Available online at www.sciencedirect.com

ScienceDirect

Transportation Research Procedia 33 (2018) 235–242

Transportation Research Procedia

www.elsevier.com/locate/procedia

XIII Conference on Transport Engineering, CIT2018

Main Trends and Challenges in Road Transportation Electrification

Paulo G. Pereirinha[a,b,c,*], Manuela González[d], Isabel Carrilero[d], David Anseán[d], Jorge Alonso[d], Juan C. Viera[d]

[a]*Coimbra Polytechnic – ISEC, Rua Pedro Nunes, 3030-199 Coimbra, Portugal*
[b]*INESC Coimbra, Pólo II, Rua Sílvio Lima, 3030-290, Coimbra, Portugal*
[c]*APVE, Edif. LNEG - Zambujal – 2610-999 Amadora, Portugal*
[d]*Depart. of Electrical and Electronic Engineering, University of Oviedo, 33204 Gijón, Asturias, Spain*

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 (EVs), 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 EVs 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.

Keywords: electric vehicles; electric mobility; road transportation; sustainable mobility; transportation electrification; batteries.

* Corresponding author. Tel.: +351-239-790-200
E-mail address: ppereiri@isec.pt

2352-1465
10.1016/j.trpro.2018.10.096

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 at European Union level. Indeed, 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, from 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). Nevertheless, this trend of increasing mobility has some important negative consequences, like oil cost's impact on the economy, concerns about energy availability and 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. Moreover, road transportation accounted for 72.9 % of all GHG emissions from transport in EU-28 in 2015 sector.

In spite of some discussion, it is clear that from a life cycle analysis point of view, battery EVs 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) 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 are presented in this section in three groups: 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' 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…" (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 electric buses in decreasing the gases emissions in cities. Consequently, one major trend in public transportation is to promote the adoption of cleaner buses, in particular battery electric buses. The important report ZeEUS (2017) presents the state of the art of electric buses (including Plug-in Hybrid Buses and battery trolleybuses) by October of 2017. As shown in this report (and in Harrop, 2017), China is absolutely leading the way in electric buses: in 2016, of the nearly 345 000 electric buses worldwide, around 345 500 were in China, of which about 300 000 battery electric buses. Also, 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 EVs (Lambert, 2017a). This transition also started in other cities, with Nissan saying that its EV 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 EVs in Europe and USA and nearly 700 hybrid EVs, 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 EVs sales' forecasts varies with the sources and are being frequently updated, they agree on an increasing market share for EVs. Bloomberg (2017) foresees 24 %, 43 % and 54 % share of EVs on the annual global light duty vehicle sales 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. It is worth to note that the sales share forecast in 2016 by the same Bloomberg 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 EVs 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). Renault intends to have 8 pure EVs and 12 electrified models by 2022 (Renault, 2017).

There has been also an impressive price decrease and performance improvement of the batteries used in EVs. The 2010 average cost of 750-1000 USD/kWh and around 400 USD/kWh in 2014 (Nykvist and Nilsson, 2015), has decreased to 190 USD/kWh for Tesla battery packs and to 145 USD/kWh for the cells used by General Motors by mid-2016 (Voelcker, 2016), and is approaching 100 USD/kWh for Tesla cells (Holland, 2018). 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 EVs, 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 in road transportation electrification

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 addressed 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 (“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 EVs and, finally, a fifth point is related to the need of education and technical formation for EVs. There are some other important challenges like those posed by self-driving cars, fleet-platooning, cyber security, the impact of the EVs 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 EVs 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”: $LiFePO_4$) 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 needs 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. Currently, most cells of the EVs 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 Aluminum 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, which 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 using 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). As seen on section 2.3, battery technology has already reached a quite good development level, but there is still room for improvement on most of the objectives mentioned in the beginning of the current section. 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's 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 EVs sold in that year, plus 500 000 heavy plug-in vehicles, most of them Chinese electric buses (EVVolumes, 2018). The previously mentioned very high EVs 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 cases to more than 100 kWh for passenger vehicles (Meilhan, 2017) and 350 kWh for electric buses and premium cars (ZeEUS, 2017; 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 EVs 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 EVs 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), by using V2G to return electricity to the smart grid (for "peak shaving"), by avoiding building new peak power plants, and by 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, remakes, and recycles the equipment when this is no longer usable. The simple disposal of EVs' 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 EVs, 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 evaluation of project proposals to the call GV-06-2017. 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 EVs

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 standardization technical committees IEC TC69 – Electric road vehicles and electric industrial trucks, and ISO/TC 22/SC 37 – Electrically Propelled Vehicles. 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 EVs

The use of EVs has some differences in relation to the ICEV. The foreseen explosion of the EVs' 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 EVs. Another important aspect is the training of security forces, medical emergency and firefighters for the potential risks associated with EVs, particularly in the event of an accident or fire involving EVs. That is why it is necessary to increase the training of professionals. This can be done at senior staff level's, usually engineers, such as at Polytechnic of Coimbra (Pereirinha, 2016) and at the electrical mobility master given by a consortium of universities (Diaz et al., 2016; EMJMD STEPS, 2018), or at repair technicians' level (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 (Renault, 2017), 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, EVs 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 manufacturers 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 EVs 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 EVs 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.

Acknowledgements

This work has been partially supported by FEDER and Portuguese OE (Project ESGRIDS, Project no. 01643, POCI-01-0145-FEDER-016434), the Science and Innovation Spanish Ministry and FEDER (Project TEC2016-80700-R (AEI/FEDER, UE)) and the Principality of Asturias Government (Project FC- 15-GRUPIN14-07).

References

Anderman, M., 2017. Extract from The Tesla Battery Report, Total Battery Consulting, July 2017.

Associated Press, 2017. Smog pushes Beijing residents to innovate for the world, Associated Press, 26 Jan. 2017.

Automotive IQ, 2018. Progress Towards fast charging for electric vehicles, Automotive IQ report, January 2018.

Bloomberg, 2017. Electric Vehicle Outlook 2017 - Bloomberg New Energy Finance's annual long-term forecast of the world's electric vehicle market. Executive summary, Bloomberg New Energy Finance, July 2017.

BBC, 2017. China looks at plans to ban petrol and diesel cars, BBC News, 10 Sept. 2017.

BU, 2017a. BU-212: Future batteries, Battery University (update of 29 August 2017). http://batteryuniversity.com.

BU, 2017b. BU-205: Types of Lithium-ion, Battery University (update of 15 November 2017). http://batteryuniversity.com.

Carrilero, I, Anseán, D., Pereirinha, P., Viera, J.C., Fernández, Y., González, M., 2017. Impact of fast-charging and regenerative braking in LiFePO4 batteries for electric bus applications, 14th IEEE Vehicle Power Propulsion Conf., VPPC 2017, Belfort, France, 11-14 Dec. 2017.

Chatelain, A., Mauro, E., Moulière, P.-Y., Schäfer, P., 2018. What a teardown of the latest electric vehicles reveals about the future of mass-market EVs, McKinsey & Company, March 2018.

Daly, T., 2018. Chinese carmaker BYD close to completing battery recycling plant, Reuters, 21 March 2018.

Díaz, J., Pernía, A.M., Guerrero, J.M., Pereirinha, P.G., Williams, A., 2016. Learning Energy Storage in Hybrid/Electric Vehicles: Erasmus Mundus Master Course in Sustainable Transportation & Electrical Power Systems, VPPC 2016, Hangzhou, China, October 17-20, 2016.

Ding, H., Hu, Z., Song, Y., 2015. Value of the energy storage system in an electric bus fast charging station, Applied Energy, Vol. 157, 630-639.

ELEVTRA, 2014. Project Training for the Electric Vehicles (ELEVTRA): Docentes de la Universidad de Oviedo diseñan formación específica para reparar y mantener vehículos eléctricos, Universidade de Oviedo, 26 Nov. 2014.

EMJMD STEPS, 2018. Erasmus Mundus Joint Master Degree in Sustainable Transportation and Electrical Power Systems, www.emmcsteps.eu.

European Commission, 2017. EU Transport in Figures Statistical Pocketbook 2017, European Commission.

EVvolumes, 2018. Global plug-in vehicle sales for 2017 – Final results, EV-volumes.com, 2018.

Farand, C., 2017. France will 'ban all petrol and diesel vehicles by 2040', The Independent, 6 July 2017.

Garfield, L., 2018. 13 cities that are starting to ban cars, Business Insider, 27 Feb. 2018.

Geuss, M, 2017. Does a lower "total cost of ownership" boost electric car sales?, Arstechnica, 29 Dec. 2017.

Ghoshal, A., 2017. Watch: India unveils ambitious plan to have only electric cars by 2030, International Business Times, 30 April 2017.

Gibbs, N., 2018. Tesla Model S outsells German luxury flagships in Europe, Automotive News Europe, 20 February 2018.

Green Car Congress, 2018. Ford ups its electrified vehicle ante to $11B; 86% trucks and SUVs in the product mix by 2020, Green Car Congress, 16 March 2018.

Harvey, F., 2016. Four of world's biggest cities to ban diesel cars from their centres, The Guardian, 2 Dec. 2016.

Harrop, P., 2017. Electric Buses: Hotbed of Innovation and Large Orders - Some findings from the new IDTechEx report, "Electric Buses 2017-2027", webinar IDTechEx, 25 May 2017.

Hammerschmidt, C., 2018. VW plans to massively expand production of electric cars, eeNews Automotive, 13 March 2018.

Hodges, J., 2018. Electric cars may be cheaper than gas guzzlers in seven years, Bloomberg New Energy Finance, 22 March 2018.

Holland, M., 2017. EV revolution timeline — EVs cheaper than ICEVs by 2022, EVObsession, 12 Dec. 2017.

Holland, M., 2018. Tesla aiming to break $100/kWh at cell-level later this year, EVObsession, June 6, 2018.

Ibison, D., 2017. Volvo Cars to go all electric, Press Release, ID: 210058, Volvo Car Group, 05 Jul. 2017.

IEA, 2017. Global EV Outlook 2017, International Energy Agency, June 2017.

Iyengar, R., 2014. New Delhi, the World's Most Polluted City, Is Even More Polluted Than We Realized, Time, 27 Nov. 2014.

JMBS, 2017. Our Guide to Batteries 3.ed, reprint 2017, Johnson Matthey Battery Systems, 2017.

Kane, M., 2018. Nissan Introduces $2,850 Refabricated Batteries For Older LEAF, insedeevs, 26 March 2018.

Konecky, K., 2017. Extract from The Battery Packs of Modern xEVs Report, Total Battery Consulting, June 2017.

Kumar, P., Khare, M., Harrison, R.M., Bloss W.J., Lewis, A.C., Coe, H., L. Morawska, 2015. New directions: Air pollution challenges for developing megacities like Delhi, Atmospheric Environment, vol. 122, Dec. 2015, Pages 657-661.

Lambert, F., 2017a. Beijing wants to replace its 70,000 taxis with electric vehicles to fight local air pollution, electrek, 28 Feb. 2017.

Lambert, F., 2017b. Nissan's all-electric Leaf is becoming increasingly popular with taxi companies, electrek, 30 May 2017.

Lambert, F., 2017c. 12 major cities pledge to only buy all-electric buses starting in 2025, electrek, 23 Oct. 2017.

Lambert, F., 2017d. Shenzhen shows the world how it's done, electrifies all public transit with massive fleet of 16,000+ electric buses, electrek, 28 Dec. 2017.

Leahy, S., 2017. Electric cars may rule the world's roads by 2040, National Geographic, 13 September 2017.

Lotrakul, P., Pereirinha, P.G., Bouscayrol, A., 2017. Reduced-scale Hardware-In-the-Loop Simulation of an Urban Electric Minibus using Energetic Macroscopic Representation, VPPC 2017, Belfort, France, 11-14 Dec. 2017.

McGrath, M., 2016. Four major cities move to ban diesel vehicles by 2025, BBC News, 2 Dec. 2016.

Meilhan, N., 2017. EV Car Wars - Who will win the battle between BEVs, PHEVs & FCEVs?, IQPC E-Motor Conf., 15 Feb. 2017.

Messagie, M., Boureima, S.-B., Coosemans, T., Macharis, C., Van Mierlo, J., 2014. A Range-Based Vehicle Life Cycle Assessment Incorporating Variability in the Environmental Assessment of Different Vehicle Technologies and Fuels, Energies, 2014.

Muoio, D., 2017a. Mercedes-Benz will test its all-electric truck on German roads this year — here's everything you need to know, 16 Feb. 2017.

Muoio, D., 2017b. These countries are banning gas-powered vehicles by 2040, Business Insider, 23 Oct. 23, 2017.

C40 Cities, 2018. About C40, www.c40.org/about.

Noel, L., McCormack, R., 2014. A cost benefit analysis of a V2G-capable electric school bus compared to a traditional diesel school bus, Applied Energy, Volume 126, 1 August 2014, Pages 246-255, https://doi.org/10.1016/j.apenergy.2014.04.009.

Nykvist, b., Nilsson, M., 2015. Rapidly falling costs of battery packs for electric vehicles", Nature Climate Change 5, 2015. https://doi.org/10.1038/nclimate2564.

OECD, 2015. The Economic Consequences of Climate Change, Organization for Economic Cooperation and Development, Nov. 2015.

OECD, 2016. Air pollution to cause 6-9 million premature deaths and cost 1% GDP by 2060, *ibid*, June 2016.

Palmer, K., Tate, J.E., Wadud, Z., Nellthorp, J, 2018. Total cost of ownership and market share for hybrid and electric vehicles in the UK, US and Japan, Applied Energy, Vol. 209, 1 Jan. 2018, pp. 108-119. http://dx.doi.org/10.1016/j.apenergy.2017.10.089.

Paris Agreement, 2015, 21th Conference Of the Parties, United Nations Framework Convention on Climate Change (UNFCCC), Paris, 30 Nov. to 12 Dec. 2015.

Pereirinha, P. G., Trovão, J. P., 2012. Multiple energy sources hybridization: the future of electric vehicles?, In: Z. Stević (ed.), New Generation of Electric Vehicles, InTech, Dec. 2012. DOI: 10.5772/53359. http://dx.doi.org/10.5772/53359.

Pereirinha, P. G., Trovão, J. P., Santos, V., 2016. Electric Propulsion Vehicles Standardization: Where Are We?, Electrical Engineering Electronic Journal, AEDIE, Vol.1, No. 3, May 2016, ISSN 2172-1246. www.aedie.org/papers/16116-pereirinha.pdf.

Pereirinha, P.G., 2016. Learning Electric Vehicles and Traction at the Polytechnic of Coimbra", VPPC 2016, Hangzhou, China, 17-20 Oct. 2016.

Phillips, T., 2017. China's premier unveils smog-busting plan to 'make skies blue again', The Guardian, 5 March 2017.

Prince, R., 2018. BMW to Introduce New Electric Concepts in 2018, hybridCARS, 21 March 2018.

Randall, T., 2016. Here's how electric cars will cause the next oil crisis - A shift is under way that will lead to widespread adoption of EVs in the next decade, Bloomberg New Energy Finance, 25 Feb. 2016.

Renault, 2017. Drive The Future 2017-2022: New strategic plan, Press Release, Oct. 06, 2017.

Rodrigue, J-P et al., 2017. The Geography of Transport Systems, Hofstra University, New York, 2017.

Science X, 2017. Europe chokes under freezing smog, Phys.Org, 24 January 2017.

Shahan, C., 2017. The Economist: Global tipping point for electric cars in 2018 (Video), CleanTechnica, 5 November 2017.

Taylor, E., 2018. BMW says electric car mass production not viable until 2020, Reuters, 22 March 2018.

TESLA SEMI, 2017. Tesla Semi & Roadster unveil, Tesla, 16 November 2017. Available at https://www.tesla.com/semi.

Trovão, J.P., Pereirinha, P.G., Jorge, H.M., Antunes, C.H., 2013. A multi-level energy management system for multi-source electric vehicles – An integrated rule-based meta-heuristic approach, Applied Energy, Vol. 105, May 2013, pp. 304-318, ISSN 0306-2619.

UPS, 2018. UPS to deploy first electric truck to rival cost of conventional fuel vehicles, Press Release, UPS, 22 February 2018.

UVE, 2017. 2017: Ano do veículo elétrico para as empresas, UVE, 13 May 2017.

Van Mierlo, J., 2015. Clean Vehicles - A Life Cycle Assessment point of view, VPPC 2015, Montréal, Canada, October 19-22, 2015.

Voelcker, J., 2016. Electric-car battery costs: Tesla $190 per kWh for pack, GM $145 for cells, Green Car Reports, 28 April 2016.

Wagman, D., 2018. Electric school buses motor ahead in pilot project, IEEE GlobalSpec, 14 March 2018.

Wuttke, W., 2016. Electric truck for the city, Mercedes-Benz, 5 August 2016.

ZeEUS, 2017. ZeEUS eBus Report #2 - An updated overview of electric buses in Europe, FP7 European Project ZeEUS, October 2017.