bus

operational time, e.g. heating, ventilation and air conditioning (HVAC) are an important area for improvement due to their high power need. A combination of measures can increase the efficiency of air conditioning units as well as reduce heat loss via the interior and exterior design of buses especially during winter conditions;

- First standards of automatic charging and signal interfaces are developed and welcomed by the e-bus stakeholders (various charging concepts);
- First automation in depot movement, docking and charging activities make its entrance;
- First smart-charging in bus depots and bus routes are prepared;
- All the previously cited activities drives towards an increase of e-bus routes in both number and operational hours driven.

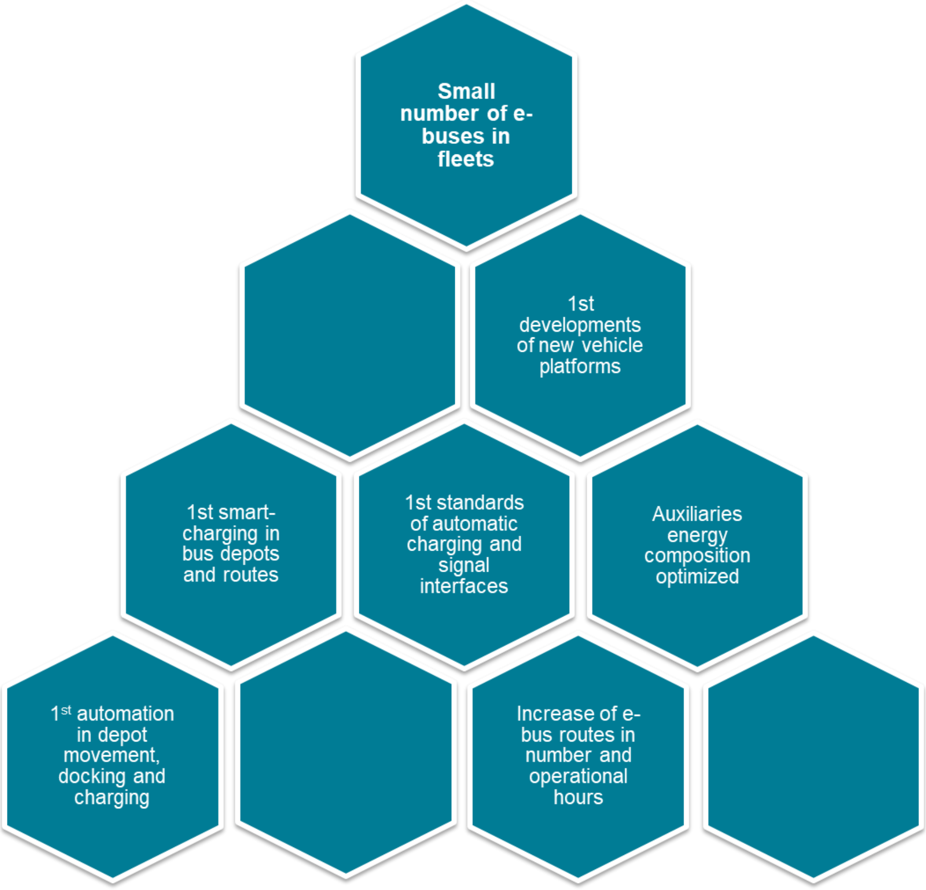


Figure 12. Market wider implementation: key elements
Source: UITP, ZeEUS project (2018)

However, the risk of a fragmented clean transport system based on uncoordinated policies could greatly hinder the successful introduction of clean bus technologies, in general, and e-bus technology in particular. A range of new policies, measures and actions beyond clean fuel sources and technological developments shall be explored in order to allow and encourage a shift from fossil fuels to low- and zero carbon solutions, taking into consideration the evaluation and prioritisation of the different modes and their (combined) usage, depending on their space and energy use. Resolute and effective political support is required at all levels to reinforce the success of the current experiences and ensure further market consolidation.

Lastly, there is a significant evolution in the EU fiscal guidance regarding the fully e-bus systems. As requested in ZeEUS ("Recommendation for ideal Funding Instruments for Urban Electric Buses", ZeEUS deliverable 51.7, September 2019), the EU develops accurate fiscal guidance more consequent to promote electric public transport and especial zero emission electric buses. EU Regulation that permits the reduction of the energy tax rate makes a step from optional to mandatory for the Member States, in particular in the most polluted urban areas.

3.3 From 2025 on: Mass production

The acceptance of e-bus technology and e-buses is almost complete across Europe. Around 2025 the industry has completely reached the phase of e-buses mass production, a step further in the previous moderate and medium scale. Encompassing it, there is an increasing investment in R&D activities, allowing an important improvement of the vehicles, some of them listed below:

- Mass production of electric vehicles may be fully established in Europe;
- Improved battery technology providing about doubled lifespan and energy density compared to 2009 Li-Ion technology status, at about half of the cost compared to 2010 will be aimed for;
- Highly integrated and cheap electrical motors and power electronics, highly efficient and cheap thermal solutions and particularly batteries, the most crucial component, need to be on the market in big quantities;
- Lower need for purchase subsidies, but for support of sound financial tools developed by funding/financing entities;
- The infrastructure for grid integration may be expected to provide on a broad scale advanced levels of convenience through e.g. contactless and (given the availability of appropriate power lines and batteries) quick charging at high efficiencies;
- Bidirectional energy flow between the vehicle and the grid has great potential to develop to an interesting option for fleet applications;
- Data communication further developed.

Figure 13. Mass production: key elements.
Source: UITP, ZeEUS project (2018)

The exploitation of the full potential of e-buses regarding energy savings and reduction of environmental impact requires to not only "electrify" the common car, but to totally revise the vehicle automobile concept. This will lead to increased energy efficiency and enable synergies of improvements in various technology fields (e.g. batteries, vehicle weight etc.) which again lead to step changes in energy efficiency and cost. Hence, the achievement of this major innovative step will greatly contribute to the availability of E-buses at the cost of an ICE vehicle without incentives.

The production portfolio of e-buses is enhanced as buses have been improved regarding weight, costs, energy demand and efficiency, among others. E-buses can operate in longer routes, and the energy consumption is fairly improved. Standards for automatic charging and information exchange have been not further developed and established. As a result, there is higher confidence and acceptance of e-buses by end user: public authorities find easier to enlarge the e-bus fleets in the cities and bus operators largely increase the number of e-bus vehicles and gather further experiences out of them.

At this moment the European e-bus market is maturely deployed and could easily interact with other stakeholders from counties beyond Europe to support the international coordination of joint initiatives about innovative bus systems (e.g. between EU and relevant partners in US, Latin America, India, Asia, Australia, through small regional replication actions, exchanges of practices, local training adapted to developing countries, collection of statistics from different cities worldwide, cooperation on IT standardisation and human factors).

3.4 2030: Fully revised e-Bus concept in cities

Operators have converted the majority of their fleet to e-buses assuming that economic targets have been met and in consideration of procurement cycles. The 2nd generation of improved e-buses is introduced to the market, and there are full interactions between vehicle and infrastructure (energy and grid management). E-buses contribute to Smart Cities and Smart Grid concepts, already developed during the previous years. For instance, smart stations/interchanges will be deployed and fully organised.

Moreover, radically new vehicle design for e-buses will be part of the R&I activities of this time, if not already entering in the market. These activities will deal purely with vehicle design, although further improvements in powertrain are expected. A vehicle is a key part of the whole transport system. Motors are a key component, but not only. Interior parts, accessibility and safety issues, comfort and new high technological interfaces are also key components to offer the travellers the best travel experience. It is therefore the right time to rebuild the vehicles from zero and welcome a new generation of vehicles.

Applying new design options for the exterior and interior layout of buses may contribute to efficiency improvements by optimising accessibility and internal passenger flow, reducing dwell time at bus stops and, consequently, improving commercial speed of the vehicles and in the end resulting in more efficient bus operation, especially in terms of energy and maintenance cost. In addition, citizen's perception of these vehicles will be positive, as they will have a high technology appearance, in line with the new citizen's needs and expectations from the public transport sector.

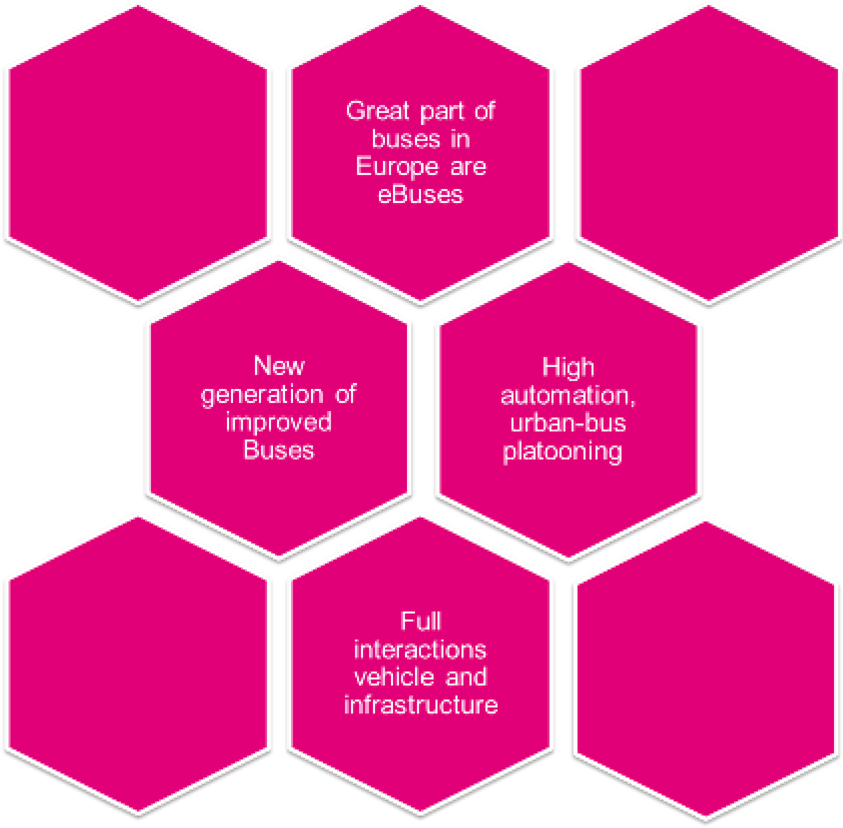


Figure 14. Fully revised e-bus concept: key elements.
Source: UITP, ZeEUS project (2018)

3.5 Enablers

This section details the different enablers that will help advance in the research activities and address the defined milestones.

3.5.1 ENERGY STORAGE SYSTEMS

The sustainability of bus systems can be reached by means of smart energy use all along the e-bus system (to which the electric powertrains offer an important contribution), and the improvement of the environmental, economic and social performances under a life cycle perspective. This is applicable to all sections below. One important aspect of evaluation is the definition of a robust baseline (i.e. current status quo), which allows the quantification of the achieved improvements.

- Particular technologies:
    - Li-Ion technology batteries;
    - Post-Li-Ion technology batteries;
    - Super/outer/ultra-capacitors:
        - Double-layer capacitors;
        - Pseudo-capacitors;
        - Hybrid capacitors.
- Horizontal challenges:
    - Safety of the energy storage systems;
    - Performance of the energy storage systems;
    - Lifetime of the parts and the whole of the energy storage systems;
    - Whole life cycle resources utilization and waste management;
    - Wide spread fast charging and bi-directional capabilities.
- Roadmap contribution:
    - Market wider introduction: Extended charging capability research & development; first steps for the full integration into the grid regulations; public power supply (DC and AC / up to 137 kW) at local level;
    - Mass production: Batteries providing compared to 2009 Li-Ion technology status doubled energy density, double-tripled life-spam at about 50% of cost compared to 2010 status and matching V2G in mass production;
    - Fully revised e-bus concept: Move towards post Li-Ion batteries. Batteries providing 4-5 times higher energy density and tripled lifetime at 50% cost compared to 2010 technology and cost status. Wide spread fast charging and bi-directional capabilities; public power supply (DC and AC up to 137 kW) at global level.

3.5.2 DRIVETRAIN TECHNOLOGIES

- Particular technologies:
  - Energy recovery systems: energy regeneration and harvesting system;
  - Power inverter;
  - Power electronics;
  - Motor controller;
  - Range extenders:
    - Extended-range electric vehicles (EREV);
    - Range-extended electric vehicles (REEV);
    - Range-extended battery-electric vehicle (BEVx);
    - Multi-fuel compatible range extenders.
- Horizontal challenges:
  - Noise production and mitigation technologies: acoustic shields, etc.;
  - Vibration: production and mitigation technologies: dampers, shock absorbers, etc...;
  - Motors performance: improving traction and propulsion technologies;
  - Predictive maintenance methodologies (non-disruptive technologies for inspection) ;
  - Functionalities optimized for varying driving modes/conditions.
- Roadmap contribution:
  - Mass production: Implementation of powertrain systems providing a range comparable to ICE at sharply reduced emissions in mass produced vehicles;
  - Fully revised e-bus concept: Drivetrain systems based on innovative concepts. Distinctly improved energy recovery. Use of novel materials. Functionality optimized for varying driving modes/conditions. Zero emission EV. Multi-fuel compatible range extenders.

3.5.3 SYSTEM INTEGRATION: VEHICLE TECHNOLOGIES

- Particular technologies:
  - Charging vehicles' methods: adaptive process to both user and grid needs:
    - Cable & plug;
    - Conductive;
    - Inductive;
    - Fast charging;
    - Overhead line.
  - Optimised auxiliaries for EV (thermal, energy, IT, driver assistance, wheels, etc.): control and monitoring:
    - Wheels;

        - HVAC (Heating Ventilation and Air Conditioning);
        - IT: Hardware and software (e.g.energy and thermal flows).
    - Driver assistance systems.
- Horizontal challenges:
    - Novel materials: reducing the weight of vehicles (smaller and lighter sub-systems and components, etc.);
    - Modularity in vehicles: modular buses, buses design (passengers capacity and comfort);
    - Modularity platform - vehicles: new modular bus platform adaptable to the different possibilities in terms of alternative fuels and for electric charging mode, EV modular bus platform including revised ICT reference architecture/middleware;
- Roadmap contribution:
    - Mass production: Mass production of novel platform based in overall improved system integration; the nationwide service operators will need smart charging stations based on ICT in order to operate smoothly charging stations at service stations and other roadside locations. Safety systems and functionalities follows the innovations in EV development. Enhanced exploitation of active safety measures for electric vehicles including safety of vulnerable road users;
    - Fully revised e-bus concept: Entirely revised EV modular platform including revised ICT Reference architecture/middleware; the ICT network is needed to ensure the interconnection of all EVs into the grid architecture. In this scenario, a congestion management system may become mandatory. Active and passive safety measures for EVs used in multimodal transport. Updated safety systems to enhanced modular vehicle platform with multiple integrated functions.

3.5.4 GRID INTEGRATION: SMART GRIDS AND CHARGING SYSTEMS

- Particular technologies:
    - Charging infrastructures including the physical interface:
        - Battery only;
        - Pantograph;
        - Inductive charging;
        - Articulated arm.
    - Optimising supply inter-systems:
        - Improving the network distribution and integration in smart grids (optimising supply): inter-systems interaction.
- Processes:
    - Methodology: Interaction between vehicles and charging infrastructures: Solutions for safe, robust and energy efficient interplay of power train and energy storage systems;

- Adaptive process to both user and grid needs: in place, contactless, bi-directional capabilities, charging-while-driving (inductive, conductive processes…).

- Regulations and standardisation:
  - Standardisation of charging-while-driving;
  - Standardisation of depot charging CCS-based;
  - (New) charging and pricing policies strategies;
  - Regulation on business models for charging - Energy supply market;
  - Standardize services, billing and use concepts;
  - Trade-offs and relationships between land use public policies and real estate private development;
  - Regulation on business models for bidirectional trading.
- Roadmap contribution:
  - Market wider introduction: The role of ICT in the charging infrastructure is a key issue in the full integration of the EV into the grid. At the present time, ICT is well equipped to deal with the interconnections of EV charging infrastructures; network infrastructure planning for an extended charging capability scenario is needed, starting with an impact analysis depending on the charging mode and the number of e-buses charging in the network at the same time;
  - Mass production: Standardized quick, contactless and smart charging with bidirectional capabilities;
  - Fully revised e-bus concept: Full integration into the grid with charging-while-driving functionality. Wide spread use of inductive charging. Enhanced bidirectional energy flow.

3.5.5 TRANSPORT SYSTEM (METHODOLOGIES)

- Planning:
  - Spatial interaction: traffic and city planning;
  - Spatial interaction: land planning;
  - Interchanges including e-vehicles, co-modality and smart grids planning.
- E-vehicle integration: management:
  - Drivers operations (including safety measures);
  - Integration of electric vehicles with other non-automated vehicles and modes of transport (including PT);
  - Integration of electric vehicles with semi-automated driving systems: active safety systems and car-to-x communication;
  - Full automated and cooperative driving: car-to-x communication;
  - New quality educational electric-mobility courses and training: Updating of current staff;

  - Nurturing collaboration across the sector: Cooperation models (EU and non-EU actors).
- Whole system integration: management and maintenance:
  - (Smart) energy management: bus sub-systems, bus system and transport system level;
  - Interchanges including e-vehicles, co-modality and smart grids management;
  - Network management methodology: optimised network management and charging spots (flexibility);
  - Infrastructure maintenance methodology: predictive and timely interventions.
- Roadmap contribution:
  - Mass production: Semi-automated driving based on active & passive safety systems and car-to-x communication;
  - Fully revised e-bus concept: Enhanced usage of car-to-x communication for automated and cooperative driving for zero accident road safety and highly convenient driving. Integration of EV in multi-modal transport system; urban e-buses platooning.

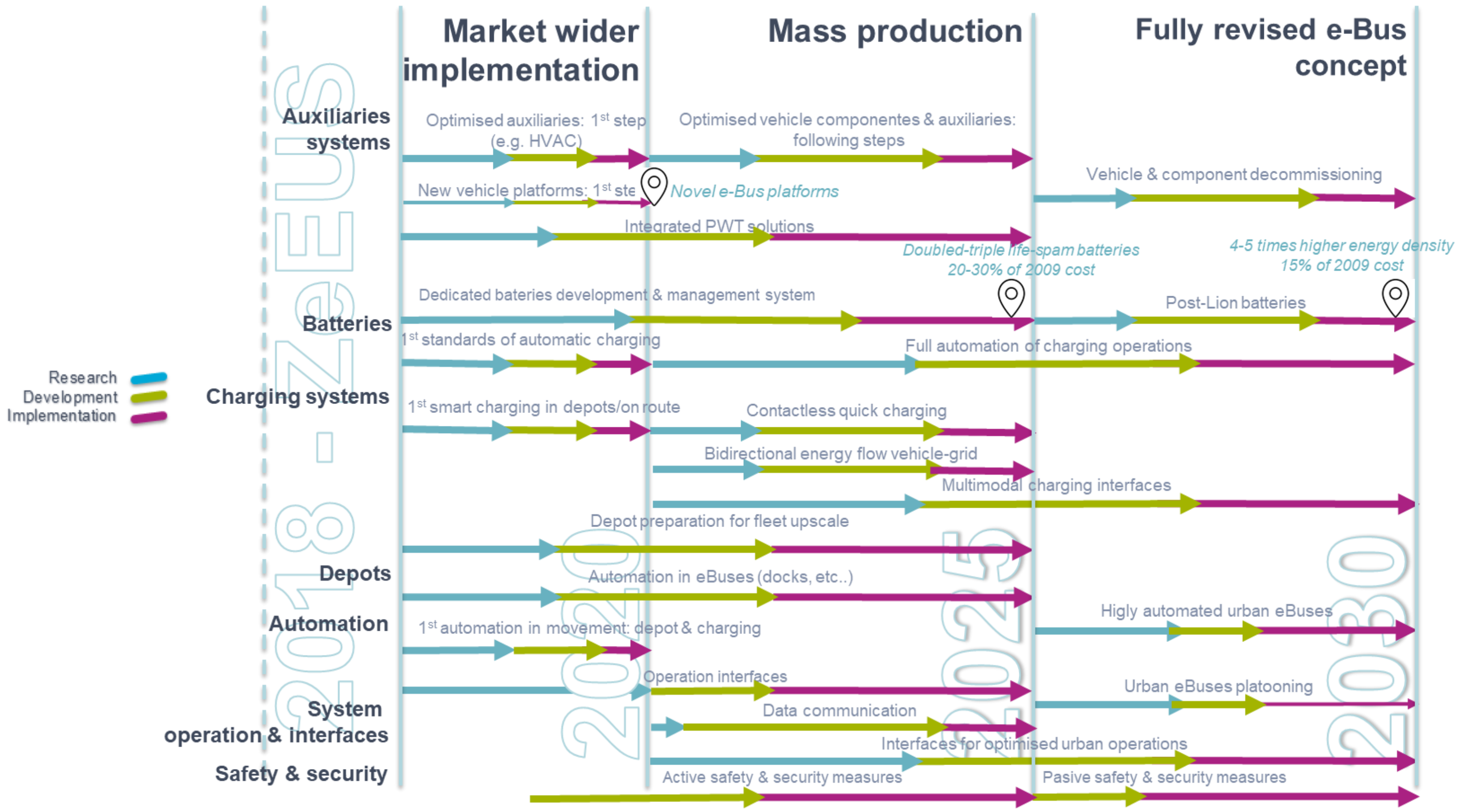
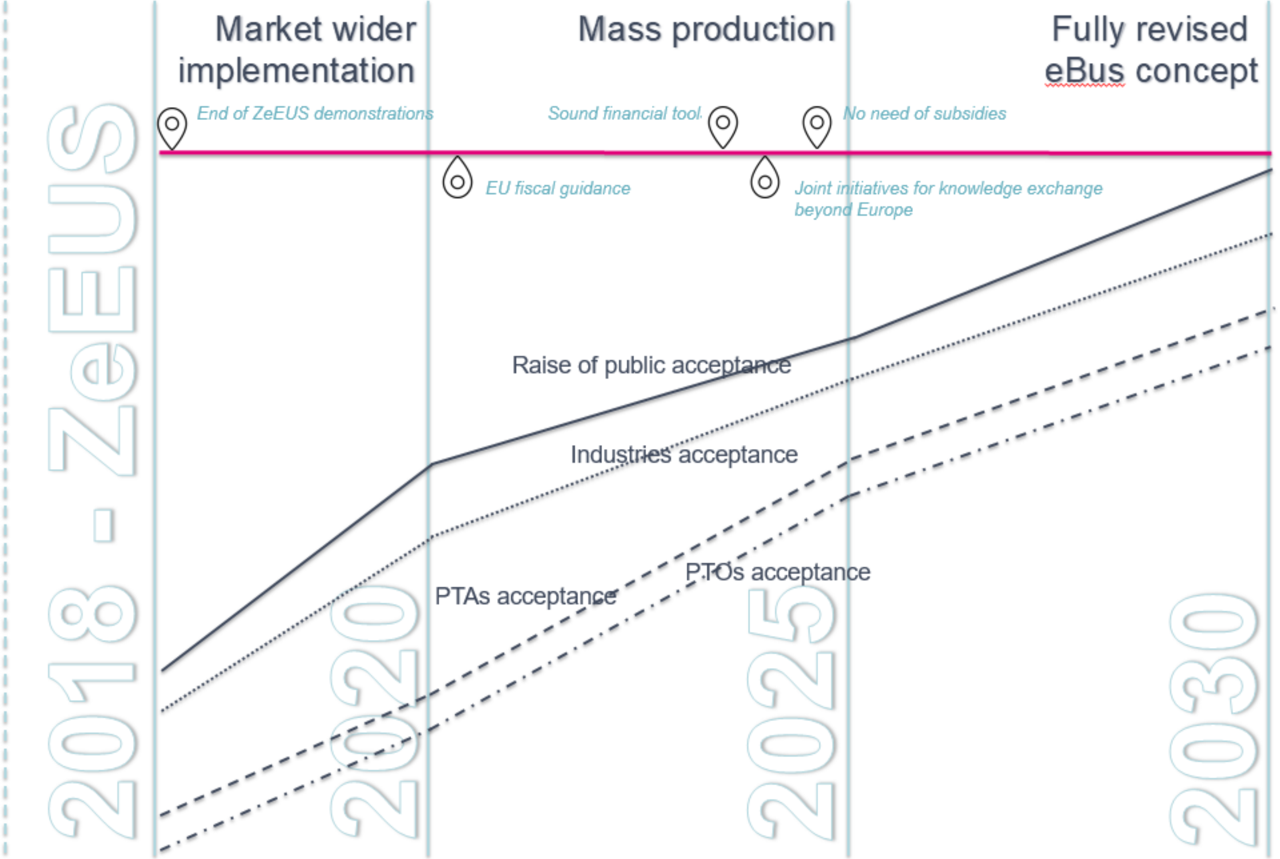


Figure 15. Fully Electric Bus Systems Roadmap
Source: UITP, ZeEUS project (2018)

TOP CHALLENGE		KPI	2020-2025 MARKET WIDER IMPLEMENTATION	2025-2030 MASS PRODUCTION	2030 FULLY REVISED e-BUS CONCEPT
1.- HIGH UP-FRONT COST	**Battery / Vehicle cost**	Battery price/type	↓	↓↓	=
		e-Bus price/unit	↓	↓↓	=
	Charging infrastructure cost	e-infrastructure price/type	↓↓	↓	=
	Local depreciation rules	Knowledge	↑↑	↑	=
		Economic impact	↓	↓	↓↓
		Appearance of reliable financial tools	↑	↑↑	=
	Daily operational range	Battery autonomy/type/line	↓	↓↓	=
		Energy consumption/km/type/line	↓	↓↓	=
	Maintenance	Knowledge	↑↑	↑	↑
		Cost/type/line	↓↓	↓	↓

TOP CHALLENGE	KPI	2020-2025 MARKET WIDER IMPLEMENTATION	2025-2030 MASS PRODUCTION	2030 FULLY REVISED e-BUS CONCEPT
2.- NEW OPERATIONS	Knowledge	↑↑	↑	↑
	Deployment	↑↑	↑	↑
	Operational monthly average cost/type/line	↓	↓↓	↓
3.- TRENDS AND CONTRACTS	PTO confident level regarding the e-buses related tenders	↑	↑	↑
	PTA confident level regarding the e-buses related tenders	↑	↑	↑
4.- INTEROPERABILITY AND FLEXIBILITY	Achieved standards	↑	↑↑	↑
	Existence of interoperable solutions	↑↑	↑↑	↑
5.- ENERGY PROVISIONS	Increasing/decreasing cooperation	↑↑	↑	↑

Table 2. Briefing of KPIs impact per milestone.
Source: UITP, ZeEUS project (2018)



One of the biggest expectations regarding ZeEUS project and the subsequent roadmap is a general increase of the acceptance of e-bus systems in Europe.

It is expected that key stakeholders (industries, PTOs, PTAs and citizens) will increase both the knowledge and the acceptance of these systems at a similar path. Citizens may be the leading partners in this path, as all the industries, PTOs and PTAs answer to their needs and expectations. In other words, without the acceptance of the general public, the entrance of the fully electric bus systems will face higher risk. ZeEUS partners are confident that the different demonstrations developed now (and in the future) will continue to ensure this entrance.

Figure 16. e-Bus system acceptance evolution based on the roadmap milestones
Source: UITP, ZeEUS project (2018)

4. CONCLUSIONS AND FURTHER RECOMMENDATIONS

4.1 Conclusions

Electric mobility and e-bus systems will change the way we conceive urban mobility. Not only in terms of transport philosophy but also through to its positive impact on citizen's well-being and quality of life.

As the new market trends clearly develop towards cleaner technologies like e-buses, the end of the conventional mobility is getting closer. Indeed, experiencing how e-buses are introduced in the cities boost the change of mentality at all levels, and in all transport stakeholders from policy makers (in need of reliable and clear evidence) to the final users: the citizens.

Indeed, our society is changing. Currently there is a clear global movement towards the electrification of transport. Some industry stakeholders have already confirmed their interest in the area as a key one to lead their strategies:

- Volvo: "Every Volvo from 2019 on will have an electric motor"
- Toyota: "All cars will be only battery electric or fuel cell by 2050"
- France & UK: "Planning to ban sales of combustion engines by 2040"

This is just part of the picture as citizens are progressively opening up to EVs. Indeed, it is well known that the transport sector is responsible for 30% of all CO_2 emissions in the EU, of which road transport accounts for 73%. Bridging the "emissions gap" will require even more commitment from governments, which means an increased focus on developing public transport, in particular bus transport. And electric mobility is currently seen as the most promising technology to curb CO_2 emissions at the local level (ideally supplied by renewable energy sources).

This new shared concern is changing not only our mentality but our mobility patterns, and technology needs to adapt to them, even, being driven by them. The new era of environmentally friendly (and maybe also digital) passengers has only started, encompassed by a growing interest in urban quality and vitality. Public transport, in particular road public transport, that has significant impact on the urban realm, is led by e-buses to make cities better places to live and thrill in.

4.2 Recommendations

Nevertheless, this is just the half of the way. From the adaptation of a bus conceived to be diesel as an e-bus, to the full deployment of e-buses, there are many steps to take. And as technology changes, so do policy makers perceptions and policy measures. After a range of development and demonstration activities, economic stakeholders will need to make a step forward to provide a confidence on EVs and e-buses. European research should encompass this evolution, ensuring an easy fast path towards cities designed for citizens, not for vehicles.

These main challenges of the large deployment of e-buses are internationally shared, discussed during the ZeEUS project, and involved the following areas.

4.2.1 ROAD CHARGING INFRASTRUCTURE

The deployment of charging infrastructure is essential (a prerequisite) to facilitate the development and spread of electric mobility. However, there are different charging methods and solution in Europe, so there are the charging infrastructures and its density around the network. Indeed, this density is highly dependent of the quantity of EVs (e-buses in our case) in the area. Therefore the planning of this charging infrastructure is encompassing the adoption of private EVs, creating anxiety and inconveniences when charging the vehicles. Being as we are right now in the earlier years of the market introduction of e-buses and other EVs, it is crucial to ensure a quick deployment and main trend adoption. The uptake of EVs, and in particular e-buses, depends on the existence of sufficient charging infrastructure in place to support it.

In addition to the planning challenge, permissions to build a road charging infrastructure seems to involve more sectors than the ones involved in a traditional petrol station process. Ever more, the complex electricity supply licence regime may be engaged by some electric vehicle charging schemes. So who are the additional stakeholders to be involved? Landlords? Urban planners? Moreover this infrastructure needs to meet the latest standards on health and safety, even more considering that they will be built inside the city. It is still unclear how this process could be defined to make the set up quicker and safer. On the other hand, in some countries (mainly outside Europe) it seems that there will be more flexibility on the permissions/licences and the process will be more decentralised if applicable to private EVs. The permission/licence process should be clearly improved.

Lastly, there is an international interest on interoperable charging infrastructure. There is a common need of charging everywhere at any time. So far, vehicle interoperability with infrastructure is not close to reality and needs to be guaranteed.

4.2.2 Depot transformation

The introduction of a new technology requires the acquisition of additional new skills and knowledge. Electric mobility and especially the operation of e-buses bring with it a number of vehicle safety, health and environmental challenges. The handling of the charging infrastructure and its elements must be performed in a secure and safe way to prevent any injury and potential reluctance by the staff to carry out the necessary maintenance and daily activities, who need to be adequately trained and qualified in order to perform them.

4.2.3 Operational excellence

Different lessons learned have helped ZeEUS to address better the causes of the energy efficiency of the e-buses. First of all, battery weight affects energy efficiency. It is desirable that further research developments leads to higher specific capacity to not only lower energy storage costs but also decrease the weight, indirectly increasing the energy efficiency of the vehicle for a given range. Reductions in overall vehicle weight also contribute to increasing range. For this, additional lightweight actions related to the e-bus construction may also be on the spot, including from new materials – maybe biomaterials to continue with the environmental philosophy – to smaller components.

Secondly, the non-engine related parts of the e-buses, such as the HVA system, did also concur in high energy composition. This problem is a traditional one in the conventional diesel buses, opening and closing the doors constantly to allow the flow of passengers, but not in the other private EVs. In order to increase the range (the distance reached by the e-buses), new approaches to vehicle air-condition from research may target a crucial reduction of energy consumption thanks to a new generation of HVA systems, among others.

Thirdly, being the most important conclusion of this section, operations have also a direct impact on energy composition. Nevertheless, even if the authorities may have a say to better shape the network line, therefore designing a more linear non-curbs path, the way to follow is highly determined by the city shape. In addition, extra needs such as serving a determined area or reaching a fixed interchanged/urban node could determine at least part of the e-bus path. Therefore, operational excellence should be tested in real conditions, according to each network line planned (or suggested). It should be also considered that road and weather conditions combined with vehicle control and safety consideration have a direct impact on energy consumption. In a nutshell, the energy characteristics for electric and conventional buses in different situations needs to be compared in a case by case situation, as the e-bus might not superior in all situations.

4.2.4 IT TOOLS FOR FLEET MANAGEMENT AND DIAGNOSTIC

A key issue is the field of standardization and data generation and management. Some of the most demanded research activities are listed below:

- National and international standards encourage the convergence of technology, e.g. the interface between the charging station and the energy storage unit is decisive an asset to standardize;
- Standards involves transparency and shared knowledge, levering the feeling of uncertainties still remaining in this sector;
- Standards and furthermore, certifications, may be perceived as insurance against other
- Factors such as unsafety and unhealthy, still to be solved, in particular for the workers.

As explained, this factor will not only improve the societal perception of the e-buses but will drive the technology towards an easy usage. A main factor limiting the implementation/acceptance of e-buses is the lack of interoperability in charging infrastructure and other electric mobility services. Actors in this domain currently need to deal with a broad spectrum of charging systems, creating a weakness in their system – if they want to change the charging system, everything, the infrastructure and e-buses should be updated!! Obviously, this process will need to pass through all the heavy bureaucracy to get the pertinent permissions/license.

Last, entering in a digital society means working with data as a general tool to handle the EV itself and to communicate with others to improve the seamless travel experience. In addition ICT systems improves the connectivity with the vehicles and the charging infrastructure (charging and fleet management). This area is still object of research and will definitely incur in other positive impacts, such as a better relation between the energy consumption and the e-bus range thanks to its monitoring in details by the driver, etc.

4.2.5 COST AND FINANCE

As said previously, currently the operation of e-buses is still more expensive than with diesel buses. Some concerns about the limit range needs to be further explorer to clarify the relation with internal and external factors, including the charging system, the type of route and the weather influence.

The cost of an e-bus is almost the double of a conventional bus, including the battery that can represent about 45% of the final cost. TCO must include the maintenance cost, and probably the update of the workers (trainings and similar). There are significant differences of TCO among the different manufacturers and European bus manufacturers tend to be much more conservative than the Chinese manufacturers.

The infrastructure, e.g. charging system, shall be included and will remain longer than the conventional vehicles lifetime. The issue of equipment ownership it is still unclear. Concerning the set up and installation costs of the infrastructure, what happens at the end of a contract? Who is the responsible of the charging system?

The size of the bus fleet has a direct impact on the charging infrastructure and both should increase at the same path.

Operations have a direct impact on energy consumption and therefore on the network planning.

4.2.6 PLATFORMS FOR EXCHANGE AND DISCUSSION

If electric mobility is fully deployed in Europe, apart from the technology developments and building capacity, other factors mainly related to the general acceptance, e.g. passengers, policy makers, authorities, are the key factors of its success. This socio-economic component still requires further research. Some of the activities that could be covered by such platform are:

- Exchange of knowledge and operational experience;
- Identification of technical trends and evolutions (incl. Standards);
- Marketplace for financing tools and for products;
- Observatory of products, solutions and developments.

Moreover, new trends may have also a direct impact not only on the e-buses but in the whole mobility system. Considering their entrance in the market, it is worthy to dedicate some thoughts to the interactions with the e-buses:

- Digitalisation;
- Mobility as a Service and shared economy trends impacting on the mobility sector;
- Automation;
- Smart grids.

For instance driving might bring, either to accommodate automated driving on dedicated infrastructure or to make investment decisions to have new electric vehicle fleets. The coexistence of autonomous vehicles and non-autonomous vehicles, as well as the seamless coordination of autonomous private transport and public transport, may be based on shared information in real time. The impact of these changes is starting to emerge and will provide market opportunities, notably for key enabling technologies. The EU, Member States, regions and industry have a role to play in fostering electric mobility and creating areas of collaboration aligned with the societal trends.

In this regard, if e-buses are the natural step in the evolution of bus systems, autonomous, electric, bus rapid transit (BRT) is the ultimate step into the future, combining the best of the electric technology (emissions-free, silent), BRT (segregated lanes, right-of-priority) and autonomous and connected driving (comfort, safety, efficiency). This solution requires additional research as it is likely to transform completely the urban bus services, helping cities to reduce transport externalities and enhance their liveability.

Finally, the European deployment of e-bus systems will create many opportunities, e.g. new research areas, new jobs, etc. that need to be properly supported and catalysed. Electric mobility could be also the backbone asset of some European regions, playing a key role in the social network.

Nevertheless, there is still work to do achieve the fully deployment of e-bus networks in Europe, which will set the foundation for the transition to the cleaner and more sustainable urban mobility system.

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