Main Trends and Challenges in Road Transportation Electrification

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ABSTRACT

Climate changes and pollution are putting high pressure on finding more sustainable and effective transportation means. After Kyoto Protocol in 1997, Paris Agreement at COP 21 in 2015 and posterior announcements of limitations to internal combustion engine vehicles' (ICEV) sell and circulation by several key countries and cities are clear demonstrations of this increasing will. It is quite likely that a pure ICEV produced today will not be allowed to freely circulate everywhere during all the extension of its lifetime, especially if it is a diesel car. Therefore, every major car manufacturer is announcing new electrified models for the next years and some of them are stating that all their models will be electrified in less than 5 years. As a consequence of the impressive price decrease and performance improvement of the batteries used in electric vehicles, the typical battery capacity of a regular passenger car rose from 20-24 kWh to 30-40 kWh in just 3 years without significant car price increase. The total cost of ownership (TCO) of the electric vehicles is approaching and will be lower than that of ICEV in less than 5 years. In some cases, the TCO is already lower than that of ICEV. Autonomous cars and the shift from individual car ownership to transportation sharing poses additional challenges.
In this paper, the main trends and technical challenges related to the electrification of the road transportation are presented, as well as some defies for the transportation sector.

1. INTRODUCTION

Mobility is a key aspect of our modern societies. It can be said that our well-being and economic development is quite connected to it. Indeed, there is a strong correlation between mobility, of both people and goods, and the Gross Domestic Product of a country or region, as can be seen in Figure 1. At European Union level, considering its 28 member countries, EU-28, the Transport Sector in 2015 accounted for nearly € 561 billion in Gross Value Added, GVA (around 5.0 % of the total. It was 4.2% in 2006), and employed around 11.2 million persons (circa 5.2% of the total workforce). The families spent 1044 billion euros on transport, which is 13% of their total consumption. Of these, 78 % were spent in personal transport equipment, split into 28 % on vehicles purchase and 50 % on vehicles' operation (European Commission, 2017).

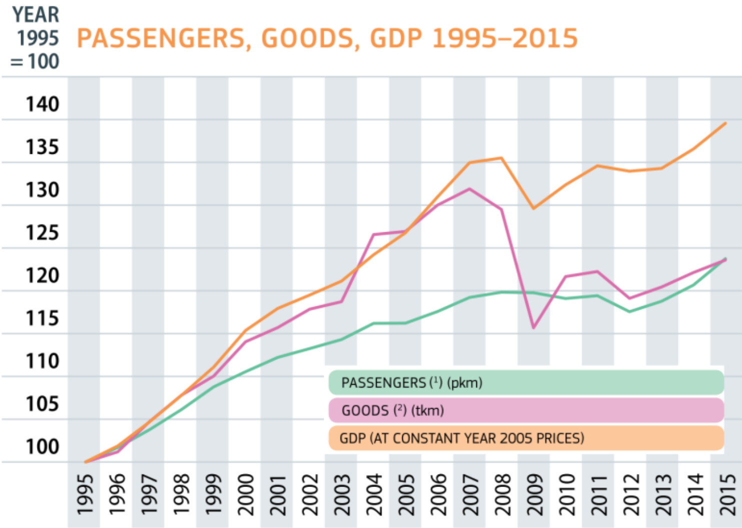

Fig. 1 – Relationship between people and goods mobility in EU-28 from 1995 to 2015 (adapted from European Commission (2017))

Nevertheless, this trend of increasing mobility has some important negative consequences, like oil cost's impact on the economy, concerns about energy availability and energy dependence, problems of urban mobility, accidents and the corresponding material and human consequences, traffic noise, congestion of roads, with local and global environmental issues, as introduced for example by Pereirinha and Trovão (2012). As shown by European Commission (2017), in the EU-28, in 2015, the Transport Sector was responsible for 33.1 % of the Final Energy Consumption, for 23.5 % of the Green House Gases' (GHG) CO_2 equivalent emissions, and was the only sector whose emissions have risen (by 20.9 % in 2014 and 23.1 % in 2015) above 1990 levels as can be seen on Figure 2. Furthermore, road transportation accounted for 72.9 % of all GHG emissions from transport in EU-28 in 2015 sector (European Commission, 2017).

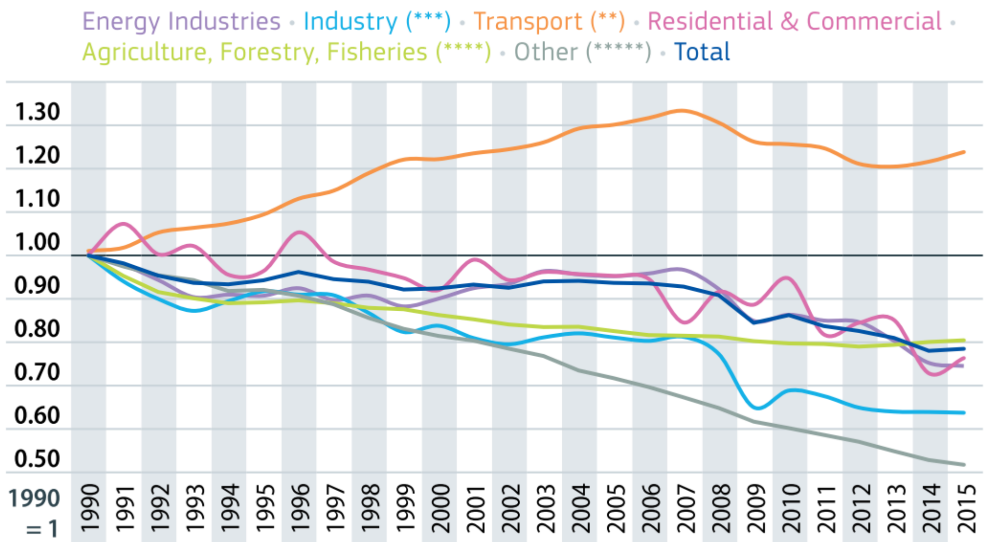

Fig. 2 – GHG Emissions in EU-28, by sector (European Commission, 2017)

In spite of some discussion, it is clear that from a life cycle analysis point of view, battery electric vehicles have much less overall impacts over the vehicles lifetime, particularly if the electricity is produced by renewable energy sources (Messagie, 2014; Van Mierlo, 2015). There is an increasing civil society awareness of these problems, in particular related to climate changes and health issues. In OECD (2015), the Organization for Economic Cooperation and Development, addressed the economic impact of Climate Change and on another report, OECD (2016), stated that outdoor air pollution was the cause of more than 3 million premature deaths in 2010 but that this number could rise up to 6 to 9 million/year by 2060, with a cost of around USD 2.6 trillion per year.
Severe pollution problems, like the ones in London, Paris (Science X, 2017) and Oviedo (Perez, 2015) or the permanent in Beijing and in the most polluted city in the World, Delhi, are increasing the pressure over politics and decision makers to address these problems, as expressed in Iyengar (2014), Kumar *et al* (2015), Associated Press (2017) or Phillips (2017). All this needs new solutions, leading to a general trend to road transportation electrification but that poses also many challenges and opportunities. The most important of these will be addressed in the next sections.

2. MAIN TRENDS IN ROAD TRANSPORTATION ELECTRIFICATION

The main trends presented in this section will be grouped in three points: first, the pressure posed by cities and towns for a more electric mobility. Second, the importance of electric buses, taxis and delivery trucks for public transportation and for goods displacement. And third, the market trends and how the car manufacturers are dealing with it.

2.1 States and Cities’ and policies pushing electrification

After Kyoto Protocol in 1997, the Paris Agreement at COP 21 in 2015 led to a higher level of commitment from most of the 197 Parties 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”. By March 2018, 175 Parties have ratified it (Paris Agreement, 2015). The individual measures will depend on each country or Party, but some bold announcements were already made regarding electrification of mobility. For example, Netherlands and Norway announced they wanted to stop selling petrol and diesel vehicles by 2025, India and Germany announced the end of sell of petrol and diesel vehicles by 2030 (Ghoshal, 2017) and France by 2040 (Farand, 2017). China has not yet defined a date for a similar ban, but has announced already that at least 20 % of the new vehicles’ sales must be electric battery or plug-in hybrid cars by 2025, requiring that 8 % in 2018 and 12% in 2020 be already of these types (BBC, 2017). Being the biggest world market with more than 30 million cars and trucks a year, this marks a strong path into road transportation electrification. A side effect seems to be the announcement that all new car models of Volvo, owned by the Chinese Geely company, would have an electric motor from 2019 (Ibison, 2017). Scotland is pointing to 2032 and the rest of the United Kingdom to 2040 to stop selling new petrol and diesel cars (Muoio, 2017b).

Besides countries, some important cities have also announced future restrictions to the circulation of the most polluting cars, with special focus on diesel vehicles. The Mayors of Madrid, Paris, Mexico and Athens, at the C40 conference of mayors (which groups more than 90 megacities, with circa 10 % of the world population and one quarter of the global economy (C40 Cities, 2018)), announced that their goal is to ban diesel vehicles from their cities' center by 2025 (McGrath, 2016, and Harvey, 2016). This example will very likely be followed by other big cities, with Los Angeles, Seattle, Barcelona, Vancouver, Milan, Quito, Cape Town, and Auckland having already expressed the intention to ban gas- and diesel-powered cars from large parts of the cities by 2030. But Copenhagen will start much soon, in 2019 (Muoio, 2017). There is also a tendency to extend this ban to all cars at least in some cities' center (Garfield, 2018).

2.2 Public and goods transportation

One very important contributor to city pollution is public transportation, particularly old diesel buses (Rodrigue, 2017). There is an increasing number of studies like the ones mentioned in Lotrakul *et al* (2017) and Carrilero *et al* (2017) showing the effectiveness of the full electric buses (and also hybrid electric buses) in decreasing the gases emissions in cities. For example, a 2016 report states that if the entire 5700 New York buses' fleet would be substituted by electric buses it would result in a decrease of nearly 575000 metric tons of CO_{2eq} emissions within the city per year. Consequently, one major trend in public transportation is to promote the adoption of cleaner buses, in particular battery electric buses. The important ZeEUS eBus (2016) report presents the state of the art of electric buses (including Plug-in Hybrid Buses and battery trolleybuses) by the end of December 2016. It gives some of the main global figures, has a second part with a technical description of the experiences done in 71 cities over Europe (one page per city), and a third part with one or two page's technical description of 26 electric bus manufacturers acting in Europe and their commercial products. As shown in this report, China is absolutely leading the way in electric buses. In 2015, of the nearly 173 000 electric buses worldwide, more than 170 000 were in China. According to Harrop (2017), 115 700 fully electric buses were sold in China in 2016 and the 12 million people city of Shenzhen has completely electrified all its more than 16 thousand buses by the end of 2017, anticipating the initial goal of doing it in 2018 (Lambert, 2017d). At worldwide level, the electric buses' numbers and market share is much smaller than in Chine but this will be forced to change. For example, the mayors of 12 major world cities, including London, Paris and Los Angeles, have pledged to only buy all-electric buses from 2025 (Lambert, 2017c).

Regarding public transportation, taxis will also undergo a similar trend. In Shenzhen, nearly 63 % of over 12 500 taxis run on electricity, and this will soon pushed be to 100 % (Lambert, 2017d). Beijing also announced in February 2017 that it wants to convert all its 70000 taxis fleet into electric vehicles (Lambert, 2017a). This transition also started in other cities, with Nissan saying that its electric vehicle Leaf was being used in taxi fleets in 26 countries and 113 cities around the world by May 2017 (Lambert, 2017b).

Other particular but important market, is the one of school buses, particularly in the USA, where they carry "more than twice the number of passengers as the entire U.S. transit and rail sectors" (Wagman, 2018).

Goods transportation will also undergo a shift to electric propulsion. After announcements in August 2016 of "the first all-electric truck for heavy distribution worldwide", with a 212 kWh Li-ion battery and 200 km range (Wuttke, 2016), Mercedes-Benz entered the trial phase on German roads in 2017 (Muoio, 2017a). Tesla responded in November 2017 with the announcement of its Semi truck for 2019, with unusual and very performant characteristics like a drag coefficient of 0.36 (a record for a truck), an acceleration from 0 to 100 km/h in about 20 seconds with full load and 5 seconds without load, and autonomies of 300 and 500 miles, around 483 and 805 km, respectively (Tesla Semi, 2017). The electric delivery trucks market is also preparing to increase sharply. UPS, which has already more than 300 electric vehicles in Europe and USA and nearly 700 hybrid electric vehicles, has announced in February 2018 a collaboration with Workhorse Group to deploy 50 plug-in electric delivery trucks with an autonomy of around 160 km and "comparable in acquisition cost to conventional-fueled trucks without any subsidies". Furthermore, UPS also pre-ordered 125 Tesla Semi trucks (UPS 2018).

2.3 Sales forecasts and car manufacturers' answers

Pressure posed by public opinion and countries&cities, as well as a growing interest from consumers and the attention gathered by Tesla models in particular, which has for the first time sold more luxury vehicles in Europe than the corresponding Mercedes class S and BMW 7 (Gibbs, 2018), has forced the mainstream car manufacturers to take the electrification of their fleets very seriously. Indeed, even though the electric vehicles sales' forecasts varies with the sources and are being frequently updated, they agree on a increasing market share for electric vehicles, as can be seen, for example, in Figure 3 where a 24 %, a 43 % and a 54 % share of electric vehicles on the annual global light duty vehicle sales is expected by 2030, 2035 and 2040, respectively. This represents a share of 7 %, 19 % and 33 %, for the same years, on the global light duty vehicle fleet (Bloomberg, 2017).

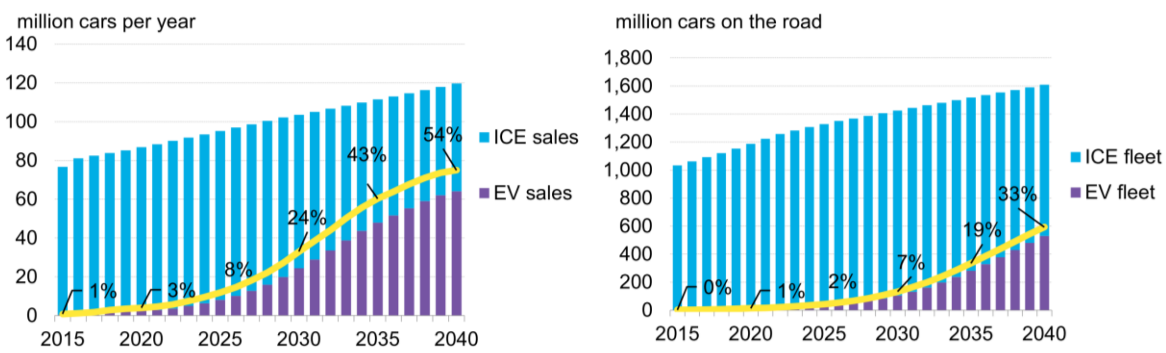

Fig. 3 – a) Annual global light duty sales and b) Global light duty vehicle fleet (Bloomberg, 2017)

It is worth to note that the sales share forecast in 2016 by the same Bloomberg New Energy Finance firm for 2040 was only 35 % (Randall, 2016). This trend can be even much sharper in some scenarios, for example “more than 90 per cent of all passenger vehicles in the U.S., Canada, Europe and other rich countries could be electric by 2040” (Leahy, 2017).

The vehicle manufacturers are responding with a constant flow of announcements regarding new electric and electrified models. It is difficult to keep track of all but, besides Volvo statements previously mentioned, and to indicate just a few, Ford has publicized in January 2017 that in the next five years it would introduce 13 new global electrified vehicles, and in a new announcement in March 2018, stated that it will spend USD 11 billion on electrified vehicles (Green Car Congress, 2018), Volkswagen said that battery electric vehicles will be produced at 16 factories worldwide by the end of 2020, with up to three million electric cars per year by 2025 and 80 new electrified models (nine of them in 2018 and of which three will be pure electric (Hammerschmidt, 2018)), and BMW intends to add 25 new electrified vehicles by 2025, half of them all-electric (Prince, 2018).

There has been also an impressive price decrease and performance improvement of the batteries used in electric vehicles. In 2010 they had an average cost of around 750-1000 USD/kWh and around 400 USD/kWh in 2014 (Nykvist and Nilsson, 2015), but by mid-2016 the cost had decreased to 190 USD/kWh for Tesla battery packs and to 145 USD/kWh for the cells used by General Motors (Voelcker, 2016). This is quite close to the goal value of 100-150 USD/kWh for mass commercialization that was forecast just a couple of years ago to be reached by 2030 (Nykvist and Nilsson, 2015)! Consequently, the typical battery capacity of a regular passenger car rose from 20-24 kWh to 30-40 or even 60 kWh, with the corresponding range increasing from around 130 km (Environmental Protection Agency, EPA, data. For New European Driving Cycle, NEDC, values would be higher) to 200-370 km in just 3-4 years without significant car price increase, for vehicles with sales price below 40 k€ (Chatelain *et al*, 2018). Some consultant companies forecast that electric cars will be cheaper than same ICEV models by 2025 (Hodges, 2018), others point 2022 for the turning point (Holland, 2017). However, in some cases, the Total Cost of Ownership, TCO, is already favorable to electric vehicles, specially taking into account tax benefits, unrestricted access to city center, free parking and other benefits that are being given by governments and municipalities. This was shown in a study about Japan, UK and USA relative to 2015 (Palmer *et al*, 2018, resumed in Geuss, 2017) and also from 2017 for vehicles owned by companies in Portugal (UVE, 2017).

3. MAIN CHALLENGES

The main challenges posed by road transportation electrification, are grouped here in five topics. The first one is the need for suitable rechargeable energy storage systems, being here only mentioned the batteries. The second is related to the charging process management, the return of energy from the vehicle to the grid (V2G) and the convenience of smart(er) grids for dealing with the vehicles’ charge. As a third point, the subject of the battery end of life and its recycling or further usage for stationary energy storage, as a "second life", and the need to be possible to repair or change damaged batteries in an affordable way is addressed. The fourth point expresses the importance of standardization in electric vehicles and, finally, a fifth point is related to the need of education and technical formation for electric vehicles. There are some other important challenges like those posed by self-driving cars, fleet-platooning, cyber security, the impact of the electric vehicles in the spare parts industry and in dealer networks and garages, some raw materials availability and profitability for car manufacturers (Taylor, 2018) that are not analyzed in this paper for space reasons.

3.1. Suitable batteries*:* chemistries, cost, energy density, lifetime, security, autonomy

The fundamental challenge regarding electric vehicles for more than 120 years has been the energy storage system. This means to be able to produce in a cost effective way, cells and battery packs that are safe, with long cycle life (ideally more than 4000 cycles) and calendar life (more than 10 years), with high energy density (kWh/l) and specific energy (kWh/kg), as well as high power density (kW/l) and specific power (kW/kg). Usually, the cells are optimized for energy (related to vehicle range) or for power (related to acceleration), but not both. It has been shown that it is possible to fast charge at least Lithium Iron Phosphate ("LFP": LiFePO4) cells at 4C (high current equal to 4 times the capacity) without significant degradation but that the peaks from usage (in particular with high regenerative breaking currents) have higher impacts on the battery lifetime (Carrilero, 2017). One possibility to overcome this is to use multiple energy sources on the same vehicle, in particular for vehicles with very dynamic driving cycles. Nevertheless, besides more complex and expensive, this approach need a more complex energy management strategy (Trovão *at al*, 2013). Other aspects are the thermal management and the life cycle impacts, which include the manufacturing and disposal/recycling. For all these objectives, a huge effort has been done particularly in the last 10 years with the arrival of Li-ion chemistries to the market. As seen on the previous section, battery technology has already reached a quite good development level. Nevertheless, there is still room for improvement on most of these topics. Currently, most cells of the electric vehicles in the market use graphite anodes (negative electrode) but Tesla X and Tesla Model 3 use graphite-silicon anodes, and for the cathode (positive electrode) use either Lithium Nickel Cobalt Manganese Oxide (known as "NCM": $LiNi_xCo_yMn_zO_2$. Also "NMC"), Lithium Cobalt Aluminium Oxide ("NCA": $LiNiCoAlO_2$), Lithium Manganese Oxide Spinel ("LMO": $LiMn_2O_4$) or LMO-NCA (Anderman, 2017; Konecky, 2017). There are also some models, in particular Chinese, that use LFP in the cathode. There is also the possibility of using an anode of Lithium Titanate Oxide ("LTO": $Li_4Ti_5O_{12}$), compatible with those cathodes, but usually uses for Manganese-based materials for it (JMBS, 2017). The main characteristics and differences between these different lithium chemistries are summarized in JMBS (2017) and BU (2017b). The possible future technologies, Zinc-Air, Lithium-Air, Sodium-Air, Lithium-Sulphur (Li-S), Sodium-ion (Na-ion) and Solid-state Lithium, are shortly described in JMBS (2017) and BU (2017a).

3.2 Charging management, V2G and Smart Grids

There were more than 2 million electric cars on the world roads by the end of 2016 (IEA, 2017) and 3.2 million electric chargeable light vehicles by the end of 2017, due to more than 1.2 million light electric vehicles sold in that year, plus 500 000 heavy plug-in vehicles, most of them Chinese electric buses **(**EVVolumes, 2018)**.** The previously mentioned very high electric vehicles sales' growth expectation (24% and 54% of new car sales and 7% and 33% of world light duty vehicles on road by 2030 and 2040, respectively), poses important challenges to the grid. This is aggravated by the tendency to increase the capacity of the batteries (in some case to more than 100 kWh for passenger vehicles (Meilhan, 2017) and 350 kWh for electric buses and premium cars (ZeEUS eBus, 2016; Automotive IQ, 2018)) and to increase the charge rates, with fast and opportunity charging in many cases with ultrafast charging (Carrilero, 2017). Besides the aforementioned technologies, in a smart grid context, the EV can also be used to increase the flexibility through the Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G) operation modes (IEA, 2017; Noel and McCormack, 2014). This is more relevant considering its dynamic and distributed integration into the power grid, where it can be plugged in to charge the batteries (G2V) in a place and plugged in to deliver energy back to the power grid in a different place (V2G). As the charging power is increasing, some charging stations are already including local energy storage to smooth the peak demands from the grid (Ding, Hu, and Song, 2015). Consequently, besides the individual EVs G2V and V2G, this charging stations' local storage should also be considered for energy management, both as G2LS (Grid-to-Local-Storage) and LS2G (Local-Storage-to-Grid). Some electric vehicles in the market have already V2G capability as well as the UPS delivery trucks under development (Wagman, 2018).

Another challenge is to aggregate thousands of electric vehicles and manage their G2V and V2G energy flow as a single power plant that can enter the electric energy market, fulfilling the grid needs and the vehicle owners' interests, by allowing to increase the use of renewable energy sources (controlled G2V to charge at night, i.e. "filling valleys" on the load diagram), return electricity to the smart grid, using V2G for "peak shaving" and avoiding building new peak power plants, and the possibility to be used as power backup (in particular for detached houses).

3.3. Battery recycling vs. second life and affordable battery replacement

To reduce and minimize the health and environment impacts of any product it is fundamental to keep in mind the eco-design, to foster a circular economy that uses, reuses, remake the equipment and recycle it when this is no longer usable. The simple disposal of electric vehicles' batteries directly to trash, is not only unacceptable for environment impact reasons, but also due to the fact that even when a traction battery reaches its end-of-life for electric vehicles, it usually can still be used for stationary energy storage for some more years, which is called second life. Furthermore, when it is not really possible to continue to use it, the battery still contains valuable materials that should be recycled. This reduces the impacts, might be economically profitable, and reduces the pressure also over raw materials' need for its manufacturing, in particular cobalt and some rare earths. For all these reasons, the technical procedures for industrial recycling of the batteries have been under development and Li-ion battery recycling facilities are appearing (Daly, 2018) and the European Commission took into account explicitly the "Design for manufacturing, recycling and second use" on the project proposals' evaluation of the call "GV-06-2017: Physical integration of hybrid and electric vehicle batteries at pack level aiming at increased energy density and efficiency" (GV, 2016).

Another relevant aspect for the vehicle user, is the possibility of the battery replacement at a reasonable price. This is critical, as the battery pack is the most expensive component of the car, accounting currently for 30 % to 40 % of the cost. Due to the relatively reduced age of the current generation of electric cars, this is not yet a very pressing question. Nevertheless, at least one manufacturer, Nissan, announced a battery replacement price of 2850 € for a refabricated 24 kWh battery, associated with a new plant in the town of Namie (devastated by the March 2011 earthquake and tsunami) specialized in the reuse and recycling of Li-ion batteries, the first in Japan (Kane 2018).

3.4 Standardization in electric vehicles

This is a very important topic for professionals working in the area, namely on vehicles and components' development, but also on charging systems and V2G systems. There is a very intense activity in this area particularly by the IEC TC69 – Electric road vehicles and electric industrial trucks, and by ISO/TC 22/SC 37 – Electrically Propelled Vehicles standardization technical committees. The main areas currently under standardization work are conductive charging systems, wireless power transfer, electric double-layer capacitors for use in HEV, conductive power supply system for Light Electric Vehicles (LEV), EVs battery swap systems, vehicle to grid communication interface, safety specifications for electrically propelled road vehicles, and test specification for lithium-ion traction battery packs and systems (Pereirinha, Trovão and Santos, 2016).

3.5 Technical education for electric vehicles

The use of electric vehicles has some differences in relation to the ICEV. The foreseen explosion of electric vehicles on the market brings with it the need to prepare qualified professionals to frame their use, both in the management and maintenance of fleets, in particular with the management of charging and fast charging, and in the maintenance and repair of electric vehicles. Another important aspect is the training of security forces, medical emergency and firefighters for the potential risks associated with electric vehicles, particularly in the event of an accident or fire involving electric vehicles. That is why it is necessary to increase the training of professionals, either at the level of senior staff, usually engineers, such as at the Polytechnic Institute of Coimbra, Portugal (Pereirinha, 2016), or at the electrical mobility master given by a consortium of universities that includes the University of Oviedo (Diaz *et al.*, 2016; EMJMD STEPS, 2018), or repair technicians (ELEVTRA, 2014), also with the Univ. de Oviedo. The car manufacturers also play a key role in the training of their technicians who are usually more geared towards mechanical issues, and must prepare their staff for this recent but increasing need.

4. CONCLUSIONS

With more than 120 years, after starting in parity with ICEV at the beginning of the 20th century, electric vehicles have finally reached the level of development that will allow them to be a viable solution for more and more private and public transport drivers. Despite the significant progress that still can be made, in many cases the total cost of ownership over the life of the vehicle has already been achieved in relation to ICEV. Environmental and population pressures, increasingly aware of pollution problems, have already forced some countries and cities to announce measures towards the transition to electrified mobility. Car builders are responding with a growing announcement of new electrified models, either hybrid or pure electric. In this paper, the main trends and challenges, in the view of the authors, were presented for this electrification of mobility. In our opinion, and as is presented in a video of the *Economist* (Shahan, 2017), 2018 may very well be the turning point. But even if this turn takes a little longer, it is already at a point practically irreversible. Public transport, in particular electric buses and electric taxis are the vehicles whose electrification has higher positive impact, in terms of urban pollution, noise and fuel economy, and should play a fundamental and growing role in a more sustainable urban mobility. Europe should take proper actions to not be overcome by China not only in this domains but on electric vehicles in general.
It is important for decision-makers, particularly those with transport responsibilities, to be aware of these trends and of the challenges posed not only by the electrification of mobility, were pure electric vehicles will have a growing share, but also the challenges posed by autonomous vehicles and the increase in new forms of mobility, where the vehicle tends to move from individual ownership to a shared service such as carsharing.

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