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# Electric Vehicles in an Urban Context: Environmental Benefits and Techno-Economic Barriers

Adolfo Perujo<sup>1</sup>, Christian Thiel<sup>2</sup> and Françoise Nemry<sup>3</sup>

*European Commission, Joint Research Centre,*

*<sup>1</sup>Institute for Energy (IE) Ispra (VA)*

*<sup>2</sup>Institute for Energy (IE), Petten,*

*<sup>3</sup>Institute for Prospective Technological Studies (IPTS), Seville*

*<sup>1</sup>Italy*

*<sup>2</sup>The Netherlands*

*<sup>3</sup>Spain*

## 1. Introduction

Mobility of persons and goods is a crucial component of the competitiveness of the economy; mobility is also an essential citizen right. Effective transportation systems are important for social prosperity, having significant impacts on economic growth, social development and the environment. The goal of any sustainable transport policy is to ensure that our transport systems meet society's economic, social and environmental needs.

In 2006 the transport sector consumed 31% of the total final energy consumption (of which 82% is due to road transport) and was responsible for 25% of CO<sub>2</sub> emissions (EU-27). In 2007 road transport constituted about 83% of passenger total transport demand. Road transport accounts for 71% of transport related CO<sub>2</sub> emissions and passenger cars constitute 63% of these road transport related CO<sub>2</sub> emissions. Currently, road transport is also totally dependent (>90%) of fuel oil making it very sensitive to foreseeable shortage of crude oil, besides largely contributing to air pollutants such as NO<sub>x</sub>, PM10 and volatile organic compounds.

It is estimated that more than 80% of the developed world population lives in an urban environment and therefore it is in this environment where a larger concentration of vehicles are found. As example there were about 230 million passenger vehicles in the EU-27 in 2007 and the new vehicle sales were nearly 16 million vehicles in that year. Consequently the urban population is very much at risk by directly suffering the impact of conventional vehicles because their closeness to the pollutant source. Air pollution is one of the important external costs of transport as it impacts on the health of the population (it is estimated to be 0.75% of the EU GDP). On the other hand, the large concentration of vehicles causes traffic congestions in metropolitan urban areas that can be considered a threat to economic

competitiveness (a recent study on the subject showed that the external costs of road traffic congestion alone amount to about 1.25% of the EU GDP) and it also increases the inefficiency of an overcrowded transport infrastructure.

Electric vehicles (EV) might offer a step change technology based on the much higher efficiency of electric motors compared to ICEs as well as the potential to de-carbonise the energy chain used in transportation and in particular in the well to tank pathway (JRC et al., 2008, Thiel et al., 2010). This will also open the possibility to use alternative energy paths to secure mobility and making the road transport more independent from crude oil.

This chapter analyses the possible role that EVs (it includes Battery Electric Vehicles –BEV, and Plug-in Hybrid Vehicles – PHEV) might play within the urban environment in the short, medium and long term, discusses the expected gains in environmental performance, presents the main bottlenecks in its deployment and addresses the possible additional cost bare by the technology.

The chapter also examines the possible business models and policy options that might be put in place in order to support a faster market intake for the electrification of the urban transport.

However, the potential of EV to reduce the impact of transportation varies from impact to impact and also depends on the time scale. In other words it does not represent the “silver bullet” to face the problem of environmental decay and transportation inefficiencies (traffic congestions) in our metropolitan areas and as such, it needs to be considered as an option in a wide range of possibilities at our disposal to meet this challenge. These options include also non-technological alternatives that together with the technological ones need to be considered in a holistic approach.

The chapter finalises with a summary and recommendations on how EVs can be brought to the forefront of urban/city vehicles as a good option to reduce the impact caused by transportation in the urban environment.

## **2. Technical characteristics of available electric vehicles**

Recently customers are continuously impacted by announcements of new electrical vehicles models by the automotive industry that seems to be putting a large effort in bringing to the market electrified vehicles. The analysis of the technical features of the electric vehicles already available or that will be available in the next years is fundamental in order to understand their potential penetration. The understanding of their characteristics (range, battery capacity, energy consumption and others) as well as its limitations will define the type of customers attracted to this technology as well as the type of operations these vehicles will undertake. The automotive industry plans for the roll-out of EV have been recently reviewed in different literature sources (City of Westminster, 2009, Hacker et al, 2009). How these plans will materialise in the short to medium term will depend on both the manufacturing capacities and on the number of car models proposed to the consumer. This last aspect will indeed determine the variety of choices offered for the consumer, and thus the probability of purchase of BEVs and PHEVs.

A non-exhaustive list of available vehicle models is reported in Table 1. The data presented in the table are consistent with both; what is declared by the manufacturer and what can be found in the open literature.

|             | Brand               | Model              | Capacity (kWh) | Range (km) | Consumption (kWh/100km) | Vehicle segment |
|-------------|---------------------|--------------------|----------------|------------|-------------------------|-----------------|
| Cars        | Audi                | e-Tron EV          | 42.40          | 248        | 17.10                   | Large           |
|             | BMW                 | MINI-E             | 35.00          | 180        | 19.44                   | Small           |
|             | BYD Auto            | BYDe6              | 72.00          | 400        | 18.00                   | Large           |
|             | Chery Automobile    | S18 EV             | 15.00          | 135        | 11.11                   | Small           |
|             | Chrysler            | Dodge Circuit EV   | 26.00          | 175        | 14.86                   | Large           |
|             | CODA                | Sedan-EV           | 33.80          | 180        | 18.78                   | Large           |
|             | Daimler             | SmartED            | 14.00          | 125        | 11.20                   | Small           |
|             | Detroit             | e63                | 25.00          | 180        | 13.89                   | Mid-Size        |
|             | Fiat                | Panda              | 19.68          | 120        | 16.40                   | Small           |
|             | FIAT                | 500                | 22.00          | 113        | 19.53                   | Small           |
|             | Ford                | Focus Ev           | 23.00          | 160        | 14.38                   | Mid-Size        |
|             | Ford                | Transit Connect    | 24.00          | 160        | 15.00                   | Mid-Size        |
|             | Heuliez             | WILL EV            | 18.00          | 300        | 6.00                    | Small           |
|             | Hyundai             | i10 Ev             | 16.00          | 140        | 11.43                   | Small           |
|             | Lighting            | GTS                | 35.00          | 175        | 20.00                   | Large           |
|             | Loremo EV           | Loremo Ev          | 10.00          | 150        | 6.67                    | Mid-Size        |
|             | Lumeneo             | Smera EV           | 10.00          | 150        | 6.67                    | Small           |
|             | Mercedes            | SLS eDrive         | 48.00          | 160        | 30.00                   | Large           |
|             | MILES               | ZX40S/ZX40ST       | 10.00          | 105        | 9.56                    | Small           |
|             | Mitsubishi          | i-MIEV             | 20.00          | 160        | 12.50                   | Small           |
|             | NICE                | Micro-Vett         | 10.50          | 80         | 13.05                   | Small           |
|             | Nissan              | Leaf               | 24.00          | 160        | 15.00                   | Mid-Size        |
|             | Peugeot             | iOn                | 20.00          | 140        | 14.29                   | Small           |
|             | Phoenix             | SUV/SUT            | 35.00          | 209        | 16.73                   | Mid-Size        |
|             | Pininfarina         | Bluecar            | 30.00          | 250        | 12.00                   | Small           |
|             | Citroen             | C-Zero             | 16.00          | 110        | 14.55                   | Small           |
|             | Renault             | Kangoo             | 15.00          | 160        | 9.38                    | Small           |
|             | Renault             | Zoe ZE             | 15.00          | 160        | 9.38                    | Small           |
|             | Renault             | TwingoQuickshift E | 21.45          | 129        | 16.60                   | Small           |
|             | Renault             | Fluence            | 30.00          | 160        | 18.75                   | Mid-Size        |
|             | REVA                | NXR                | 14.00          | 160        | 8.75                    | Small           |
|             | REVA                | NXG                | 25.00          | 200        | 12.50                   | Small           |
|             | Rud. Perf. Roadstar | Spyder             | 16.00          | 125        | 12.80                   | Large           |
|             | SUBARU              | R1e                | 9.00           | 80         | 11.25                   | Small           |
| SUBARU      | Stella              | 9.00               | 80             | 11.25      | Small                   |                 |
| Tata Motors | Indica EV           | 25.00              | 200            | 12.50      | Small                   |                 |
| TESLA       | Roadster/Model S    | 55.00              | 300            | 18.33      | Large                   |                 |

|      |              |              |                       |                   |                                |                       |
|------|--------------|--------------|-----------------------|-------------------|--------------------------------|-----------------------|
|      | Think        | City         | 28.50                 | 180               | 15.83                          | Small                 |
|      | Toyota       | FT-Ev        | 11.00                 | 150               | 7.33                           | Small                 |
|      | Volkswagen   | E-Up!        | 18.00                 | 130               | 13.85                          | Small                 |
|      | Volvo        | C30 BEV      | 24.00                 | 150               | 16.00                          | Mid-Size              |
|      | Zenn         | CityZENN     | 52.00                 | 400               | 13.00                          | Small                 |
|      |              |              |                       |                   |                                |                       |
|      | <b>Brand</b> | <b>Model</b> | <b>Capacity (kWh)</b> | <b>Range (km)</b> | <b>Consumption (kWh/100km)</b> | <b>Classification</b> |
| LDVs | Alke         | ATX          | 8.40                  | 70                | 12.00                          | LDV                   |
|      | Piaggio      | Porter       | 25.74                 | 110               | 23.40                          | LDV                   |
|      | Melex        | XTR          | 4.32                  | 60                | 7.20                           | LDV                   |
|      | Modec        | Delivery     | 50.00                 | 100               | 50.00                          | LDV                   |

Table 1. Main features of the fully electric vehicles (cars and light duty vehicles) already present in the market or expected to be commercialised in the near-term (energy consumption is not well-to-wheel). Technical information has been retrieved from different official and non-official sources. Official sources have been reported in the references.

### 3. Electrical vehicles and the urban environment

It can be said that the main reason for urging towards the introduction of Electric Vehicles in the private vehicle market is its possibility to reduce the pollutant emissions in the urban environment. This consideration only partially holds for greenhouse gases and in particular for the carbon dioxide (CO<sub>2</sub>). Indeed considering that a high percentage of electric energy is produced by means of power plants using fossil fuels and that the impact of greenhouse gases has to be seen at a global level, it is worth estimating the possible reduction (if any) of the total CO<sub>2</sub> emitted by the vehicle fleet in an urban environment. It is obvious that to be able to do this an estimation of the electric vehicle market penetration and its evolution in an urban environment is required.

#### 3.1 Market penetration of electric vehicles

The deployment of electric vehicles will depend on a large variety of factors. This includes the performance and costs of batteries, the access to the distribution grid and its efficiency, the type of business model implemented to supply the consumer with reliable batteries and electricity, the acceptance by the consumer of new vehicle types and possible implied driving habits.

This diversity of, and interlinks between these factors make any market projection extremely difficult and impossible to define one single scenario about the penetration of electric vehicles. Several sets of assumptions can be made on the above-mentioned aspects, resulting in different expectations on the market penetration of electric cars.

In the open literature it is possible to find studies in which the market penetration estimation is very optimistic. In Clement et al. (2007-2008), PHEVs reach the 28% of the total Belgian vehicle fleet in 2030. In Hadley and Tsvetkova (2008), it has been estimated that by the year 2020, PHEVs will achieve a constant 25% market share, reaching the number of 50 million of vehicles in 2030 in the USA. Other studies also confirm these estimations although present fleet composition does not seem to support these penetration scenarios; however, as

already stated above, the problem has too many degrees of freedom (as outlined also in Simpson, 2006).

More recently two studies addresses within the broader aim of the work the market penetration of electrical vehicles. In the first one (Perujo and Ciuffo, 2010) the approach was to make three scenarios and it was constraint to the case study of the city of Milan and its metropolitan area:

Scenario (1) assumed in 2010 that 0.5% of the vehicle fleet is made up of electric vehicles. Then the number of vehicles evolves in time assuming that the forecasted market share follows a logistic trend calibrated on the trend that methane (CNG) and Liquefied Petroleum Gas (LPG) powered vehicles have had in the period 2000-2009. This assumption is based on the idea that from the consumer perspective the electric technology has fairly the same appeal as the other "alternative" ones.

Scenario (2) assumed in 2010 that 1% of the vehicle fleet is made up of electric vehicles. Then the number of vehicles evolves in time assuming that the forecasted market share follows a logistic trend double than the one calibrated on the trend that CNG and LPG powered vehicles had in the period 2000-2009. This assumption is based on the idea that from the consumer perspective the electric technology has fairly the same appeal than the other "alternative" ones apart from the fact that electric vehicles do not suffer from the limited availability of service stations.

Scenario (3) did not considered a specific future trend, the impact of different percentages of electric vehicles on the whole fleet at a 2030 time horizon were evaluated (from 10 to 30%). This evaluation was carried out in order to show the impact on the electric supply system of a wider penetration of electric vehicles on the vehicle market, also according to the scenarios forecasted in Clement et al. (2007-2008) and in Hadley and Tsvetkova (2008).

With these assumptions the authors arrived to an EV-fleet share in the area of study in 2030 of 1.55 and 3.09% for scenarios (1) and (2) respectively.

The second study addresses the market share at European level. Having developed an enhanced version of the TREMOVE 3.1 model, Nemry and Brons, (2010) constructed and compared four market penetration projections taking into account two major drivers, i.e. technology progress of batteries and access to charging infrastructure. For each of them, two extremes scenarios (conservative and ambitious) were considered. The four projections are compared with a reference scenario in which the electric vehicle market doesn't develop. The energy efficiency of ICE cars gradually improves in accordance to the EU target on CO<sub>2</sub> emissions. This means that by 2015 and 2020, new ICE cars average emissions in the EU would be respectively 135 g CO<sub>2</sub>/km and 115 g CO<sub>2</sub>/km. Then, from 2025 onwards, the emissions are limited to 95 g CO<sub>2</sub>/km.

In all four scenarios, the market deployment of pure electric cars and plug-in cars is endogenously determined by the cost efficiency (especially fuel costs and investment/maintenance costs) and by their effective range (determined by both battery capacity and access to charging).

Scenario assumptions on batteries cover two extreme future trends. In the conservative case, technical progress is slow and limited to a better durability while the usable SOC window remains unchanged. A continuous cost reduction is assumed, up to ~300 €/kWh. In the ambitious case progress is faster and more radical (200 €/kWh by 2030). Technology progress results in a much better durability and, also a higher useable SOC window.

With respect to infrastructure charging, given the already planned investments in various countries, the access to charging facilities is expected to increase in the future. At least,

current charging possibilities – mainly at home, where garages exist - are already or will be extended in a relatively short term. These existing national plans are implicitly considered in the most conservative scenario but are not assumed to get much more ambitious in the future. In the second scenario (ambitious scenario), an even larger scale infrastructure charging deployment is assumed for all countries. It is to be noted that the potential role of fast charging is neglected in both scenarios.

Without surprise, the estimated market shares drawn by Nemry and Brons (2010) of electric cars (BEVs and PHEVs) are shown to increase when charging infrastructure deployment and battery progress are fast and significant. Charging infrastructure deployment, through a wide access to the grid at home and in other places (especially work places) contribute to offer to more car buyers a wide range of car options able to meet their need – not only conventional car but also electric cars. Battery progress seems to be the second-order driving factor and contributes to make the electric cars more performing and cost efficient so that it can better compete with its conventional counterparts.

The expected trends on these two aspects explain that in all cases the BEVs sales shares remain limited until 2020 (0.5% to 3%). On the contrary, PHEVs, rapidly penetrate as soon as they are available on the market. This results from the fact that battery and charging infrastructure represent higher constraints for BEVs.

The EV-fleet share calculated (modelled) by both studies are consistent in the time horizon 2020-2030 albeit the area of study (metropolitan area of Milan and the EU) are quite diverse and the bases for the scenario choice are different.

### **3.2 Potential EV impact on the overall CO<sub>2</sub> emission in an urban environment**

In 2009, both the European Union (EU) and G8 leaders agreed that CO<sub>2</sub> emissions must be cut by 80% by 2050 if atmospheric CO<sub>2</sub> is to stabilise at 450 parts per million (CO<sub>2</sub> equivalent) keeping the global warming below what it is considered to be the safe level of 2°C. But 80% decarbonisation overall by 2050 requires 95% decarbonisation of the road transport sector.

There are many options to achieved decarbonisation (through efficiency, biofuels and electric power-trains including hydrogen). However with a forecasted large increase of the number of passenger cars (rising up to 273 million only in Europe – and to 2.5 billion worldwide) by 2050, full decarbonisation may not be achievable through the expected improvements in the traditional internal combustion engine or alternative fuels alone. Furthermore if this scenario is combined with the increasing scarcity and cost of energy resources, it seems that electrification of road transport using low-carbon electric power-trains and hydrogen fuel cells is vital to ensure the long-term sustainability of mobility in Europe (European Commission, 2010a)

It is obvious that electric vehicles do not have tailpipe emissions of pollutants i.e. CO, NO<sub>x</sub>, THC, NMHC, particles or others (aldehyde and VOCs). However, the electricity needed to propel the vehicle needs to be produced somewhere and that energy production depending upon the type of power station used will contribute to the overall environmental impact of EV. Nevertheless, it can be argued that the pollutants mentioned above have a local impact and therefore the use of EV in the urban environment will contribute to a drastic reduction of those pollutants in the urban air. One major benefit of electric vehicles is the "displacement" of harmful air pollutants from urban to rural areas, where population exposure is lower. Noise levels are also lower, particularly in urban driving conditions. However, the GHG (here we are mainly referring to CO<sub>2</sub>) emissions have a more global

effect and therefore the energy production needed to be used in EVs have a role in the overall global CO<sub>2</sub> balance. This section addresses the levels of CO<sub>2</sub> reduction that the introduction of electric vehicles could provide depending upon the different EV penetration levels in an urban vehicle fleet.

This duality of electrification of road transport and emissions from the power sector has been studied by Unger et al. (2009). They compared the overall impact on climate and air quality by using energy resources for electric power for vehicles with zero carbon intensity, such as wind and solar power, and those from standard power plants. Their study suggests that a 50 per cent reduction in road transport emissions as a result of using more electric vehicles will result in a cooling effect on the climate. Their conclusion is based on different combinations of the warming and cooling effects due to the contribution of road transport and power plants to climate change by emitting long-lived CO<sub>2</sub> and short-lived pollutants. Non-CO<sub>2</sub>, short-lived pollutants also contribute to air pollution and include ground-level ozone and the fine aerosol particles: sulphates, organic carbon and black carbon. CO<sub>2</sub>, ozone and black carbon contribute to global warming, but sulphates and organic carbon reflect the sun's heat back into space, causing a cooling effect. They considered scenarios over 20-year and 100-year periods. For all scenarios, they estimated whether emissions from road transport and power generation would have a warming or a cooling effect on the climate. For both cases (no carbon base and standard power plants) a net overall cooling effect is achieved, albeit in the first case the level of cooling achieved is higher and in a shorter period.

The effect on CO<sub>2</sub> reduction of different penetration level in the urban fleet has been studied recently for the case of Milan and its hinterland (Perujo & Ciuffo, 2010). They used for their calculation the Italian electricity mix that consist of 81% non-renewable sources, thus causing important emissions of CO<sub>2</sub> to the atmosphere, and assuming that for 2030 the CO<sub>2</sub> emissions due to electric energy production will not change as compared with the present values (worse case scenarios as it is expected that the mix will change to lower CO<sub>2</sub> intensities). A similar approach was used for the evaluation of the CO<sub>2</sub> emissions generated by a number of vehicles equal to the number of electric vehicles estimated for the year 2030 in the different scenarios (resulting from the estimated EV share in the passenger cars fleet as reported above). In this case, however, due to the constant technological improvements, it was not realistic to think that in 2030 the vehicles' CO<sub>2</sub> emissions will have the same levels as today. For this reason they evaluated three cases: a) 2030 emission factors equal to 2005 ones (considering only EURO IV technology); b) 2030 emission factors reflecting European 2012 objective to have an average of 120 g CO<sub>2</sub>/veh\*km on the passenger cars fleet and a 50% emission reduction for LDVs, and c) 2030 emission factors reflecting European 2020 objective to have an average of 95 g CO<sub>2</sub>/veh\*km on the passenger cars fleet and a 50% emission reduction for LDVs. This three scenarios goes from a very pessimistic one (scenario a) to a very optimistic one (scenarios b) and c)), since the European objectives refer to a standard driving cycle whose emission factors are lower than those deriving considering an urban real driving cycle.

The results of this exercise showed that even in the most optimistic case, the emission due to ICE vehicles is much higher than emissions due to the electrical power generation. In particular the abatement of CO<sub>2</sub> emissions ranges from the 90% in the scenario a) case, to the 70% with the most optimistic scenario c).

Furthermore, the authors also estimated the average vehicles' emissions value under which the introduction of electric vehicles would not lead to any emissions abatement. An emission



value for CO<sub>2</sub> of 40 g CO<sub>2</sub>/km for ICE vehicles was estimated, which is much lower than that reported in previous studies (e.g. Mackay, 2009). It is worth underlying that these results strengthens the claim that the potential impacts on emission abatement of introducing electric vehicles is larger than further development of engines only apparently “clean”.

The authors also indicated that in order to reach a 20% of global CO<sub>2</sub> emissions reduction, in 2030 the electric vehicles should represent approximately the 25% of the entire fleet of passenger cars and light duty vehicles. Although it could seem quite difficult to be reached, this target may represent a practical objective for policy makers.

#### 4. Cost of EV as compared with other technologies

Consumers buy a new vehicle because many and diverse reasons, including purchase price (one of the main concerns of the majority of buyers when approaching to purchase a new vehicle), depreciation rate, styling, performance and handling, brand preference and social image. However, car owners tend to underestimate the costs of running a vehicle. Although they are very well aware of fuel costs, road tax and insurance, they do not always account for servicing, repair and cost of depreciation. Therefore, if one is interested in comparing the cost of EV with other competing vehicle technologies the parameter of interest should be the Total Cost of Ownership (TCO). The TCO takes into consideration not only the purchase price but also the running cost of the vehicle (i.e. the cost of maintenance, replacement and repair costs, reliability, insurance premiums, taxes, and fuel/energy cost) in other words it describes the costs associated over the vehicle's entire lifetime.

At present the additional purchase costs of a plug-in hybrid electric vehicle as compared with a gasoline one is almost 11000 € and for the case of a pure battery electric vehicle the amount is more than 15000 €, this cost takes into consideration the underlying specific battery costs that is assumed to be 600 €/kWh for hybrid vehicles as well as the PHEV and BEV. This indicates that the high cost driver for both PHEV and BEV is the battery. In reality, the hybrid vehicles will likely use power batteries, while the batteries in the PHEV and BEV will likely be more biased towards higher energy capacity (JRC et al., 2008, Thiel et al., 2010). At the moment the additional cost born by BEV and PHEV is a challenge for the uptake of this class of vehicles.

Many studies have been published trying to look into the future (2020, 2030 horizon) cost of electric vehicles. Most of them include essentially three types of scenarios that can be described generally as a low, medium and high EV uptake (see for example McKinsey, 2009 and Deutsche Bank, 2008).

A recent study (Thiel et al., 2010) makes forecasts of the cost of EV in the above indicated scenarios by taken into consideration the indicative improvement levels in vehicle technology for both EVs and ICEs (including a broad spectrum of vehicles technologies: gasoline, gasoline hybrid, diesel, diesel hybrid, PHEV and BEV). They considered that ICE powered vehicle would have 15% better energy efficiency in 2020 than in 2010, while for the BEV and PHEV no further efficiency improvement was anticipated for 2020 versus 2010 as these vehicles probably feature all near-term conceivable advanced efficiency measures.

In the 2030 time horizon no further energy efficiency improvements were assumed for any vehicle type as they considered that possible incremental improvements were equal for ICE powered vehicles, PHEVs and BEVs in this time frame. Hence, in the relative comparison this would not change the picture.

Learning effects and cost reduction by economies-of-scale are related to the volume production of vehicles. For 2010 it can be considered that all the compared vehicle types would have annual sales volumes above 100,000 units. This number needs to be understood

as a proxy for wider market introduction as the 100,000 unit volumes might not be reached by every compared vehicle type exactly in 2010, but for some only in the following years. However, this would not change the comparison as the 2020 snapshot has to be understood as a proxy for the medium term and the 2030 snapshot should be seen as a longer term outlook. With realized production volumes for the years subsequent to 2010 the authors (Thiel et al., 2010) obtained learning effects that should reduce the costs of the newly introduced components. For the non-hybridized ICE vehicles, a learning rate of 5% was applied only on the newly introduced powertrain/vehicle components. The considered components were those contemplated in a previous study (JRC et al., 2008) and they are amongst others: (i) additional exhaust aftertreatment measures due to stricter emission limits, (ii) starter based stop-start systems, (iii) more sophisticated injection systems for gasoline direct injection but also downsized diesel engines and (iv) turbocharger for the downsized gasoline engine. The 5% learning rate was also applied on 50% of the costs of the ICE engine in the case of the PHEV as a dedicated range extender design of the ICE engine creates cost reduction possibilities. For PHEV and BEV, a learning rate of 10% was applied on the battery, electric motors and other vehicle upgrade costs that are directly linked to the electrification of the vehicle.

The possible cost reduction achievable by learning effect for the components necessary for vehicle electrification (i.e. cooling system upgrade, high voltage wiring, electric power steering, electric drive AC compressor, power electronics and modifications to enable regenerative braking) were based on the cumulative global sales volumes of the respective components. For the year 2020 only one volume scenario was used, while for 2030, two volume scenarios were used, a medium volume scenario and a high volume scenario for the number of BEVs and PHEVs.

These numbers are based on the assumption of 61 million new vehicle sales in 2010, 75 million new vehicle sales in 2020 and 90 million new vehicle sales in 2030, globally. The 2010 figures were used as a starting point for the subsequent calculation of the cumulated volumes (McKinsey, 2009). The 2020 new sales volume of the BEV and PHEV were also derived from McKinsey, 2009 using their mixed technology scenario. Advanced gasoline and diesel vehicles are already on the market today and it was assumed that they continue to penetrate the market reaching each 5 million global sales by 2020. For 2030 it was assumed that advanced diesel and gasoline new sales reach 15 million vehicles each. For these vehicle types, no distinction was made between the high and medium scenario.

The above assumptions, scenarios and learning rate leads to significant cost reductions for the BEVs and PHEVs. In the 2030 high scenario, their calculated purchase costs are already very close to the one of the diesel hybrid. However the additional purchase costs for EV versus the advanced gasoline vehicle in the 2030 high volume scenario is still over 2800 €. This value implies that the specific costs for the battery pack would reach a level below 200 € per kWh for the BEV and PHEV.

The above analysis only considered purchase costs, however concerning the TCO it must be recognized that apart from taxes and incentives, many of the above listed additional factors that influence the TCO most probably play further against the BEV and PHEV in the beginning. For example, the higher vehicle component costs in the BEV and PHEV lead to higher replacement costs and these again adversely influence insurance premiums. However, through continuous improvement and learning effects these disadvantages versus the conventional vehicles presumably reduce over time.

If one considers the long term energy prices (the cost of crude oil will always increase) the payback time for off-setting the higher initial investment for the car owner through the savings that will be achieved in the use phase as a result from the lower use of energy and

lower energy prices for this technology can also be estimated. With a very much conservative calculation of 2030 oil price of 62.8 US \$ per barrel crude oil (2010: 54.5 US \$ per barrel; 2020: 61.1 US \$ per barrel, all given in 2005 \$) the estimated payback time for EV are about 20 years for 2010; however, for the time horizon 2020 the time is reduced to about 8 years while in 2030 (medium scenario) this become 6 years and for the high scenarios it reaches below 5 years. If the longer term oil price is significantly higher (as it can be expected) than the assumed 62.8 US \$ per barrel, the payback period would further improve for the BEV and also the PHEV.

## 5. Challenges in the deployment of electric vehicle fleets

A number of factors can hamper or attenuate a larger scale deployment of electric vehicles. They can be grouped into factors that influence on the one hand the attractiveness of the EV for potential customers and subsequently the field experience of the EV users, and on the other hand the commercial interest of the industry to invest in EV development, manufacturing, sales as well as in re-charging and maintenance networks.

The customer interest will be amongst others determined by:

- Purchase price or lease costs
- Total cost of ownership
- Market offers (brands, models, trim levels etc.)
- Driving experience
- Convenience of re-charging
- Safety perception
- Familiarity with EV technology

The commercial interest of the industry will be constrained by:

- Potential EV market size and its uncertainty
- Profit margin
- Investment needs
- Supply risks
- Risk averseness.

Most experts are in agreement that the technology costs and here mainly the battery costs make the currently offered EVs uncompetitive for the mainstream market when compared with conventional vehicles, even when total cost of ownership (TCO) is taken into consideration. Once, this initial barrier can be overcome learning effects and further technology progress could lead to acceptable payback periods for rational customers in the long term (Thiel et al., 2010). An important factor for the TCO is the residual value of the car. The residual value of EVs is strongly influenced by the expected durability and lifetime of the batteries. Appropriate warranty schemes can help to alleviate related customer concerns. As many private customers do not necessarily perform a TCO calculation but focus very much on the purchase price during their purchase decision, the higher purchase price will remain an attenuating factor in the longer term.

Driving range limitations of fully electric vehicles are a critical factor when comparing to conventional vehicles. Although this factor might not play a big role in the urban and sub-urban context for most of the vehicle users today, it can prevent potential customers from choosing an EV if they are unwilling to compromise vis-à-vis current conventional vehicle ranges. Fast charging or battery swapping could be one possibility to overcome this negative aspect of today's EVs. Other driving aspects like limited top speed and other

typical characteristics of EV driving are not expected to create major acceptance problems for EVs, in particular in the urban and sub-urban context.

EVs are a new vehicle propulsion technology that requires the set-up of a new re-fuelling or in this case re-charging infrastructure in parallel to the vehicle technology deployment. Research work by Flynn (2002), and Struben and Sterman (2008) have studied in more detail the interaction between infrastructure and vehicle deployment. The main lessons that can be learned from these studies are that a strong synchronisation is needed regarding an adequate coverage of re-charging points and the deployment of electrified vehicles. As electricity distribution systems are abundant especially in urban and sub-urban areas, the main challenges remain with the actual set-up of re-charging points and associated to this the setting up of standardised re-charging interfaces, vehicle to grid communication protocols as well as billing procedures and payment schemes. All these aspects need to be carefully addressed to ensure convenient EV re-charging for the EV user. In the urban context adequate re-charging solutions need to be found for city dwellers that have no possibility to re-charge their EV at home.

An important aspect for the potential EV users is that the EVs fulfil the same high safety standards as the conventional vehicle options. The fact that the recently launched EVs fulfil all pertinent safety standards for vehicles and also achieved a high EURO-NCAP rating should positively influence the safety perception of EVs. Nevertheless, some further work needs to be done on improving or creating EV safety, electromagnetic interference and health standards.

Before a larger deployment of EVs is reached, the familiarity of the broader public with this new propulsion technology can be a challenge. The familiarity can be increased through dedicated marketing and media campaigns before a critical mass of EVs is on the road and word of mouth enhances further the public attention.

As already outlined in chapter 3.1, the future market size of EVs is unknown and predictions are highly uncertain. In the past, there have been examples of unsuccessful attempts to bring BEVs into the market. Some of these attempts were accompanied by optimistic outlooks on the future deployment of electromobility; however, a broader EV roll-out did not become reality (Frery, 2000). This uncertainty reduces the willingness of the industry to invest into EV and its related infrastructure. As the automotive industry and the needed infrastructure investment is capital intensive, the industry players are rather risk adverse in this context.

The profit margin for the first EVs will be low. As a matter of fact, it can be expected that the first generation of EVs that are currently deployed will constitute a negative business case for the industry that can be justified as an upfront investment into a potential future growth market. Although, as seen in chapter 2, many manufacturers are preparing for entering the EV market, they will try to limit their investment risk by deploying a limited number of models in the beginning. This limits the offered choices and can turn away potential customers that have a certain affinity to specific brands or models. Another possibility for the manufacturers to limit their investment needs in the beginning is to share common component sets across brands (e.g. Mitsubishi i-MiEV, Citroen C-Zero, Peugeot iOn) or to focus their deployment on selected lead-markets. The latter option will on the one hand limit the necessary investments in the dealer and maintenance network, but on the other hand also reduce the number of potential customers. The re-charging infrastructure providers will also want to ensure an adequate return on their investment which could potentially lead to unsatisfactory infrastructure coverage in the beginning.

Supply chains need to be built up for the new EV specific technologies and components. This can slow down the ramp-up of the EV deployment in the beginning but should not

lead to a sustained supply bottleneck. Material bottlenecks are expected to become an issue for permanent magnet motors (e.g. neodymium) and some cathode materials for lithium ion batteries (e.g. Cobalt) (European Commission, 2010b).

## 6. Policy options and business model for EV penetration

It may be considered that the trend towards transport electrification is on its way and is irreversible. This is for instance suggested by the fact that every large automotive company has or is currently developing electric models and that a considerable number of countries have established plans to foster the development and deployment of EVs.

However, overcoming the challenges discussed in the previous section is essential to enabling a viable market for electric-drive vehicles. This requires strategic planning, public intervention and synergies with private initiatives.

Developing advanced common standards for safety, environmental performance and interoperability are seen as indispensable (European Commission, 2010a).

Both public and private initiatives are needed, and given that electric cars are expected to deploy faster in urban and sub-urban zones, such intervention would, at least in a first stage focus on such areas.

Public-private collaborative strategies at different levels (supra-national, national and local) are needed to address different types of barriers. For instance, within the Public Private Partnership (PPP) “European Green Car Initiative” (EGCI) which is part of the European Economic Recovery Plan<sup>1</sup> these barriers are addressed through a mix of R&D funding and other instruments. A broad range of improvements of performance, reliability and durability of batteries need to be achieved to increase the attractiveness, range and affordability that will condition the consumer willingness to purchase electric-drive cars.

In parallel to those R&D funding initiatives, charging infrastructure needs to be deployed progressively, taking into account of travel patterns, achievable autonomy ranges, urban land use constraints and time availability for car charging at the different parking places, e.g. residential, workplaces, commercial centres, shopping, cinemas.

In Europe, several national or local governments have adopted charging infrastructure plans (e.g. Portugal, Denmark, Netherlands, Spain, Germany). As it is hard to predict how fast and to which extent the market will grow, achieving any "optimal" deployment is improbable. Continuous monitoring of the market, including on consumer attitudes should however guide public planning. Surveys often represent the available basis for establishing such plans. In a survey carried out on behalf the South and West London Transport Conference (Sweltrac), towns - followed by home, work and supermarkets - appeared to be the most popular location for charging points (SWELTRAC, 2007)<sup>2</sup>. In many cases, Governments plans are targeting specific areas and networks (first residential areas and urban zones) and niche markets. Several plans concentrate in cities (Berlin<sup>3</sup>, Paris<sup>4</sup>, London). Besides charging spots in towns, incentives can also be created to broaden the access to the grid at home and at work place. For instance, the French Government plans to require, by 2012, new apartment's buildings with parking to include charging stations. It also plans to

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<sup>1</sup> <http://www.green-cars-initiative.eu/public/>

<sup>2</sup> SWELTRAC, 2007, Provision of Electric Vehicle Recharging Points Across the SWELTRAC Region

<sup>3</sup> Two projects planned covering 100 electric vehicles and 500 charging points (Daimler and RWE)

<sup>4</sup> A network charging was already installed by EDF over the last ten years (84 charging points through 20 Arrondissements in Paris)

make the installation of charging sockets mandatory in office parking lots by 2015. Member States are introducing incentives to companies to install recharging spots (21.5% tax exemption is granted in Belgium). The requirement of installing charging infrastructure could also be integrated into sustainability housing plans and renewable energy targets (see for instance Sheffield - UK).

Progress on battery performance, especially on energy density should help reducing the upfront costs of electric vehicles. In the meantime, innovative policy instruments and business models need to be envisaged and put into place for improving affordability and reducing risk perception associated with a non mature technology could be facilitated with different instruments.

Various business models are being explored and tested involving the automotive industry and new emerging business companies in order to spread the costs of batteries over several years. This includes Battery leasing, Mobile phone style subscription service. Vehicle leasing and Car-sharing also constitute solutions.

Subsidies targeted to niche markets (e.g. taxi fleet), and specific provisions for electric in public purchase procurement (Green Public Procurement) could be used as an instrument in favor of technology learning, experience acquiring of user attitudes, and consumer trust to the new technology.

For the short term, generalizing such subsidies to the mass market may be both unrealistic given available public budget and counterproductive, especially as long as technology maturity is not fully achieved. Also, it is to be expected that ICE cars will still represent an important fraction of the future fleet (by 2030 and even beyond), this also means that their energy performance will largely determine the energy consumption and CO<sub>2</sub> emissions of the transport sector, especially road transport.

For the longer term, a consistent overall fiscal and regulatory framework will be needed to both encourage the most energy efficient technology options and secure public budgets, in accordance with the new fuel consumption revenues.

Long term prospect is also needed with respect to the reliability and sustainability of the supply chain, especially regarding raw materials such as Lithium and rare materials.

These different policies and initiatives will need to be designed and implemented in the light of continuous experience on the new electric car market, both at producer and supply sides and at consumer side. Demonstration projects can help improving knowledge and understanding about consumer behaviour.

## 7. Sustainability of urban transport

In previous sections we have seen how the electrification of the road transport and in particular its use in the urban environment has the potential to reduce the CO<sub>2</sub> and other pollutants emissions in our cities. However this technological change only address one of the three pillars of sustainability; i.e. the environmental dimension, while the other dimensions, economy and society, needs also to be addressed if the challenge of sustainability will be met.

The concept of sustainable transport is derived from the general term of sustainable development. Sustainable transportation can be considered by examining the sustainability of the transport system itself, in view of its positive and negative external effects on: the environment; public health; safety and security; land use; congestion; economic growth; and social inclusion (OECD, 2000).

The social dimension of sustainability of transport is at the core of the main reason for the transport system to exist - to provide access to: resources, services and markets (central

components for the generation of welfare). While the notion of economically sustainable transport relies on full cost accounting and full cost-pricing systems reflecting economic factors which originate from transport activity inhibiting sustainable development (namely, externalities; spillover effects and non-priced inter-sectorial linkages; public goods; uncompetitive markets; risk and uncertainty, irreversibility and policy failures) (Panaytoulou, 1992). Other definitions of economically sustainable transport state that transport must be "cost-effective and responsive to continuously changing demands in a way that commercial and free market can operate without significant adverse externalities and distributional consequences" (UN, 2001).

To achieve sustainable transport a wide range of positive and negative effects (contribution to climate change, congestion, local air pollution and noise) need to be addressed. Research on public attitudes to transport (Goodwin and Lyons, 2010) identifies congestion as a key issue and behaviour change to address environmental issues.

In order to address these negative effects three measures can be identified: (i) pricing measures, most typically road pricing; (ii) alternatives to car based transport (here investment in public transport is a key theme); and (iii) new technologies and fuels.

The use of pricing measurements will reduce transport demand and/or ensure that the demand is "optimal" hence positively impacting on congestion of urban roads. However in order to make pricing generally accepted, alternatives to car based transport needs to be considered. This could include for example increased public transport levels which might ensure that modal shift from car will be met. This measure will contribute to the public perception that non-coercive or "pull" measures are fairer, more effective and correspondingly more acceptable in comparison with "push" measures such as pricing (e.g. Eriksson et al, 2008).

Furthermore, measures to reduce distance travelled, for example through telecommuting or spatial planning, are identified as helping to reduce kilometres travel by personal cars and therefore positively impacting on achieving carbon reduction in the transport sector as well as improving congestion levels in cities and generally on roads.

## 8. Conclusion

With more than 80% of the European population concentrated in an urban environment, the need to insure their mobility while at the same time to safeguard their health and their environment becomes a paradox. Several overarching European policies both in the energy and transport front are trying to change the mobility versus environment conflict.

Electrification of road transport in the urban environment has the potential to significantly reduce the CO<sub>2</sub> emissions (and other pollutants) in the roads of our cities as well as our nearly complete reliance on fossil fuels. This is based on the much higher efficiency of electric motors compared to ICEs as well as the potential to de-carbonise the energy chain used in transportation and in particular in the well to tank pathway. BEVs are much more favourable from a CO<sub>2</sub> Well-to-Wheel emission perspective and PHEVs are a good option as an intermediate step.

However, the high cost penalty that is linked to BEVs and PHEVs will remain a problem until 2030 when learning effects could have reduced the cost penalty to a level that would guarantee acceptable payback periods shorter than six years for the BEV and a level that is comparable to other hybrids cost penalties for the case of the PHEV. If the replacement costs for components or insurance premiums are higher and stay higher than for conventional cars, it could take a longer time until a competitive level for the TCO is reached. Therefore a consistent overall fiscal and regulatory framework will be needed to both encourage the

most energy efficient technology options and secure public budgets, in accordance with the new fuel consumption revenues.

Moreover, to reach a larger deployment of EVs, the familiarity of the broader public with this new propulsion technology need to be addressed. The familiarity can be increased through dedicated marketing and media campaigns before a critical mass of EVs is on the road and word of mouth enhances further the public attention.

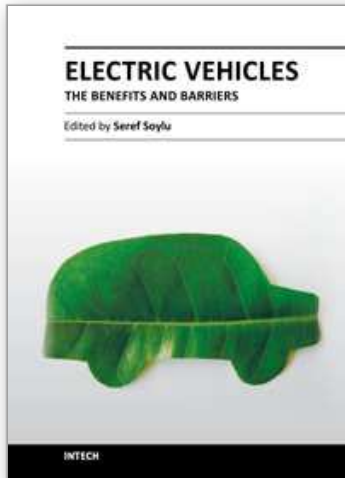
Finally, a word of caution: supporting an extensive use of EV will not contribute per se to the development of a sustainable transportation system. Indeed it can contribute to reduce the environmental pressure due to road transportation, but this represents only one aspect of the sustainable development. In order to really address the paradigm of sustainability it is definitely necessary to implement appropriate measures to reduce the usage of personal transport means (personal car) in favour to collective public transport. This means changing the decisional perspective from a sustainable transport to a sustainable mobility stand point.

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## **Electric Vehicles – The Benefits and Barriers**

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In this book, theoretical basis and design guidelines for electric vehicles have been emphasized chapter by chapter with valuable contribution of many researchers who work on both technical and regulatory sides of the field. Multidisciplinary research results from electrical engineering, chemical engineering and mechanical engineering were examined and merged together to make this book a guide for industry, academia and policy maker.

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Unit 405, Office Block, Hotel Equatorial Shanghai  
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Phone: +86-21-62489820  
Fax: +86-21-62489821

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