International and European Legislation and Standards for Battery Electric Buses

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***Abstract*—The European Union is pushing forward its European Green Deal where sustainable mobility is one of the main areas of interest, especially after the COVID-19 crisis. The role of battery electric buses (BEBs) in public transit is key to achieve sustainable mobility and to reduce city pollution and greenhouse gas emissions and, therefore, global warming. Standardization plays a key role to ensure the deployment of a safe, cost effective, energy efficient, sustainable BEBs fleet. Standardization of components, interoperability, generalized recharge possibility, and even the possibility of using the BEBs as controllable loads, with energy storage that can be returned to the grid, must be done. This paper presents the most relevant legislation at European level, the International and European standardization outline in the field of BEBs, and the most important standardization activities going on. It gives references to deal with the very high number of standards relevant for the BEBs and the related activities that are in constant update, from different standardization entities.**

Keywords—Battery Electric Buses (BEBs), Standards, Charging infrastructure, Grid integration, European Green Deal

I. Introduction

Scientists around the world are claiming for urgent actions to mitigate the climate emergency that planet Earth is facing [1]. Transport has been identified as one key aspect to be addressed and decision-makers are passing legislation related to limit the emission of toxic gases generated in the transport sector. Electric mobility, especially when used in public urban transport, is key to decrease congestion levels and GHG and noise emissions.

Pollution is directly responsible for over seven million premature deaths every year [2]. More than 80% of people living in urban areas are exposed to air quality levels that exceed World Health Organization's (WHO) guideline limits. In addition to that, recent studies [3] identified a correlation between air pollution and COVID-19 mortality. As a response to the COVID-19 pandemic, the European Commission is putting forward a proposal for a recovery plan [4] where sustainable transport will be key. The Commission is proposing to support the transition towards climate neutrality via funds from Next Generation EU and funding the Just Transition Fund to up to €40 billion.

As a result of the coronavirus crisis and the historic global shutdown of economic activity, there has been a historic fall in air pollution. The strict confinement measures, in a bid to curb the coronavirus outbreak, had pollution levels plummeted. For instance, smog [5] has decreased in many urban areas in China [6]; as an example, in Wuhan, NO_2 concentrations fell by as much as 24 ug/m^3 during the lockdown (a reduction of 63% from the pre-lockdown level) [7]. Comparably, confinement brought NO_2 levels down by 33% in Los Angeles and even 70% in Delhi. In Europe, Paris saw a 60% drop in NO_2 emissions and a 20-30% improvement in air quality to reach a level never seen in the past 40 years [8].

Cities around the world temporarily reallocated road space from cars to people on foot and on cycles, in order to keep key workers moving while socially distancing. This has prompted many cities to consider further restricting private vehicle access to city centers and to encourage public transport with the return to normality [9]. The mass introduction of battery electric buses (BEBs) requires rigorous planning [10] as it can lead to serious disruptions in the electricity grid. Therefore, standards need to be defined at a European and global level to ensure the safe and efficient implementation of both bus lines and their recharging points.

The standardization framework for electric vehicles has been previously presented, namely in [11]. However, there is a lack of a similar work for electric buses. This paper summarizes the most relevant legislation and standards for sustainable buses in usage and development in Europe.

II. Legislation

The European public transport community was already preparing for electric buses before the COVID crisis and legislation was already in place. The pandemic has been an extra motivation for the European Union to further encourage the implementation of sustainable mobility. This is not only a political commitment but also has strong citizen support. European cities such as Bonn, Brussels, Dublin or Milan are requesting the EU to boost public transport during the post-virus rally, suggesting a zero-emissions bus fund worth €3.5 billion [12].

The key legislation regulating electric mobility at European level is the following:

- EU Directive for deployment of alternative fuels infrastructure (AFI - Directive 2014/94/EU). This directive requires member states to develop national policy frameworks for the market development of alternative fuels and their infrastructure. It also sets technical specifications.
- Clean Vehicles Directive (2009/33) which requires public procurers to take into account energy consumption, CO_2 and pollutant emissions from vehicles.
- Renewable Energy Directive (2009/28) that requires a share of 10% of Renewable Energy Sources in motor fuels by 2020.
- EU Clean Air Policy Package of 2013, that regulates a reduction of air pollutants by 2030.
- The Paris Agreement (2015) and the Katowice [13] climate package (2018) that oblige transport sectors to reduce carbon dioxide [14][15]. Moreover, Madrid COP25 (2019) indicates that renewable energies must account for more than 10% of energy in transport by 2020. This last resolution is in line with the Renewable Energy Directive (2009/28).
- The 2013 Urban Mobility Package [16] describes the rollout of Sustainable Urban Mobility Plans. It also offers a range of guidelines on clean city logistics, access regulations, urban safety and sustainable mobility development [17].
- Moreover, EU 2014/94/EU directive coordinates the implementation of electric mobility and ensures safety, interoperability between operators and service providers, generalized recharge possibility and even the use of electric buses as controllable loads with energy storage that can be returned to the grid (V2G).

As it can be seen, European regulations are extensive and constantly evolving in search of increasingly sustainable public transport. Moreover, European strategy for Sustainable and Smart Mobility was delayed because of the COVID-19 pandemic. Europe's Recovery Plan outlines the Commission Work Programme for 2021 and focus on building a more resilient, sustainable and fair Europe. Sustainable mobility is key and legislation will continue to be enforced as described on Table I.

III. STANDARDIZATION

Even though standards are not legally binding unless they are transposed to regulations, standardization will be decisive for a massive deployment of electric buses. The competence for standardization at global level lays in the "International Electrotechnical Commission" (IEC) and in the "International Organization for Standardization" (ISO), in particular in the "IEC/TC 69 - Electric road vehicles and electric industrial trucks" and "ISO/TC 22/SC 37 - Electrically propelled vehicles", for electric vehicles. The European bodies are the "European Committee for Electrotechnical Standardization" (CENELEC) and the "European Commission for Standardization" (CEN), of which "CENELEC 69X – Electrical systems for electric road vehicles" follows the activities of IEC/TC 69 and "CEN TC 301 – Road Vehicles" follows ISO/TC 22/SC 37. The reference institution in the U.S.A. for standardization is the "Society of Automotive Engineers" (SAE), while in Japan is the "Japanese Electric Vehicle Association" (JEVA). Of high importance for electric mobility are also the China national standards, also called as "Guobiao Standards" (GB).

TABLE I. EUROPEAN COMISSION FUTURE LEGISLATION

Policy Objective	Initiatives	Status
The European Green Deal	Communication on the European Green Deal (non-legislative, Q4 2019); European Climate Law enshrining the 2050 climate neutrality objective (legislative, Article 192(1) TFEU, Q1 2020); The European Climate Pact (non-legislative, Q3 2020)	adopted Q4 2020
Financing the sustainable transition	European Green Deal Investment Plan (non-legislative, Q1 2020); Just Transition Fund (legislative, Article 175 TFEU, Q1 2020); Renewed Sustainable Finance Strategy (non-legislative, Q3 2020); Review of the Non-Financial Reporting Directive (legislative, incl. impact assessment, Article 114 TFEU, Q4 2020)	adopted adopted Q4 2020 Q1 2021
Commission contribution to COP26 in Glasgow	2030 Climate Target Plan (non-legislative, incl. impact assessment, Q3 2020); New EU Strategy on Adaptation to Climate Change (non-legislative, Q4 2020); New EU Forest Strategy (non-legislative, Q4 2020)	Q3 2020 Q1 2021 Q1 2021
Decarbonising energy	Strategy for smart sector integration (non-legislative, Q2 2020); Renovation wave (non-legislative, Q3 2020); Offshore renewable energy (non-legislative, Q4 2020)	Q2 2020 Q3 2020 Q4 2020
Sustainable production and consumption	New Circular Economy Action Plan (non-legislative, Q1 2020); Empowering the consumer for the green transition (legislative, incl. impact assessment, Article 114 TFEU, Q4 2020)	adopted Q2 2021
Protecting our environment	EU Biodiversity Strategy for 2030 (non-legislative, Q1 2020); 8th Environmental Action Programme (legislative, Article 192(3) TFEU, Q2 2020); Chemicals strategy for sustainability (non-legislative, Q3 2020)	adopted Q4 2020 Q3 2020
Sustainable and smart mobility	Strategy for sustainable and smart mobility (non-legislative, Q4 2020); ReFuelEU Aviation - Sustainable Aviation Fuels (legislative, incl. impact assessment, Article 100(2) TFEU and/or Article 192(1) TFEU, Q4 2020); FuelEU Maritime - Green European Maritime Space (legislative, incl. impact assessment, Article 100(2) TFEU and/or Article 192(1) TFEU, Q4 2020)	Q4 2020 Q4 2020 Q4 2020

Two key standards are: ISO 6469-3 that defines the safety specifications for EVs in order to ensure protection of persons inside and outside the vehicle against electric shocks, and the ISO 15118 series. The last update of ISO 15118 is from 2019, "Road vehicles, Vehicle to grid communication interface, Part 1: General information and use-case definition" [18]. This regulation aims to improve communications between recharging points, electric vehicles and the electricity grid.

Electric buses (EBs) require high power installations, in some cases placed in public areas, and appropriate safety and security measures and standards are needed to avoid incidents regarding: normal operation, accidental contact or arc, physical security, vandalism, and cyber security. Appropriate means must be established in the EBs and in and around the charging point design to avoid incidences during operation, charging and even parking time.

The standardization framework in the field of EBs should address: Depot, opportunity and on-route charging standards, and the possibility to have the same opportunity solution (pantographs) across Europe. [19] [20]

Currently, to ensure interoperability, charging solutions are usually built in accordance with ISO 15118, DIN70121, OCPP 1.6 CE mark, EMC 61000-6-2, 61000-6-4, IEC 61851, and IEC 61000. These standards are evolving and European bus manufacturers (Irizar, Solaris, VDL and Volvo) along with charging system suppliers (ABB, Heliox and Siemens) agreed to define common, preferred interfaces. These interfaces are opened-up for all market participants that use buses with opportunity charging (fast charging at selected stops) and for overnight charged EBs. The objective is to facilitate the transfer to EBs systems in cities, in order to ensure reliability and compatibility across bus brands and charging systems.

The group contributes to European standardization activities and shares experiences with CEN/CENELEC and ISO/IEC to establish a common European standard for EBs systems. However, though the group is representative of strong European electric bus stakeholders, the biggest market player (BYD) does not participate limiting, therefore, its application.

The group has defined that for opportunity charging, the system includes automatic contacting by a pantograph, wireless communication, contacting plates and infrastructure equipment that automatically contact vehicles with a pantograph.

For overnight charged EBs, the fast charging standard for cars, "Combined Charging System" (CCS) will be used (however, BYD usually uses their own chargers with Type 2 plugs, "Mennekes", like in Coimbra Municipality). At depot charging, usually manual connector is preferred in BEB. The charging process itself is regulated by standards IEC 61851-23, IEC 61851-24 and IEC 61851-1. The high-level communication utilizes PLC (Power Line Communication) according to EN ISO 15118-3. The contact pin follows standards IEC 61851-23 (vehicle) and IEC 61851-24 (charger). The standard evolves as higher DC charging capacities are achieved [21].

The ZeEUS project [22], jointly with "Association of German Transport Companies (VDV)" and "International Association of Public Transport (UITP)", prepared 2 documents:

- Use cases and requirements concerning the opportunity charging.
- Use cases and requirements concerning the charging of buses in depots.

These guidelines aim to describe the processes and needs of operators and were created to be used as the basic documents for the European standardization activities.

The use cases are being currently analyzed by the CEN-CENELEC eMobility Steering Group.

ASSURED [23] is a project co-funded by the European Commission to promote the electrification of urban transport vehicles. It studies e-bus interoperability and conformance testing. It has analyzed the most common automated fast charging solutions in the market, and aims to fill the gaps between already available draft standards.

The ASSURED 1.0 Interoperability Reference is a bridging document that can be utilized in implementations by municipalities, public transport authorities, original equipment manufacturers or public transport operators alike. The objective is to ensure that interoperability can be tested until standardization defined by the European Commission is officially published.

The final standard adopted by the Commission should define at least:

- The position of the charging system on the vehicle.
- The maximum space available on the vehicle for electrical components.
- The position of the electric outlet on the vehicle and infrastructure.
- The positions of the mechanical fastening points on the vehicle.
- The area intended for contacting.
- The sequence of connecting, charging (CCS), disconnecting, and emergency conditions.
- The maximum noise generation at contacting and during charging (transient and continuous)
- The minimum and maximum voltages that a bus may request from a charging station.
- The minimum height above the road surface for any mechanical part of the charging station when not charging.
- The minimum and maximum height and width of vehicle that can be charged.
- The minimum distance between bottom edge of charging infrastructure and upper edge of road
- The safety protocols (power failure, fire…)
- The basic security requirements for wireless communication.
- The communication interface.
- The systems that can be used to ensure positioning tolerances.

Finally, all charging standards should assure energy and power quality respecting the European Standard EN 50160.

IV. Driving Test Cycles

To test vehicles, namely regarding fuel consumption and tail pipe emissions, standard driving cycles are also need. Evaluation of electric vehicles (EVs) is carried out at the test bench for type approval. Tests should reflect as realistically as possible the operation conditions of the vehicle. Standard constant power/speed tests are not sufficient as they are not representative of actual vehicle battery use; so, driving cycles are favored. Driving cycles are speed profiles representing the typical use of the vehicle, and the power demanded from the storage system in relation with the vehicle speed is calculated using mathematical models.

Several organizations have developed different test protocols with the aim to standardize storage systems testing in electric vehicles. Historically, the most widely used has been the DST (Dynamic Stress Test), developed by the USABC (United States Advanced Battery Consortium) [24], which consists of a power profile obtained based on the FUDS (Federal Urban Driving Schedule) cycle, a standard driving cycle used in the United States. This test is part of the requirements for the evaluation of electric vehicle batteries in the European Union. Figure 1 shows the power profile of the DST cycle.

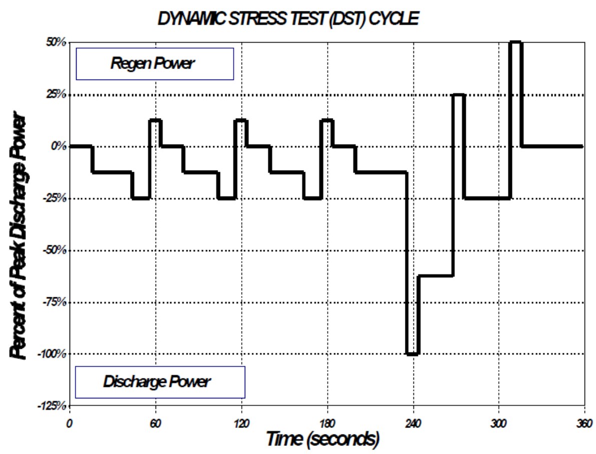

Figure 1: DST cycle power profile [24].

In September 2019, a new standard was required , based on the WLTP (Worldwide Harmonized Light Electric Vehicle Test Protocol) procedure [25]. This test is based on real driving cycles data in Europe. Unlike the DST, the cycles of the WLTP protocol are not simplified, allowing for battery evaluation with profiles closer to reality. There are several versions of the WLTP cycle classified to consider different orographies. The standard is divided into four categories and the weight-power ratio of the vehicle determines the applicable version. Figure 2 shows the WLTP cycle in its most demanding version.

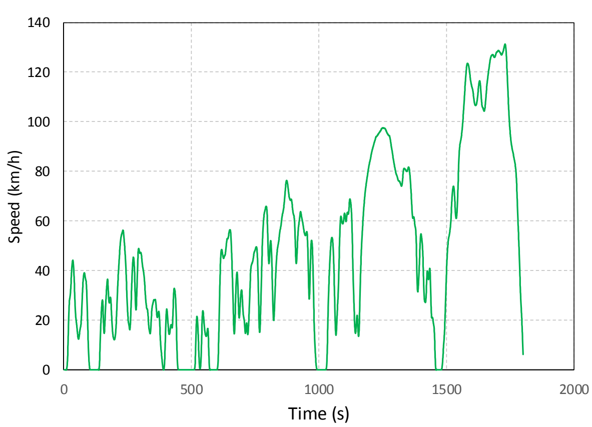

Figure 2: WLTP cycle category 3, composed of the four standards defined by the regulation [25].

However, these test cycles do not adequately reflect the driving regime (stop-and-go operation) of a scheduled service bus nor their greater weight in comparison with utility buses. It is therefore necessary to develop specific tests for electric bus batteries to account for their specific demand on the energy storage system [26]. One of the most common tests are the SORT cycles (Standardised On-Road Test Cycles) developed by the International Union of Public Transport (UITP); they are based on statistically generated data from several European transport companies. SORT cycles consider: commercial speed, average time spent at stops, average distance between them, the load, etc.

SORT cycles are not constructed from real profiles, but they consist of a series of trapezoids (acceleration, constant speed, stop) at different speeds. There are three levels (SORT-1, SORT-2 and SORT-3) with different levels of speed, so that different types of route (namely urban, mixed and suburban) are reflected [27]. SORT cycles are only defined in speed so conversion to power profiles is still necessary. For this purpose, mathematical models of the powertrain of real buses have been used.

The USA EPA (Environmental Protection Agency) has proposed several driving cycles, including the FUDS. This cycle is only representative of driving a conventional vehicle in an urban environment. For heavy vehicles, such as buses, they propose using the UDDS (Urban Dynamometer Driving Schedule) standard. It is based on driving in an urban environment with high speed zones. Figure 3 shows the speed profile of the UDDS cycle.

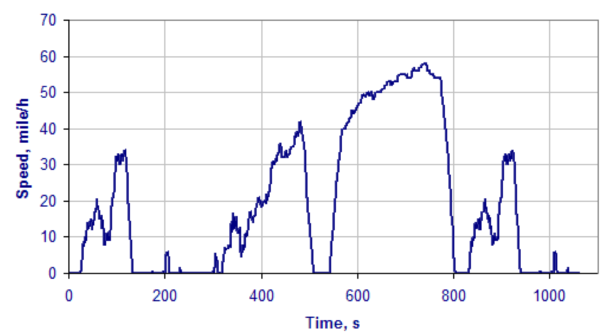

Figure 3: UDDS cycle for heavy vehicle assessment [28].

Another specific standard for heavy vehicles is the OCBC (Orange County Bus Cycle), developed by West Virginia University, which is representative of city bus driving in the city of Los Angeles [28]. Figure 4 shows the OCBC cycle.

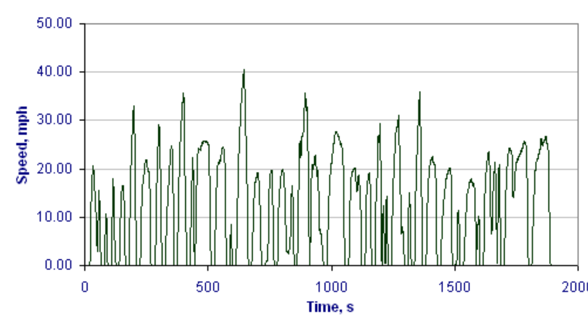

Figure 4: OCBC cycle speed profile [28].

Another similar cycle is the Manhattan Bus Cycle (MBC), obtained under similar conditions to the OCBC, in this case in the Manhattan district of New York. Like the previous cycles used to simulate public transport, it has a notable number of stops and low average speed. Figure 5 shows the speed profile of the BCM cycle.

The OCBC and MBC cycles are representative of USA cities. In the case of Europe, there is a cycle with similar characteristics, the BCDC (Braunschweig City Driving Cycle), developed at the University of Braunschweig. Figure 6 shows the BCDC cycle. [28]

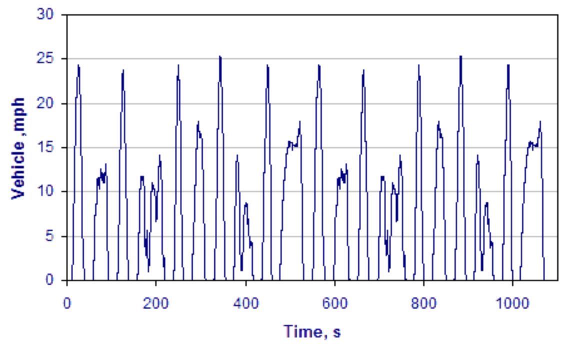

Figure 5: BCM cycle speed profile [28].

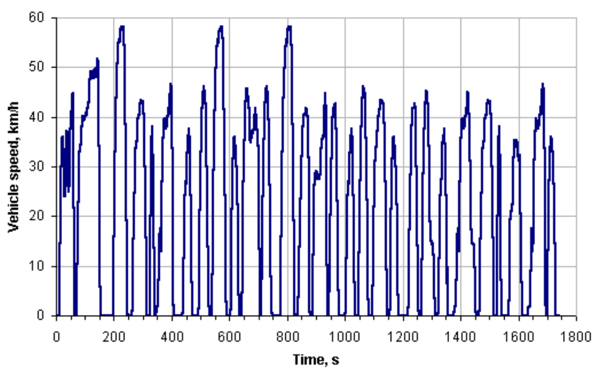

Figure 6: BCDC cycle speed profile [28].

V. Infrastructure for BEB Charging

Electric Buses can be divided into two main categories: hybrid electric buses (HEBs) and all-electric battery buses (AEVs). AEVs are equipped with only electric motors powered by electrical sources. AEVs can be further classified into Battery Electric Buses (BEBs) and Fuel Cell Electric Buses (FCEBs). A FCEB uses a hydrogen tank to supply a fuel cell that converts the hydrogen into electricity. A BEB uses external power from the grid to charge the batteries. If the electricity to charge the batteries or to produce the hydrogen is of renewable origin, these kind of mobility is the most sustainable and energy efficient.

As shown in Figure 7, there are multiple charging solutions for BEBs because they have different energy requirements depending on use (urban, suburban,...), number and length of the bus stops, orography driven, climate and so on. Different factors will define the final selection of charging strategy [19], such as:

- the available time per stop on route and the recovery time at end-line stops.
- the infrastructure of the power grid.
- the electric tariffs.
- the ability of the BEB battery to accept fast-charging.

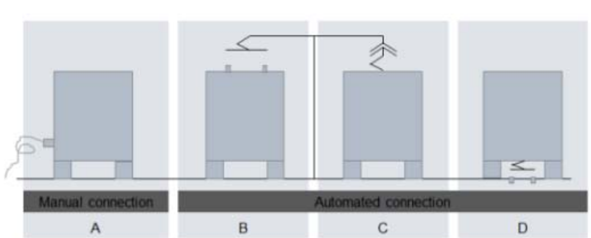

Figure 7: Different BEBs charging solutions [21].

Depot charging

Electric energy supply to the batteries generally takes place during the night, if low value currents are used and a long-term charging is needed (4–6 hours). In this case, it is usual the direct coupling to the public tri-phase network 400 V. As this generally happens during the night, when the buses are parked at the ends of the lines/in the garage, the impact in the electricity grid is minimized compared with fast charging. Therefore, the main problem is only represented by the available electric power.

Opportunity charging

Energy density in batteries is low compared to diesel. Therefore, when passenger capacity is favored over operating range, buses use low-capacity batteries (lighter) that must be recharged along their route (opportunity charging). Directive EU 2014/94/EU obliges member states to expand the network of charging points and create charging infrastructure.

In this type of charging infrastructures, an automatic high-power connection is used. The issue could be a capacity and power quality challenge, especially with electric heavy duty vehicles (HDVs) in urban areas. The measurements at the charging point should be able to provide the following information:

- the energy (kWh).
- the AC currents (A) of the secondary of the transformer.
- the AC voltages (V) of the secondary of the transformer.
- the total harmonic distortion (THD) (%) of the 3-phase currents and voltages systems.
- the active power (kW), reactive power (kVAR), and power factor.

and it should be compared to IEC 6100 standard. In addition to that, power quality should also be assured, respecting the European Standard EN 50160.

Buses

In order to define transport systems able to interoperate different kinds of buses, it would be key that the standard will ensure that the vehicles provide to the infrastructure this minimum information:

- Mileage.
- Time of departure.
- Next customer service.
- Indoor temperature of bus.
- Power consumed by heating or air conditioning.
- HV system fault.
- Charging 24V and HV battery.
- Supply of auxiliaries.

VI. Conclusions

Following the COVID-19 pandemic, the European Union is more committed than ever to a Green Recovery through the European Green Dean and to promote sustainable public transport. The EB market is flourishing and the shift from demonstrations and pilots to real large-scale fleet deployment has started.

EBs are constantly evolving and introducing new technologies; so, proper legislation and standards should frame this important asset for sustainable mobility. In particular, driving test cycles must also evolve to reflect the changing demand on the energy storage systems and the specific characteristics of weight, use, etc., of electric buses. SORT tests and other driving test cycles like BCDC cycle speed profiles are already used in Europe but they need to progress to include also power profiles and the specific characteristics of European cities. Additional characteristics such as the impact of fast charging and regenerative braking should also be considered as its impact on batteries life is well known.

Moreover, an appropriate fleet deployment implies to ensure interoperability of the vehicle and the charging unit, as this will simplify the tendering and implementation of the charging infrastructure. To achieve effective interoperability, standardization of the safety measurements, charging infrastructure and high-quality conformance testing are essential.

Finally, a key point that needs to be standardized and legislated is the impact of the massive recharging of EB fleets on the electricity grid. Vehicle-to-grid concepts, where EBs are considered as dispatchable loads and power plants used to flatten the power demand curve, should also be considered.

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