# Mastering changes in urban public transport: introducing high-capacity e-buses in cities

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## Abstract

With 30 billion passengers in the EU per year representing half of all public transport passengers, quality and cohesion of the bus services are decisive. Public transport and urban buses are crucial for the image cities want to reflect on and e-buses represent a big change in how people experience their ride. Strongly contributing to cleaner environment, smoother driving and minimising noise levels, they help reinforce the attractiveness of the bus. Demonstrations of high capacity e-buses are an innovative and necessary intermediate step to demonstrate the economic, environmental and social viability of systems of electric buses for mass commercialization. The Zero Emission Urban Bus System [ZeEUS] project, co-funded by the European Commission's FP7 Programme and coordinated by UITP, aims to bring electrification to the heart of the urban bus network. Ten live urban demonstrations in nine European countries will test and validate a range of plug-in hybrid, full electric and battery trolley buses with fast and slow charging strategies with different energy supply modes. The results and experiences gathered will help support decision makers with guidelines and tools on 'if', 'how' and 'when' to introduce electric buses.

*Keywords: electric bus; high-capacity; fast/slow charging; charging infrastructure; energy supply modes; KPI*

## 1 Introduction

With 30 billion passengers in the EU per year representing half of all public transport passengers, the quality and cohesion of the bus services are decisive. Unfortunately, they are too often overlooked. E-buses represent a big change in how people experience their ride on public transport as they strongly contribute to a cleaner environment, smoother driving and minimising noise levels. Today, the

e-buses which have been introduced in our cities are mostly mini and midi buses with a limited capacity and autonomy. The current challenge is to implement the electric technology on high capacity buses (12m + or equivalent in terms of capacity, double-deckers) in European cities with important historical structures, complex topography and limited space. E-buses shall be able to carry a high number of passengers with greater energy autonomy, allowing the fulfilment of daily hours of operation.

The ZeEUS project gathers 40 partners representing the entire value chain of standard electric bus: cities, operators, industries, researchers and energy providers. Together, they lead live operational tests in 10 European cities - Barcelona, Bonn, Cagliari, London, Muenster, Paris, Plzen, Eindhoven, Stockholm and Warsaw - demonstrating that several electric bus solutions can be implemented on high capacity buses under full revenue and normal service conditions. The demonstrations are accompanied by local and horizontal evaluations, with the goal to provide decision makers with the necessary tools to evaluate the economic, environmental, operational and societal feasibility of electric urban bus systems.

In Europe, between 40 and 50% of public transport is already powered by electricity presently [1]. Electric buses have been used by public transport operators since trolley bus systems were established in several EU Member States. Besides trolley buses, hybrid electric buses are on the verge of becoming a reliable technology, while fully electric buses of high capacity are still considered an experimental technology [2].

The demonstrations of high capacity e-buses are an innovative and necessary intermediate step to demonstrate the economic, environmental and social viability of systems of electric buses for mass commercialization. Standard e-buses experiences are led in a full range of climate conditions across Europe. Different systems and technologies for electric buses are being tested on the market at the moment.

## 2 Buses' modern propulsion technologies

For the time being, diesel and biodiesel buses constitute by far the largest part of the bus fleet (90% of the bus fleets in Europe, according to the results of the 3iBS survey) [2]. Since the 1990's, every few years a new "Euro" standard set new mandatory emission limits for certain pollutants, amongst which NOx and PM. European bus manufacturers have invested heavily in new engine development in order to comply with these standards: the development of Euro IV, V and VI engines required up to 50% of their total product development investment resources. These costly investments have led to a significant reduction in local pollutants, close to the limit of the ability to detect them (see graph below).

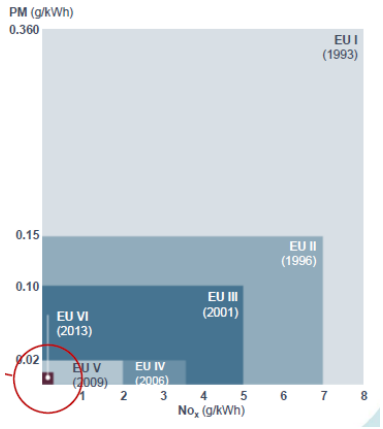


Figure 1: Pollutants by EURO VI standards in comparison with previous EURO norms.

Therefore, the focus should no longer be just on developing further Euro standards, but rather on investing into bus systems as a whole, leading to a stronger modal shift. Despite the outstanding results achieved so far, diesel buses still suffer of a negative reputation and politicians start to call for a "clean fleet" composed only of electric and alternatively-fuelled buses. This negative perception of diesel buses may be due to the fact that almost 50% of buses used across the EU are still Euro III and older (see graph below).

Whilst a regular percentage (ca. 8%) of the bus fleet is renewed every year, the renewal of an entire fleet is achieved over a full bus lifecycle, i.e. ca. 12 years, sometimes longer. An accelerated renewal of the oldest parts of a fleet and substitution by modern Euro VI buses and (partly) electric or alternatively fuelled buses would trigger an immediate reduction of particles and GHG emissions in the respective city or region.

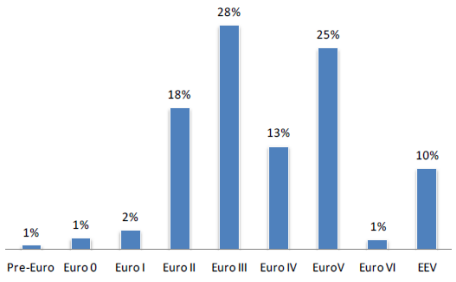


Figure 2: Bus fleets breakdown by EURO standards, 2015 (Source: 3iBS project, elaboration based on city and regional bus services in operation in France, Italy, the Netherlands, Poland, Sweden and the United Kingdom).

Buses powered by alternative fuels have been available for more than ten years and have gained popularity in recent times due to their advantageous $CO_2$ balance. Besides trolley buses, solutions vary from mature and reliable technologies to new and experimental ones. Some of the electric and alternatively-fuelled buses are currently still significantly more expensive than diesel buses. However, it is important to look at the life-cycle costs of these vehicles, which must take into account the cost of fuel or energy consumption, as well as positive externalities such as a reduction in emission and low noise levels.

## 3 Evaluating the core demonstrations: Key Performance Indicators

One of the key objectives of the ZeEUS project is to provide decision makers with guidelines and tools to determine 'if', 'how' and 'when' to introduce electric bus systems in the core urban network. In the ten core demonstrations, buses are running in full revenue operation in a range of different geographical, climatic, environmental and operational conditions. Both low and high rate data collected across such different systems will produce statistically meaningful evidence.

The data will be collected from all demonstrations in the form of Key Performance Indicators and aggregately analysed. The methodology covered all aspects of the sustainability paradigm, along the Triple Bottom-Line (TBL) concept first articulated by Freer Spreckley in [3], and later more widely known in the form of "People, Profit, and Planet" by John Elkington [4], as the three pillars of sustainability.


Figure 3: The sustainability paradigm: the triple Bottom-Line of J. Elkington.

Using this basis, the ZeEUS project identified the roots of the KPI tree for an electric bus system and each demo site selected their own KPIs from the pre-defined list. Indicators were to be selected in a way that they are usable for comparison in before-after analyses; therefore, they have to allow the measurement for different technological options, i.e., both the one currently in use and the demonstrated one, which will likely replace (or be an alternative to) the existing one. No single KPI was mandatory, but each demonstrator was able to choose the KPIs, depending on the characteristics of the implemented electric bus system (e.g., extension of the case, technologies applied, current operation, etc.).

However, for the benefit of successful global and horizontal analysis between the demonstrators, as many common KPIs as possible was encouraged.

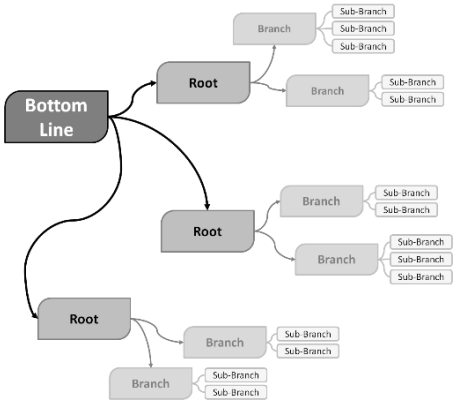


Figure 4: KPI Root Concept.

The root was populated with further branches (in principle to be located under the current nodes), to cover the specific characteristics of the bus systems. Eventually, the list of indicators had to be exhaustive, and had to prevent that other indicators, which cannot be reported or easily converted to the selected ones, are used in the performance analysis and evaluation of each demonstrator.

## 4 Summary of core demonstrations KPIs selection

The KPIs are not only elements contributing to answers the “if”, “how” and “when” questions. The objective is to develop a set of guidelines and tools for that. Within them, tender structure and test cycle will be defined based on the KPI that will be demonstrated as being the most relevant for the evaluation of the performances of an electric bus.

Originally, the main idea was to collect as much relevant data as possible, and by a “root-cause” –analysis let the evaluation show what are the real Key Performance Indicators that have high relevance to the performance. However, during the progress of the work, it was felt necessary to rate the different indicators and analyse how well those are supported by data collection in order to have better understanding of the success in global evaluation. Therefore, data collection should primarily be linked to these “high-rated” indicators as being the Key Performance Indicators. The choice and acceptance of indicators by the demos is also expressed as a “hit rate”. Combining these two ratings allows us to see, if the acceptance of the indicators was sufficient to support the most highly rated KPI’s. More data regarding our root-cause analysis shall be available in the upcoming months.

The table below summarises the selection of the KPIs from the amount available by 7 out of the 10 demos:

| | Root Root Segments | | | |
|---|---|---|---|---|
| | **People** (34) | **Profit** (43) | **Planet** (21) | **Total** (98) |
| Barcelona | 31 | 38 | 19 | 88 |
| Bonn | 12 | 15 | 3 | 30 |
| Cagliari | 13 | 17 | 6 | 36 |
| London | 32 | 36 | 20 | 88 |
| Muenster | 29 | 38 | 16 | 92 |
| Plzen | 32 | 34 | 11 | 77 |
| Stockholm | 24 | 8 | 7 | 39 |

Table 1: Summary of the distribution of chosen KPI's in different ZeEUS demonstrations.

As you can see from the table above all but three of the core demonstrations have selected most of the Key Performance Indicators that were available to them. Therefore, there will be many data sources that can be compared from one demo to another in varying operational conditions.

For each single demonstrator:

- Indicators are to be selected in a way that are usable for comparison in before-after analyses
- They have to allow the measurement for different technological options (electric and ICE-buses)
- The selection has to take into account the current status and prepare also the ways of doing measurements for the current services
- The any single KPI are not mandatory, but each demonstrator can choose the KPIs, depending on the characteristics of their implemented system. In Bonn, for example, the fact that "planet" has 0 indicators selected does not mean that "planet" indicators are less important for the city. On the contrary, the city's strategy in this core demonstration is to validate that new environmentally-friendly solutions such as full electrification of their bus fleet can be implemented at the same costs as today's solutions.

The data will be aggregated and made available for the bus stakeholders to calculate their own Total Cost of Ownership (TCO) analysis. No TCO analysis will be derived with the ZeEUS partners because of the high diversity of operational scenarios, both in terms of necessary range and vehicles availability. The work led in the project aims mostly to identify which are the most relevant KPIs to measure e-buses performance: at this very moment, we can all very well imagine which KPIs shall impact the system's performance but a reality check has

to be led in order to identify these KPIs at the system level, taking into account 3 core elements: vehicle, infrastructure and operation.

This systemic approach adopted in the European Bus System of the Future project (EBSF) built the clear message that a chosen technology can only perform well if it is implemented in its best operational conditions. This means that many ingredients have to be taken into account in order to make a bus system efficient and attractive, even before introducing a new propulsion technology into the fleet:

- Accessible, Comfortable, Cleaner Vehicles
- Improved commercial speed
- Public Transport Dedicated Infrastructure (dedicated bus lanes which are operational and fully enforced)
- Traffic & operations management
- Efficient Combined mobility
- Smart use of energy in vehicles

## 5 Initial results of the ZeEUS core demonstrations

The data collected by the ZeEUS demonstrations are being analysed locally and globally. The local evaluation will allow to assess the bus performance against specific parameters identified as specifically relevant based on local particularities, e. g. topography, climatic conditions. The evaluation of the data collected by the core demonstrations from the beginning of the project until the end of April 2017 is detailed as aggregated data below.

The ZeEUS fleet has driven almost two million km (hybrid buses in both modes and electric buses total km driven) of which 70 % were performed in pure electric mode.

The energy consumption for the period was calculated in terms of electricity and fuel (diesel). The total electricity consumption arising from charging the buses was 1.2 GWh which corresponds to a saving of about 400,000 l of fuel, equivalent to refilling the tank of about 7,000 cars, and contributed to avoid the emission of 657 t $CO_{2e}$ [5,6]

## 6 Summary of core demonstrations' charging infrastructure systems

The Table 2 below summarises the main features of each demonstration:

| | |
|---|---|
| **Barcelona**<br>DC Slow charging overnight at the bus terminal (12m buses).<br>AC fast opportunity charging at end stations (18m buses). | **Bonn**<br>DC Slow charging overnight at the bus terminal |

| | |
|---|---|
| **Cagliari**<br>Overhead contact line recharging (battery trolley bus) and slow DC charging at the depot. | **London**<br>Wireless opportunity charging along the route and at the depot (induction). |
| **Muenster**<br>Fast opportunity charging at end stations and bus depot via bus shelter to roof connection and stationary battery system | **Paris**<br>Slow at depot (overnight) for entire day service (target)<br>some fast recharging systems at terminals could be necessary |
| **Plzen**<br>DC Slow charging overnight at the bus terminal and AC fast charging at end stations. | **Eindhoven**<br>Pantograph for DC slow charging overnight in depot and fast opportunity charging |
| **Stockholm**<br>Fast opportunity charging via pantograph system at the roof of the bus.<br>Additional slow charging at the bus depot | **Warsaw**<br>Slow at the depot (overnight); fast at terminals |

Table 2: Summary of the main features of each demonstration.

The charging infrastructure has a very important impact on both the management of the fleets and on the cost. Moreover, many technical questions are being raised by the "simple technology" of overnight charging of hundreds of buses if the fleets are entirely converted to fully electric from one day to the other. The ZeEUS project is collecting all the challenges, barriers and opportunities faced by the public transport stakeholders in their daily implementation.

# 7 The ZeEUS project as instigator e-bus market development

## 7.1 Beyond the ZeEUS project: an Observatory to share knowledge, best practices, challenges and experiences

On top of the live operational tests conducted in 10 European cities, ZeEUS' partners are also observing, compiling and sharing experiences with other cities which are leading electrification projects.

Project partners are compiling information at the different national levels in order to get a better understanding of the trends and current developments in terms of: e-bus legislation, local urban policies (i.e.: Low Emission Zones), funding and financial initiatives, national standards and energy & climate policies.

In relation with local experiences taking place outside of the scope of the ZeEUS project, UITP has set up the ZeEUS e-Bus Observatory which follows the evolution of the different experiences taking place all over Europe. This Observatory gathers valuable information about each Observed Site and provides bus practitioners and stakeholders with a useful platform for knowledge-sharing and discussion on best practices and key issues. Members of the ZeEUS e-Bus Observatory can also have more in-depth discussions on the progress and deployment strategies of e-buses in the urban context.

Another important networking activity is led at a cross-sectoral level. Exchanges are regularly taking place in Brussels between the three main sectors dealing with transport electrification in cities, namely e-cars, e-freight and e-buses during a public event entitled "European Electromobility Stakeholder Forum", co-

organised by the ZeEUS project under the leadership of the European Commission – DG MOVE. Despite some deep differences across the three sectors, triggering discussions on some common topics can also foster a better integration of the different transport systems at the city level.

### 7.2 Screening and defining the necessary funding tools for cities to make the step towards cleaner and zero emission bus fleets

The funding of electric buses has been identified as a key point to be addressed if we want European cities but also cities beyond Europe to make the step towards cleaner and zero emission bus fleets. This question is actually at the heart of an activity as part of the ZeEUS project. In the frame of this activity, we are currently identifying and defining the needed financial tools which will support the purchase of high capacity e-buses. Discussions are currently being led with different European entities and international organizations, including the European Investment Bank and a global report will be published on this key matter.

Other recommendations focusing on spatial and urban planning as well as operational concepts will also be developed in order to provide the necessary support for introducing of electric buses of high capacity in urban fleets.

### 7.3 Standardisation, tendering and e-SORT cycle

The European Commission has given a mandate to CEN/CENELEC for the elaboration of a standard in the field of e-buses within the ambitious target of 2019. ZeEUS is leading a Standardisation Steering Group which gathers members of UITP Bus and VEI (Vehicle Equipment Industry) Committees as well as representatives from Public Transport National Associations (i.e. VDV for Germany) and other key actors. The main goal of the ZeEUS Standardisation Steering Group is to identify which different elements of the system shall be standardised and to closely link the work of the project to the CEN/CENELEC Working Groups.

UITP, the International Association of Public Transport has developed its own Standard On Road Test (SORT) cycle which allows to test buses on track under controlled conditions in order to compare buses performances. This work is the result of cooperation between VDV, public transport operators and the leading European manufacturers of vehicles and transmissions. Its main aim is to design reproducible test cycles for on-road tests of buses in order to measure their fuel consumption. The document provides definitions under accurate and explicit measuring conditions to compare fuel consumption at the tender stage. Such document is currently available and used by public transport operators and authorities in the elaboration of their tenders' documents. Currently available for diesel, gas and hybrid buses, the ZeEUS project will contribute to update the SORT cycle document, as well as the tender structure to adapt both procedures to high capacity electric buses.

### 7.4 Know, Plan, Procure and Operate e-buses

The ZeEUS project is developing a wide number of tools mapped on the main functions shared between public transport operators and organising authorities. Four key steps have been identified to manage the introduction of e-buses in the most efficient way.

#### 7.4.1 Know

Knowing the environment, regulatory framework and operational conditions/network is the first important step in the deployment process. As part of this work, the ZeEUS project is working on the development of different tools. The ZeEUS e-bus Vision is a Strategy Document enabling to:

- Identify the strategic, technical, operational and policy aspects to be developed in order to efficiently introduce e-buses in urban fleets
- Share key messages that the ZeEUS partners and the EC share on the future of e-buses
- Be used as an advocacy tool by the ambassadors of ZeEUS in key events and meetings

The eBuses Roadmap for research and deployment will propose an analysis of the vehicles' demand and offer evolution, while setting out the priorities for further research with their relative timeline. The Electric Bus Systems definition document will adapt the main requirements and functions identified as part of the European Bus System of the Future project to the specificities of the electric buses. A collection of e-buses study cases from the core demos as well as from the observed cities will enable to provide recommendations to the cities willing to introduce e-buses in their fleet. Lastly, the urban electric bus systems Charging Use Cases for standardization are preparing the ground for the standardization work led by ZeEUS in close cooperation with CEN/CENELEC [7]

#### 7.4.2 Plan

Once the implementation context has been duly analysed, the stakeholders are able to deliver a strategy towards a clean bus fleet and to make a choice among the numerous alternative-fuels solutions available. Should the e-buses be the chosen one, the operators and authorities need to start planning together the introduction of e-buses in their city. In order to provide the best tools in line with the stakeholders' needs, the ZeEUS project plans to deliver a simulator for assessing technical solutions in own scenario and a handbook for common simulation rules. These tools will support the stakeholders in the performance analysis they need to conduct, in accordance to the requirements of their own bus network. Moreover, test procedures for electric charging system interoperability and recommendations for urban and spatial planning regulations and guideline principles will complete the set of tools under development.

### 7.4.3 Procure

The procurement phase is a big milestone of the implementation phase, and it is important to clarify what exactly needs to be procured at this stage and how to shape the tender document to achieve the main objectives

ZeEUS is developing another set of tools for this particular phase:

- The core KPI for eBus Procurement will be available as a list
- A methodology for procurement-oriented evaluation is being developed
- The most suitable regulatory and funding frame are under identification
- The tender structure (and process) procurement and related services will be enriched with the inclusion of the e-buses specificities [8]
- The SORT-E Cycle is being developed and will be validated [9]
- Business cases for electric bus charging operation at depot will be made available

### 7.4.4 Operate

Operating electric buses implies many changes with regards to the operation of conventional diesel buses. Therefore, it is key to develop the necessary tools for supporting operators and authorities to:

- Train their staff: guidelines for optimal operations are under development
- Optimise the effects of electric buses on the Bus Network operations
- Optimize the charging at the bus depot
- Optimise the charging by opportunity

## 8 Conclusions

As stated, the key objectives of the ZeEUS project is to provide decision makers with guidelines and tools to determine 'if', 'how' and 'when' to introduce electric bus systems in the core urban network. The ZeEUS project is not going to perform a benchmark between the different solutions tested due to two main reasons:

Firstly, direct experiences and analysis done in past project like the European Bus System of the Future (EBSF), shows that one single technology solution for urban electric bus systems suitable for every operational and environmental condition does not exist, due to the large difference in terms of geographical, climatic, environmental and operational conditions. EBSF showed that every technical solution has its optimal place for operation.

Secondly, the public transport authorities of each city will take the decision about the electric bus solution to be implemented based on the Total Costs of Ownership (TCO). Today a single accepted model of TCO adopted by each city does not exist. Similarly for cost-benefit analysis, each city has developed its "trusted" model. For this reason, the aim of ZeEUS is to provide a set of data-set (aggregated measures statistically meaningful, for example) that could be used by the different cities to validate their model.

ZeEUS is the very first project of its kind to test and validate a wide range of electric bus technologies with different fast and slow charging strategies and energy supply modes. Not only will the buses are running in full operational conditions, but they are running in varying geographical climatic and operational conditions across the different demonstration sites that will bring invaluable results and experiences. We are looking to find technically, economical and operationally suitable solutions for public transport stakeholders. Such information will support ZeEUS' mission as the flagship electric bus project in Europe to bring electrification to the heart of the urban bus network. Finally, we are developing the relevant tools necessary for the public transport stakeholders to know, plan, procure and operate electric buses in the most efficient and coherent manner, as part of their fleets. This way ZeEUS encourages the deployment of these electric vehicles on the market, as supported by the European Commission legislation [10].

## References


[1] Decarbonisation: the public transport contribution, UITP Paper, http://www.uitp.org/sites/default/files/Decarbonisation%20-%20the%20public%20transport%20contribution.pdf

[2] 3iBS Priority actions for the fast development of innovative Bus Systems in European cities, http://www.3ibs.eu/uploads/fichiers/publications/priority-actions-for-the-fast-development-of-innovative-bus-systems-in-european-cities.pdf

[3] Spreckley, F. *Social Audit - A Management Tool for Co-operative Working*, Beechwood College, UK, pp.47, 1981.

[4] Elkington, J., *Cannibals with Forks: the Triple Bottom Line of 21st Century Business*, Capstone Publishing, Oxford, UK, pp.424, 1st edition 1997, 2nd edition 1999.

[5] ISO 16258 factor for Diesel and GaBi factor for EU electricity grid mix were used in emission calculation.

[6] Diesel spared is calculated as a theoretical baseline with a diesel consumption of 38 L per 100 km for a new Euro VI bus with reference to VDV Germany.

[7] See paragraph 7.3 above

[8] Tender Structure for the tendering of buses and related services, document available for UITP Members Only. Contact: info@uitp.org

[9] See paragraph 7.3 above

[10] Clean Power for Transport Package, http://ec.europa.eu/transport/themes/urban/cpt/index_en.htm