The ZeEUS Vision of Electric Bus Systems

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SUMMARY SHEET

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Abstract	The ZeEUS project envisions a zero-carbon urban bus system that actively contributes to the make cities more liveable, healthy and competitive with clean air, less noise, fewer cars and congestion, and more space to enjoy urban life. The present document provides a deep insight into the ZeEUS Vision for the deployment of e-bus systems in its different fields of action, the barriers and opportunities associated to them and the measures to reach the wished scenario.
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1	INTERNATIONAL ASSOCIATION OF PUBLIC TRANSPORT	UITP	Belgium

ACRONYMS

CNG: Compressed Natural Gas

EEA: European Environment Agency

EBSF: European Bus System of the Future

EBSF_2: European Bus System of the Future_2

ELIPTIC: Electrification of Public Transport in Cities

ICTs: Information and Communication Technologies

LCC: Life Cycle Cost

MaaS: Mobility-as-a-service

NO_X: Oxides of nitrogen

PM: Particulate Matter

PT: Public Transport

PTA: Public Transport Authority

PTO: Public Transport Operator

TCO: Total cost of Ownership

3iBS: Intelligent, innovative, integrated Bus System

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1. EXECUTIVE SUMMARY

Public transport contributes to meeting the mobility needs of citizens but also to enhance urban development and quality of life in cities. Today, the deployment of electric bus systems is politically-driven as a strategic decision to meet the needs and expectations of cities and citizens. At the crossroads between environment, economy, social inclusion and transport, the e-bus system contributes to achieving the mobility visions, declarations and also strategies of regions and cities, also supporting the deployment of consistent integrated policies.

As a fundamental part of public transport, the bus system shall strive for service excellence providing seamless, reliable and safe mobility, and ensuring accessibility and affordable services for all.

Against this backdrop, the ZeEUS project envisions a zero-carbon urban bus system that actively contributes to the make cities more liveable, healthy and competitive with clean air, less noise, fewer cars and congestion, and more space to enjoy urban life.

The ZeEUS Vision embraces thus a number of key action fields in order to ensure a clean, safe, affordable, reliable and comfortable mobility. It foresees electric bus systems in an optimised, efficient and integrated mobility strategy which is planned to meet not only mobility needs but to effectively address urban planning, energy, economic development, environmental, and social challenges.

The present document provides a deep insight into the ZeEUS Vision for the deployment of e-bus systems in its different fields of action, the barriers and opportunities associated to them and the measures to reach the wished scenario.

We wish you a pleasant read!

2. INTRODUCTION

The ZeEUS Vision is aimed to be an inspirational rather than a technical document highlighting the potential of electric bus systems to address the environmental, social and economic challenges of our cities.

At a global scale, megatrends[1] like the demographic shift leading to a rapid urbanisation and climate change and scarce resources are posing new threats and challenges for cities across the world. The urban landscape is in constant evolution in order to respond to these new changes.

Climate change has been acknowledged as the most severe and dangerous threat of this century, having major impacts, e.g. heat waves, droughts, hurricanes, coastal flooding, heavier precipitation, etc. The effects are already visible in many regions, which responded with emergency plans rather than with a holistic mitigation and adaptation strategy.

Meanwhile, greenhouse gas emissions (GHG) continue rising. According to data from the EEA, if the 2006-2015 trend of annual increases in total GHG concentration (i.e. 3.5 ppm/year) will continue in the coming years, the 480 ppm threshold could be exceeded within the next 10 years. A 50% likelihood of keeping the increase in the global average temperature below 2°C corresponds with a concentration level of 500 ppm CO_{2eq} (range 480-530 ppm) (IPCC, 2013). Under a continuation of current trends, this level will be reached in about 16 years. [2]

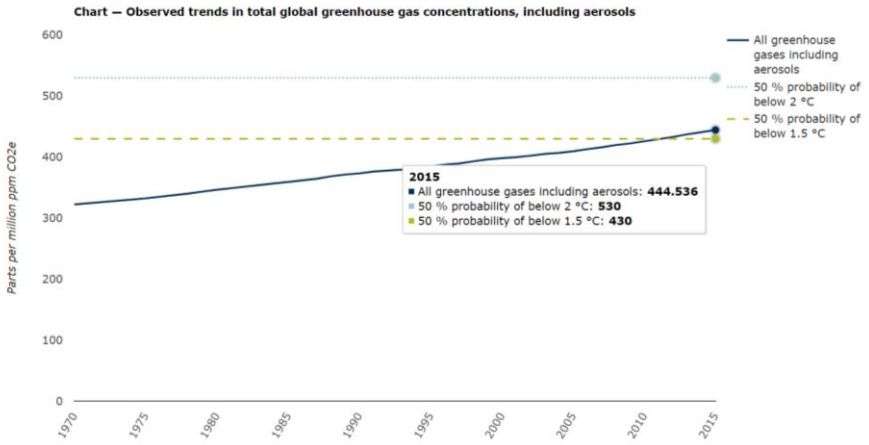

Figure 1. Global trend on GHG emissions vs 2° and 1.5° target.
Source: EEA (2018)

At the local level, air pollution, noise and congestion levels from transport are increasing likewise in many cities across the globe. Finding ways to mitigate and reduce their impact is part of the strategies and plans of local authorities to increase quality of life and liveability, with a direct effect in citizen's health and well-being, the environment and the economy. In this regard, the role of cleaner and efficient public transport is fundamental to achieve global sustainability.

[1] Megatrends are macroeconomic and geostrategic forces that are shaping the world. Source: "Five Megatrends And Their Implications for Global Defense & Security"; PwC (2016).
[2] Note: Data are expressed in CO_2 equivalents (CO_{2e}). The 430 and 530 ppm CO_{2e} correspond to a 50% probability of limiting the increase in global mean temperature to 1.5°C and 2.0°C, respectively, above pre-industrial levels. Note that the trend only covers the 1970-2015 period because of the limited availability of historical data on ozone forcing. The second dashed line depicts the greenhouse gas concentration between 1970 and 2015. (*) assuming radiative forcing values for aerosols from previous IPCC reports.
https://www.eea.europa.eu/data-and-maps/indicators/atmospheric-greenhouse-gas-concentrations-10/assessment

Nevertheless, tackling these challenges is a joint responsibility of government, industry and citizens alike. Even if the competence of the final decision relies on the government responsible for the creation of appropriate policy and regulatory frameworks, the industry has the key role of developing environmental-friendly, cleaner technologies and products to meet the customer's expectations and needs, while citizens shall use their power as customers to send clear signals to governments and industry on the kind of society and cities they aspire to be part of and live in.

2.1 Where do we stand now?

In the face of a changing urban landscape, where population, global emissions, congestion, air pollution and noise continue rising, while resources like public space is decreasing, cities need to adopt global strategies to ensure a fair and efficient planning of the urban realm.

In this sense, urban buses play a major role in public transport as they contribute to addressing some of the economic, social and environmental challenges faced by our cities. Nevertheless, they are often overlooked and perceived as an unappealing option that citizens have to take rather than to choose. To overcome this dislike, big efforts have been undertaken in the last fifteen years by the industry on the one hand, updating the design, internal layout and external appearance of public buses, and by public transport operators and authorities on the other hand in improving their mobility offer and quality of service.

Public transport and urban buses are strongly linked to the city image. They are often the very first interaction a citizen or a visitor has with the services offered by the city. All the conditions to allow the implementation of a highly performing bus system must be taken into account to make citizens aware that the city they live in is enjoyable and attractive.

Projects such as EBSF (www.ebsf.eu) and EBSF2 (www.ebsf2.eu), both led by UITP, have contributed greatly to advance the attractiveness and quality of the bus services, through the development of principles for the design of the innovative electric buses (see section 4.7).

Finally, in addition to cleaner bus fleets, cities shall favour integrated, multimodal transport. Combined mobility solutions offer the most energy-efficient mobility, with public transport ensuring 21% of total motorised mobility and being responsible for roughly 10% of transport related greenhouse gases (GHG) in comparison with private modes (UITP, 2004). Urban buses contribute to achieving this great result but the European bus sector is aware that more effort is needed to reach the EC 2020 climate change and energy targets[3] and is ready for the upcoming more ambitious objectives in terms of emissions' reduction.

2.2 A high standard bus service for greener and more liveable cities

Medium and large European cities have a key role to play in improving the quality of life of their citizens, to create goods and jobs and to improve their attractiveness for tourists. With 30 billion passengers per year in the EU (half of all public transport passengers)[4], the quality and cohesion of the bus services are decisive in the ability to attract, promote and export

[3] Europe 2020 Strategy: *https://ec.europa.eu/info/business-economy-euro/economic-and-fiscal-policy-coordination/eu-economic-governance-monitoring-prevention-correction/european-semester/framework/europe-2020-strategy_en*

[4] Urban and regional bus systems transport count around half of all public transport passengers (30 billion per year) in the EU, and this average pattern changes from a 50% share in large cities with multimodal networks up to 100% in smaller towns and medium-sized cities. In comparison, it is interesting to note that only 800 million passengers travel by air. Urban and regional bus systems transport count for around 450 billion journeys per year worldwide, which is equivalent to 83% of the entire public transport offer. Source: UITP

products, knowledge, creativity and expertise from and to the city. To be efficient, the urban bus must be approached as a system which includes the vehicle, the infrastructure and the operation. This system must be integrated in a total network together with the multiple transport modes available in the city. All the steps of the multimodal journey must be accessible, user-friendly, comfortable, reliable, punctual, efficient and safe and secure. Frequent bus services providing accurate real-time information contribute to a well-organised bus network where room is kept for stops along streets, spaces for platforms and bus lanes are protected, priority at traffic lights and appropriate geometric features of roads and infrastructure are implemented in new neighbourhoods. Efficient bus networks require the implementation of the above key functions to ensure a smarter use of energy sources for greener cities[5]. This way, buses can be fully considered as a cost-efficient, flexible, fast, capacity-appropriate and clean tool to cope with the growing sustainable mobility needs of our cities and regions. Currently, almost 50% of the buses used across Europe are Euro III or older. In total, 80% of the bus fleets are still running with diesel engines that are becoming cleaner and cleaner whilst the European bus sector has heavily invested in the development of cleaner propulsion technologies which are increasingly diversified: bio-fuels (bio diesel, bio-gas and bio-ethanol), natural gas, hydrogen, bio-waste, fuel cells and electric powertrains.

At present, between 40-50% of public transport in Europe is already powered by electricity in the form of metro, tram and light rail tram services. For decades, public transport has provided electric mobility offers such as trolley bus systems which have a long tradition in several EU Member States. Besides trolley buses, electric buses are on the verge of becoming a reliable technology, achieving major technological developments, and solutions have been researched, developed and tested in many cities since the beginning of ZeEUS in 2013. Supporting this development, PTAs and PTOs showed their commitment towards cleaner technologies and are progressively electrifying part of their fleet, or even the entire fleet[6].

2.3 Introducing high capacity e-buses: dream or reality?

Electric buses have indeed been introduced in our cities mostly operating mini and midi buses with a limited capacity and autonomy. This is a first great step to adapt the mobility offer in low density areas, city centres and to reduce occupancy levels on a specific bus line at some point of the day.

The current challenge is to implement the electric technology on high capacity buses carrying over hundred passengers with a greater autonomy, allowing to reach a minimum of 16 hours of service autonomy (i.e. normal operational service) in European cities with important historical structures, complex topography and limited space. The ZeEUS project[7] gathers 43 partners representing the entire value chain of standard electric bus and is coordinated by UITP[8]. Together, they fully embrace the challenge to extend the fully-electric solution to the core part of the bus network. Live operational scenarios across 10 European cities demonstrate that several electric bus solutions can be implemented on high capacity buses. The demonstrations are accompanied by local and horizontal evaluations, providing decision makers with the necessary tools to evaluate the economic, environmental, operational and societal feasibility of electric urban bus systems.

[5] An increase of 5 km/h in buses' commercial speed on a busy line leads to 20% less energy consumption and attracts more passengers. Source: UITP

[6] ZeEUS eBus Report#2: *http://zeeus.eu/uploads/publications/documents/zeeus-ebus-report-2.pdf*
[7] Zero Emission Urban Bus System project, *www.zeeus.eu*
[8] International Association for Public Transport, *www.uitp.org*

The ZeEUS project has made a crucial contribution to boosting the market uptake of e-buses by creating a solid knowledge base on how to operate and deploy electric bus systems and providing the tools that support decision-making and creating networks for knowledge exchange. Transport authorities, operators, the energy industry and academia have joined forces to establish the base for the effective electrification of public transport. This will lead to healthier, more attractive and more liveable city environments.

The ZeEUS Vision – this document – presents the ZeEUS view on how PT and cities scan look like if high capacity electric bus systems become the core of PT services, contributing to enhance quality of life in cities. It highlights some of the barriers and opportunities to achieve this and identifies the strategic, technical, operational, as well as policy aspects which need to be developed in order to efficiently introduce urban electric bus systems.

3. WE HAVE A DREAM…

3.1 Looking back to define the future

Growing concerns among the general public and governments over urban congestion, air pollution and its associated health threats have led to calls for policies to curb the emissions from transport. Influenced by national energy policies and more driven by environmental and societal requirements than by commercial considerations, low- and zero-emissions transport systems are increasingly favoured, triggering significant developments in the deployment of electric buses in recent years.

But the electric revolution started in the 19th century with the deployment of the first commercial electric tramline operated in Lichterfelde (Berlin) in 1882[9], which substituted horse powered tramways. Indeed, the topic of how to reduce the cost of horse-powered transport services was already discussed at early UITP Congresses back in 1880s'.[10]Since then, public transport services have been constantly evolving towards operational and service excellence and now it is time for the consolidation of another electric revolution, this time for public bus services.

The increasing interest from urban mobility stakeholders in deploying clean buses is a clear signal. A survey carried out in the frame of the 3iBS [11]project shown that over 40% of the operators and authorities surveyed were keen to switch to electric traction options and, within that category, mainly to hybrid and fully electric with batteries. Exploring this further, ZeEUS and the industry members of the UITP VEI Committee investigated scenarios for how the urban bus market will evolve in Europe by propulsion technology (Fig. 1). 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.

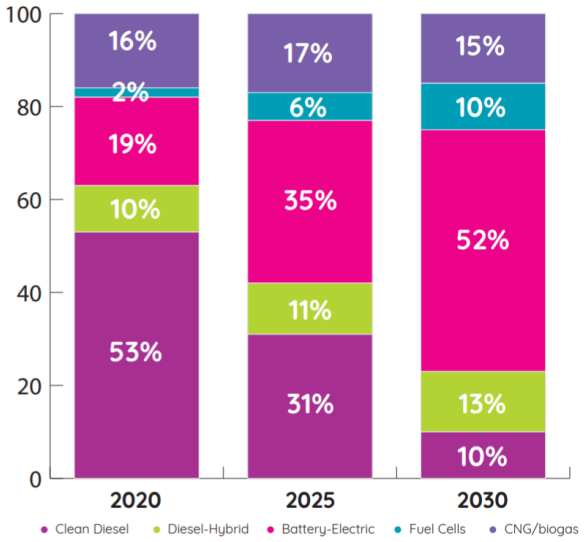

Figure 2: European Urban Bus Market Evolution.
Source: ZeEUS and UITP VEI Committee

[9] Wikipedia, "The history of trams", accessed August 2018: https://en.wikipedia.org/wiki/History_of_trams#cite_note-18
[10] In August 1885, Europe's 50 main tramway operators came together in Brussels to create the "Union Internationale de Tramways/Internationaler Permanenter Strassenbahn-Verein". The association we know now as UITP was thus born with 63 member companies from nine countries.
[11] *www.3iBS.eu*

For the demand side in Europe, it appears to indicate a preference for battery-electric buses among operators and authorities, with almost 75% of the current e-bus stock powered by batteries alone.

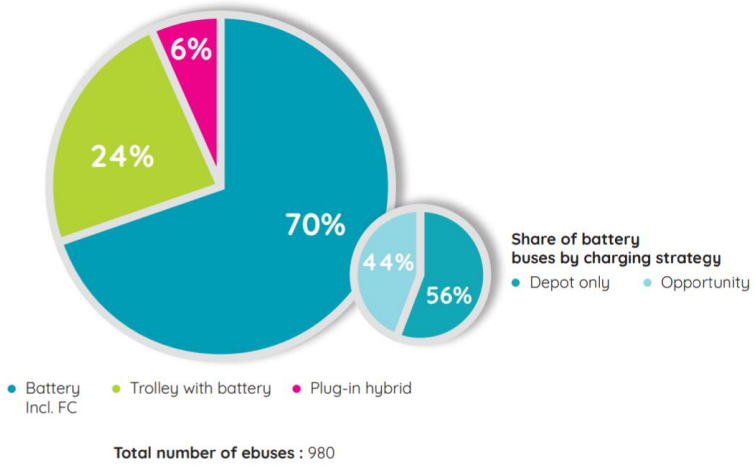

Figure 3: Electric bus technologies in Europe in 2017.
Source: Alexander Dennis Limited

At ZeEUS, we believe that part of the current mobility challenges faced by our cities can be addressed through the contribution of public transport, particularly by advanced cleaner bus systems. These will help reduce emissions and achieve a modal shift from private cars to public transport.

A successful transition to a low- and zero-carbon transport system is now more pressing than ever. The rapid growth of urbanisation affects the city resources and infrastructure. Effective and prompt action is needed to put mobility solutions in place able to address the needs of users and society sustainably.

What urban bus system are we aiming for?

"An endless number of green vehicles does not make a sustainable transport system" [12]

Public transport and urban buses are a vital component of city life; the quality of life and the attractiveness of a city is regularly reflected in the standard of its public transport. While urban mobility needs continue to grow, designing a public transport system capable of attracting citizens and visitors is a major goal for ensuring the sustainability of our cities.

To be efficient, urban buses must be approached as a coherent system that embraces the vehicle, the infrastructure, the operation and the users. The bus system should act as the backbone of road mobility chain, integrating with the various transport modes available (hence ensuring an efficient and user-friendly combined mobility) and whenever possible with priority over non-collective modes in order to improve the commercial speed. This way, the bus can contribute to fostering modal shift from private cars to public transport, thus helping alleviate road congestion. Finally, cleaner bus technologies will dramatically help reduce global emissions, local air pollution and noise levels. For this it is essential that the electricity is supplied by renewable energy sources in order to ensure the emissions are not just shifted to other regions.

[12] Paraphrasing Jan Gehl, Gehl Architects, on green cities.

Figure 4. Electric vehicles won't make it alone
Source: ZeEUS project

3.2 The future is electric!

The deployment of e-buses is politically-driven as a strategic decision to meet the needs and expectations of cities and citizens. At the crossroads between environment, economy, social inclusion and transport, the e-bus system contributes to achieving the mobility visions, declarations and also strategies of regions and cities, also supporting the deployment of consistent integrated policies.

Against this background, in 2004 UITP developed the UITP Decarbonisation Strategy to respond to the global policy context regarding the international and European targets; i.e. limiting the average temperature rise below 2°Celsius (Paris Agreement), the EU climate and energy 20-20-20 targets, and the EU target to achieve 60% CO_2 emissions reduction by 2050.

Public transport, despite already having an excellent track record in ensuring low-carbon emissions compared to other transport modes, can do more to reduce its carbon footprint. Alongside changes that can be made directly by the public transport sector, other solutions will come in the form of urban planning and urban policy. The following list gathers the solutions that can accompany the further deployment of e-bus systems:

- Modal shift: Strong modal shift towards public transport, walking and cycling is needed, as technology alone cannot deliver the required changes in a short time frame. Modal shift will also generate a number of additional benefits in terms of improved health, reduced car congestion, etc.
- Giving priority to collective transport: increasing commercial speed and reliability for buses, e.g. priority at traffic lights and reserved corridors/lanes. An increase of 5 km/h in the commercial speed on a busy bus line leads to 20% less energy consumption and attracts more passengers as the service is improved through lower travel times.
- Buses account for 50-60% of the total public transport offer in Europe, and about 79% still use diesel fuels. Long-term decarbonisation efforts shall include fleet renewal with e-bus technology, but also other clean technologies.
- Operational efficiency gains in terms of reduced energy consumption of auxiliaries, new driving skills for e-buses, monitoring support from IT tools, etc. to increase passenger comfort and reduce energy consumption and GHG emissions.
- Ensuring clean energy supply to charge the fleet: the production of renewable electricity from photovoltaic panels installed on roofs of maintenance and parking/stabling facilities when tax or investment incentives are available.

Clearly, the choice towards e-bus technology is fully in line with the signature of the Paris Agreement[13] which main goal is decarbonisation. This objective can be achieved through a shift from private modes towards public transport and other combined mobility solutions such as carpooling, car sharing, walking, cycling, etc.

Modal shift is indeed one of the best carbon reduction strategies. A city of 400,000 inhabitants with good public transport saves 1 million tons of CO_2/year compared with a city with poor public transport. E-bus systems go beyond this goals as they improve air quality and reduce noise levels.

This is one of the reasons why public transport itself has committed to decarbonise ahead of COP21. At the occasion of the UN Climate Summit in September 2014, UITP members confirmed this leadership through the Declaration on Climate Leadership[14]. This Declaration demonstrates the sector's support to double the market share of public transport by 2025 and a commitment to support cities to enhance, accelerate and ensure the efficiency of urban mobility as well as to intensify efforts to prepare for and adapt to climate change. Over 350 pledges to future action were made from over 110 public transport organisations in support of the Declaration. Actions aimed at giving a greater role to public transport in mobility which will help decrease the regions carbon footprint as well as reducing their corporate carbon footprint. One of these pledges is the ZeEUS project[15].

However, the decarbonisation goal should not undermine the need to set in place affordable transport system. Even with limited infrastructure investment, bus systems shall remain flexible as well as subject to fast implementation and great responsiveness to the local operational context and resilient to the different situations. Although the e-bus technology is still under development compared to a century of diesel bus developments, e- buses are the natural step in the evolution of bus systems.

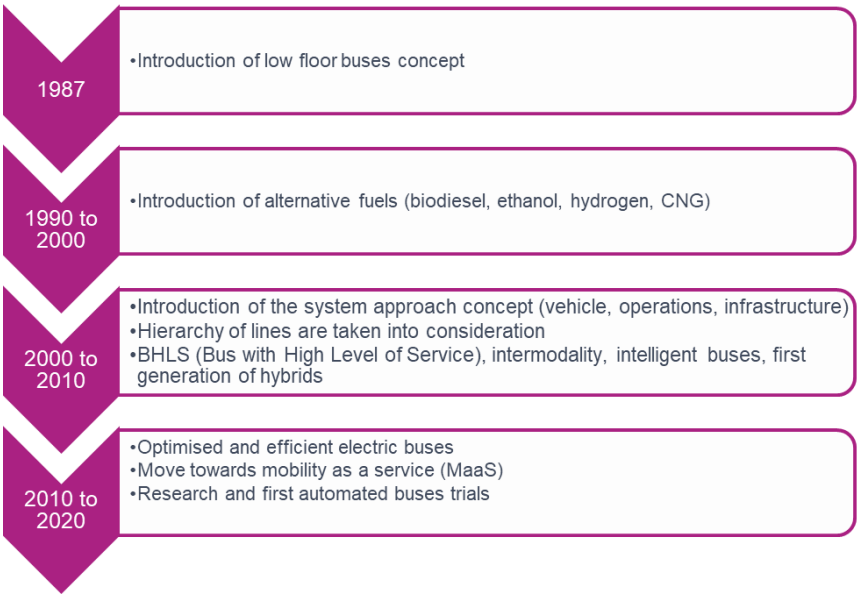

Figure 5. Evolution of buses 1987-2020
Source: UITP

[13] The Paris Agreement central aim is to strengthen the global response to the threat of climate change by keeping a global temperature rise this century well below 2 degrees Celsius above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 degrees Celsius.
[14] UITP Declaration on Climate Leadership, Update on Implementation 2016, *http://www.uitp.org/sites/default/files/documents/Advocacy/UITP_climate_leadership_implementation_2016_report_20161010.pdf*
[15] COP21 countdown : ZeEUS is part of UITP plan to tackle climate change, 1/09/2015, *http://zeeus.eu/news/cop21-countdown-zeeus-is-a-part-of-uitp-plan-to-tackle-climate-change*

Beyond decarbonisation, a key issue that is being put forward is noise. Electric buses offer the possibility to significantly reduce noise levels in the city. Noise maps are being commissioned by cities in order to set up the most suitable policies. An example is the City of Gothenburg Noise Action Plan 2014-2020, which states that “keeping noise from buses and trams to a minimum is essential if Gothenburg is to be a pleasant city for residents and visitors”.

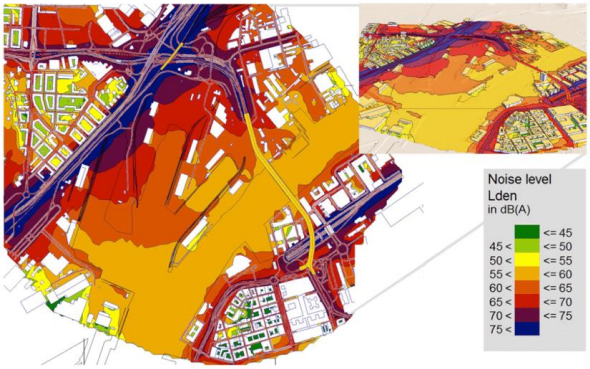

Figure 6. Example: Frihamnen area noise map.

Source: Gothenburg future Riverbank city visions and the Frihamnen project

However, today’s e-buses cannot replace all type of operations due to the limited range compared with other propulsion technologies. Still, there is a significant part of the journeys that can be replaced with electric powertrains, especially the inner-city routes, as shown in the figure below which presents each propulsion technology in its best operational conditions, needs and technological state-of-the-art. It is worth to underline that this is a general model and as such shall be revised and adapted to each specific local context. The technological evolution will reshape it and extend the range to longer routes beyond the inner-city.

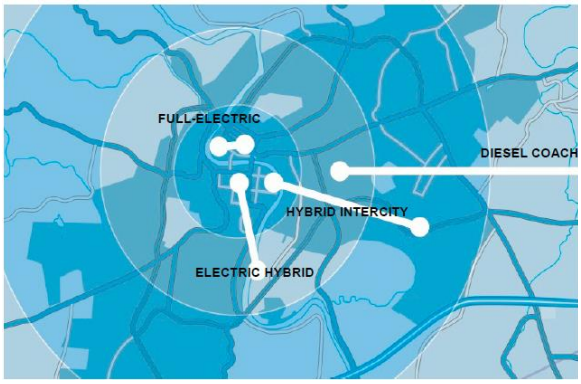

Figure 7. Example of propulsion technology mapping per range and type of operation
Source: UITP

In addition, in order to accelerate clean fleet deployment, in 2017 the European Commission launched the European Clean Bus Deployment Initiative[16], with a Declaration of Intent on promoting the large-scale uptake of clean, alternatively fuelled buses[17]. ZeEUS contributed actively to this initiative supporting the experts group with the knowledge gathered in the project.

[16] https://ec.europa.eu/transport/themes/urban/cleanbus_en

[17] https://ec.europa.eu/transport/sites/transport/files/2017-05-05-european-clean-bus-deployment-initiative-declaration.pdf

4. THE ZEEUS VISION

Public transport contributes to meeting the mobility needs of citizens but also to enhance urban development and quality of life in cities. The urban landscape can be dramatically improved by the positive impact of efficient public transport services through reduced congestion levels, air pollution and noise, but also increased connectivity, liveability and cohesion of the different city areas, with more walkable neighbourhoods and pedestrian zones, as well as higher land value of the areas served with public transport.

As a fundamental part of public transport, bus systems shall strive for service excellence providing seamless, reliable and safe mobility, and ensuring accessibility and affordable services for all.

Against this backdrop, ZeEUS envisions a zero-carbon urban bus system that actively contributes to the make cities more liveable, healthy and competitive with clean air, less noise, fewer cars and congestion, and more space to enjoy urban life.

The ZeEUS Vision embraces thus a number of key action fields in order to ensure a clean, safe, affordable, reliable and comfortable mobility through bus service excellence. It foresees electric bus systems in an optimised, efficient and integrated mobility strategy which is planned to meet not only mobility needs but to effectively address urban planning, energy, economic development, environmental, and social challenges.

This section details the ZeEUS Vision in its different fields of action, the barriers and opportunities associated to them and the measures to reach the wished scenario.

4.1 Creating liveable, healthy, competitive cities for all

“The bus system is fully integrated into the urban lifestyle and environment, fostering social cohesion, dynamism and well-being while offering efficient, sustainable and affordable transport, which effectively achieves modal shift from individual motorised modes to public transport”.

Cities are interconnected environments where success is based on all components (education, culture, transportation, resiliency) working together.

Creating vibrant, healthy and attractive urban realms requires setting in place a global master plan – which can be also the decarbonisation strategy – with a common, integrated mobility vision able to fulfil the expectations and needs of the city as a living ecosystem and the citizens as main users.[18]

Public and local authorities underline the importance of the bus system to promote the image and the attractiveness of the city. This is crucial as mobility is a driver of economic development, enabling accessibility to jobs and leisure, and all other activities for both citizens and visitors. Moreover, and as indicated in previous sections, e-buses greatly contribute to reduce air pollution and noise levels, with positive impact in citizens’ wellbeing and urban space.

[18] UITP (2014), “Connecting people and places, Integrated Mobility Plans for Sustainable Cities”: *http://www.uitp.org/sites/default/files/cck-focus-papers-files/AP%20-%20Integrated%20mobility%20EN_0.pdf*

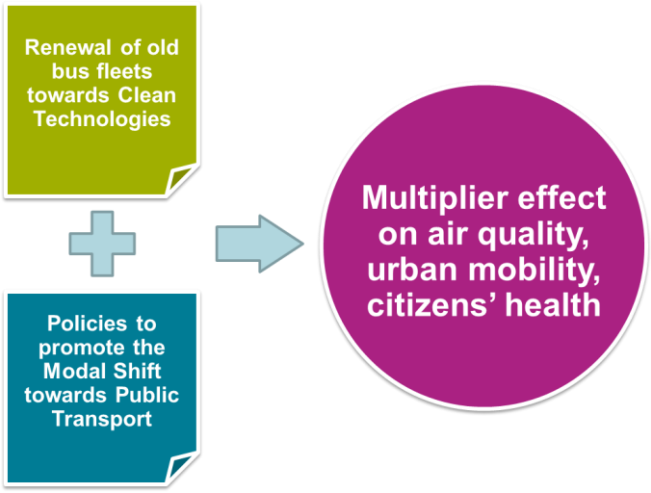

Figure 8. The multiplier effect of the UITP Decarbonisation strategy.
Source: UITP

To achieve this, the bus system shall be clean, accessible and affordable to all, have high commercial speed through dedicated infrastructure like bus lanes, and deploy traffic & operations management. Additionally, the system shall be efficiently combined with shared mobility modes (car sharing, carpooling, bike sharing, etc.) to support modal shift and implement smart energy management integrated in the overall PT system. All these elements are part of the UITP Decarbonisation strategy described in section 3.

4.2 Energy transition towards cleaner fleets

"Bus fleets are emissions-free and are supplied with renewable energy sources, being an integral part of the decarbonisation of transport and the backbone of public transport"

As mentioned previously, 50 % of the European bus fleet is still Euro III or older. Fleet renewal towards cleaner technologies is high on the political agenda as a measure to support the decarbonisation of transport, as well as on the renewal and expansion and plans of the operators as a way to improve vehicle and energy efficiency whilst reducing operating costs and emissions.

However, the decarbonisation of transport can only be successful if fleets are supplied with clean energy, for which the combination of vehicle efficiency and low-carbon fuels is key. Policies supporting the use and further expansion of renewable energy sources can highly contribute to reducing global emissions.

In addition, more effective policies promoting modal shift towards PT, e.g. introduction of low emission zones, congestion charges, park & ride facilities, monetary incentives to reduce car ownership, etc. can greatly support the transition to cleaner fleets by securing ridership whilst benefitting from the multiplier effect on improved air quality, noise levels, overall urban mobility, and citizens' health.

But is electrification really a revolution? Electrification already transformed PT in the past with the transition from horse-powered carriages to the electric tramways. Back in 1886, the higher maintenance costs of traction-horses vs the benefits of electric traction was one of the key topics of the UITP Congress in Berlin.

Following such revolution, 50% of PT today are electric transport modes: tram, metro, trolleybus, and now, progressively increasing also the bus.

4.3 Common charging infrastructure & smart use of energy

"Interoperable, standardised, high power charging infrastructure which is shared among all urban transport modes, and connected to the PT power grid to improve energy efficiency and accessibility to low-carbon fuels and clean energy".

The standardisation of electric bus charging started with the EC Mandate M/533 (12th March 2015), which issued a request to CEN/CENELEC to make a recommendation for standardisation of the charging systems by the end of 2019. For this purpose, a WG led by UITP was set up.

The ZeEUS project, UITP, ACEA, VDV and many other organisations have been involved in this work since 2016. Part of the results of the working group are two e-Bus Charging Use Case documents for "opportunity charging" and "charging in depots".

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 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 teh elaboration of an "application note" or "good practice" document, most likely to be published by UITP in the coming future.[19]

A shared infrastructure where PT vehicles (buses, trams, metros, trolleybuses) and shared e-modes (cars, bikes), as well as freight and logistics and other e-vehicles (private e-cars) can charge without hassle and as a part of the daily operations supported by a careful charging strategy, planning and monitoring.

Smart charging will be thus key to balance the overall power grid and contribute to its stability, securing a reliable and efficient energy supply which is guaranteed under all circumstances.

4.4 Simpler operation and maintenance

"Smart operation and maintenance of electric bus systems thanks to the use of IT monitoring tools, predictive maintenance and interoperable, high power charging, which make the daily service and maintenance easy and hassle-free"

Electric bus systems require a new way of operation as the vehicles are linked to a dedicated charging infrastructure, which implies major adaptations and new infrastructure both in depot and – if decided so – en route. In this sense, the design and implementation of e-bus systems shall be addressed as a complex system, where the synergic

[19] The progress achieved within ZeEUS through the CEN-CENELEC ad hoc group 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.

superposition of vehicle, infrastructure (dedicated lanes and charging infrastructure) and operations (climate, topography, urban landscape and city layout, etc.) shall be considered as a whole.

The standardisation and interoperability of operation and maintenance of e-buses brings a series of major benefits to operators, including lower costs and improved security thanks to a reduction of the number of breakdowns.

The standardisation of the charging infrastructure is thus key to secure a safe and reliable operation. Currently there is a wide variety of chargers and charging solutions and suppliers preventing a wider deployment of electric buses. To overcome this barrier, cities and operators need to be reassured that the different buses' brands will be compatible with different opportunity and overnight chargers.[20]

Interoperable fleet management systems for multi-brand fleets using IT monitoring systems and tele-diagnostic (predictive maintenance) based on common standard can relief the operation and maintenance tasks and costs. The IT support enables to continuously improve diagnostic operations, thus lessening maintenance costs, breaks, spare-parts usage, and amount of waste material.

Effective, predictive and real-time alerts improve both reliability and vehicle availability, contributing to keeping scheduling on track. Interoperability for depot operations reduces training needs and increases hard skills as well as improving maintenance efficiency and staff allocation to added-value operations. The interoperability for ITs offers lower costs and improved purchasing flexibility. Also the vehicle lifetime is extended and smooth transitions are supported by the opportunity to implement retrofitting programs. The global quality of service of the PT network is improved, while TCO is reduced.[21]

Also, the economic benefits of interoperable charging can boost the resale value of the vehicles, which help build confidence in the technology and boost further market take-up.

Finally, from the vehicle point of view, electric powertrains have less moving parts which potentially require lower maintenance demand. This could enlarge the vehicle lifetime though this is still not widely acknowledged, mostly due to the lack of experience on e-bus operation and the uncertainties linked to the battery lifetime.

4.5 Environmental-friendly depot management

"Zero-waste and zero-emissions depot with complete recycling procedures on site and renewable energy electricity supply"

As indicated above, electric powertrains have no oil or other fluids requirements as the motor has less moving parts and is much simpler than in conventional buses. This reduces considerably the management, maintenance and waste disposal tasks at the depot, and makes the depot a healthier environment with less hazardous substances and pollutants.

[20] To help address this issue, the ZeEUS project, jointly with VDV and UITP, prepared two documents:
- Use cases and requirements concerning the opportunity charging: http://www.uitp.org/sites/default/files/Newsmedia/News/Final%20-%20Standardisation%20-%20Opportunity%20Charging.pdf
- Use cases and requirements concerning the charging of buses at depots: http://www.uitp.org/sites/default/files/Newsmedia/News/Final%20-%20Standardisation%20-%20Depot%20charging.pdf

[21] EBSF_2 Project: www;ebsf2.eu

Because second-life batteries will retain significant capacity, they may be well-suited for various customer and grid applications, particularly if aggregated for bulk energy storage. However, the most important issue is its disposal. Research is ongoing to address this issue.

Also, the use of renewable energy sources in the form of roof photovoltaic panels, rooftop wind turbines shall be considered to ensure the electricity supplied is emissions-free. Moreover, the surplus produced can be resold to the network operator or stored on site if the depot works in island mode (no connection to the grid).

4.6 Optimised global costs

"TCO of electric buses is lower than the TCO of conventional buses due to improved battery technology and the inclusion of the external costs of transport"

Both at the investment and operational levels, electric bus systems imply today higher upfront costs than conventional systems, due mainly to the battery price and the additional cost of the charging infrastructure, a cost to which the bus sector is not used.

The battery price and lifetime is a key concern as it represents almost half the cost of the bus. In order to achieve a more advantageous TCO the vehicle lifetime shall be at least equivalent to that of conventional buses. This is the case for trams, which are simply refurbished after a period and can last up to 30 years.

The operation is more expensive than for diesel buses in terms of range autonomy and reliability which though improving, it is not the same yet. The choice for an investor thus lies between the installation of a fast charging infrastructure en-route or at the terminus and the acquisition of spare buses to secure the daily operating range.

Another element to include in the TCO is the maintenance cost. The experiences within the ZeEUS project indicate that maintenance appears to be less costly for e-buses in comparison with diesel buses. Still, trainings for maintenance staff and drivers constitute an additional upfront cost.

Additionally, the depreciation rules appear to be defined locally, which enables a real adaptation to each city's specific context, but also makes the transferability of the e-bus technology from one city to the other more complex.

A lower TCO can be achieved by extending the contract period to match the vehicle lifetime that in the case of e-buses is much longer than conventional buses. Additional, the daily mileage is key to achieve lower TCO: the higher mileage, the lower operational costs.

However, there are huge differences of TCO models. New cost models are appearing to support investors in taking the risk which, if implemented, will need to be carefully assessed over the coming years, e.g. vehicle or technology leasing, lifecycle guarantee/insurance or back-buy condition.

Finally, cities and operators shall value the positive externalities of electric buses (better air quality and lower noise levels), and with that the positive effect on citizens' health when estimating the costs. This could be done through favouring measures for the deployment of e-bus systems, subsidies for vehicle purchase, or more directly, restrictions on the type of vehicles that can be implemented in a PT fleet.

4.7 New vehicle and stops design

"Urban buses are perceived as the most convenient and advanced transport mode thanks to an outstanding travelling experience"

The introduction of e-bus technology in the current fleet is a fantastic opportunity to improve the image and attractiveness of the urban bus. Linked to clean energy sources and sustainability, the e-bus becomes a new, recognisable object in the city landscape and it is a message itself of a modern, comfortable and green mode of transport.

The EBSF2 project explored these aspects and conceived a Design Charter for E-Buses[22] aimed to promote buses as a mode of transportation in their own right, matching the mobility industry trends and the wider social evolution. Both elements, the vehicle and the stops were rethought in order to bring the bus experience to its best.

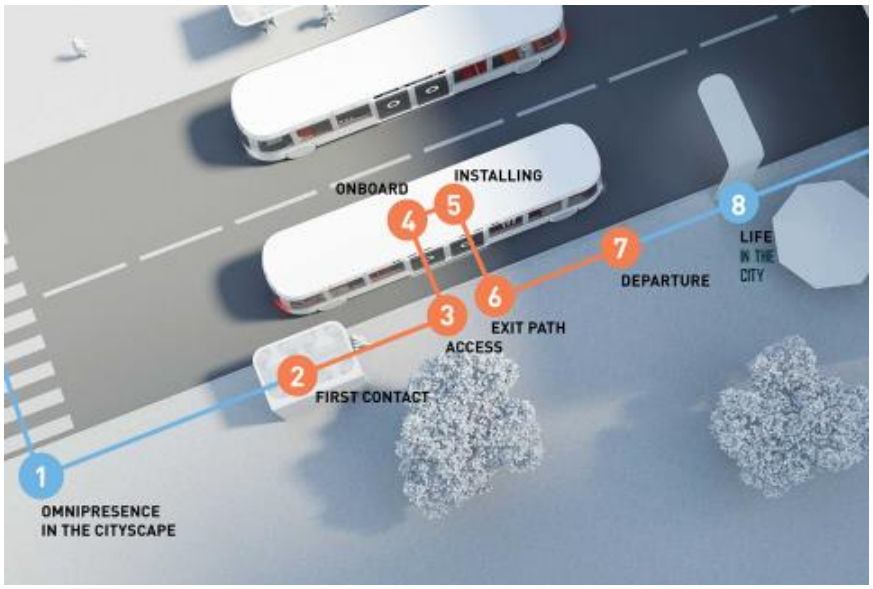

Figure 9. Example of design principles for innovative e-bus systems
Source: EBSF2 Project

The characteristics of e-buses, e.g. clean, high-tech appearance, low noise, zero local emissions, present major advantages to improve the image of bus services and with it of public transport. The interface between the bus and urban infrastructure, in particular bus stops and terminal (by harmonising vehicle layout and bus-stop design) but also intermodal hubs and running ways, can greatly contribute to improve the bus experience, determining the passengers' perception and acceptance of the whole bus system.

Traditionally, bus stops have been designed to provide travellers with a landmark indicating where the bus will stop as well as protecting them from bad weather conditions.

Today, bus stops can be perfectly integrated in the city landscape in a highly functional way, becoming intermodal hubs combined with multimodal centres, enabling passengers to fill transfer times conveniently and become an important part of the image of the brand for both the operator and the city. In addition, bus stops could also offer further services, e.g. information features (touch monitors), Wi-Fi, USB-charging, etc. to travellers or passers-by.

[22] EBSF_2 Project (2018): Design Charter for E-Buses:
http://www.ebsf2.eu/sites/default/files/180410_EBSF_2%20Design%20Charter%20LR.pdf

In addition, as e-buses have no tailpipe emissions, it possible to design concepts and new functionalities for bus stops, e.g. indoor stops[23], as well as address interactions between passengers, vehicles and urban infrastructures.

4.8 Backbone of future road mobility

"The urban bus becomes the leading and most valued transport mode providing advanced and excellent service for all"

The future of road transport is going to be defined by the technological innovations like electric powertrains and autonomous vehicles, which will be integrated in the right mix of mobility-as-a-service solutions and combined mobility, supported by high capacity e-buses as the backbone of the road mobility chain.

Mobility is evolving towards a model of service provision, enabled by ICTs and trends like MaaS to offer transport solutions based on the passengers' travel needs.

If the right policies and decisions are set in place, this future scenario will bring major environmental and social improvements in terms of quality of life and safety of transport (e.g. reduced global emissions, air and noise pollution, reduced congestion levels, etc.).

New business opportunities will arise but also risks. Business shall be able to understand and fulfil the needs inherent to an evolving mobility system. Policy-makers shall create appropriate policy frameworks to incentivise and support investment decisions with a positive impact on the wellbeing of people and the environment.

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.

Volvo, partner of the ZeEUS project, is currently testing an autonomous 12 m e-bus in Gothenburg.[24]

The numerous advantages of autonomous, connected e-BRT and autonomous e-bus itself are many, and very powerful. The autonomous driving and the electric powertrain components enable a gentle driving without rushed accelerations and brakes ensuring a comfortable ride. The bus sensors adapt speed accordingly to the route development and needs. Parking at the bust stop is automatized, keeping the same gap bus-stop platform, easing the entry and exit of the passengers. Also, the dedicated, segregated lanes enable opportunity charging whenever needed at convenient bus stops. At the bus depot, vehicle handling is simplified as the bus can drive himself to the charging, washing lane and parking slot, releasing the staff who can focus on other maintenance and service tasks.

Autonomous e-BRT would add flexibility to the operation as it would enable adapting to demand and add capacity whenever needed. Bus platooning is currently being explored as in theory, it could scale up to as many vehicles as needed, which would help operators

[23] A pioneering experience on bus indoor stops has been implemented in Gothenburg and analysed in EBSF2. Indoor stops can be located in a context of university buildings, office buildings, hospital, etc. which can then be used as a shared space for PT and other urban activities, thus changing the perception of a bus stop: from a mere "bus stop" to a space for activities including travel, bringing passengers closer to the outstanding travelling experience that the urban bus is meant to become.
[24] *https://www.volvobuses.com/en-en/news/2018/jun/pioneering-automation-volvo-demonstrates-autonomous-bus.html*

maintain bus headways (the time between consecutive buses) and adapt to demand peaks and rush and off hours.[25]

This solution can rebrand the bus and bus service as a new, modern and highly convenient, dominant mode in the city landscape.

[25] *https://www.masstransitmag.com/article/12270117/is-autonomous-bus-rapid-transit-the-next-evolution-of-brt*

5. WHAT AFTER ZEEUS?

Only five years ago it would have been challenging to explain to any stakeholder in the bus sector that electric powertrains could go as far as they have reached. The beginning of ZeEUS launched the start of a new era in the deployment of e-bus systems, with the active involvement of the project partners and a growing network of engaged stakeholders. The efforts of this enthusiastic community, “the ZeEUS Family” as we call it, have led to place we are now.

A brief look into the these last five years shows us that that the developments achieved are major and have set a new pace for urban e-bus systems. At the beginning of ZeEUS we saw pilots with small numbers of e-bus, two or three, integrated in the overall fleet. Operators and authorities started from scratch, learning by doing, and encountering a series of barriers that were common to all the project pilots: 1) higher up-front costs (vehicle, infrastructure); 2) charging infrastructure; 3) new ways of operation; 4) new tenders and contracts; 5) need to build alliances with other sectors (energy).

These barriers have been overcome and today we can see parts of the line, small lines and even complete bus lines in operation in many of the ZeEUS cities, and this not only in the frame of the project pilots but also in the frame of the ZeEUS Observatory[26]. The evolution has been quick and fruitful, and this has been possible thanks to the diversity of activities and initiatives triggered by ZeEUS together with a large collaboration platform, involving more than 100 organisations who committed to jointly bring electric bus fleets right into the heart of our public transport systems.

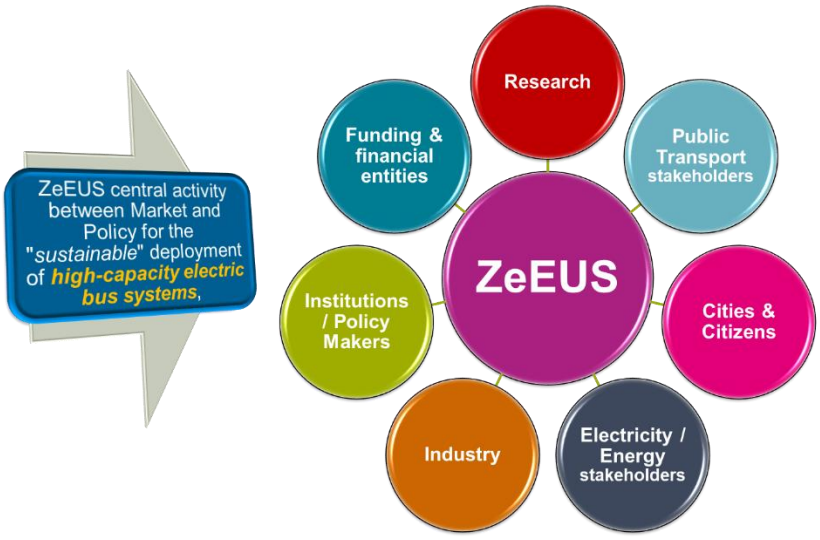

Figure 10. The ZeEUS Network
Source: ZeEUS project

These efforts have not been only focused in Europe, but worldwide. ZeEUS has brought his passion for e-bus deployment all over the globe, launching and participating to training workshops, conferences, seminars, market places, and other events to share and enlarge the knowledge basis on e-bus technology and operation.

[26] *http://zeeus.eu/demonstrations-activities/observatory-of-electric-bus-systems-activities*

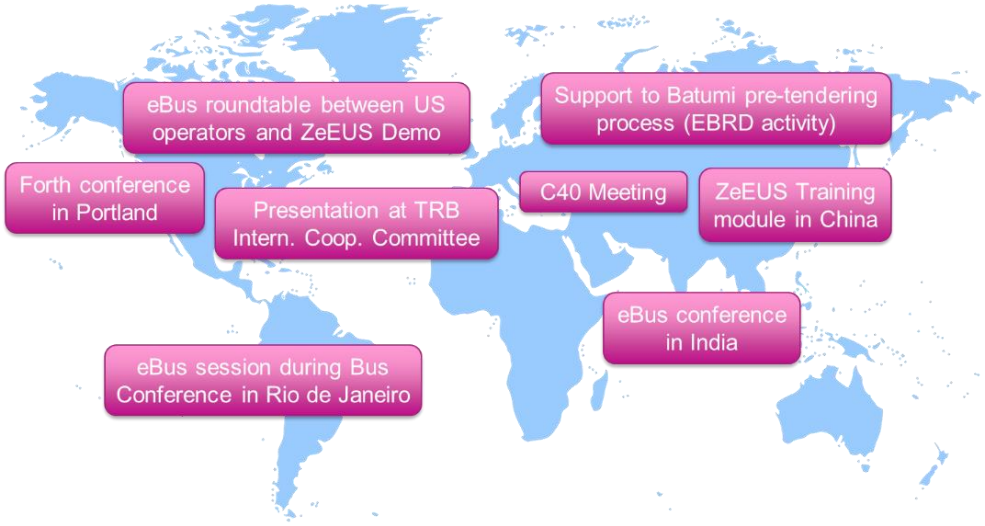

Figure 11. ZeEUS worldwide activities
Source: ZeEUS project

All this has brought confidence to market, providing solutions to the barriers and increasing the expertise and knowledge on e-bus operation, and most importantly, the perception of the solutions by the end users (operators and authorities) to which ZeEUS has strongly contributed. This is reflected in the trend that can be anticipated in the number of e-bus orders in the last year, which clearly show the exponential grow of e-bus orders foreseen by 2020 and after.

Improvements have been done also on the policy side. A survey led by ZeEUS examined European cities' strategies set for the introduction of e-buses over the coming years. It revealed that 18 public transport stakeholders in around 25 cities had published an electric mobility strategy up to 2020. At that time, the number of e-buses expected also showed the trend towards higher implementation of e-buses: over 2,500 e-buses out of a total fleet of 35,000 (=7%) by 2020; but, by 2025 more than 6,100 e-buses in service out of a 15,000 bus fleet (=40%) [27].

Still, there is work to do in order to ensure that e-bus systems reach every city. For this reason we need to keep on cooperating, promoting, and favouring e-bus technology in a fair, open and cooperative way. The actors involved in the e-bus sector are growing as new business models arising from the definition of new market opportunities.

As said previously, e-bus systems shall become the backbone of urban road transport, supported by MaaS and combined mobility solutions, backed up by political will and a solid policy framework – integrated in the global city's electric mobility strategy, SUMPs – and understood by the industry as the future of sustainable and clean urban transport.

Only this way it will be possible to engage operators and authorities to invest in clean buses to provide the public with a bus service which is future looking, highly innovative and above all, tailor-made to the passengers' needs.

The next pages summarise some aspects to be taken into account to continue ZeEUS work and secure a global leadership at the European level.

[27] Of 13 transport stakeholders operating in some 18 cities (target by 2025).

5.1 The role of cities and decision-makers

As previously mentioned, going for electric buses is today a political choice which needs to be fully supported at the local level, both politically and financially.

Cities cause 40% of all transport related CO_2 emissions generated and congestion which costs nearly 100 billion Euro, or 1% of the EU's GDP, annually. Replacing the entire car fleet with e-cars will not solve the congestion issue and related cost because a green traffic jam is still a traffic jam.

Today the cost incurred by emissions impacting healthcare is widely underestimated, if not ignored. Poor air quality due to exhaust gases from traffic causes the premature deaths of almost 300,000 citizens per year in the EU. E-bus systems, by contributing to the decarbonisation of transport are a viable solution for the internalisation of the negative external cost (negative externalities) of the current transport model.

Financial packages supporting the deployment of e-buses can be stimulated by decision makers while the bus sector can cooperate to deliver a proven sustainable business model for future electric bus fleets. Political support is needed for acting as an enabler and facilitate the large investments required for the introduction of e-buses through the appropriate framework and instruments, as well as to ease access and raise attractiveness for private capital. Decision makers can also support the set-up of relevant legislation through for example the creation of incentives for the procurement of e-buses using renewable electricity to offset the price premium.

Implementing electric buses can improve the city identity and image as it can been seen as an innovative city providing a more sustainable mobility while answering to the environmental concerns of its citizens. But it must be done carefully, with a global goal to reach a high standard of bus service. A positive thinking around the e-bus project can be created, with technology supporting political will and political decisions supporting, triggering and stimulating innovation.

Many European cities face similar transport problems, but technical, social, economic and institutional circumstances vary. Therefore, no single solution can serve all needs, and it is a great challenge to make the best choice among the available options. Local governments and cities must consider the full range of options for reducing emissions from the transport sector, including behavioural and technological interventions that are best tailored to local circumstances. Although the ZeEUS demonstrations show a variety of technological solutions and the sites cover a large set of different boundary conditions, they cannot directly cover all possible combinations. Therefore, one of the goals of ZeEUS is to add up our common knowledge-base and produce tools for the decision makers to make the right choices, thanks to the projects recommendations[28]. Life-cycle carbon footprint analysis can support the selection of transport infrastructure schemes.

5.2 Tackling a higher price tag

New clean technologies such as e-buses often come with a higher price tag. The specificities of the urban buses niche market and considerable efforts of bus manufacturers and public transport undertakings in cleaning up bus fleets require further support of the sector's initiatives and recommendations, but not through further legislation[29]. The electrification of bus systems is a process that will require a major effort by all stakeholders,

[28] ZeEUS Recommendations and Results are accessible here: *http://zeeus.eu/deliverables/public-deliverables*
[29] See « A comprehensive approach for bus systems and CO_2 emission reduction », A UITP Position Paper, November 2011.

as it implies new infrastructures and a whole set of new on-board equipment. ZeEUS has analysed current financing instruments and has browsed European funding schemes. It did so taking into account the specific needs linked to the bus market specificities while remaining neutral in terms of the different electricity technologies available. Thanks to projects like ZeEUS, it is possible to support the European industry in validating the quality of their developed products and solutions in a very competitive scenario as new non-European competitors are approaching the European bus market with their own solutions for economically and environmentally sustainable buses. The project enabled to lead and promote a European vision to develop common test tools, guidelines and roadmaps.

In addition, ZeEUS supported the development of standard cycles of measurement of energy consumption such as the E-SORT protocol. The project contributed to the validation and fine-tuning of the protocol, which resulted in the creation of a new chapter included in the UITP E-SORT cycle for full-electric buses.[30]

Figure 12. From SORT to E-SORT thanks to ZeEUS
Source: ZeEUS project

Another key aspect of the project was the launch of the interface standardisation to generate easy implementations and economies of scale for the European bus industry. ZeEUS was actively contributing to the Standardisation working group led by UITP in order to support CEN/CENELEC[31] to define charging standards by 2019. It is worth to mention that the USA and China are following the EU standardisation process to develop a harmonised one.

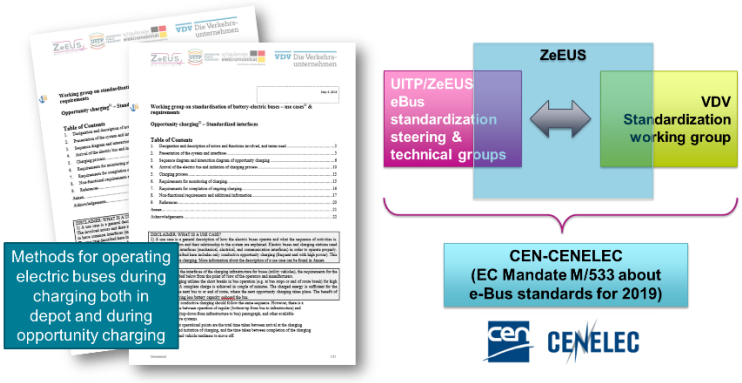

Figure 13. The Standardisation process within ZeEUS
Source: ZeEUS project

[30] *http://www.uitp.org/news/E-SORT-addendum*
[31] See section 4.3 pp.20 of this document.

This work is still ongoing and has been taken over by the ASSURED project (*www.assured-project.eu*). ASSURED is aimed at boosting the electrification of urban commercial vehicles and their integration with high power, fast charging infrastructure, evaluating several infrastructures in different cities across Europe. Building on the results of ZeEUS and other EU-projects, ASSURED will develop solutions and tools to ensure the upscale of urban commercial fleets, both for passenger (bus fleets) and freight (trucks and vans) transport. Today, one of the main challenges is enabling faster and interoperable charging. As in ZeEUS, ASSURED will continue working with CEN-CENELEC to provide European standards and thus support a wider deployment of electric mobility in our cities.

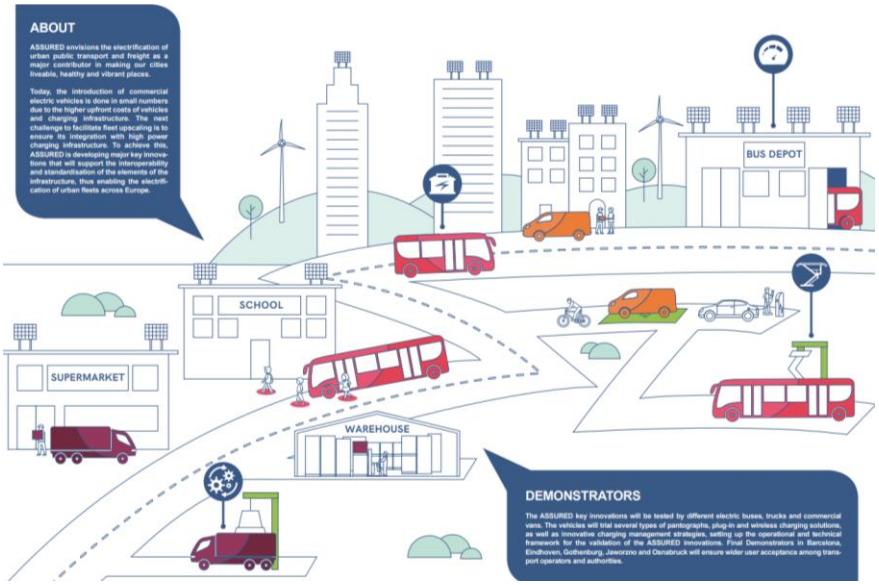

Figure 14. ASSURED: Interoperable, high power, fast charging infrastructure

Source: ASSURED project brochure

Lastly, ZeEUS has been key in providing operators and authorities with guidelines for tendering and procuring e-buses. The new needs for clean and sustainable public transport include ensuring reduced emissions, local air pollution and noise, that can be effectively supported by cleaner bus fleets. As indicated previously, the orders of e-buses in the European market are growing, a fact that underlined the need of supporting cities, authorities and operators with clear advice on how to procure e-buses. The ZeEUS Tender WG was set up with this purpose; its work resulted in the development of a special new chapter dedicated to e-buses included in the UITP Tender Structure document.

5.3 Call for economic support

The transition towards new clean bus technologies, especially new propulsion technologies for buses and other public transport vehicles normally come with extra costs for public transport operators and authorities – at least during a first phase of market introduction. Experiences with hybrid buses have shown that this is also the case with electrified bus systems. In order to facilitate the market uptake of e-buses, financial support from European, national and regional/local level is and will be necessary.

ZeEUS investigated possible financial support measures and instruments/tools, not only at European, but also at national level. The project identified their integration in national and EU funding programs/ initiatives in cooperation with European funding institutions (EIB, EBRD, use of unspent funds from the European Energy Program for Recovery - EEPR,

etc.), and local, regional and national governments and bank authorities (e.g. ERA-NET Plus "electric mobility", ELENA (European Local ENergy Assistance). Part of the results of this work are published under the ZeEUS results.

5.4 Knowledge-sharing on e-buses

The ZeEUS project has gathered numerous guidelines and tools to accompany public transport practitioners in their e-bus projects: public transport authorities, operators, industry, drivers, students, etc. The collected material provides an overview of evaluated and recommended solutions adaptable to each city and/or bus line context (climatic conditions, local constraints, specific operational situation, etc.). With the numerous and deep exchanges of knowledge, experiences and best practices triggered by ZeEUS, two main conclusions were reached to reinforce the links between energy and bus domains on two aspects:

1. Clarify the framework for and foster successful partnerships between the two domains, depending on the different national laws.
2. Create a more extended platform to allow the necessary exchanges between energy suppliers and distributors, PTO, PTA, bus manufacturers and industry suppliers. Such platform shall also include the ITs companies which can support the set-up of smart charging strategies.

This point cannot be underlined enough: advancing and making progress in an unknown, new field is only possible by fostering and enabling the cooperation and knowledge exchange among the key actors related.

ZeEUS has been fundamental in bringing together different stakeholders with different needs and perspectives around the same table. As said, this work is not concluded and now is the time for other projects and initiatives, like the ASSURED project, to take over the ZeEUS legacy and make the best of it in order to serve and pursue their own goals towards a brighter and more sustainable urban transport, no matter where, the electrification of urban bus systems.

Some of the possible solutions for an innovative and future looking implementation of e-buses are autonomous e-BRT systems. The coming years will be decisive to define the needs and the role of this solution to provide further answers to the urban mobility challenges. Dedicated research is fundamental to elicit knowledge and create the stakeholder network required to explore its potential and opportunities. UITP will follow up closely its development.

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