INSTITUTE OF ENERGY
FOR SOUTH-EAST EUROPE

"Prospects for the Electric Vehicle Market in Greece and Business Opportunities"

An IENE Study Project (M47)

Final Report

Athens, July 2018

Prospects for the Electric Vehicle Market in Greece and Business Opportunities

Contributors:

Main Author, Alexandros Perellis, Research Associate, IENE

Contributor, Costis Stambolis, Executive Director, IENE

Institute of Energy for SE Europe (IENE)
3, Alexandrou Soutsou, 106 71 Athens, Greece
tel: 0030 210 3628457, 3640278 fax: 0030 210 3646144
web: www.iene.gr, e-mail: secretariat@iene.gr

Prospects for the Electric Vehicle Market in Greece and Business Opportunities

July 2018

This IENE Study Project (47) was financially supported by a number of companies and organizations whose valuable contribution and support is acknowledged herewith with great thanks. The following companies acted as sponsors of the present study

SUNLIGHT Reliable Battery Solutions

HELLENIC PETROLEUM

MYTILINEOS

KG KYRIAKIDES GEORGOPOULOS Law Firm

Contents

List of Figures

List of Tables

Executive Summary

The electrification of the transport sector is projected to play a key role in the decarbonization of the energy system, as long as the grid is powered by "green" power. Electric Vehicles (EVs), which come in various drive train architectures, enabling different mobility features and inside-the-vehicle energy management, consume significantly less primary energy than conventional internal combustion engine (ICE) vehicles. EV technology development has been dictated by the need to provide energy efficient mobility, while providing sufficient electric driving range. Various EV drivetrain and EV battery technologies have been proposed and matured in the early EV market, as presented in **Chapter 2.** The simplicity of the drivetrain architecture of EVs has focused the research and development efforts towards motor control and inside-the-vehicle energy management. Technologies like regenerative breaking/decelerating and autonomous driving have become highly incorporated on EVs. On the other hand EV Battery Technology has transitioned towards batteries featuring cathode materials with excellent electrochemical performance, like Lithium Nickel Cobalt Aluminum Oxide (NCA), which provide high specific energy, reasonably good specific power and a long lifespan. The state of the art NCA batteries can reach significant higher energy densities of 248Wh/kg than their predecessors, namely the highly utilized Lithium nickel manganese cobalt oxide (NMC) batteries. The future of EV batteries is prominent and is likely to feature solid state batteries with low-power but high-energy density, which could provide two to three times the energy storage capability of the current average EV Li-ion batteries, reaching energy densities of 1000 Wh/l (400 Wh/kg).

The Electric Vehicles (EVs) due to their rapid technological evolution are expected to reach parity with the petrol fueled ones during 2018 and eventually achieve a cheaper cost of ownership by 2022, even if the conventional ICE vehicles improve their fuel efficiency by 3.5% per year. It is now obvious that the vehicle market is gradually shifting towards electricity. The EV market overview of the current study, presented in **Chapter 3**, showed that the global sales of plug in electric vehicles reached 753,000 in 2016, 60% of which were battery-electric vehicles (BEVs). China was for the 2nd consecutive year the largest EV market in the world with more than 40% of the global sales, while Europe was the 2nd largest market with 215,000 EVs sold, which corresponds to 28,5% of the global market.

By the end of 2016, the global EV stock surpassed 2 million units, however, despite the rapid developments; EVs are still a minor fraction of the total cars in circulation (0.2%).

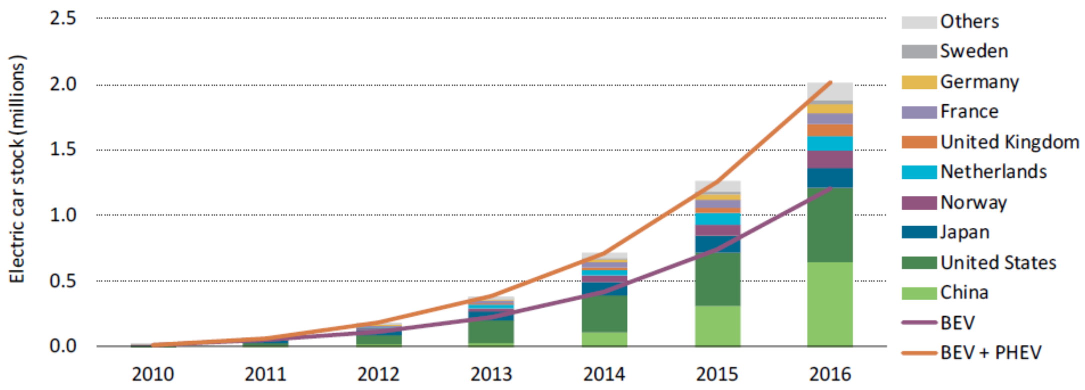


Figure E.1 The Evolution of the global electric car stock, 2010-2016 (Source: IEA)

However, OEMs globally are differentiating their production to include EVs on the aftermath of governmental mandates, declared in major European markets and China. In that direction the presented production targets of OEMs not only seem plausible but are expected to be revaluated upwards as the cost reduction of EVs is exceeding the market expectations.

Table E.1 List of OEMs announcements on electric car ambitions (April 2017) (source: IEA)

OEM	Announcement
BMW	0.1 million electric car sales in 2017 and 15-25% of the BMW group's sales by 2025
Chevrolet (GM)	30 thousand annual electric car sales by 2017
Chinese OEMs	4.52 million annual electric car sales by 2020
Daimler	0.1 million annual electric car sales by 2020
Ford	13 new EV models by 2020
Honda	Two-thirds of the 2030 sales to be electrified vehicles (including hybrids, PHEVs, BEVs and FCEVs)
Renault-Nissan	1.5 million cumulative sales of electric cars by 2020
Tesla	0.5 million annual electric car sales by 2018 1 million annual electric car sales by 2020
Volkswagen	2-3 million annual electric car sales by 2025
Volvo	1 million cumulative electric car sales by 2025

The early stage of EV market has shown peculiarities, which derive from the nature of the technology. EV technology, being an important structural component of the global strategy for Climate Change mitigation, it substitutes the proven ICE vehicle technology, which has undergone many years of development and regulatory integration. It is therefore obvious that EVs cannot compete in economic terms with ICE vehicles, at least in this early stage of their development. Thus, so far EV introduction has been policy driven and is also subject to further global policy imposition until the technology, the manufacturing methods and the supporting infrastructure technology matures to form economies of scale, achieving a significant decline in the value of EV acquisition and ownership cost. A variety of means to promote EVs such as incentives, policies, targets, mandates and regulations have been used by many countries during this early phase of the EV market development.

These include national targets, mandates and regulations, financial Incentives, policies aiming in increasing the value proposition of EVs, public fleet procurement etc. Moreover, market experience in various European countries has shown that influence of applied policies and incentives reflect directly on the EV sales.

In Europe, the second largest EV market globally, electrification of the transportation sector is moving ahead rapidly. At a central policy level, the European commission is considering the introduction of a zero emission vehicles (ZEV) mandate. This regulation is expected to tighten the CO_2 standards for light duty vehicles with the inclusion of a targeted mechanism, mandating quotas for the sales of ZEV. Such legislation is deemed required by many European organizations in order for EU to reach its target of reducing CO_2 emissions from transport by 60% and eliminate the use of fossil fuels in cars by 2050.

However, the restructuring of the automaker industry has already been initiated in a policy level with the introduction of decentralized policies of various member states, like UK and France that announced a ban of conventional Vehicles in their cities in 2040. The bans have prompted intense skepticism and criticism by analysts with regards to their implementation approach. Despite those concerns, the European motor industry has made a turn towards this direction, with biggest European automakers already having made big steps towards prioritizing manufacturing of zero emissions vehicles. The adoption of electric vehicles is within reach, but it is driven by policy rather than demand. Demand and consumer behavior is expected to shift as the sales of diesel/petrol vehicles are banned by member states in the near future (UK, France 2040).

In addition EU is major producer of lithium-ion batteries for EVs, second only to China, with planned capacity of 78.5GWh (2017). Prior to 2017, the EU was falling behind, having inadequate capacity to support its local EV industry, with just one plant planned by LG Chem in Poland with 5GWh capacity. However, the EV battery production activity was accelerated by two facilities, the 34GWh plant of Terra E in Germany and Northvolt' s 32GWh facility in Sweden, with the 7.5GWh plant of SK Innovations in Hungary also playing an important role in the region.

In South East Europe, according to market analysis, the EV deployment has been in a primary state, even though it shows significant annual growth. The main barrier for adoption of electric mobility in the region is the inadequate publicly accessible charging network, which however shows signs of development with most significant initiatives being the activity of ABB in Bulgaria and the prospect of charging network development by HEDNO, the local DSO in Greece, smaller private initiatives, and initiatives of local municipalities, local businesses and institutions.

In Greece, 2017 has been a significant year for electric mobility, as the local EV market share jumped up from 0.06% to 0.19 % with the market almost tripling in volume, achieving a market growth of +243%. The most significant trend is the turn of the consumers towards PHEVs which accounted for 80.1% of the total sales. This turn is prompted by the new PHEV models that were introduced in the Greek market in 2017 mainly offered by BMW and Volkswagen. On the other hand, the sales of BEVs remained stable (-3%), indicating a market stagnation due to lack of fiscal incentives and supporting infrastructure.

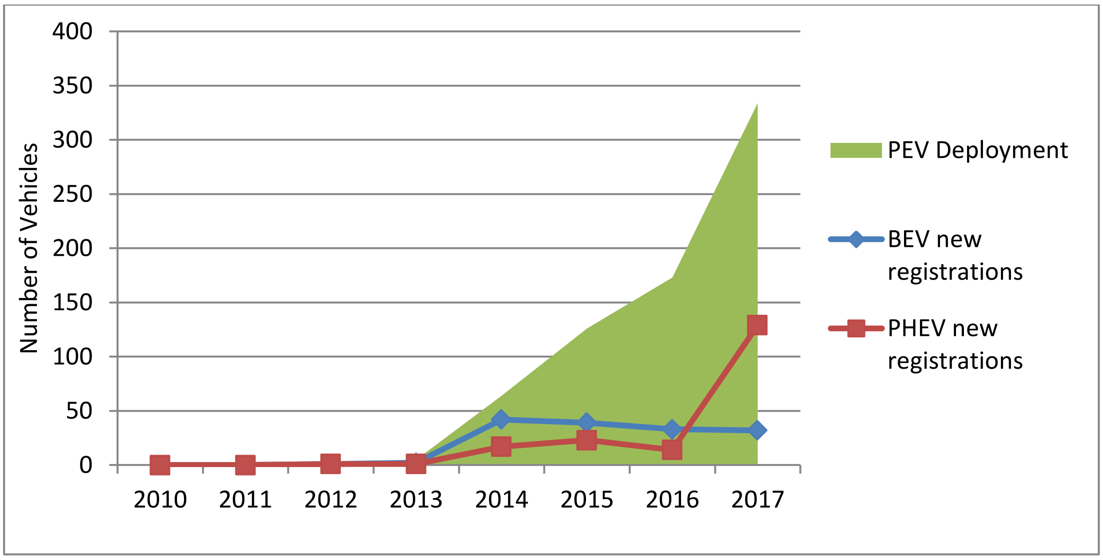


Figure E.2 New registrations of plug in electric vehicles in Greece. (2010-2017) (source: EAFO)

The charging infrastructure development in Greece has been slow and while initially EKO ABEE, a Hellenic Petroleum (HELPE) Group company, has made an attempt to introduce EV charging infrastructure in Greece in 2011, its effort has not resulted in fruition, due to the slow development of the corresponding national legal framework, which is required to regulate charging operations. Currently, there are 45 publicly accessible charging stations in operation in the country, providing 64 charging ports, while operating in a variety of pricing schemes.

Greek EV market is currently experiencing a vicious cycle fed by the inability of the market to provide sufficient publicly accessible charging infrastructure to halt the electric driving range anxiety of the consumers. To break this cycle, in order to initiate the market expansion, the Hellenic Electricity Distribution Network Operator (HEDNO), the local DSO, proposed to the Greek Regulatory Authority for Energy (RAE) a plan for the development of Greece's first country scale charging network, composed of 1,200 to 1,500 EV charging stations connected to the national grid. The implementation of HEDNO's plan is crucial for both the development of the EV market and the development of the retail electricity prices, as the charging network investment costs will be passed over to consumers via their electricity bills. This is an important disadvantage of the DSO model since it will add further socioeconomic costs to Greek consumers who have to confront a continuous economic recession. However, market signals are pointing towards the DSO model since it is the only option for the EV market initiation.

At global level, there has been a significant effort over the past decade to promote interoperability and standardization of conductive EV charging. In **Chapter 4** the current study presents the various technical characteristics of current standardized charging service equipment. Namely, IEC 62196 has introduced 4 standardized charging modes identified by (a) type of current (AC/DC), (b) voltage level, (c) maximum current input (A), (d) maximum power input (kW), (e) communication between the charging infrastructure and the vehicle, (f) type of connectors and (g) circuit protection requirements (earth leakage, circuit breaker protection) as illustrated in the following diagram.

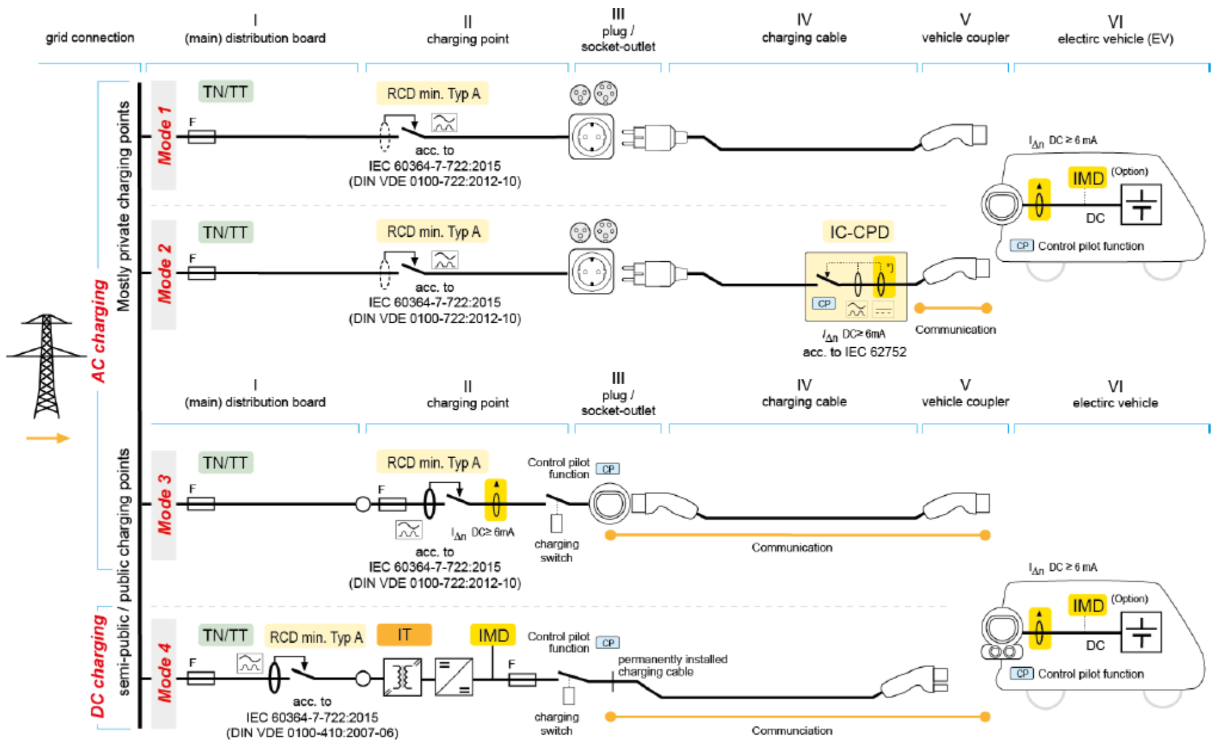


Figure E.3 Charging Modes and technical characteristics of the corresponding charging infrastructure

The Society of Automotive Engineering (SAE) (USA) has also defined through its standard, SAE J1772, charging methods based on limitations in the nominal AC Supply Voltage, the maximum current and maximum power. CEN-CENELEC with the publication of IEC 62196-2 and IEC 62196-3 have issued the technical specifications of 4 type charging connectors corresponding to the standardization of regionally developed charging solutions, with Type 2 (Mennekes) being the one adopted by EU. The main DC fast charging connectors are the CHAdeMO (Japan), CCS (EU), GB/T (PRC), which share similarities but are differentiated in terms of geometry (what type of slow AC connector they accommodate), standardized power output and communication protocol.

Figure E.4 Charging systems illustration (Source: IEC)

Charging safety features on EVSE, protect from potential electrical and fire hazards while connecting, disconnecting, and charging the vehicle. Utilization of battery management system BMS for charging control is also very important for the safe charging operation and vehicle performance. Such a system monitors and regulates the key battery operating parameters of voltage, current and temperature, controls the charging rate to provide the required constant current / constant voltage (CC/CV) charging profile and triggers the protection circuits if the battery's operating limits are exceeded, isolating the battery if needed. The Underwriters Laboratory has issued a series of standards to address the EV charging safety issues.

Furthermore, the study identifies the impact of EV charging on the grid, specifically reflected on power quality, voltage drops and power losses. Battery chargers are power electronics devices, which due to their nonlinear nature can produce deleterious harmonic effects on the electric utility distribution system. According to studies the magnitude of the total harmonic distortion (THD) of the charger device's actual current (THDi) varies from 2.36% to 5.26% in the begging of charging and could reach up to 28% at the end of charging, while other researchers claim lower THD values ranging between 1 and 2% with a power factor very close to unity. Research also pointed out that Total Demand Distortion (TDDi) limit analysis should be applied instead of the THD limitation since there is a variation of the current during charging cycles. Research also investigated the ideal topologies for residential, power level 2 (Mode 2), EV charging, which are proposed to be distribution systems with system voltage of 240/250V and power level of 8 kVA.

A significant impact of EV introduction is the voltage drop caused by system congestion induced by simultaneous EV charging. A typical charging load is between 10 to 30 kW, so a simultaneous charging of multiple vehicles in the same distribution branch might cause congestion. Under these circumstances, the voltage at customer premises might drop below acceptable and/or statutory limits. Moreover, in the case of severe overload, the distribution conductors might get damaged due to overheating. In addition, academic literature pointed at the impact of EV charging in the aging of the transformers of the power distribution system. Extended research focused on the impact of fast constant power charging has been recently commenced. Also increasing EV charging could multiply feeder losses, which would affect the power distribution system based on their relation to the load factor and load variance as illustrated in recent research works.

The growing number of EVs will eventually drive peak demand higher, which, in turn, might compromise the overall reliability of the grid. Insufficient generation and transmission, commonly referred to as blackouts and rolling brownouts, will be the impact of imbalance on the system. The grid must be capable of delivering the power necessary to charge EVs, even on the most congested days. Because of that, the peak capability serves as the limiting factor for EV adoption under the current grid constraints. To mitigate the effects on the distribution system the distribution system operator (DSO) may upgrade the network infrastructure by installing bigger transformers and thicker conductors, but such an upgrade could be very costly, especially, if the durations of overloaded periods are short and hence will result in underutilized assets for most of the time.

The future of electric mobility lies in efficient integration of charging needs with power demand. This future becomes a necessity, when , currently, power generation is transitioning towards high integration of Renewable Energy Sources (RES), while in the transport sector the effort for decarbonization has been focused in a turn towards electric mobility powered by “green” electricity. While RES penetration has introduced temporal and spatial uncertainty to power generation, due to the decentralized and interruptive nature of wind and solar power, the mass electrification of on-road transport has also introduced spatial and temporal uncertainty on the demand side with the introduction of Plug-in Electric Vehicle (PEV) charging. Keeping the real-time balance between electricity supply and demand, while also providing PEV charging services according to the needs of consumers, in such uncertain conditions, it is imperative that a demand response from charging operations and consequently increased flexibility of PEV charging loads is present in the power system. Such requirements have prompted the emergence of new market entities, namely PEV Aggregators, which aim at facilitating

PEV smart charging services, while they participate actively in the electricity market via complex interactions with other market entities.

There are two approaches in performing demand response through PEV smart charging. The centralized approach is focusing on aggregation of charging operations, where emerging market entities (i.e. PEV Aggregators) manage temporally and spatially the charging load of a large EV fleet with advanced optimization models which are aiming at improving the quality of charging services, providing the state of charge (SOC) required by the user, while they provide ancillary services to the grid by participating in the day-ahead, intraday and balancing electricity market. The decentralized approach is focusing on individual scheduling and demand response of EV agents. Such approach is only effective when the intelligence is distributed among the power system components with the integration of smart metering and other automated processes chosen by each electric vehicle-charging infrastructure system by reflecting the condition of the local power system.

Smart Charging can also include discharging of electricity from EVs to the grid. Vehicle to Grid (V2G) technology, which is the bi-directional electrical energy flow between plug-in electric vehicles and the power grid, is used to sell demand response services by throttling the charge rate, shifting the charging time or returning electricity to the grid. Namely the benefits of V2G technology are financial benefits, which occur when efficient management of the energy stored in the vehicle can be used to avoid both peak tariffs at times of high demand and an extra strain on the power grid. The vehicles through V2G can be used as a home energy storage system helping home-owners to perform cost-effective management of power resources. V2G can also contribute in avoiding start-ups of carbon intensive units, thus contributing to the reduction of the carbon intensity of electricity. However, V2G has drawbacks in regards to the extra energy cost resulting from the extra charging, which would be required for the maintenance of the required state of charge (SOC). The extra charging also is responsible for battery depreciation roughly equivalent to 83% of the price of electricity (Greece) and capacity reduction due to battery aging. In addition maintaining the required SOC would be harder with a V2G system; thus emergency driving needs might not be covered adequately.

Various business models have been developed either individually or in collaboration with various municipalities globally for the facilitation of EV charging and integration. Namely Autolib' in Paris, Spark in Sofia as well as various EV charging applications bringing together all parties participating in EV charging market (DSOs, charging infrastructure operators and EV user). Such applications, like "Virta" are aiming in optimizing the charging process for the benefit of all EV charging market participants.

In an EV price decomposition presented in **Chapters 3 and 5**, it is highlighted that the most expensive component of EVs is currently the battery, which corresponds approximately to 50% of their value, while it is projected to sustain a massive cost reduction due to technological development and scaling up of production, reaching between 18%-23% of EVs price by 2030.

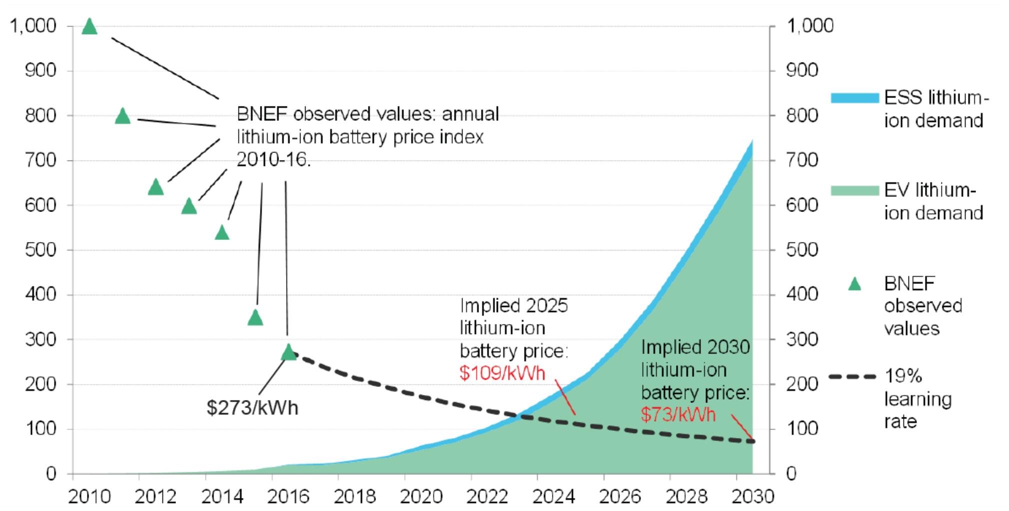


Figure E.5 Lithium- ion battery historical and forecasted prices and projected demand (source: BNEF 2017)

In a recent study Bloomberg New Energy Finance (BNEF) it was estimated that the EV battery cost will decrease below $100/kWh by mid-late 2020s, reaching an average price of $73/kWh in 2030. The same study predicts that economies of scale for an average, state of the art, battery production unit of 3GWh/year capacity, will have an effect in battery price reduction of 2.5% while technological advancement will lead to a battery pack capacity increase of 5% per annum, achieving a twentyfold production of 60GWh/year by 2030. The battery price reduction development will lead to a steady decline of EV cost, with expected acquisition cost equivalence with ICE vehicles expected to be achieved in 2025.

Also, an analysis by MIT researchers indicated that without proper planning there would be short-term shortages of some metals required for the rapidly increasing lithium-ion EV battery manufacturing. The specific study, showed that while nickel and manganese, being materials used much more widely in other industries, are not affected even if the battery production ramps up in very high levels in the next decade, a short term scarcity could appear in Cobalt and Lithium supply. Moreover, according to BNEF the global reserves of lithium are not close to depletion even with the consideration of the great growth of the EV market, which is expected to increase more than thirtyfold by 2030 dragging upwards the battery manufacturing and the lithium demand. It's characteristic that in the next decade, taking into account the great increase of the EV market, it's expected that less than 1% of the known lithium reserves will be extracted. Market experts estimate that even if the market triples there are 185 years' worth of known reserves in the ground. Even though the price of lithium has skyrocketed, reaching approximately $22/kg (02.2018), it is still relatively low to significantly affect the battery pack price, since indicatively the highly utilized NMC(111) battery pack contains only 12% Lithium compared to the 30% of the expensive cobalt.

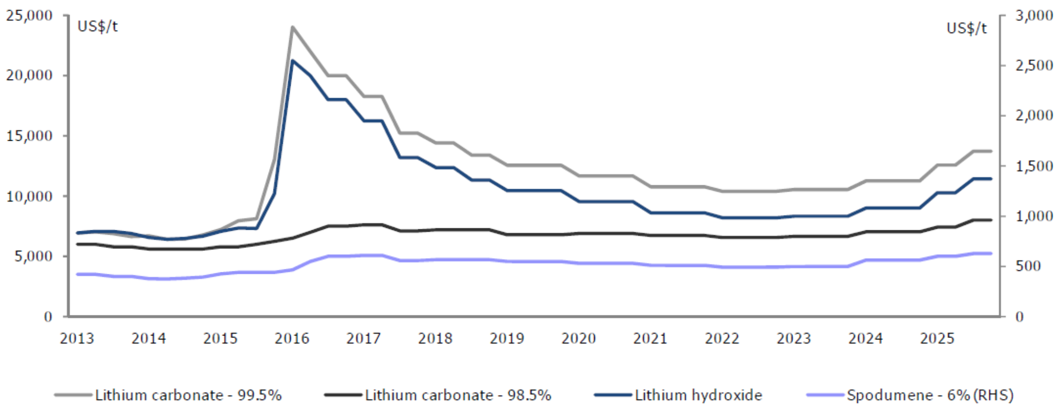


Figure E.6 Price forecasts for 99.5% & 98.5% lithium carbonate, lithium hydroxide and 6% Spodumene concentrate (sources: Deutse Bank & Asian Metal company data)

Cobalt supply is a more complicated case since it is typically a byproduct of other mining activity, namely nickel and copper extraction. The main problem that disrupts the cobalt supply is focused on the inability to initiate new mining operations, since higher prices induced by scarcity won't stimulate new supply in the way they would in other commodity markets. Even so, the market of cobalt has doubled from the end of 2016 to the end of 2017 reaching a market value of $8 billion, but its value is expected to be stabilized or even drop by 5.3% in 2018, as projected by BMO Capital Markets, while Glencore Plc and Eurasian Resources Group ramp up major new cobalt projects in 2018 and 2019. Cobalt has the biggest price leverage on EV battery pack cost, which indicatively is reflected on the NMC(111) battery pack price as an increase of 4.3% per doubling of its price, which occurs due to its already high price of $75/kg. This leverage of the cobalt in battery packs is also more impactful because of the volatility of cobalt's price caused by short term bottlenecks in supply.

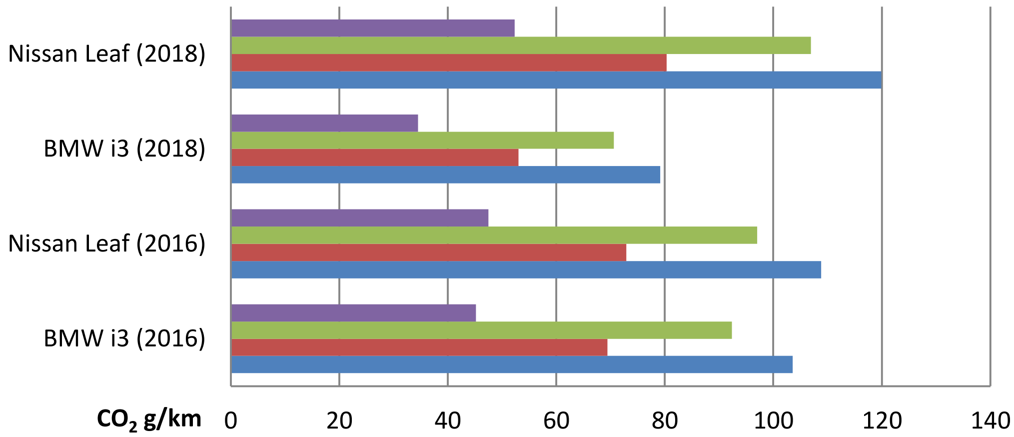
Moreover, the Lithium-ion battery industry has seen a transformation since 2014 with the introduction of larger facilities with producing capacity on a multi gigawatt scale, being the dominant trend in today's industry (2017), with 26 battery cell plants that are either in production and due to expand capacity, or new operations due to be in production by 2021 with a combined operational and planed capacity of 344.5GWh/year. Also the need to localize production to support the local EV industry is also one of the highlighted trends in the battery industry. China is the dominant force in the industry with 49% of the planned capacity totaling 169 GWh followed by Europe with 23% consisting of 78.5 GWh.

Expectations for base vehicle cost reduction include body and chassis production cost reductions, which are expected to drop for battery electric cars, due to simpler design and easier manufacturing. Such Chassis have been developed by various OEMs with the most research and cost efficient material so far been carbon fiber. However, even though there are certain OEMs moving towards reduction cost of the low weight car chassis, so far industry is offering the same category vehicles with the new lightweight carbon fiber chassis in non-cost effective value of more than double the price in comparison to conventional constructions.

It is also expected that electric powertrain costs for BEVs, such as motors, inverters and electronics, will drop by about 20-25% by 2030, mainly due to volume manufacturing. A study by the investment bank UBS found out that EV powertrains are $4,600 cheaper to produce than the cost the vehicle industry endures, leaving a lot of reduction potential to be exploited in the future.

One of the high advantages of EVs is the low operational cost resulting from the low electricity prices in comparison to oil products consumed by conventional Internal Combustion Engine (ICE) vehicles. As highlighted in **Chapter 5** EV sales are correlated and should be influenced by petrol prices. As declining or stable petrol prices help the market move towards peak oil demand, it is evident that the projected ownership cost competition between EVs and conventional ICE vehicles will turn in favor of ICE vehicles. This is due to the fact that EVs are not projected to achieve acquisition value parity with ICE vehicles until the mid-late 2020s' and at this point a rapid decline of oil prices driven by the trending electrification of the transport sector would be most probable. However, operational cost parity of ICE vehicles with EVs will is most unlikely to be achieved. Petrol's price decomposition for 2017 showed that in the US's market petroleum retail vendors cannot offer petrol below $1.22 per gallon to compete with electricity prices because such a transaction would be a loss-making one. However, this petrol floor price could vary due to spatial and micro-economic characteristics of the market, the exploitation of which could potentially formulate a marginal price of oil for which running costs of an ICE vehicle would be competitive to the ones of an EV. In addition this competition between oil/gas prices with electricity could potentially push marginally the electricity prices in retail market upwards as the demand increases and more cost intensive power generation units enter the energy mix.

The most important Environmental impact of EV introduction, as presented in **Chapter 6** of the current study, is the avoided CO_2 emissions by the substitution of carbon intensive vehicles. Indicatively, an introduction of 1,000,000 EVs in Greece, assuming they substitute the most carbon intensive passenger vehicles in circulation, can lead to a total fleet tailpipe CO_2 emission's reduction of 1.8 million tons of CO_2 per year. Moreover, considering the current carbon intensity of electricity of Greece, of 582 g CO_2 /kWh (2015), such introduction could result to 1.02 million tons of CO_2 per year equivalent to 12.5% total CO_2 fleet emissions' reduction. The effect of such a substitution could become more significant as the power system transitions to higher RES integration.



	BMW i3 (2016)	Nissan Leaf (2016)	BMW i3 (2018)	Nissan Leaf (2018)
IEA's RTS Scenario for 2060	45.212	47.498	34.544	52.324
Global Average (2014)	92.382	97.053	70.584	106.914
IEA Member Countries' Average (2015)	69.42	72.93	53.04	80.34
Greece (2015)	103.596	108.834	79.152	119.892

Figure E.7 Indirect CO_2 Emissions of reference EVs in systems with different carbon intensity of electricity
NOTE: [1] For BMW i3 (2018) the fuel consumption and CO2 emissions utilized in the formulation of this graph were determined in accordance with the measurement process as defined by European Regulation (EC) 715/2007 in the versionapplicable at the time of type approval.

Moreover, EVs also transition towards lower carbon footprint exploiting the decoupling of CO_2 emissions, energy consumption, water usage and waste generation from production growth, which automotive industry has achieved the past decade, while the second life of EV batteries will further enhance their low carbon footprint profile. The avoidance of major air pollutants emitted by the substituted conventional ICE vehicles in major cities is also of great significance. Air pollutants like non-methane hydrocarbons, CO, NO_x, SO_x and particulate matter (PM10 and PM2.5), responsible for environmental pollution, biodiversity disruption and effects on human health are now avoided and their emissions are decentralized towards carbon intensive power generation units, where their monitoring and mitigation are most effective. Other environmental benefits of EV are summarized on the avoided waste water generation by the ramping down of oil refinery processes, resulting from the reduction petrol demand for mobility and noise pollution mitigation at low speeds, below 30 km/h, occurring in urban mobility.

The opportunities for the economies of South East Europe resulting from the emerging electric mobility as illustrated in **Chapter 7**, are various. The local automotive industry of the region mainly located in Turkey, Romania, Slovenia and Serbia has not made a significant turn to EV manufacturing. However, Turkey being one of the major auto-manufacturing economies of the region, producing more than 1.7 million vehicles per year, while having 9 R&D facilities, which extend their operation beyond supporting the local industrial operation, has a lot of untapped potential in becoming an important market for the EV transition. In Romania the prospect of Dacia, in producing a very cost-effective EV, while utilizing the underpinnings and the electric motor of Renault ZOE, thus exploiting the advantage of its participation in Renault-Nissan Alliance, is deemed very important for the acceleration of EV adoption in the region. South East Europe also has highly trained engineering professionals, who can help meet the requirements of EV R&D operations in the region. Significant, to that extent, is the fact that according to the Technical Chamber of Greece (TEE), the 35,000 academically trained mechanical and electrical engineers currently active in the local labor market, could help attract the automotive industry operators mainly in the fields of electrical motors, power systems electronics, traction control and information technology and networks.

The automotive component industry being a very significant economic activity in the region must also adapt to the EV transition. Significantly the regional markets segments associated with ICE Engines, transmission systems, fuel systems, exhaust, forging components and small general parts manufacturing are expected to be negatively affected by the transition to gearless, fuel-less, robust new vehicles. However, important segments of the regional manufacturing activity such as wiring, electric component development, electronic architecture systems and components and telematics are expected to attract new investors and expand their activity. Moreover, the RES and electricity distribution industry is expected to be driven by electric mobility acceleration in the future with numerous new projects for new capacity installation and grid enhancement to facilitate “green” power to the electrified on-road transport.

Concluding, the rapid decrease of battery prices is expected to drive the EVs to acquisition cost parity with ICE vehicles by mid-late 2020s’. Consequently such development, given the lower operational cost of EVs to competing alternatives, is projected to escalate the EV adoption worldwide. Market experts predict 60 million new EV sales annually by 2040 corresponding to 54% of new light duty vehicle sales worldwide.

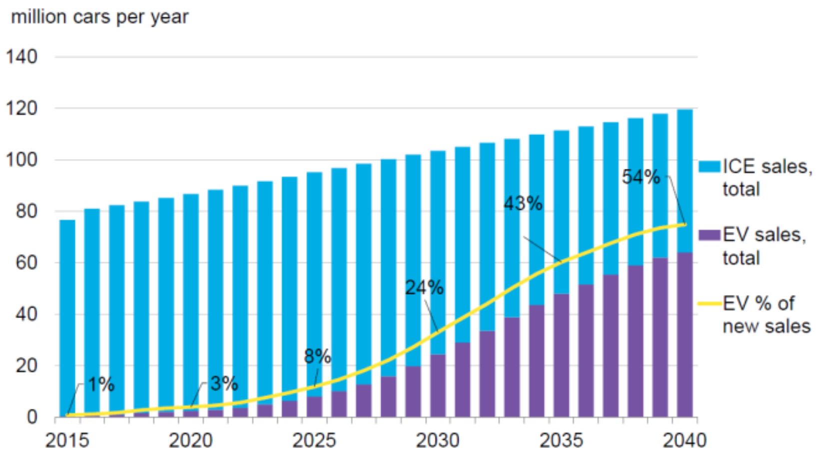


Figure E.8 BNEF's predictions (2017) for the new EV sales till 2040 (source: BNEF)

While, transition towards electric mobility is becoming a reality, the region of South East Europe is presented with an opportunity to adapt its automotive, automotive component, power transmission and RES industry and help thus to facilitate such a transition not only locally but also at European and global level.

1. Introduction

The combination of various parameters which have matured at global level, as well as IEA's scenarios for energy planning reflecting COP21's commitments for climate change mitigation, have helped our understanding and needs for energy transition. The adoption of the 2DS scenario is a milestone for the whole energy sector underlining fundamental changes in the future approach of sectorial energy consumption including transport. These policies focus on the adoption of electric vehicles' (EVs) as a pillar for the support of global action for the decarbonization of the energy and transport sector. Hence, the study of EV development in Greece and in other selected countries in South East Europe becomes imperative for the formulation of a regional planning approach for energy use in transport, in accordance with global environmental policy as it is being proposed by prominent international organizations. Consequently, individual research, aiming towards the reform of the operational objectives of the relevant local industry, becomes crucial towards the formulation of those strategies. The Petroleum Industry, Power Generation Producers, Power Distribution Companies, the Vehicle and Battery Industry should all adapt to the new environment from the perspective of energy transition promotion and decarbonization of the transport sector.

The study places the development of EVs in the future landscape, where in accordance to the 2DS scenario, electrification and high penetration of renewable energy resources will shape the main strategy for the formulation of the future of the global energy mix. In such a framework, it is expected that power producers will be challenged to reduce their carbon footprint by promoting the transition to less carbon intensive fuels such as natural gas and RES, with the gradual phasing out of coal plants. Towards this direction some of the biggest power producers, which were traditionally involved in power generation using oil and coal, are now switching to low carbon technologies and RES. In this framework the introduction of EVs will provide an extra step towards transport decarbonization, thus enhancing mobility which will be supported by low carbon intensive electricity.

The adaptation of EV technology to the mobility needs of the consumers is considered most crucial for the achievement of the new energy mobility transition. The rapidly improving Battery Technology, in terms of cost and energy density, and the diffusion of EV charging technology will play a vital role towards this direction. The power distribution grid and power generation will also have to adjust their capacities to facilitate the electrification of the transport sector. The restructuring, enhancement and expansion of the power distribution network is also important since it will be necessary for securing the system capability for charging in high EV penetration markets. This will constitute one of the great challenges of the system from an economic standpoint, with a large number of parameters at play, each of them crucial for the viability of the system from socioeconomic perspective.

The evolution of the EVs over the past decade was critical in formulating a vehicle technology that is oriented towards diversification of transportation products. The steps taken since 2011 towards standardization and interoperability in charging infrastructure have helped develop the framework of operation, adaptation and market penetration of the EV technology. It is further anticipated that, EVs will be integrated in smart grid systems to act both as a flexible load and as energy storage. This is expected to unlock further the global RES potential by lowering the marginal price of electricity. This will highlight further the importance of coordinated dispatchability of energy resources and flexibility of demand towards a more integrated, smart, low carbon intensive energy system. Hence, the EV Aggregators, which will be the EV charging providers, are charged with the important task of the charging load management.

Furthermore, the cost of vehicles is expected to decline rapidly in the mid-2020s', causing the rapid increase of EV deployment, due to the steepness of the learning curve in production technologies of scale, the new cheaper and more efficient battery technologies, the increment of support infrastructure and charging stations and the establishment of a global EV market experience. The environmental benefits of EV introduction will be very promising with a rapid decrease of the carbon emissions from transport, the decentralizing of the pollution and significant reduction of traffic noise in urban areas.

The main scope of the present Research Note is to inform about the global developments in the EV market and technology as described above, but also to assess the dynamics of EV market development. The study focuses on Greece as a reference country and expands in other South East European countries. It is important to record and describe the crucial technical and non-technical parameters involved in EV technology and its future development as well as the boundaries of the EV adaptation to the present mobility market. In an economically challenging region, it is necessary to proceed with an approach partially detached to the global development to interpret current local economic values and regional peculiarities. Furthermore, EV market experience, derived from more mature markets, will be used in the formulation of predictions for the future development of the EV market in the Balkan Peninsula.

Finally, the study explores the opportunities for economic development derived from electric mobility as well as new types of employment and dynamic entrepreneurship. Furthermore, the study aims in the planning review of EV market interactions as well as the need for undertaking feasibility studies for the development of the market with regard to power generation, power distribution and socioeconomic cost allocation for infrastructure installation etc. For this reason the study concludes with a roadmap proposal that summarizes the findings of the study and offers guidelines for promotion of EV deployment, in the present economic and legal framework, and adaptation to the future power system challenges caused by the electric mobility.

2. Technology

A. Vehicle Technology

A. (i) Advantages and Disadvantages of EVs

Electric vehicles (EVs) have gained a lot of attention in the beginning of 21st century and this attention was related to the ongoing crisis of the energy sector due to an imminent energy transition towards less carbon intensive energy sources, dictated by the need for climate change mitigation. Transportation sector is one of the main contributors to in the greenhouse gas (GHG) emissions globally. Conventional vehicles are the main GHG emission contributors of the transport sector due to the fact that their powertrain is run on fossil fuels (i.e. gasoline or diesel) and its operation emits gases such as carbon dioxide, hydrocarbons, carbon monoxide, nitrogen oxides etc. , further described in Chapter 7.

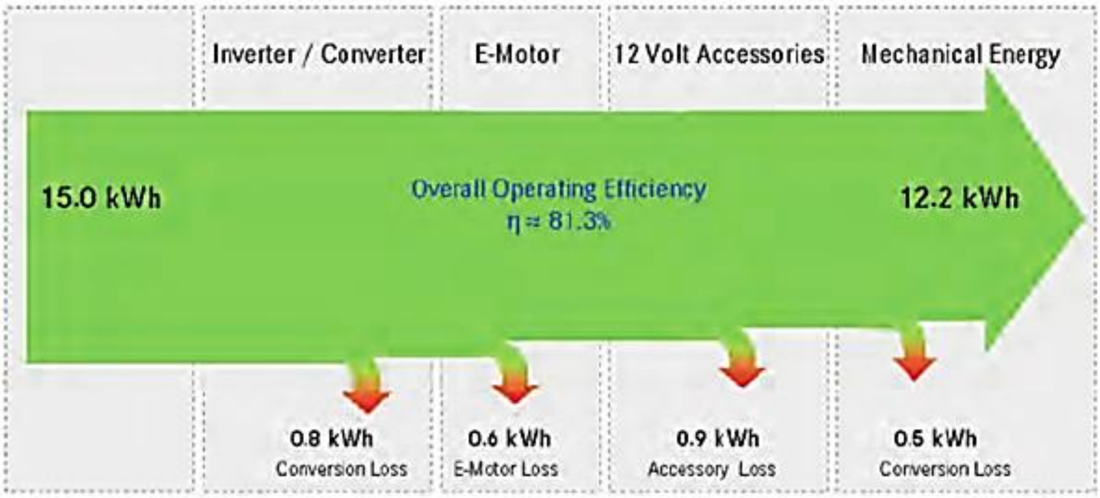


Figure 1 EV Operating Energy Flow and Efficiency Diagram (Source: Abdul-Hat et al. [59])

EVs are part of the solutions that IEA is promoting, which is aiming in large scale electrification, powered by low carbon intensity energy sources of all sectors of human activity. According to the US DoE about 15% of the total fuel energy consumption is utilized to run a conventional car and its other accessories. Most of the energy is transformed into heat during the combustion which consequently and directly is contributes towards global warming [51]. On the other hand EVs use more than 75% of the energy to run the vehicle [51]. Moreover, a survey conducted by Ecofys in 2010 showed that an EV (Nissan leaf) consumes 63.3% less primary energy (0.22 kWh/km) from the source, including transmission losses, than a diesel car (VW Golf 1.6 D blue Motion Technology) (0.60 kWh/km) when the electricity is coming from renewables and 8.4% less primary energy when the EV's power consumption is generated by gas turbines (0.55kWh/km EV, 0.60 kWh/km) [53]. Other studies focusing on the Operating efficiency of EVs showed that the more than 81% of the incoming Electrical Energy, stored in the high voltage (HV) battery of EVs is transformed to Mechanical Energy for the propulsion of the vehicle.[59]

Combining the EV overall charging efficiency with the EV overall operational efficiency, the EV efficiency becomes approximately 67.9 % around four times more efficient than an ICE propelled vehicle with an overall efficiency of approximately 14% [59].

In extend the low operational costs which derive due to the low price of electricity make EVs an attractive solution in markets that subsidize their sales. EVs are also offering transportation free of noise pollution caused by internal combustion engines.

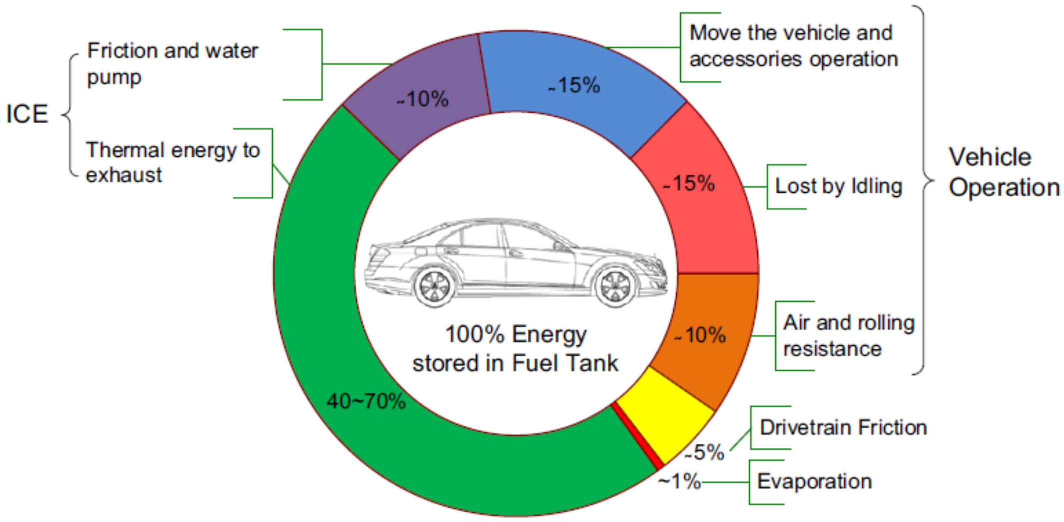


Figure 2 The typical energy flow of conventional internal combustion engine vehicle (source: Tie et al. [52])

The main disadvantages of Electric Vehicle Technology is: (a)The limited driving range, which is enhanced by (b) the lack of publicly available charging infrastructure, (c) The charging time which is spanning from 1 to 40 hours, depending on the power output of the available charging infrastructure and the battery size of the EV, and (d) the high acquisition cost of EVs due to low technology maturity which can be identified in ongoing production ramp ups and adjustments, which are present today in the EV industry.

Table 1: Estimated Charge Times for BEVs for 0 to 100% SOC (State of Charge) (Source: Clipper Creek [64])[1]

VEHICLE	ACCEPTANCE RATE (kW)	BATTERY SIZE (kWh)	LEVEL 1 ACS-15 1.4 kW	LEVEL 1 PCS-15 1.4kW	LEVEL 2 LCS-20 3.8kW	LEVEL 2 LCS-25 4.8kW	LEVEL 2 LCS-30 5.8kW	LEVEL 2 HCS-40 7.7kW	LEVEL 2 HCS-50 9.6kW	LEVEL 2 HCS-60 11.5kW	LEVEL 2 HCS-80 15.4kW
BMW ActiveE	7	32	23	23	8.5	6.5	5.5	4.5	4.5	4.5	4.5
BMW i3 2014-2016	7.4	23	16.5	16.5	6	5	4	3	3	3	3
BMW i3 2017 (60 Ah battery)	7.4	23	16.5	16.5	6	5	4	3	3	3	3
BMW i3 2017 (90 Ah battery)	7.4	32	23	23	8.5	6.5	5.5	4.5	4.5	4.5	4.5
Chevy Bolt	7.2	60	43	43	16	12.5	10.5	8.5	8.5	8.5	8.5
Chevy Spark	3.3	23	16.5	16.5	7	7	7	7	7	7	7
Coda	6.6	31	22	22	8	6.5	5.5	4.5	4.5	4.5	4.5
Fiat 500E	6.6	24	17	17	6.5	5	4	3.5	3.5	3.5	3.5
Ford Focus EV	6.6	23	16.5	16.5	6	5	4	3.5	3.5	3.5	3.5
Ford Focus EV 2017	6.6	33.5	24	24	9	7	6	5	5	5	5
Honda Clarity EV	6.6	25.5	18	18	6.5	5.5	4.5	4	4	4	4
Hyundai Ioniq	6.6	28	20	20	7.5	6	5	4	4	4	4
Kia Soul	6.6	27	19.5	19.5	7	5.5	4.5	4	4	4	4
Jaguar I-Pace	7	90	64.5	64.5	23.5	19	15.5	13	13	13	13
Mercedes B Class B250e	9.6	28	20	20	7.5	6	5	3.5	3	3	3
Mitsubishi i-MiEV	3.3	16	11.5	11.5	5	5	5	5	5	5	5
Nissan Leaf 2011-12 (3.3kW onboard charger, S S Upgrade, SL & SV Model)	3.3	24	17	17	7.5	7.5	7.5	7.5	7.5	7.5	7.5
Nissan Leaf 2013-16 S (3.3 onboard charger)	3.3	24	17	17	7.5	7.5	7.5	7.5	7.5	7.5	7.5
Nissan Leaf S 2013-15 (6.6kW onboard charger, S Upgrade, SL & SV Model)	6.6	24	17	17	6.5	5	4	3.5	3.5	3.5	3.5
Nissan Leaf S 2016 (6.6kW onboard charger, S Upgrade)	6.6	24	17	17	6.5	5	4	3.5	3.5	3.5	3.5
Nissan Leaf S 2016 (6.6kW onboard charger SL & SV Model)	6.6	30	21.5	21.5	8	6.5	5	4.5	4.5	4.5	4.5
Nissan Leaf 2017 (3.3kW onboard charger S Model)	3.3	30	21.5	21.5	9	9	9	9	9	9	9
Nissan Leaf 2017	6.6	30	21.5	21.5	8	6.5	5	4.5	4.5	4.5	4.5
Nissan Leaf 2018	6.6	40	28.5	28.5	10.5	8.5	7	6	6	6	6
Smart Car	3.3	17.6	12.5	12.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
Smart Fortwo ED 2017	7.2	17.6	12.5	12.5	4.5	3.5	3	2.5	2.5	2.5	2.5
Tesla Model 3 Standard	7.7	50	35.5	35.5	13	10.5	8.5	6.5	6.5	6.5	6.5
Tesla Model 3 Long Range	11.5	70	50	50	18.5	14.5	12	9	7.5	6	6
Tesla Model S 60 Single	9.6	60	43	43	16	12.5	10.5	8	6.5	6.5	6.5
Tesla Model S 70 Single	9.6	70	50	50	18.5	14.5	12	9	7.5	7.5	7.5
Tesla Model S 75 & 75D	11.5	75	53.5	53.5	19.5	15.5	13	9.5	8	6.5	6.5
Tesla Model S 85 Single	9.6	85	60.5	60.5	22.5	17.5	14.5	11	9	9	9
Tesla Model S 90 Single	9.6	90	64.5	64.5	23.5	19	15.5	11.5	9.5	9.5	9.5
Tesla Model S 60 Dual	19.2	60	43	43	16	12.5	10.5	8	6.5	5	4
Tesla Model S 70 Dual	19.2	70	50	50	18.5	14.5	12	9	7.5	6	4.5
Tesla Model S 85 Dual	19.2	85	60.5	60.5	22.5	17.5	14.5	11	9	7.5	5.5
Tesla Model S 90 Dual	19.2	90	64.5	64.5	23.5	19	15.5	11.5	9.5	8	6
Tesla Model S 100D & P100D	17.2	100	71.5	71.5	26.5	21	17	13	10.5	8.5	6.5
Tesla Model X 60 Single	11.5	60	43	43	16	12.5	10.5	8	6.5	5	5
Tesla Model X 75 Single	11.5	75	53.5	53.5	19.5	15.5	13	9.5	8	6.5	6.5
Tesla Model X 90 Single	11.5	90	64.5	64.5	23.5	19	15.5	11.5	9.5	8	8
Tesla Model X 60 Dual	17.2	60	43	43	16	12.5	10.5	8	6.5	5	4
Tesla Model X 75 Dual	17.2	75	53.5	53.5	19.5	15.5	13	9.5	8	6.5	5
Tesla Model X 90 Dual	17.2	90	64.5	64.5	23.5	19	15.5	11.5	9.5	8	6
Tesla Model X 100D & P100D	17.2	100	71.5	71.5	26.5	21	17	13	10.5	8.5	6.5
Tesla Roadster	17.2	56	40	40	14.5	11.5	9.5	7.5	6	5	3.5
Toyota Rav4	9.6	41.8	30	30	11	8.5	7	5.5	4.5	4.5	4.5
VW e-Golf (3.6kW onboard charger)	3.6	24	17	17	6.5	6.5	6.5	6.5	6.5	6.5	6.5
VW e-Golf (7.2kW onboard charger)	7.2	24	17	17	6.5	5	4	3.5	3.5	3.5	3.5
VW e-Golf 2017 (7.2kW onboard charger)	7.2	35.8	25.5	25.5	9.5	7.5	6	5	5	5	5

[1] Notes: (a) Acceptance rate refers to the nominal maximum power transfer rate of the charging process (charging level: see chapter 4), (b) Battery size of each vehicle (kWh), (c) columns 3-11 show charging times with different charging rates based on the capability of EVSE - charging infrastructure

A. (ii) EV technology and trends (EV categories)

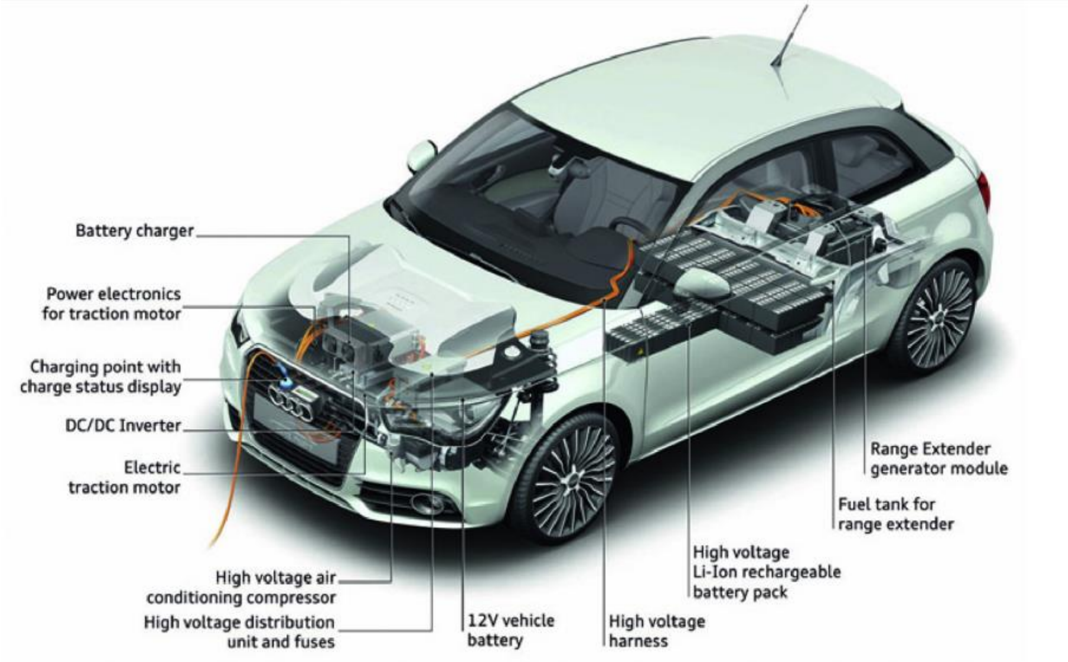


Figure 3 Illustration of the electrical traction system of a Plug-in Hybrid Electric Vehicle (PHEV)

- **Battery Electric Vehicles (BEV)**

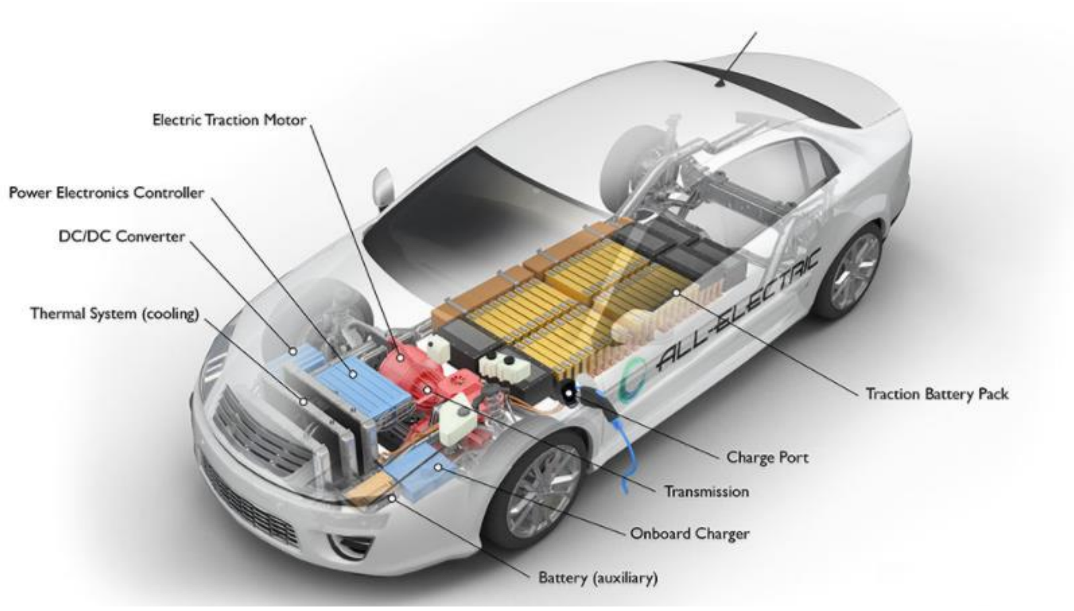


Figure 4 Battery Electric Vehicle (BEV)(source: [25])

BEVs have a purely electric drive, the concept of the battery electric vehicle is essentially simple and is shown in Figure 4. The Battery electric vehicle (BEV) consists of an electric battery for energy storage, the DC/DC converter, which adjusts the voltage of the electric current provided to 2 quadrant inverter or a 4 quadrant bidirectional inverter with a dedicated power electronics controller, which controls the power provided to (and from, in case of regeneration capability) the electric motor. The 4 quadrant inverter utilizes inertia for regeneration (recharging) during deceleration and breaking. The battery, which has a larger capacity than in the same type of PHEVs, is normally recharged through a plug and a battery charging unit, which can either be carried on board or fitted at the charging point. The power electronics controller regulates the power supplied to the motor and hence it controls the vehicle speed forwards and backwards as well as the system of regenerative braking as mentioned above. In absence of a regenerative braking system the power electronics controller is normally known as a 2 quadrant controller. It is usually desirable to use regenerative braking both to recoup energy and as a convenient form of frictionless braking. When in addition the controller allows regenerative braking in forward and reverse directions it is known as a 4 quadrant controller.

The mechanical drivetrain of the BEV configuration is very low making it highly advantageous, due to the low weight of the vehicle and consequently the proportionately low energy losses from the transformation of electrical to mechanical power. High torque traction motors for accelerating the vehicle is the main requirement for this type of configuration; nevertheless they reduce the overall high vehicle efficiency. High torque traction motors have high current flow in the armature winding, leading to heat loss in the motor [21],[22]. BEVs due to their limited range and limited speed are preferred for in-city transportation. A modified powertrain, usually with the addition of a gearbox, can add to driving range and vehicle speed. Such a modification however, lowers the vehicles energy efficiency, which is very high in a powertrain without gearbox due to the lack of moving parts, low rotational inertia and no friction energy losses in the gearbox and the differential mechanism [22],[24]. The most popular drivetrains for BEVs are displayed in Figure 5.

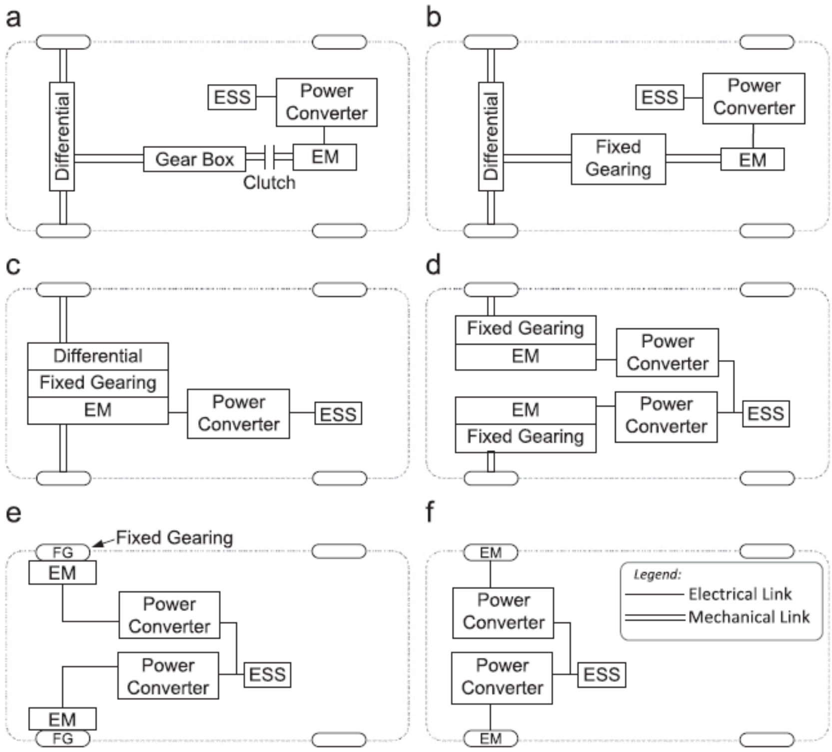


Figure 5 The drive trains architectures on BEV (source: S.F. Tie et al.[52]) :(a) conventional driveline with clutch, (b) driveline with single-gear transmission without clutch, (c) driveline with integrated fixed gearing and differential, (d) driveline with two separate motors and fixed gearing, (e) driveline with fixed gearing and motor, (f) in-wheel drive.

The most common power transfer configurations utilized by the BEV industry. A primal form of electric vehicle that is not widely utilized anymore included a direct transpose of the ICE vehicle system into the EV including the clutch and gearbox (figure 5(a)). Another configuration (figure 5(b)) utilizes a single gear transmission without clutch for as lean transmission system approach aiming in size and weight minimization. A more efficient configuration would be the one illustrated in (figure (c)) with an integrated fixed gearing and differential and a variation of it (figure 5(d)) including an extra motor, one for each driveshaft to differentiate the wheel speed during cornering. On the other hand one very popular configuration is one utilizing a direct drive (without a driveshaft) (figure 5(e)) with fixed gears and dedicated electric motor on the propulsion wheels. In (figure 5(f)) the traction motor is placed inside the wheel making the system more compact. This configuration requires a higher torque traction motor to start the acceleration, hence there are high electric heating losses caused by the high current in the motor windings. However due to the small size of the traction system and the overall mechanical drivetrain this configuration achieves low energy conversion losses (mechanical/electrical). Overall, configurations that enjoy market success in the EV market were the ones without gears which have overall increased efficiency

The battery technology is essential to the overall efficiency of a BEV, with Lithium-ion batteries being the dominant technology utilized due to their relatively low cost matched with high energy density. Moreover, EV batteries are further referred on section B.(ii) of the present chapter. Current technology in all electric powertrain can provide state of the art vehicles such as Tesla roadster, which can accelerate to 100 km/h in 4seconds and travel up to 400 km on a full battery without charging. Furthermore, within a decade (2008-2020) the state of the art BEV powertrain has managed to improve dramatically with the newest version of the Tesla roadster, being expected to reach the commercial markets in 2020, achieving acceleration of 100 km/h in 2 seconds and range of 1000 km, while it can reach max speed over 400 km/h. However, high performance and long range powertrains come yet at high cost and low energy efficiency due to the additional weight of traction control and battery system, which such technologies require [26]. In addition high performance powertrains need an additional highly advanced battery cooling system to constantly keep the battery in optimal temperature.

There is a wide range of electric vehicles of this type currently available on the market. At the simplest, there are small electric bicycles and tricycles and small commuter vehicles. There is a wide range of full sized electric vehicles, which include electric cars, delivery trucks, buses and various sized utility vehicles.

- **Hybrid Electric Vehicles (HEV)**

Hybrid electric vehicles or HEV are vehicles that use both ICE and electric motors as power sources to move the vehicle. There are currently in circulation six drivetrain architectures of HEVs.

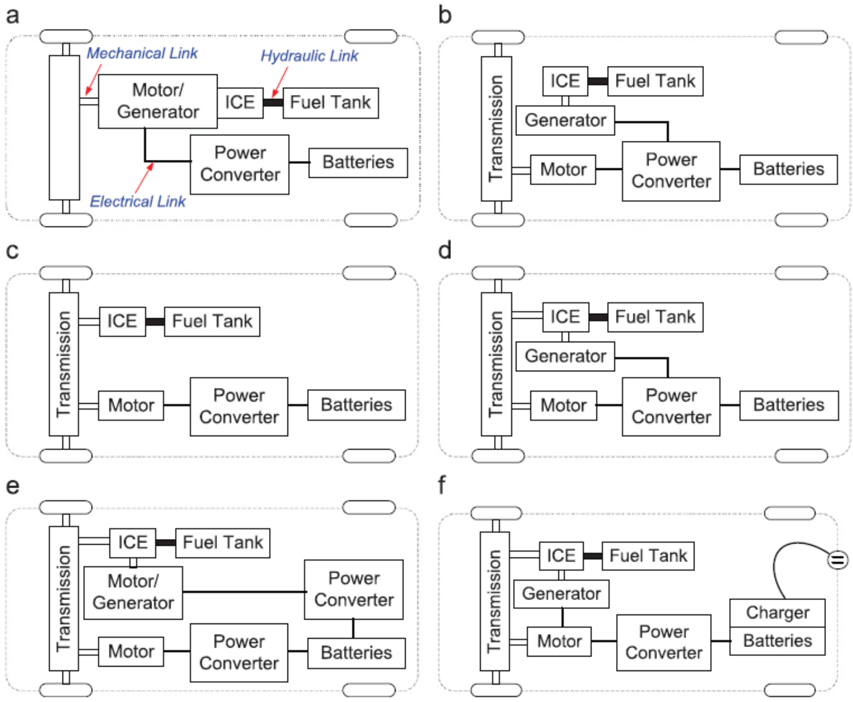


Figure 6 The drivetrains architectures on HEV (source: S.F. Tie et al.[52]): (a) mild-HEV, (b) series full-HEV, (c) parallel full-HEV, (d) series–parallel full-HEV,(e) complex full-HEV, (f) series– parallel PHEV.

The mild-HEV drivetrain has a battery system and electrical motor/generator operating at 7-12kW with 150 V (140V) operating voltage that assists the ICE. Because ICE (primary power) and the electrical motor share the same shaft the drivetrain cannot operate on the battery system alone. This type of configuration can gain up to 30% fuel efficiency by reducing the size/weight of the ICE [52]. However, the mild-HEV (fig. 6(a)) is not very commonly used in the latest HEV models in circulation due to the industry's pursue of the advantages of the split power path that allows separation and optional utilization of the ICE and the electric motor (EM). Full-HEV configuration can gain up to 40% fuel efficiency by employing a high capacity energy storage system (ESS) operating at 330V (288 V). Full-HEV can be either extended range vehicles (ERVE) or series full HEV (fig. 6(b)), parallel full HEV (fig. 6(c)), series parallel full-HEV (fig. 6(d)), complex full HEV (fig. 6(e)), and plug in hybrid electric vehicles PHEVs (fig. 6(f)) [52]. EREV employs an electric motor as the only powertrain but also includes an efficient ICE power generator for battery charging when batteries are in a low state of charge (SOC). EREVs, depending on the availability of external battery charging option, can be recognized as either series full-HEV or series PHEV. One of the most successful EREVs in the market is Chevrolet Volt [54] The advantage of this configuration is that vehicle's battery design can be adjusted to the mobility needs and can be reduced depending on the generator power and fuel capacity. Even though this reduces the overall vehicle efficiency to around 25.7% which is the lowest among all other full-HEVs, the option of switching either to exclusively electric or ICE drivetrain is highly advantageous. Parallel full-HEV (fig. 6(c)) configuration has two propulsion power systems ICE and electric motor in a mechanical coupler improving the mechanical efficiency to up 43.4%. In such configurations the battery capacity and the electric motor are reduced in size to gain efficiency due to weight reduction. Efficiency is also improved additionally with the parallel utilization of both propulsion systems making this drivetrain ideal for adjusting to highway and in-city driving conditions. Series-parallel HEV configuration employs two couple powers that are both mechanically and electrically powered and though it enjoys the advantages of full-HEV and parallel full-HEV the control system and the configuration is more complex and cost intensive. Complex HEV configuration (fig. 6(e)) is similar to the Series-parallel HEV with the difference that the generator employed to utilize the ICE cycles either for generating power for battery storage either for powering the electric motor, can here act reversely as an electrical motor to assist the ICE operation, making the system more controllable, as both propulsion system can assist each other. The latter two configurations (Parallel full-HEV & Complex full-HEV) are more flexible in regards to their control strategies, but nevertheless all strategies need precise control strategy.

- **Plug in Hybrid Electric Vehicles (PHEVs)**

The range problem of BEVs is addressed successfully with another vehicle configuration similar to the one of BEV, but with the addition of an internal combustion engine (ICE) to provide the powertrain with energy when the discharge capacity of the onboard battery is depleted. The solutions, promoted by PHEV configuration, either use the ICE to provide generated energy to the battery, which fall as mentioned to the extended range electric vehicles (EREV) category or directly to the electric motor [29]. The ICE is utilized when the PHEV's battery reaches a specific state of charge (SOC). Typically the fuel consumption in such drivetrains is significantly less than conventional gas vehicles. In a typical PHEV like BMWi3 REX the test-estimated fuel consumption by the manufacturer is 6l/100km [31] but this can reach very low levels when the vehicle in its everyday schedule doesn't exceed its electric range [30].

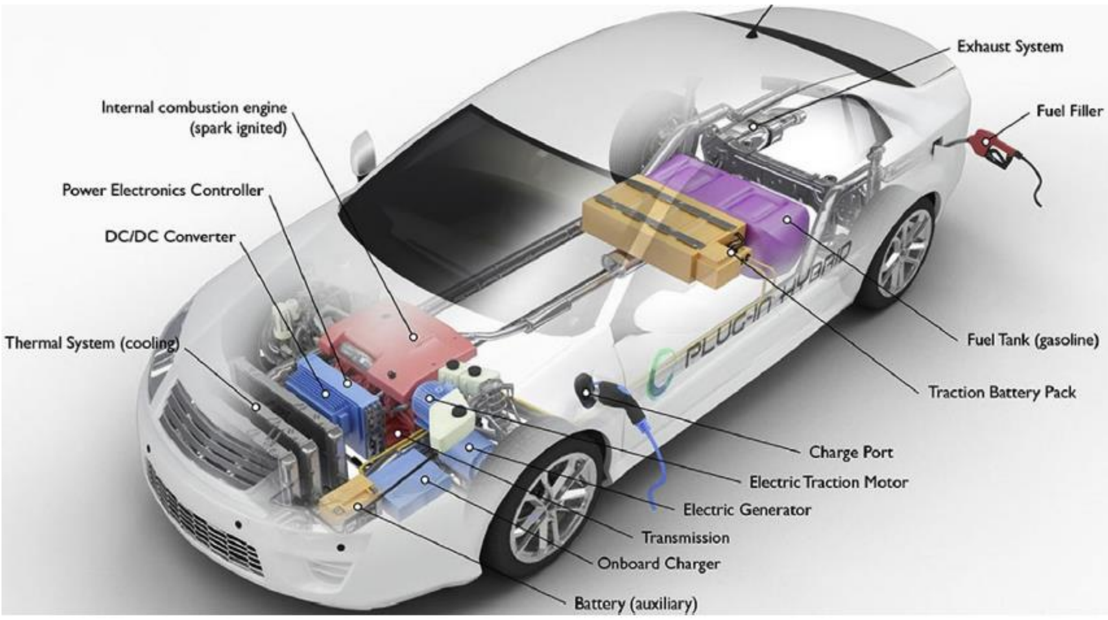


Figure 7 Plug in Hybrid Electric Vehicle (PHEV)(source: [23])

This differentiates PHEVs significantly to non-plug-in HEVs which are approached in this study as economic conventional fueled vehicles. Like the BEV powertrain PHEVs utilize energy saving technologies like regenerative braking, which recharges the batteries. There are also PHEVs which, in low SOC of their battery, can utilize both ICE and battery discharge for powering the motor at the same time leading to greater fuel economy of up to 30% [32].

- **Fuel Cell Electric Vehicles.**

Any electrochemical device that transforms chemical energy of any fuel directly into electrical energy is called a fuel cell. Fuel cell electric vehicles (FCEVs) are all electric vehicles hence they share a similar powertrain with BEVs but its energy source is a fuel cell stack. The FCEVs are powered by hydrogen induced electrolysis, with water and heat being the only byproducts of this process, hence FCEVs are zero emission vehicles. The polymer electrolyte membrane fuel cell (PEMFC) is the most preferred fuel cell due to its high power density, low operating temperature (60 ^{o}C- 80) and low corrosion in comparison to other fuel cell solutions.[20] Other types of FC, which are direct methanol fuel cells (DMFC), proton exchange membrane fuel cells (PEMFC), alkaline electrolyte fuel cells (AFC), phosphoric acid fuel cells (PAFC), molten carbonate fuel cell (MCFC) and solid oxide fuel cells (SOFC). [55]

Various power sources are available and utilize in various EV configurations such as:

- Solar Electric Vehicles
- Vehicles supplied by power lines

- Fly wheels and super capacitors

B. Battery Technology

B.(i) Structure and Battery Components

The battery consists of one or more battery elements connected in series or in parallel to regulate the voltage output and the battery capacity. Specifically, the Battery Element contains:

1. The Anode or the negative electrode which releases electrons in the external circuit and is the one that sustains oxidation (loses electrons) during the electrochemical reaction.

2. The Cathode or the positive electrode which receives electrons from the external circuit and sustains reduction (gains electrons) during the electrochemical reaction.

3. The electrolyte, which provides a mean for transferring electrons inside the battery element (from the anode to the cathode). The electrolyte is frequently a liquid, such as water or another solvent, containing salts, acid or alkali, which generates ion conductivity (enable ion transfer). Some batteries utilize solid electrolytes, which are ion conductors in the temperature-range of operation of the battery element. The electrolyte's role is to electrically isolate the two electrodes while enabling the ion transfer between them.

The electrolytes are contained inside a solid synthetic polymer material instead of a liquid solvent while electrodes are placed as plates with separators between them. The batteries are placed inside a stable frame instead of a rigid metal casing. These types of batteries have significantly lower weight and thus achieve a higher energy density in comparison with simple Li-ion batteries making the ideal for portable electronic devices and EVs [27].

B. (ii) Battery Materials

Electrode Materials

The most beneficial combination of materials used in the electrodes (anode & cathode) is one that provides high output voltage and contributes towards an overall light structure. However, such material combinations might not be as practical for various reasons, such as a combination of materials that can chemically react to one another inside the element. Some material combinations should also be avoided because of polarization (as disruption of the equilibrium potential of the redox electrochemical reaction), difficulties in utilization (manufacturing, welding, etc.) and high cost. [27]

Anode material selection parameters

The anode material must be (a) effective as reductive mean, meaning it should be effective in causing reduction, while it gets oxidized. (b) It must also have high ampere hour performance (Ah/g), practical unit for measuring electric charge, which expresses the amount of electric charge, transferred through a conductor when the electric current has amperage of 1 A during a period of 1 hour. (c) Must be conductive, (d) stable, (e) being constructed with a comprehensive, convenient procedure, (f) being abundant with a low cost. Nowadays, there are various highly capable materials to be used as a negative electrode including Hydrogen, Graphite, Zinc, Lithium, Titanium etc. [27][28]

Cathode material selection parameters

The cathode material must be: (a) effective as an oxidative mean meaning to cause oxidation, while it gets reduced, (b) stable when in contact with the electrolyte. (c) It must meet a required voltage of operation. Oxygen for the oxidation might come from air entering the battery element as it happens in zinc-air batteries. Most common cathode materials are metal oxides. [27]

Electrolyte material selection parameters

The material selected for electrolyte must have: (a) High ion conductivity but not be electrically conductive, because electric conductivity would cause constant internal short-circuits. (b) The electrolyte must not react with the electrodes and (c) must not be affected by temperature changes. Furthermore, the electrolyte material (d) must be safe and (e) produced in low cost.

Most common electrolytes in use are water solvents. Thermal batteries, Lithium batteries etc. use molten salt and other non-water based electrolytes to avoid reaction with the anode materials

B. (iii) Spatial Battery structure

The spatial Battery structure is determined based on certain principles:

- The electrodes (anode & cathode) are electrically isolated to avoid internal short circuits but are connected through the electrolyte, which enables ion transferring.
- Some practical battery designs include a separating mechanism isolating the two electrodes
- The separator is permeable by the electrolyte to sustain the ion conductivity
- Also, grid-shaped electrical conductors can be added to the electrodes to reduce the internal resistance.[27]

The battery design principle extends in geometry customization ensuring that:

- Every element can be manufactured in various set-ups and shapes (cylindrical, flat, prismatic, etc.)
- Electrodes and electrolyte are designed in a way to fit in the size and shape of the required battery element
- The elements are sealed in a number of ways to prevent leakage or drying of their materials.
- Some battery elements are equipped with ventilation devices or other means to allow the gaseous gases to escape.
- The construction of the electrochemical cell is completed with the enclosure of the battery elements in appropriate boxes or containers with binders connecting the terminal. These are the complete battery packs which are labeled by the manufacturer.

B. (iv) Principles of Battery Operation

A Battery is a device which transforms the chemical energy content in its active material, directly to electrical energy, through an electrochemical oxidation-reduction (redox) reaction. Oxidation-reduction reactions are a combination of two processes: oxidation, in which electrons are lost, and reduction, in which electrons are gained. This type of reaction utilizes the ion flow between the electrodes through the electrolyte to create opposite charge between the electrodes and thus enable the transfer of electrons from one material to another through an external electric circuit. This process can continue until the circuit is interrupted or one of the reactant materials is depleted due to chemical transformation. The electrochemical processes occurring in Rechargeable Batteries can be reversed by providing electrical energy to the battery. In the recharging process the flow of electrons between the anode and the cathode is reversed returning the electrodes to their original state.

Battery Discharge

When the electrochemical element is into circuit with an external load, electrons from the anode, which sustains oxidation, flow through the external load, towards the cathode, which receives the electrons (sustains reduction). The electric circuit is closed through the electrolyte and the anion flow (negative ion flow) and cation flow (positive ion flow) towards the anode and cathode respectively.

Battery Charge

During the process of recharging of a rechargeable element, the flow of the electric current (electron flow) is reversed; the oxidation takes place on the positive electrode (anode) while the one that is reduced is the negative electrode (cathode). Because, by definition, the anode is the electrode that sustains the oxidation and the cathode is the electrode which sustains the reduction, in the recharging process the positive electrode is the anode and the negative electrode is the cathode.

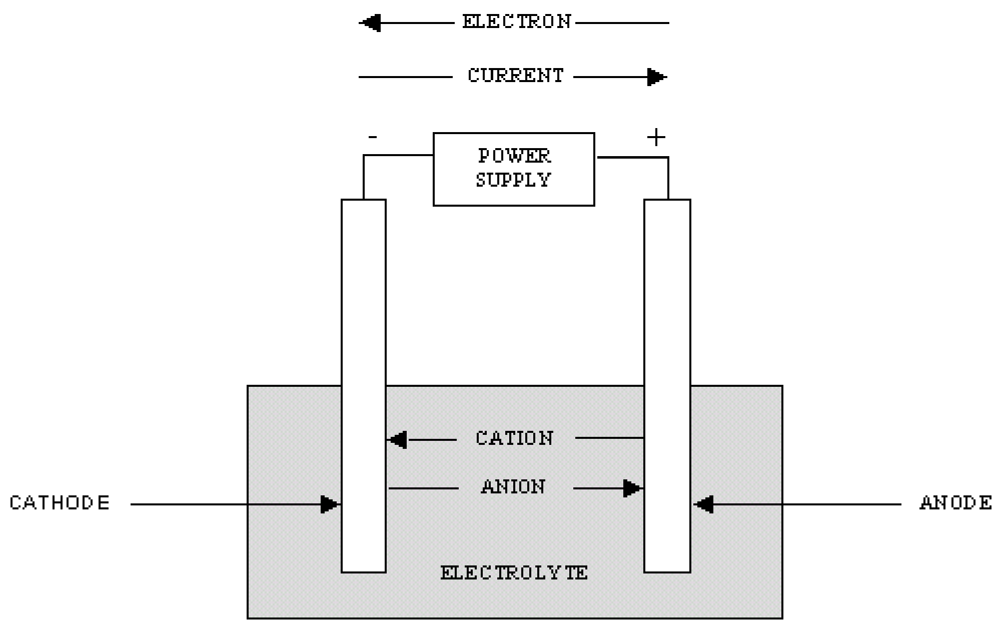


Figure 8 recharging a battery cell

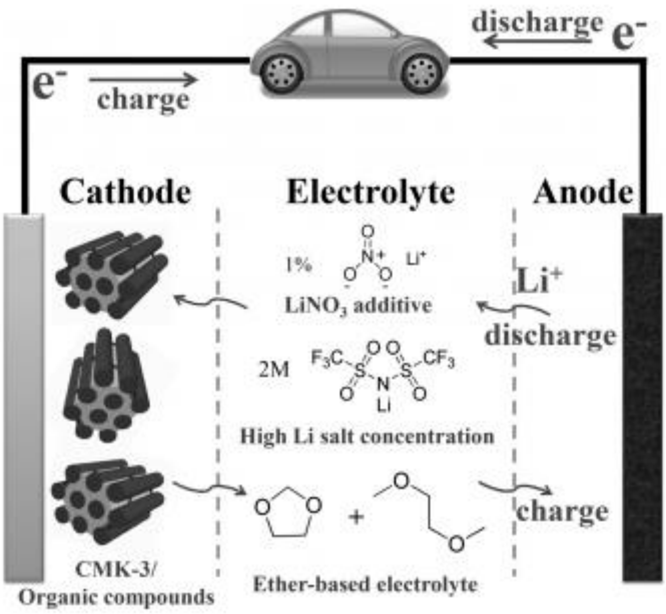


Figure 9 Illustration Example of Organic Cathode Battery charging process

B. (v) Battery Characteristics

1. Battery type

Primary batteries are not easily rechargeable, and consequently are discharged then disposed of. The cell electrochemical reactions are not easily reversible and cell is operated until the active components in the electrodes are exhausted. Generally primary batteries have a higher capacity and initial voltage than rechargeable batteries. Primary batteries are used in various applications primarily in portable devices.

Secondary (rechargeable) batteries can be recharged by applying a reverse current, as the electrochemical reaction is reversible. The original active materials at the two electrodes can be reconstituted chemically and structurally by the application of an electrical potential between the electrodes to “inject” energy. These batteries can be discharged and recharged many times. The utilization of secondary batteries can fall into two categories of applications. (a) The battery is used as an energy storage device. It is constantly connected to an energy source and charged by it. It can then release the stored energy whenever needed, e.g. in: a conventional ICE car battery used to start the engine, Standby power resources, Emergency no-fail systems etc. (b) The battery is used as a primary battery would be but is then recharged instead of being disposed of, e.g. in Electric Vehicles, Mobile phones, Cameras, Power tools, Toys, portable computers etc.

The batteries of electric vehicles fall in this category, however to meet the specific power and energy needs of the vehicle many battery cells are placed together to form modules. Each cell is a complete battery with two current leads and separate compartment holding electrodes, separator and electrolyte. A module is composed of a few cells stacked together either fitted physically or welded together. A number of modules inside a single container along with a thermal management system compose a battery pack fitted for the specific requirements of the vehicle. EVs may have more than one battery pack placed in different locations in the vehicle [33].

Reserve cells are a third battery category, which is differentiated from primary and secondary cells by the fact that a key component of the cell is separated from the remaining components, until prior to activation. The component most often isolated is the electrolyte. This battery structure is commonly observed in thermal batteries, where the electrolyte remains inactive in a solid state until the melting point of the electrolyte is reached, allowing for ionic conduction, thus activating the battery. Reserve batteries effectively eliminate the possibility of self-discharge and minimize chemical deterioration. Most reserve batteries are used only once and then discarded. Reserve batteries are used in timing, temperature and pressure sensitive detonation devices in missiles, torpedoes, and other weapon systems.

Reserve cells are typically classified into the following 4 categories: (a) Water activated batteries, (b) Electrolyte activated batteries, (c) Gas activated batteries, (d) Heat activated batteries.

Fuel cells represent the fourth category of batteries. Fuel cells are similar to batteries except for the fact that that all active materials are not an integral part of the device (as in a battery). In fuel cells, active materials are fed into batteries from an outside source. The fuel cell differs from a battery in that it possesses the capability to produce electrical energy as long as active materials are fed to the electrodes, but stop operating in the absence of such materials. A well-known application of fuel cells has been in cryogenic fuels used in space vehicles. Use of fuel cell technology for terrestrial applications has been slow to develop, although recent advances have generated a revitalized interest in a variety of systems with applications such as utility power, load-leveling, on-site generators and electric vehicles.

2. Voltage: The theoretical standard cell voltage (electric potential difference) can be determined from the electrochemical series [56] using E^o values (electric potential values):E^o (cathodic) – E^o (anodic) = E^o (cell) .This is the standard theoretical voltage.

The theoretical cell voltage is modified by the Nernst equation, which takes into account the non-standard state of the reacting component. The Nernstian potential will change with time either because of use or self-discharge by which the activity or concentration of the electro-active component in the cell is modified. Thus the nominal voltage is determined by the cell chemistry at any given point of time. Also, an important battery characteristic is the Cut-off Voltage, which is the minimum allowable voltage defined by the manufacturer, determining the lowest allowable state of charge (SOC) or the empty state of battery [1].

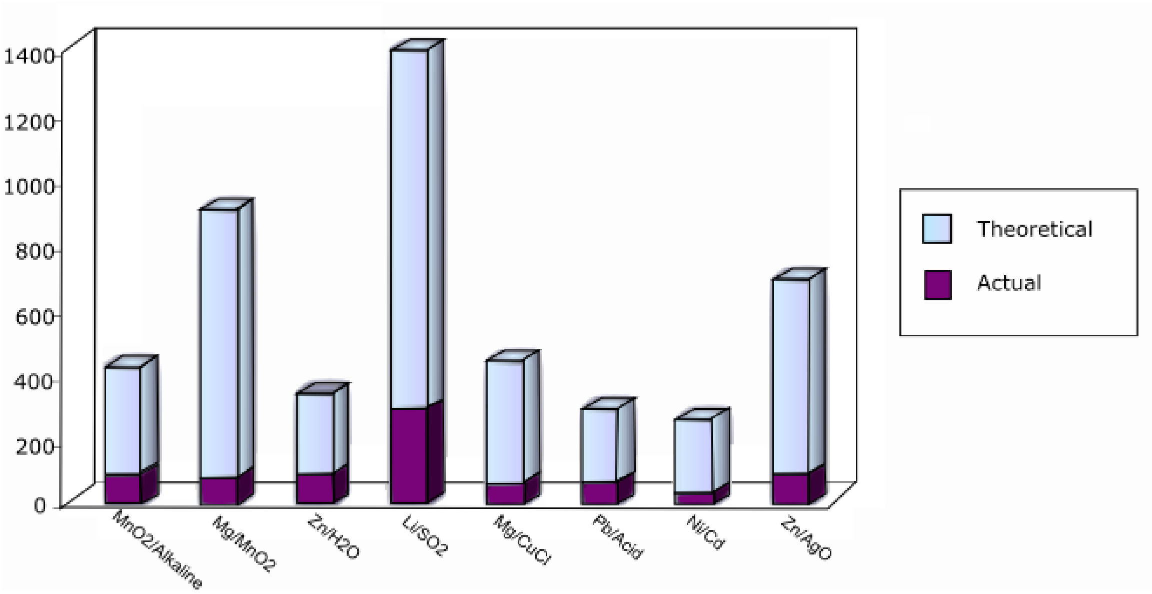


Figure 10 Theoretical and Actual Cell Voltages of a variety of Cell Systems (source: University of Cambridge))

The actual voltage, or Rated Battery Voltage, will always be lower than the theoretical voltage due to polarization and the resistance losses (IR drop) of the battery and is dependent upon the load current and the internal impedance of the cell. These factors are dependent upon electrode kinetics and thus vary with temperature, state of charge, and with the age of the cell. The actual voltage appearing at the terminal needs to be sufficient for the intended application. Typical values of voltage range from 1.2 V for a Ni/Cd battery to 3.7 V for a Li/ion battery.

3. Discharge Curve: The discharge curve is a plot of voltage against percentage of capacity discharged. A flat discharge curve is desirable as this means that the voltage remains constant as the battery is used up.

4. Capacity: The theoretical capacity of a battery is the quantity of electricity involved in the electro-chemical reaction. It is denoted *Q* and is given by: $Q = x \cdot n \cdot F$, where x = number of moles of reaction, n = number of electrons transferred per mole of reaction and F = Faraday's constant. The capacity is usually given in terms of mass, not the number of moles: $Q = n \cdot F \cdot M_r$, where M_r = Molecular Mass. This gives the capacity in units of Ampere-hours per gram (Ah/g).In practice, the full battery capacity could never be realized, as there is a significant weight contribution from non-reactive components such as binders & conducting particles, separators & electrolytes and current collectors & substrates as well as packaging.

Practically an EV battery's capacity is characterized as most application batteries with the term Rated Ampere-hour Capacity, which is the total charge that can be discharged from a fully charged battery under specific condition defined by the manufacturer. A useful unit is also the Rated Wh Capacity which is defined as:

Rated Wh Capacity = Rated Ah Capacity · Rated Battery Voltage

An important variable which determines the current charging condition of the battery as related to the battery's rated capacity is the state of charge of the battery (SOC). SOC, which is defined as the remaining capacity of a battery, is affected by the battery's operating conditions such as load current and temperature: SOC = Remaining Capacity / Rated Capacity. Moreover, to indicate the percentage of the total battery capacity that has been discharged, the term of Depth of Discharge is utilized; DOD = 1 - SOC

5. Energy density: The energy density is the energy that can be derived from each battery cell per unit of its weight. The energy density is a crucial parameter for determining the electric range of an EV. NCA batteries (Nickel-Cobalt-Aluminum) have currently the highest specific energy; however, batteries containing manganese and phosphate in their Cathodes are superior in terms of specific power and thermal stability. Li-titanate (LTO) batteries have the longest life span.

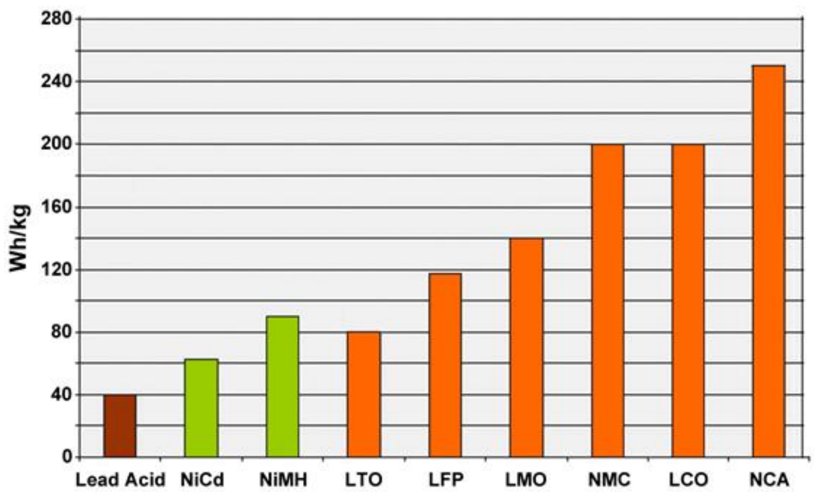


Figure 11 Typical specific energy of lead-, nickel- and lithium-based batteries. (Source: Cadex)

6. Specific energy density: The specific energy density is the energy that can be derived per weight unit of the cell (or sometimes per weight unit of the active electrode material) and can define how much energy a battery can store per unit of mass [33] . It is the product of the specific capacity and the operating voltage in one full discharge cycle. Both current and voltage may vary within a discharge cycle and thus the specific energy derived is calculated by integrating the product of current and voltage over time. The discharge time is related to the maximum and minimum voltage threshold and is dependent upon the state of availability of the active materials and/or the avoidance of an irreversible state for a rechargeable battery. It is expressed in Watthours per kilogram (Wh/kg):

Specific Energy = Rated Capacity (Wh) / Battery Mass (kg)

7. Specific Power density: The gravimetric power density or specific power is the power that can be derived per weight unit of the cell, which is the battery's peak power per unit of mass (W/kg): Specific Power =Rated Peak Power/ Battery Mass in kg. Power density may also refer to the peak power per volume unit of the battery (W/l).

8. Internal Resistance: Internal resistance is the overall equivalent resistance within the battery. It is different for charging and discharging and may vary as the operating condition changes.

9. Temperature dependence: The rate of the reaction in the battery cell, according to theories of kinetics will be temperature dependent. The internal resistance also varies with temperature, with low temperatures giving a higher internal resistance. At very low temperatures the electrolyte may freeze giving a lower voltage as ion movement is impeded. At very high temperatures the chemicals may decompose, or there may be enough energy available to activate unwanted, reversible reactions, reducing the capacity. The rate of voltage decrease, caused by increasing the depth of discharge (DOD) will also be higher at lower temperatures, and consequently the available battery capacity will be as well (see page 26-27 rated capacity equation). This is illustrated by the following graph:

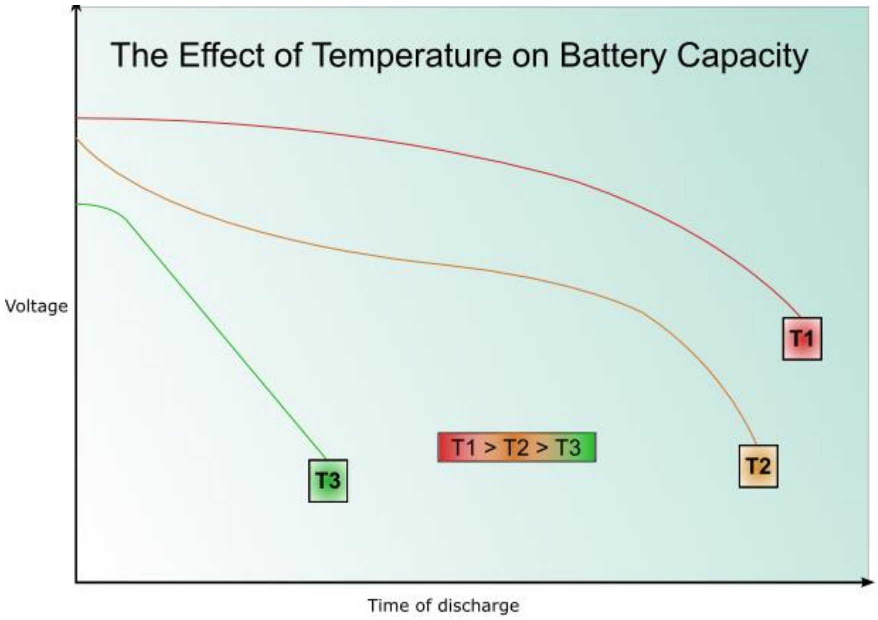


Figure 12 Effect Temperature dependence of Voltage on the Battery capacity

10. Service life: For a rechargeable battery, the battery's "cycle life" is defined as the number of charge/recharge cycles a secondary battery can perform before its capacity falls to 80% of its nominal value. This is typically between 500 and 1200 cycles. The battery "shelf life" is the time a battery can be stored inactive before its capacity falls to 80%. The reduction in capacity with time is caused by the depletion of the active materials by undesired reactions within the cell. Batteries can also be subjected to premature death by: (a) Over-charging, (b) Over-discharging, (c) Short circuit, (d) drawing more current than it was designed to produce, (e) Subjecting to extreme temperatures, (f) Subjecting to physical shock or vibrations. Furthermore, various effects are observed during a battery's service life development, which are the results of aging and over-usage:

- **Voltage delay:** In some battery systems *passivation* may occur. Passivation is the process by which the product of reduction, which is formed, often an oxide, does not dissolve into the electrolyte, or fall away from the electrode, but forms a crystalline film on the surface of the electrode instead (on the anode during charging and on the cathode during discharging). This can significantly impede the reaction as there is reduced electrical contact within the cell. Moreover, this can substantially prolong the shelf life of the battery; however, when the battery discharges the initial voltage may be lower than expected until the coating is broken. This is known as *voltage delay*.

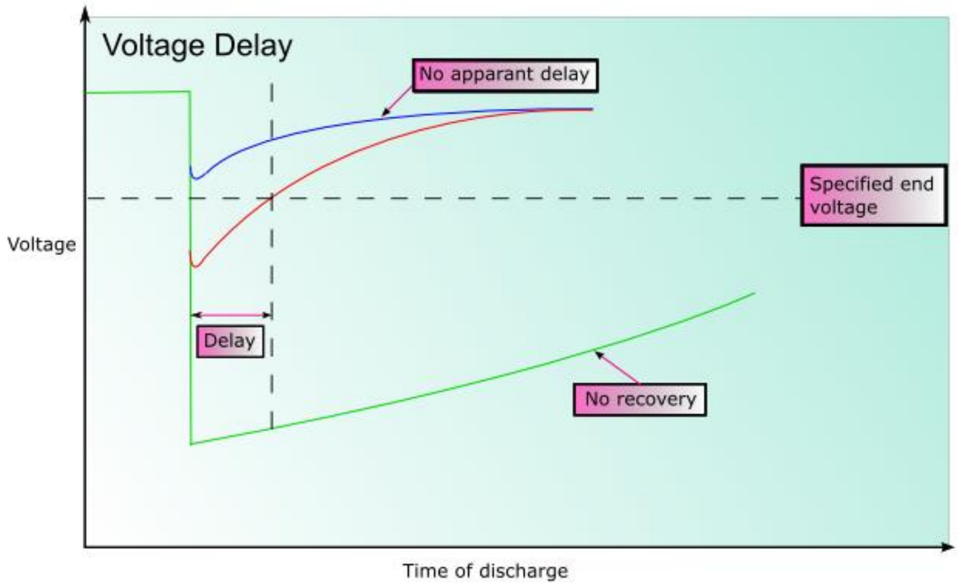


Figure 13 Illustration of the voltage delay effect during battery discharge

- **Battery death due to aging:** Over the life time of the cell the morphology of the components will change, with effects that are detrimental to the functioning of the cell. (a) The crystals formed in the cell grow larger, increasing the impedance, (b) metallic dendrites grow on the cells causing the electrodes to swell, forcing them closer together and increasing the self-discharge. (c) The dendrites may penetrate the separator giving very high self-discharge, or even a short circuit. Eventually, the internal impedance and the self-discharge will be so high that the battery will be no longer usable.

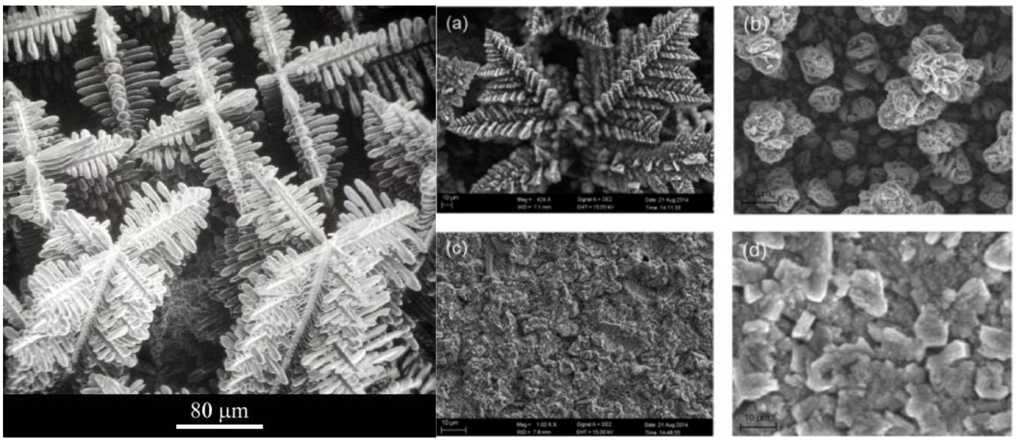


Figure 14 Metallic dendrites formed in Battery

In Lithium ion batteries, which are widely used in EVs, the most significant capacity reduction inducing aging mechanisms responsible for a battery's death, according to researchers, have identified to be:

a) The loss of lithium ions caused by the formation and thickening of Solid Electrolyte Interface (SEI) layer on the surface of the anode. Various Models have been developed to simulate the capacity loss induced battery aging process caused by SEI formation [13] [14].
b) The stress due to the lithium ion insertion/extraction of the electrode particles. Moreover, to investigate such phenomenon and its effects, R. Deshpande [15] introduces the capacity loss model based on the SEI formation and the mechanical fatigue caused by the diffusion induced stress in the carbon anode particle. On the other hand Y. Dai [16] introduces a mathematical model to simulate the stress in the LMO cathode particle.
c) "The precipitate formation in cracks propagating in the electrode materials of the cells". To describe this mechanism, the crack propagation mechanism as expressed by Zhurkov [16] shows a very good relation to experimental results. Further research showed that aging at modest stresses is highest at high temperature.
d) Various other side reactions that cause capacity loss and degradation are currently unknown, but subject of commencing scientific research.
e) The battery reversal, which occurs when a battery is forced to operate under negative voltage, (lower voltage in positive than in negative electrode) or reversed voltage, induced when the capacity of a serially connected weak battery cell is depleted and the rest of the cells continue to supply with current. The consequences of the voltage reversal is either a shortening cycle life or complete failure of the battery pack [33]

To indicate the age of the battery and also identify the deterioration and finally the battery death, induced by capacity reduction, the term *State of Health* (SOH) is utilized. SOH can be defined as the ratio of the maximum capacity of the aged battery to the maximum rated capacity when the battery was new. SOH = Aged Energy Capacity /Rated Energy Capacity [34].

11. Physical requirements: This includes the geometry of the cell, its size, weight and shape and the location of the terminals.

12. Charge/Discharge cycle (C-rate): There are many aspects of the cycle that need consideration, such as: (a) The voltage necessary to charge, (b) the time necessary to charge, (c) the availability of charging source and (d) the potential safety hazards during charge/discharge. (e) The C-rate (C), the nominal C-rate, is used to represent a charge or discharge rate equal to the capacity of a battery in one hour. For a 1.6 Ah battery, C is equal to charge or discharge the battery at 1.6 A. correspondingly, 0.1C is equivalent to 0.16 A, and 2C for charging or discharging the battery at 3.2 A. [33]

13. Cycle life: The “cycle life” of a rechargeable battery as defined by U.S. Advanced Battery Consortium (USABC), is the number of discharge-charge cycles, at a specific DOD (normally 80%)[33], that battery can experience before its capacity degrades to 80% of its initial (nominal) capacity. The cycle life is one of the most significant characteristics for power batteries in an EV as it determines the service life of the battery [1].The cycle life refers to an estimated number because of the non-linearity aspect of the battery aging problem as well as the uncertainty of occurrence of processes that define it, like the formation and thickening of Solid Electrolyte Interface (SEI) layer on the surface of the anode. Shen et al claims that the battery life cycle is more appropriately estimated via the battery performance simulation results of a model that prioritizes on depth of discharge, temperature and current rate [10]. An average time dependence factor indicates the capacity loss due to solid electrolyte interphase (SEI) growth [10][12]. All research is pointing that the higher the DOD the shorter the cycle life, consequently larger batteries with a low DOD during normal operations should be utilized to achieve larger cycle life [33].

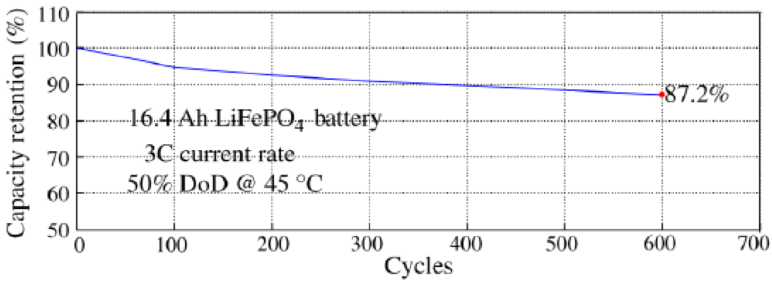


Figure 15 Estimated battery capacity degradation of 16.4 Ah LiFePO4 cell at Crate of 3C for 600 cycles. (source Shen et al.)

Batteries used in EVs need to achieve a long cycle of life by avoiding accelerated degradation due to high peak power and harsh charging/ discharging cycles during acceleration and deceleration, mainly occurring in Urban driving conditions. Such degradation can be mitigated by the use of ultracapacitors or supercapacitors hybrid energy storage systems (HESS) [10]. Ultracapacitors are characterized by high power density, high cycle lifetime and can maintain a high cycling efficiency making them ideal for an electrical energy pool for discharge.

In extend, cycle life is a very important parameter to consider when investing in energy storage systems, like EVs for a long term. The cycle life can be of significant importance when new smart technologies are involved like vehicle to grid (V2G), which utilizes EV battery capacity as a Dispatchable (dischargeable) energy pool to the grid.

14. Cost: This includes the initial cost of the battery itself as well as the cost of charging and maintaining the battery. Battery cost is determined by the technological framework of battery production and the cost of materials. The Battery industry has seen drastic changes in the past years leading to the bettering of manufacturing methods and the formation of manufacturing economies of scale, which are adjusting to the gradually increasing demand for EV batteries, leading to a significant decrease of the battery price. The battery market and the battery cost formulation are further analyzed in chapter 3.

15. Ability to deep discharge: There is a logarithmic relationship between the depth of discharge (DOD) and the life of a battery, thus the life of a battery can be significantly increased if it is not fully discharged as described in chapter B.(v).12. Special deep discharge batteries are available for applications where this might be necessary. The exception to this is the nickel-cadmium battery, as subjecting them to partial discharge introduces "memory effects;" the battery appears to "remember" how much charge is being used, and will only recharge that amount rather than the full amount of charge. In fact the repeated shallow charging causes the crystalline structure in the battery to change: the crystals in the cell grow larger, increasing the impedance and thus reducing its capacity.

16. Application requirements: The battery must be sufficient for the intended application. This means that it must be able to produce the right current with the right voltage. It also must have sufficient capacity, energy and power. It should also not exceed the requirements of the application by too much, since this is likely to result in unnecessary cost; it must give sufficient performance for the lowest possible price. In EVs the application requirements are met with a number of battery packs containing a specific number of modules meeting the required rated power of the vehicle.

B. (vi) Current and New Battery technologies for EVs

The past decade the rapid development of battery technology highlighted the advancement of Li-ion batteries over NiMH and lead-acid in both specific energy and power. Also, the high power output of supercapacitors is an indication of advantages in automotive applications, which can be promoted, as researchers propose, in combination with higher energy density batteries for an efficient well adaptive EV power drive [10],[35]. While, in PHEV's, the Li-ion and NiMH batteries have achieved a developmental success, in BEVs the specific power and energy requirements as formulated by the market through USABC [36] have yet to be reached by the average market models.

Table 2 EV Battery performance goals (source: United States Advanced Battery Consortium [33][36]

End of Life Characteristics at 30°C	Units	SystemLevel	CellLevel
Peak Discharge Power Density, 30 s Pulse	W/L	1000	1500
Peak Specific Discharge Power , 30 s Pulse	W/kg	470	700
Peak Specific Regen Power , 10 s Pulse	W/kg	200	300
Useable Energy Density at C/3 Discharge Rate	Wh/L	500	750
Useable Specific Energy at C/3 Discharge Rate	Wh/kg	235	350
Useable Energy at C/3 Discharge Rate	kWh	45	N/A
Calendar Life	Years	15	15
DST Cycle Life	Cycles	1000	1000
Selling Price at 100K units	$/kWh	125	100
Operating Environment	°C	-30 to +52	-30 to +52
Normal Recharge Time	Hours	< 7 Hours, J1772	< 7 Hours, J1772
High rate of Charge	Minutes	80% ΔSOC in 15 min	80% ΔSOC in 15 min
Maximum Operating Voltage	V	420	N/A
Minimum Operating Voltage	V	220	N/A
Peak Current, 30 s	A	400	400
Unassisted Operating at Low Temperature	%	> 70% Useable Energy at C/3 Discharge rate at -20°C	> 70% Useable Energy at C/3 Discharge rate at -20°C
Survival Temperature Range, 24 Hr	°C	-40 to + 66	-40 to + 66
Maximum Self-discharge	%/month	< 1	< 1

Currently research in Li-ion batteries for EV applications involve the development new high capacity metal oxides for cathode materials, the development of high capacity anodes and the research new electrolytes with high oxidation potential. In regards to the cathode material the research is orientated towards the development of metal oxide that can release more Lithium-ions during each charge operation. Researchers develop high voltage charging systems, which showed that can increase the number of Li that are transferred to the anode and hence provide with higher capacities [33]. The Cathode materials that show competitive oxidation capabilities, high cell voltage induced capacities and are highly utilized in the market are lithium cobalt oxide (LCO), lithium nickel cobalt manganese oxide (NMC), lithium nickel cobalt aluminum oxide (NCA), lithium manganese oxide (LMO), or lithium iron phosphate (LFP) [40].

The most commonly used cathode material is lithium nickel cobalt manganese oxide $LiNiMnCoO_2$ (NMC), which is a novel lithium insertion electrode material, in which the manganese (Mn) doping increases significantly the thermal stability achieved by its low internal resistance, which is induced by its spinel molecular structure, but offers low specific energy. NMC cathodes can have various architectures intended to be used in either energy or power cells. Their overall performance, high specific energy and low self-heating rate make them a very good candidate for EV applications. The active cathode materials, nickel, manganese and cobalt can easily be blended to be suited in various automotive powertrains that need frequent cycling. The cathode combination is typically one-third nickel, one-third manganese and one-third cobalt, also known as 1-1-1 ($LiNi_{0.33}Mn_{0.33}Co_{0.33}O_2$). This offers a unique blend that also lowers the raw material cost due to reduced cobalt content. Another successful combination is NCM with 5 parts nickel, 3 parts cobalt and 2 parts manganese (5-3-2). Other combinations using various amounts of active NMC cathode materials are also possible [20], [50].

Table 3 Characteristics of lithium nickel manganese cobalt oxide (NMC) .(source: Cadex).

Lithium Nickel Manganese Cobalt Oxide: $LiNiMnCoO_2$. cathode, graphite anode Short form: NMC (NCM, CMN, CNM, MNC, MCN similar with different metal combinations) Since 2008	
Voltages	3.60V, 3.70V nominal; typical operating range 3.0–4.2V/cell, or higher
Specific energy (capacity)	150–220Wh/kg
Charge (C-rate)	0.7–1C, charges to 4.20V, some go to 4.30V; 3h charge typical. Charge current above 1C shortens battery life.
Discharge (C-rate)	1C; 2C possible on some cells; 2.50V cut-off
Cycle life	1000–2000 (related to depth of discharge, temperature)
Thermal runaway	210°C (410°F) typical. High charge promotes thermal runaway
Applications	E-bikes, medical devices, EVs, industrial
Comments	Provides high capacity and high power. Serves as Hybrid Cell. Favorite chemistry for many uses; market share is increasing.

Another metal oxide, Lithium Nickel Cobalt Aluminum Oxide ($LiNiCoAlO_2$)(NCA), which is widely used in various EV batteries as cathode material, is an Aluminum doped Lithium nickel cobalt oxide (LNCO), in which the Al doping is found to be very effective in suppressing the cell impedance rise by stabilizing the charge-transfer impedance on the cathode side. It also shows excellent electrochemical performance with high specific reversible stability and good cycling and thermal stability [42]. Although NCA batteries offer high specific energy, reasonably good specific power and a long lifespan, they lack on safety, as high charge is likely to cause thermal runaways [20].

Table 4 Characteristics of Lithium Nickel Cobalt Aluminum Oxide.(source: Cadex [20])

Lithium Nickel Cobalt Aluminum Oxide: $LiNiCoAlO_2$ cathode (~9% Co), graphite anode Short form: NCA or Li-aluminum. Since 1999	
Voltages	3.60V nominal; typical operating range 3.0–4.2V/cell
Specific energy (capacity)	200-260Wh/kg; 300Wh/kg predictable
Charge (C-rate)	0.7C, charges to 4.20V (most cells), 3h charge typical, fast charge possible with some cells
Discharge (C-rate)	1C typical; 3.00V cut-off; high discharge rate shortens battery life
Cycle life	500 (related to depth of discharge, temperature)
Thermal runaway	150°C (302°F) typical, High charge promotes thermal runaway
Applications	Medical devices, industrial, electric powertrain (Tesla)
Comments	Shares similarities with Li-cobalt. Serves as Energy Cell.

Research and development on the cathode materials has produced a new cathode coating technology that can extend the cycle life of high voltage NMC cathodes by 100%. The coating is a type of an aluminum coating and it was developed in collaboration between Dalhousie University and Tesla Canada Industrial Research. Upon testing, it only showed signs of degradation under harsh conditions, maintaining approximately 95% of the cells original capacity after 1200 cycles at moderate temperature. The cells showed also higher energy density and better tolerance to fast charging than NMC, while the extended cycle life can propel an EV battery to last for over 450,000km [40], [44].

Commercially the most commonly used anodes in EV batteries are made of predominantly graphite (G) or lithium titanium oxide (LTO) [40]. Ongoing research in the anode field lead to, Toshiba corporation announcing, in October 2017, a next generation lithium-ion EV battery featuring a new anode material, lithium titanium niobium oxide (LTNO), which stores lithium ions more efficiently by using a proprietary method of synthesizing and processing. Moreover, LTNO anode is much less likely to experience lithium deposition during rapid discharging or recharging in cold conditions, causing battery degradation and internal short circuits. In addition, it provides twice the capacity of the standard graphite anode, realizing driving range boost to 320km and is able to maintain 90% of its initial capacity after 5000 cycles at very high charging rates (up to 10C), achieving safe full battery charging on 6 minutes [43].

The anode research is focused on the adaptation of materials with high theoretical capacity like Si, which has a tenfold capacity in comparison to graphite. However the lattice expansion of Si can reach as much as 270% after a full charge, showing signs of severe instability [33].Alloying Si with inert ingredients or depositing Si onto some types of supporting structures could counteract the instability and provide feasible high capacity anode solutions, realizing the very high capacity of Si. Moreover, scientific research is trying to investigate and counteract on the irreversible reduction of crystallinity of the silicon content of carbon coated silicon anodes which is trapping the incoming Li, progressively decreasing the coulomb efficiency[2] with cycling [37].

Table 5 Commercial EV Batteries' Chemistry and Specifications (Source: [40])

Cell Manu-facturer	Anode/ Cathode Chemistry	Capacity (Ah)	Cell Voltage, (V)	Energy Density, (Wh/L)	Energy Density, (Wh/kg)	EV Manu-facturer Model
AESC	G/LMO-NCA	33	3.75	309	155	Nissan/ Leaf
LG Chem	G/NMC-LMO	36	3.75	275	157	Renault/ Zoe
Li-Tech	G/NMC	52	3.65	316	152	Daimler/ Smart
Li EnergyJapan	G/LMO-NMC	50	3.7	218	109	Mitsu-bishi/ i-MeV
Samsung	G/NMC-LMO	64	3.7	243	132	Fiat/ 500
LishenTianjin	G/LFP	16	3.25	226	116	Coda/ EV
Toshiba	LTO/NMC	20	2.3	200	89	Honda/ Fit
Panasonic / Tesla	G/NCA	3.1	3.6	630	265	Tesla/ X, S, 3

Special research interest is focused on the electrolyte development aiming to develop an electrolyte solvent with high oxidation potential such that can withstand

[2] Coulomb efficiency describes the efficiency with which charge (electrons) is transferred in a system facilitating an electrochemical reaction

higher than 4.2 V of Li-ion battery cell voltage that the current Li-ion electrodes can reach. This will enable the use of high-voltage cathodes such as $LiCoPO_4$ [38] and $LiNi_{0.5}Mn_{1.5}O_4$ [39], which can increase significantly the battery's specific energy. In addition, the development of new solid and liquid electrolytes, aiming in replacing the flammable polyethylene separator has led to development of ceramic coated membranes providing superior adhesion, excellent stoichiometry transfer and precise porosity control, at a low temperature in a cost effective manner [45]. Moreover Kevlar membranes are also developed for the same reason with superior mechanical and electrochemical properties and the capability of withstanding high temperatures and high dimensional stress. [46]

Battery500 consortium, which is a network of universities and research laboratories, coordinated by the US Department of Energy's (DOE) Vehicles Technologies office, is currently involved in research in next generation EV lithium battery development promoting technologies involving Li-metal anodes, high energy density cathodes and researching advancements in Li-sulfur batteries. [40]

Solid State batteries for EVs

Solid state battery is a type of battery that utilizes both solid electrodes and solid electrolytes. These materials are very good ion conductors which is necessary for a good electrolyte and electrode performance, while they are essentially electrical insulators, which is desirable in electrolytes but undesirable in electrodes [2]. The high ionic conductivity minimizes the internal resistance of the battery, thus permitting high power densities, while the high electric resistance enhances the charge retention by minimizing the unwanted impact of the self-discharge phenomenon.

Candidates for solid state battery materials include Ag_4RbI_5 for Ag^+ conduction, LiI/Al_2O_3 mixtures for Li^+ conduction, and the clay and β-alumina group of compounds ($NaAl_{11}O_{17}$) for Na^+ and other mono- and divalent (Valence of 2)[3] ions. [8][9]

Solid-state batteries generally fall into the low power-density and high-energy density category. The former limitation arises because of the difficulty of getting high currents across solid–solid interfaces. However, these batteries do have certain advantages that outweigh this disadvantage: They are easy to miniaturize (for example, they can be constructed in thin film form), and there is no problem with electrolyte leakage. Solid-state batteries are comprised of proprietary inorganic materials, and contain no volatile or flammable components; consequently they can

[3] Valence is the number of chemical bonds formed

withstand high temperatures [7]. They tend to have very long shelf lives, and usually do not have any abrupt changes in performance with temperature, such as might be associated with electrolyte freezing or boiling.[8][9]

Moreover, the adoption of solid electrolyte could provide a 15-20% in energy storage capacity. There are various such solutions proposed like the one that is developed by Ionic Materials, utilizing a plastic like polymer as electrolyte and standard battery chemicals like zinc and manganese dioxide, which are advantageous due to their flexibility and thus and can be molded in different shapes. [47]

As Solid State batteries can exhibit a high energy-to-weight ratio, they may be ideal for use in electric vehicles. They also have the potential to maintain two-to-three times the energy density of existing lithium-ion automotive batteries and consequently have great potential to provide increased electric driving range [7][9]

Given the late developments in battery and Nano-technology the automotive industry is oriented towards the development of EV batteries from high performance battery materials. As such, a graphene-based hybrid material is developed by the auto producer "Fisker", allegedly offering very high energy density, 2.5 times larger when compared to Lithium ion batteries, Rapid charging times of as little as 1 min and high capacities, providing over 800 km (500 miles), which accounts for an increase in driving range of 66% in comparison to lithium-ion battery packs. The industry is addressing all of the hurdles that solid-state batteries have encountered on the path to commercialization, such as (a) performance in cold temperatures; (b) the use of low cost and scalable manufacturing methods; (c) and the ability to form bulk solid-state electrodes with significant thickness and high active material loadings [6]. Therefore, Fisker's new model, Emotion super sedan (400+ mile range, 145 kWh pack, scheduled to hit the markets in 2019), won't feature a solid state battery but NMC cells produced by LG Chem, as the graphene supercapacitor technology is still under-development to meet the requirements of the industry as mentioned above [40].

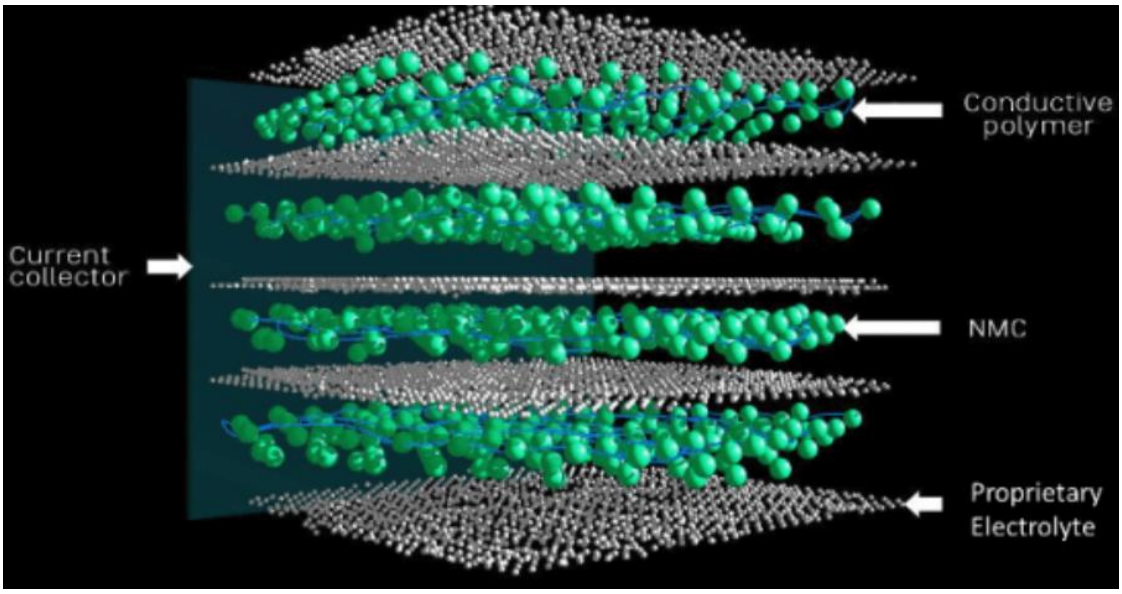


Figure 16 Structure of solid state battery cells

Moreover, Dyson Electric have invested in a solid-state battery technology developed by University of Michigan called "Sakti3", which is projected to reach double the capacity of the commonly used Lithium-ion EV batteries, reaching up to 1000 Wh/l (energy density of 400 Wh/kg). Such battery capacity is superior to the commercial state of the art EV Battery storage capacity capabilities (Tesla's cells believed to have energy density of 230-265Wh/kg) and complies with the storage capacity targets set by USABC [48]. Sakti3's battery technology is projected to be ideal for automotive purposes, expanding the electric driving range to more than 750km [49].

C Energy Savings and Emission reduction

C.(i) Electric Vehicle Efficiency

Nowadays, with the development of new EV technologies, considerable advancements in powertrain efficiency, power electronics, aerodynamics, and lightweight technologies are driving the overall improvement of EV energy efficiency. Various marketed EV models employ these strategies to improve their efficiency. One of the most notable achievements towards this direction is the EV battery technology advancements developed by the partnership of GM with LG Chem, as demonstrated by the 2016 Chevrolet Volt. Specifically, the consortium managed to improve the individual cell capacity in such a way as, a reduced by 33% number of cells in the 2016 Volt to achieve an increase of 8% or +1.47kWh in total battery capacity in comparison with its predecessor. Consequently, GM estimated that its new model is 45kg lighter and 12% more efficient [18][19].

Notable development in the automaker industry is the rapid improvement of battery energy density. The proven lithium manganese oxide ($LiMn_2O_4$) with a blend of lithium Nickel Manganese Cobalt Oxide ($LiNiMnCoO_2$) prismatic battery pack technology, used by many successful EV models such as the Nissan Leaf and BMW i3, offers a moderate energy density and it is expected soon to be compromised by more advanced technologies. Towards this direction, Tesla Motors diversified its battery technology adopting the use of Lithium Nickel Cobalt Aluminum Oxide ($LiNiCoAlO_2$) in its “18650 cell” which can deliver an impressive specific energy of 3.4Ah per cell or 248Wh/kg. However, the large 90kWh battery of the Tesla model S (2015), which is employed to extend its driving range at the impressive 424km, weighs 540kg increasing significantly its energy consumption to 238Wh/km making it one of the most energy inefficient EV models in the market.

On the other hand, BMW i3 is one of the lightest EVs in the market, hence one of the most energy efficient with consumption of 160 Wh/km. The vehicle employs a LNO/NMC battery which has moderate energy density of 120Wh/kg and in combination with its midsize 22kWh battery pack it provides a very limited battery range of 130-160km. To compensate BMW i3’s limited range the manufacturer offers a PHEV version of the model which achieves a longer driving range with the use of the additional gasoline engine (range extender), but has reduced energy efficiency due to its extra weight.

Table 6 compares the battery size and energy consumption of common EVs. The range is under normal non-optimized driving conditions.

Table 6 Estimated energy consumption of common EVs. (source: Battery University/ Cadex Electronics Inc.)[4]

EV model	Battery	Range km (mi)	Wh/km (mi)
BMW i3 (2016)	22kWh	135km (85)	165 (260)
GM Spark	21kWh	120km (75)	175 (280)
Fiat 500e	24kWh	135km (85)	180 (290)
Honda Fit	20kWh	112km (70)	180 (290)
Nissan Leaf (2016)	30kWh	160km (100)	190 (300)
Mitsubishi MiEV	16kWh	85km (55)	190 (300)
FordFocus	23kWh	110km (75)	200 (320)
Smart ED	16.5kWh	90km (55)	200 (320)
Mercedes B	28kWh (31.5)*	136km (85)	205 (330)
Tesla S 60	60kWh	275km (170)	220 (350)
Tesla S 85	90kWh	360km (225)	240 (380)

* *Driving range limited to 28kWh; manual switch to 31.5kWh gives extra 16km (10 mile) spare*

One of the systems that compensate the relatively high energy consumption of heavy electric vehicles is the regenerative breaking. The largest the mass or the speed of the vehicle the highest it's kinetic energy ($E = \frac{1}{2}mv^2$) and thus the more the energy that must be lost for its immobilization. A traditional braking energy recovery system recovers the part of the kinetic energy that is lost in the form of heat on the vehicle's brakes while slowing down. In EVs like Tesla roadster the recovery would be different than in most conventional ICE vehicles. In EVs, where there is a single AC induction motor moving part, the engine doesn't experience compression while braking. Instead, the motor controller in all times, including while in breaking or driving mode, takes command of the existing torque of the motor converting it into the appropriate 3-phase voltage and current waveforms to produce the commanded torque in the motor in the most efficient way. Torque command can be positive when driving or negative while braking returning charge to the battery.

Energy efficiency also refers to the vehicle itself regardless to its powertrain. Studies showed that reduction of the weight of a passenger car of 10% can lead to decrease in energy requirement of 6-7%. Therefore, towards this direction, reduction of the chassis' weight is of great importance and can be achieved by size reduction and utilization of lighter materials, such as high-strength steels, aluminum and aluminum alloys, magnesium and magnesium alloys, titanium and titanium alloys, carbon fiber composites, nanocomposites. [53]

[4] The common EVs presented in Table 6 are reference to the EV models of 2016. Although in latter chapters of this study more recent models have been used as a reference

D Utility Electric Vehicles

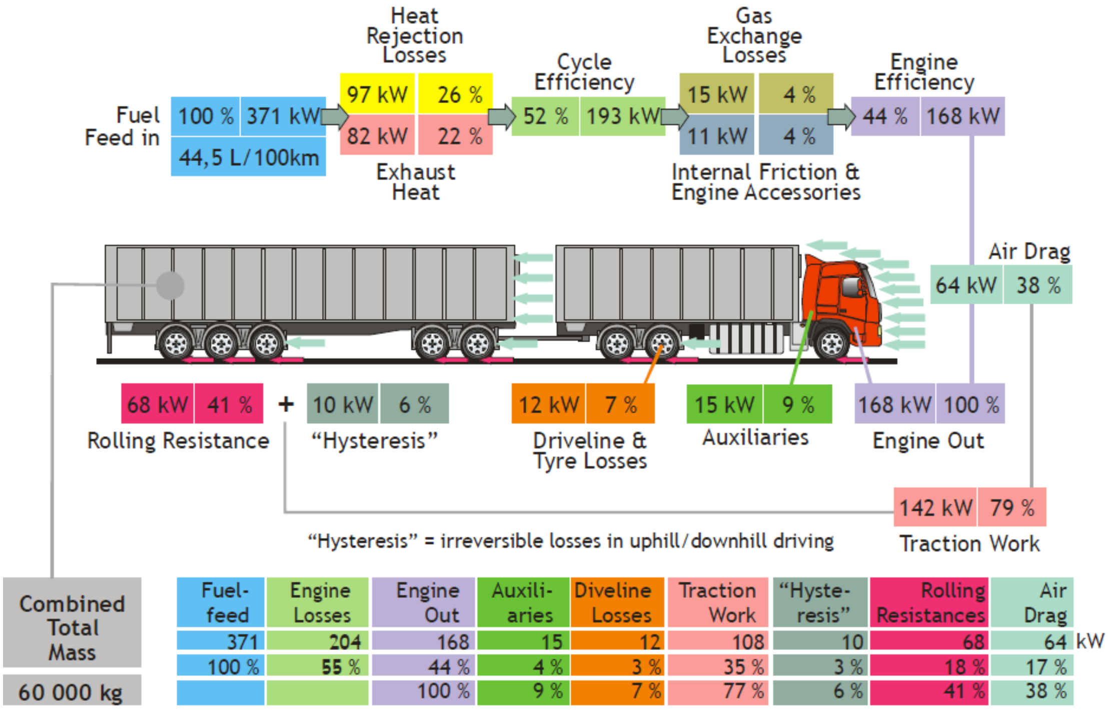


Figure 17 60 ton Tractor & Trailer, Full Payload, Freeway at 80 km/h (source: VTT Technical Research Centre of Finland [53])

Large utility vehicles face more efficiency challenges due to their large mass, rolling resistance and air drag due to the less aerodynamic shape dictated by the need of parking space minimization. The engine efficiency in a conventional utility truck powertrain of 44% [53] is relatively high and challenging for cost competitive development of EV utility tractors. Moreover, the high mobility needs of such vehicles are in mismatch with the current available battery and charging technology. This mandates that with the maturity of EV market in terms of availability of charging infrastructure, the transportation and logistics sector will also has to adapt introducing idle time for tractors for either charging or battery swapping. For that reason fuel cell (FC) powertrain technologies might be more feasible due to the large volumetric energy content of the FC [60]. Specifically, research by Gnann et al. (2017), questions the operational ability of BEVs to service the heavy duty vehicle segment of the fleet pointing towards different considerations for long-haul logistics [61].

E New Vehicle Technologies

Autonomous driving in EVs

The first attempts to create autonomous vehicles (AVs) concentrated on assisted-driving technologies (Also Defined in SAE Automation Levels [62]). These advanced driver-assistance systems (ADAS), including emergency braking, backup cameras, adaptive cruise control, and self-parking systems, first appeared in luxury vehicles and were further developed in EV applications, where the technology is more cost-effective (due to the nature of electric motor control systems). Eventually, industry regulators began to mandate the inclusion of some of these features in every vehicle, accelerating their penetration into the mass market. By 2016, the proliferation of ADAS had generated a market worth roughly $15 billion. Both the customer's willingness to pay and declining prices have contributed to the technology's proliferation. Many higher-end vehicles not only autonomously steer, accelerate, and brake in highway conditions but also act to avoid vehicle crashes and reduce the impact of imminent collisions. Some commercial passenger vehicles driving limited distances can even park themselves in extremely tight spots [63].

But while the technological basis has been developed, the industry hasn't yet determined the optimum technology archetype for semiautonomous vehicles (for example, those at SAE level 3 [62]) and consequently relevant technology remains in the test-and-refine mode. According to Mckinsey, so far, three technology solutions have emerged: (a) Camera over radar relies predominantly on camera systems, supplementing them with radar data. (b) Radar over camera relies primarily on radar sensors, supplementing them with information from cameras. (c) The hybrid approach combines light detection and ranging (lidar), radar, camera systems, and sensor-fusion algorithms to understand the environment at a more granular level.

The cost of these systems differs, with the hybrid approach being the most expensive one. Each system has its advantages and disadvantages. The radar-over-camera approach, for example, can work well in highway settings, where the flow of traffic is relatively predictable and the granularity levels required to map the environment are less strict. The combined approach, on the other hand, works better in heavily populated urban areas, where accurate measurements and granularity can help vehicles navigate narrow streets and identify smaller objects of interest.

AVs will undoubtedly be further developed and get further integrated in a new era for transportation, but the industry still needs to overcome some challenges before autonomous driving can be practical. The main challenge is that while ADAS solutions ease the burdens of driving, in some cases the drive does not become safer, highlighting the fact that some drivers rely on automation in situations beyond its capabilities. The current capabilities of ADAS are limited, something many early adopters fail to understand. In 2015, accidents involving distracted drivers in the United States killed nearly 3,500 people and injured 391,000 more in conventional cars, with drivers actively controlling their vehicles. Unfortunately, experts expect that the number of vehicle crashes initially will not decline dramatically after the introduction of AVs that offer significant levels of autonomous control but nonetheless require drivers to remain fully engaged in a backup, fail-safe role. Furthermore, safety experts worry that drivers in semiautonomous vehicles could pursue activities such as reading or texting and thus lack the required situational awareness when asked to take control. As drivers reengage, they must immediately evaluate their surroundings, determine the vehicle's place in them, analyze the danger, and decide on a safe course of action. At 100 km an hour, cars take less than four seconds to travel the length of a football field, and the longer a driver remains disengaged from driving, the longer the reengagement process could take. Automotive companies must develop a better human–machine interface to ensure that the new technologies save lives rather than contributing to more accidents [63].

Buses with regenerative breaking

A new type of regenerative breaking developed, can power the motor of the vehicle without battery discharge utilizing hydraulic kinetic energy storage. Hydraulic hybrid vehicles (HHV) technology was developed to use in public buses by a Chinese private firm. The hydraulic device can absorb and deposit energy in the process of braking and releasing the energy when the vehicles restart or speed up. They can save more than 30% of fuel consumption and reduce 20 to 27% of CO_2 emissions. This implies they are able to function as city buses with frequent braking and restarting. 50 HHVs were tested as pilot experiment in Beijing in 2006 and are already introduced in other cities in China [57 - 58]

References

[1] Dissemination of IT for the Promotion of Materials Science (DoITPoMS), (2017-2018), "DoITPoMS - TLP Library Batteries", *University of Cambridge*, Available online at: www.doitpoms.ac.uk/tlplib/batteries/index.php

[2] M. S. Reisch, Marc S. (2017). "Solid-state batteries inch their way toward commercialization". *Chemical & Engineering News.* 95 (46): 19–21.

[3] Dissemination of IT for the Promotion of Materials Science (DoITPoMS), (2017-2018), “Battery Characteristics”, *University of Cambridge*, Available online at: https://www.doitpoms.ac.uk/tlplib/batteries/battery_characteristics.php

[4] K. Zhang, C. Guo, Q. Zhao, Z. Niu, J. Chen, “High-Performance Organic Lithium Batteries with an Ether-Based Electrolyte and 9,10-Anthraquinone (AQ)/CMK-3 Cathode”, Advanced Science 2015 vol: 2 (5) pp: 1500018, Available Online at: http://www.advancedsciencenews.com/optimization-organic-li-ion-batteries/

[5] T. Stoebe, “Classification of Cells or Batteries.” Materials Science Engineering Education. N.p., n.d. *Materials Science Engineering Education*, Available online at: http://depts.washington.edu/matseed/batteries/MSE/classification.html

[6] Z. Hedge, (2017) “New Battery Design Could Crush Tesla”, *OilPrice.com*, N.p., n.d., Available online at:
https://oilprice.com/Energy/Energy-General/New-Battery-Design-Could-Crush-Tesla.html

[7] | C. Morris, (2017), “BMW partners with Solid Power to develop solid-state batteries”, *Charged EVs*, Available online at:
https://chargedevs.com/newswire/bmw-partners-with-solid-power-to-develop-solid-state-batteries/

[8] C. Stoldt, S. H. Lee, D. Campbell, L. Lennox, L. Snider, (2013), "Solid-state battery developed at CU-Boulder could double the range of electric cars". *University of Colorado Boulder,* (Archived from the original on 7-11-2013, 7-1-2018). Available online at:
https://web.archive.org/web/20131107054525/https://www.colorado.edu/news/releases/2013/09/18/solid-state-battery-developed-cu-boulder-could-double-range-electric-cars

[9] K. Bullis, (2011) “Solid-State Batteries - MIT Technology Review.” *MIT Technology Review*, Available online at:
http://www2.technologyreview.com/news/423685/solid-state-batteries

[10] J. Shen, S. Dusmez, A. Khaligh, (2014), “Optimization of sizing and battery cycle life in battery/ultracapacitor hybrid energy storage systems for electric vehicle applications”. *IEEE Transactions on Industrial Informatics.* 10, p. 2112–2121. Available online at:

https://www.researchgate.net/profile/Serkan_Dusmez/publication/270283758_Optimization_of_Sizing_and_Battery_Cycle_Life_in_BatteryUltracapacitor_Hybrid_Energy_Storage_Systems_for_Electric_Vehicle_Applications/links/55600e2608ae8c0cab30b79a/Optimization-of-Sizing-and-Battery-Cycle-Life-in-Battery-Ultracapacitor-Hybrid-Energy-Storage-Systems-for-Electric-Vehicle-Applications.pdf

[11] *Battery University*, (2018), "BU-1003: Battery Electric Vehicle", Available at: http://batteryuniversity.com/learn/article/electric_vehicle_ev

[12] M. B. Pinson, M. Z. Bazant, (2012), "Theory of SEI Formation in Rechargeable Batteries: Capacity Fade, Accelerated Aging and Lifetime Prediction", *Journal of the Electrochemical Society*. 160, p. A243–A250

[13] P. Ramadass, B. Haran, P.M. Gomadam,; R.E. White, B.N. Popov, (2004) "Development of first principles capacity fade model for Li-ion cells.", *J. Electrochem. Soc.*, 151, p. A196–A203.

[14] R. Spotnitz, (2003), "Simulation of capacity fade in lithium-ion batteries." *Journal of Power Sources*. 113, p. 72–80

[15] R. Deshpande, M. Verbrugge, Y.-T. Cheng, J. Wang, P. Liu, (2012), "Battery Cycle Life Prediction with Coupled Chemical Degradation and Fatigue Mechanics". *Journal of the Electrochemical Society.* 159, A1730–A1738

[16] Y. Dai, L. Cai, R. E. White, (2014), "Simulation and analysis of stress in a Li-ion battery with a blended LiMn2O4 and LiNi0.8Co0.15Al0.05O2cathode." *Journal of Power Sources*. 247, p. 365–376

[17] A. Millner, (2010), "Modeling Lithium Ion Battery Degradation in Electric Vehicles." IEEE Conference on Innovative Technologies for an Efficient and Reliable Electricity Supply, *CITRES 2010.* N.p., 2010. 349–356.

[18] *General Motors*, (2015), "Chevrolet Introduces All-New 2016 Volt", Available online at:
http://media.gm.com/media/us/en/gm/news.detail.html/content/Pages/news/us/en/2015/Jan/naias/chevrolet/volt/0112-volt-2016-intro.html).

[19] P. Slowik, N. Pavlenko, N. Lutsey, (2016), "Assessment of next-generation electric vehicle technologies." 10.13140/RG.2.2.17530.49601, Available online at: https://www.theicct.org/sites/default/files/publications/Next%20Gen%20EV%20Tech_white-paper_ICCT_31102016.pdf

[20] B. Isidor, (2017), "Types of Lithium-ion Batteries – Battery University." *Cadex Electronics Inc.* pp. 1–16. Available online at:
http://batteryuniversity.com/learn/article/types_of_lithium_ion

[21] C. C. Chan, (2007), "The state of the art of electric, hybrid, and fuel cell vehicles." *Proceedings of the IEEE*. 95, p. 704–718

[22] T. Wilberforce, Z. El-Hassan, F.N. Khatib, A. Al Makky, A. Baroutaji, J. G. Carton, A. G. Olabi, (2017), "Developments of electric cars and fuel cell hydrogen electric cars", *International Journal of Hydrogen Energy –Elsevier*, Vol 42, p. 0360-3199.

[23] *Alternative Fuels Data Center,* (2016), "How Do Plug-In Hybrid Electric Cars Work?", *U.S. Department of Energy - Vehicle Technologies Office*, [Retrieved on 28th December 2017], Available online at:
https://www.afdc.energy.gov/vehicles/how-do-plug-in-hybrid-electric-cars-work

[24] R. Bady, J. Biermann, H. Hacker, (1999), "SAE TECHNICAL European Electric Vehicle Fleet Demonstration with ZEBRA Batteries", doi:10.4271/1999-01-1156

[25] *US Department of Energy, Alternative Fuels Data Center*, (2014), "How Do All-Electric Cars Work?", [Retrieve on Jan 2018], Online available at:
https://www.afdc.energy.gov/vehicles/how-do-all-electric-cars-work

[26] *Tesla Inc., (2018),* (n.d.). "Roadster | Tesla.", [Retrieved on Mar 2018], Available online at: https://www.tesla.com/roadster

[27] N. Igglezou , N Chatziargiriou, (2013), "Operation analysis and Modelling of Capacitors" – Diploma Thesis (in Greek), *NTUA*

[28] A. Eftekhari, (2017),"Low voltage anode materials for lithium-ion batteries", *Energy Storage Materials,* v.7, p 157–180

[29] D. Herron, (2018), "The plug-in hybrid versus extended range electric vehicle debate", Online available at: https://greentransportation.info/transportation-tech/plug-in-hybrid-erev.html

[30] *Spritmonitor.de*, "Consumption: BMW - i3", [Retrieved on Jan 2018], Online available at: https://www.spritmonitor.de/en/overview/6-BMW/1312-i3.html

[31] *The Car Guide*, (2017), *"*BMW i3 Range Extender Specifications"*,* Online available at*:* https://www.guideautoweb.com/en/makes/bmw/i3/2017/specifications/range-extender/

[32] A. A. Pesaran, J. D. Gonder, M. Keyser, (2015), "Ultra-capacitor applications and evaluation for hybrid electric vehicles". *National Renewable Energy Laboratory*, (2009), Available online at: https://www.researchgate.net/publication/229044882_Ultracapacitor_Applications_and_Evaluation_for_Hybrid_Electric_Vehicles

[33] K. Young, C. Wang, L. Y. Wang, K. Strunz, (2013), "Electric vehicle battery technologies", "*Electric Vehicle Integration into Modern Power Networks"- Springer New York*, pp. 15–56. Available online at: https://www.springer.com/cda/content/document/cda_downloaddocument/9781461401339-c1.pdf?SGWID=0-0-45-1364113-p174121858

[34] Coleman M, Hurley WG, Lee CK, (2008), "An improved battery characterization method using at wo-pulse load test", *IEEE Trans EC* v. 23(2), p. 708–713

[35] Strunz K, Louie H, (2009), "Cache energy control for storage: power system integration andeducation based on analogies derived from computer engineering." *IEEE Trans Power Syst* v. 24(1), p. 12–19

[36]*USABC,* "Goals for Advanced Batteries for EVs - CY 2020 Commercialization", Available online at: http://www.uscar.org/commands/files_download.php?files_id=364

[37] N. Dimov, S. Kugino, M. Yoshio, (2003), "Carbon-coated silicon as anode material for lithium ion batteries: advantages and limitations", Japan, *ElectrochimicaActa* v. 48 p. 1579-1587

[38]Allen, Wolfenstein, Jow, (2009), "Technology fact sheet: High life cycle cathode for high voltage (5V) lithium ion batteries", *US Army RDECOM*, Available online at: http://www.arl.army.mil/www/pages/556/1109TFSHPCathodeLiIonBatteries.pdf

[39]. Q. Sun, X. Li, Z. Wang, Y. Ji, (2009), "Synthesis and electrochemical performance of 5V spinel LiNi0.5Mn1.5O4 prepared by solid-state reaction.", *Trans Nonferrous Met SocChin* v. 19, p. 176–181

[40] E. Timofeeva, (2017),“The Spectrum of EV Battery Chemistries*”, influitenergy,* Available online at:
http://www.influitenergy.com/the-spectrum-of-ev-battery-chemistries/

[41] K. C. Kam, M. M. Doeff, (2012), “Electrode Materials for Lithium Ion Batteries”, *Material Matters*, Lawrence Berkeley National Laboratory, v.7, n.4, Available online at:
https://www.sigmaaldrich.com/technical-documents/articles/material-matters/electrode-materials-for-lithium-ion-batteries.html

[42] *Sigma-Aldrich*, “Lithium nickel cobalt aluminium oxide”, *Material Description,* Available online at:
https://www.sigmaaldrich.com/catalog/product/ALDRICH/760994?lang=en&region=GR

[43] Toshiba, (2017), “Toshiba Develops Next-Generation Lithium-ion Battery with New Anode Material”, *Press release*, Available online at:
http://www.toshiba.co.jp/about/press/2017_10/pr0301.htm

[44] F. Lambert, “Tesla battery researcher says they doubled lifetime of batteries in Tesla’s products 4 years ahead of time [Updated]”, *Electrek*, Available online at: https://electrek.co/2017/05/09/tesla-battery-lifetime-double/

[45] *Electric Vehicles Research*, (2014), “Ceramic battery separator improves safety of lithium-ion batteries”, *Source: Porous Power Technologies*, Available online at:
https://www.electricvehiclesresearch.com/articles/6170/ceramic-battery-separator-improves-safety-of-lithium-ion-batteries

[46] *Elegus Technologies*, “Web portal”, Available online at:
https://www.elegustech.com/

[47] *Ionic Materials*, “Web portal”, Available online at: http://ionicmaterials.com/

[48] F. Lambert, (2015), “Dyson acquires solid-state battery startup Sakti3, plans $1 billion investment in a battery factory”, *electrek*, Available online at:
https://electrek.co/2015/10/20/dyson-acquires-solid-state-battery-startup-sakti3-plans-1-billion-investment-in-a-battery-factory/

[49] Nathan Bomey, (2014),“GM-backed start-up aims to make batteries within two years”, USA Today, Available online at:

https://www.usatoday.com/story/money/cars/2014/08/20/gm-backed-start-up-aims-to-make-batteries-within-two-years/14361897/

[50] *Sigma-Aldrich*, "Lithium nickel manganese cobalt oxide", *Material Description*, Available online at:
https://www.sigmaaldrich.com/catalog/product/ALDRICH/761001?lang=en&region=GR

[51] Chau KT, Chan CC. "Emerging energy-efficient technologies for hybrid electric vehicles", *Proceedings of the IEEE 2007*, v.95(4) p.821–835.

[52] S.F. Tie, C.W. Tan, "A review of energy sources and energy management system in electric vehicles", *Renewable and Sustainable Energy Reviews,* v.20 (2013) p. 82–102

[53] N.O. Nylund, (2013), "Mobility: Technology Priorities and Strategic Urban Planning", *Vehicle energy efficiencies IEA EGRD Workshop, VTT Technical Research Centre of Finland,* Presentation available online at:
http://www.iea.org/media/workshops/2013/egrdmobility/nylund_vehicle_energy_efficiencies.pdf

[54] *InsideEVs*, (2015),"Op-Ed: The Volt is an EREV, and Here's Why", available online https://insideevs.com/volt-erev-explained/

[55] G. Bromaghim, J. Serfass, P. Serfass, E. Wagner, (2010) "Hydrogen and fuel cells: The U.S. market report."

[56] *Dissemination of IT for the Promotion of Materials Science (DoITPoMS)*, "Batteries: Standard potentials in aqueous solution at 298K" , available online
https://www.doitpoms.ac.uk/tlplib/batteries/std_potentials.php

[57] B. Ma, M. Lin, Y. Chen and L. Wang, (2016), "Investigation of energy efficiency for electro-hydraulic composite braking system which is based on the regenerated energy" Advances in Mechanical Engineering 2016, Vol. 8(9) p. 1–13, available online at: http://journals.sagepub.com/doi/pdf/10.1177/1687814016666449

[58] F. Zhang, P. Cooke, (2009), "The Green Vehicle Trend: Electric, Plug-in hybrid or Hydrogen fuel cell?", *Centre for Advanced Studies, Cardiff University, UK,* available online at:
http://www.dime-eu.org/files/active/0/Cooke-09-Fang-Green-vehicle-Review.pdf

[59] M. Abdul-Hak, N. Al-Holou, Utayba Mohammad, (2011), “Predictive Intelligent Battery Management System to Enhance the Performance of Electric Vehicle”, *Sept. 2011, Electric Vehicles - Modelling and Simulations (book)*

[60] *Roland Bergen*, (2017), “Development of Business Cases for Fuel Cells and Hydrogen Applications for Regions and Cities: FCH Heavy-duty trucks”, *FCH2 JU , Roland Bergen,* available online at:
http://www.fch.europa.eu/sites/default/files/171121_FCH2JU_Application-Package_WG1_Heavy%20duty%20trucks%20%28ID%202910560%29%20%28ID%202911646%29.pdf

[61] T. Gnann, P. Plötz, A. Kühn, M. Wietschel, (2017), “How to decarbonise heavy road transport?” *Conference Paper - May 2017*, available online at:
https://www.researchgate.net/publication/318209395_How_to_decarbonise_heavy_road_transport

[62] *Dryve Index*, “SAE Automation Levels” available at:
https://dryve.com/glossary/what-are-the-sae-automation-levels/

[63] K. Heineke, P. Kampshoff, A. Mkrtchyan, and E. Shao, (2017), “Self-driving car technology: When will the robots hit the road?”, *McKinsey&Company,* Available online at:
https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/self-driving-car-technology-when-will-the-robots-hit-the-road

[64] *Clipper Creek*, (2018), “How long does it take to charge an electric car? Charging Times”, available online at:
https://www.clippercreek.com/charging-times-chart/

3. EV Market

A. Present of Global EV Market

The Paris Climate agreement (COP21) initiated a late response of the market to the Climate Change. The electrification of the energy demand along with the decarbonization of the energy generation is a first response to manmade Climate Change caused by the current carbon intensive energy sector as indicated by current policies worldwide. The electrification of the transport sector plays a large role in the decarbonization of the energy system, as long as the grid is powered by green energy. The Electric Vehicles (EVs) due to their rapid technological evolution are expected to reach parity with the petrol fueled ones during 2018 and eventually achieve a cheaper cost of ownership in 2022 even if the conventional ICE vehicles improve their fuel efficiency by 3.5% per year [45]. It is now obvious that the vehicle market is shifting towards electricity.

In 2016 the global sales of plug in electric vehicles reached 753,000, 60% of which were battery-electric vehicles (BEVs). China was for the 2nd consecutive year the largest EV market in the world with more than 40% of the global sales, while Europe was the 2nd largest market with 215,000 EVs sold, which corresponds to 28,5% of the global market. United States were left in the 3rd place with 160,000 EVs sold.[4] The market share of the plug in hybrid electric cars (PHEVs) is increased in comparison to the BEVs in EU and USA, while China is on the contrary oriented towards BEVs.

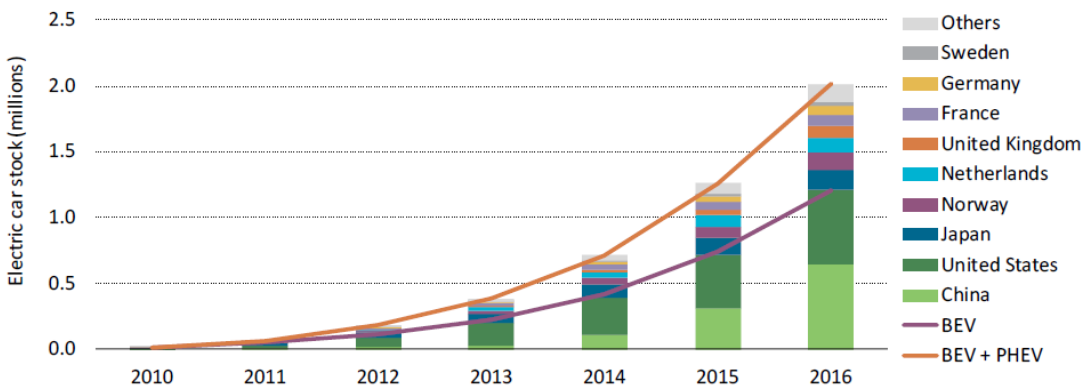


Figure 18 The Evolution of the global electric car stock, 2010-2016 (source: IEA)

Globally the EV sales showed growth of 40% in 2016. The growth declined from 70% in 2015 and it is the first time that is below 50% since 2010. This raises the concern whether the 2DS[5] scenarios' sales and stock objectives will be attained till 2025.

[5] 2DS Scenario refers to IEA's scenario for restructuring the global human activity in order to reduce the effect of climate change to a 2°C raise of the average global temperature by 2100. The 2DS lays out an energy system deployment pathway and an emissions trajectory consistent with at least a 50% chance of achieving such climate

However, the global economy is still on track with the 2DS scenario that predicts 35% of constant annual growth rate till 2025.

According to Bloomberg New Energy Finance (BNEF), the best-selling battery-only EV (BEV) since 2009 (Until Q1 2017) is the Nissan Leaf (186,000 sold) followed by the Tesla model S (79,000). The best-selling plug-in hybrid EV (PHEV)– which has both electric and conventional engine – is the Chevrolet Volt (87,000)[13]. In Europe Norway has achieved the highest EV market penetration, amounting to 29%, implementing a national strategy to exploit the benefits of the green and cheap electricity of the already decarbonized energy sector (99% of the total el. Generation is hydropower). Netherlands and Sweden follow with market penetrations of 6,4% and 3,4% respectively. In Denmark & Netherlands the EV sales dropped due to a change in policy support. In big markets such as UK and France EV market penetration amounted to approximately 1.5%. The global EV stock surpassed 2 million units, however, despite the rapid developments, EVs are still a minor fraction of all cars in circulation (0.2%)(end of 2016). However, globally the OEMs are differentiating their production to include EVs on the aftermath of governmental mandates, declared in major European markets and China (Table 7)

Table 7 List of OEMs announcements on electric car ambitions (April 2017) (source: IEA)

OEM	Announcement
BMW	0.1 million electric car sales in 2017 and 15-25% of the BMW group's sales by 2025
Chevrolet (GM)	30 thousand annual electric car sales by 2017
Chinese OEMs	4.52 million annual electric car sales by 2020
Daimler	0.1 million annual electric car sales by 2020
Ford	13 new EV models by 2020
Honda	Two-thirds of the 2030 sales to be electrified vehicles (including hybrids, PHEVs, BEVs and FCEVs)
Renault-Nissan	1.5 million cumulative sales of electric cars by 2020
Tesla	0.5 million annual electric car sales by 2018 1 million annual electric car sales by 2020
Volkswagen	2-3 million annual electric car sales by 2025
Volvo	1 million cumulative electric car sales by 2025

Barriers and Drivers for EV adoption

The main barriers that dictate the EV market penetration besides the technical boundaries that outline the capabilities of the vehicle in terms of efficiency and driving range; and the capabilities of the charging infrastructure in terms of charging

change mitigation effect. 2DS limits the total remaining cumulative energy-related CO_2 emissions between 2015 and 2100 to 1 000 $GtCO_2$.[87]

time and availability of public charging stations, are the non-technical boundaries of EV adoption that comprise of the EV acquisition and ownership cost, the lack of communication of the advantages of EVs as well as the lack of support policies like fiscal incentives and EV driving privileges that would initiate the EV market. Especially by observing the global EV market's performance one can identify that the main driver for the success of the market is focused in the existence of support policies, aiming at the consumers, which either lower the cost of acquisition and ownership of EVs or provide driving privileges to EV owners. In addition, polices that aim at the automakers by incentivizing the research and development (R&D) of EV technologies to promote economies of scale or policies in the form of mandates aiming at achieving a specific market share of EVs or gradually banning petroleum vehicles, are also deemed successful for the cause of EV market penetration.

EV adoption Policies, Regulations and Incentives

The early stage of EV market has shown peculiarities, which derive from the nature of the technology. EV technology, being an important structural component of the global strategy for Climate Change mitigation, it substitutes the proven ICE vehicle technology which has undergone many years of development and regulatory integration. It is therefore obvious that EVs cannot compete in economic terms with ICE vehicles, at least in this early stage of their development. Thus, so far EV introduction has been policy driven and is also subject to further global policy imposition until the technology, the manufacturing methods and the supporting infrastructure technology matures to form economies of scale, achieving a significant decline in the value of EV acquisition and ownership cost. A various means to promote EVs such as incentives, policies, targets, mandates and regulations have been used by many countries during this early phase of the EV market development.

Targets, mandates and regulations

Targets are an important tool for the policy-making process as they move the focus from the policy selection debate towards the policy implementation and its assessment. Mandates and regulations build on the definition of regulatory targets to provide a clear signal to manufacturers and customers as they set a medium- to long-term vision for defining the evolution of vehicle characteristics [3]. Most significant measures in this category include zero-emission vehicle (ZEV) mandates and fuel economy regulations.

- ZEV mandates are regulatory requirements for automakers to sell a set portion of ultra-low or zero-emission vehicles. They aim to promote R&D efforts for marketing ultra-low and zero-emission vehicles.
- Fuel economy regulations, by acting directly on one of the key vehicle design parameters, are an effective measure in stimulating the adoption of energy efficient and low-carbon technologies. If they are enforced beyond the efficiency potential available from improved ICEs and hybrids, they will be one of the main policy drivers for enabling the transition to electric mobility.[3]

Financial Incentives

The financial incentives directed at EV users and customers are essential for reducing the acquisition cost and the total cost of ownership, in order for EVs to compete with ICE vehicles in the open market. Despite the recent technological developments, which drove the battery cost down, EV battery packs remain a cost intensive component sustaining retail prices of EVs in high levels. The role of the financial incentives is to support the consumers and EV users financially in order to make EVs fictitiously an attractive option in the automotive market. Therefore, the financial incentives aim to initiate and reinforce a positive feedback loop, which based on sales increase will drive the production scale-ups and the technology learning to further reduce the cost of EV batteries and other components making EV ultimately a viable market option.

EV incentives can take the form of (a) direct rebates, (b) tax breaks or (c) exemptions, and can be framed in (d) technology-neutral, differentiated taxation that favors low-emission vehicles according to their GHG and pollutant emission performance and penalizes vehicles with high environmental costs [3]. Many countries, including 20 EU member states, such as the Scandinavian countries, where vehicle taxes tend to be high [47] and Brazil, Canada, China and South Africa [48], currently impose differentiated taxes on vehicle registration and/or circulation based on their fuel economy or CO_2 emissions performance. A comparison of the purchase cost and the total cost of ownership for EVs and vehicles using ICEs across European markets suggests that financial incentives are most effective when they minimize the EV purchase cost and come with a total cost of ownership advantage compared with ICE vehicles [49].

Policies aiming in increasing the value proposition of EVs

EV deployment can be supported by increasing the appeal of EVs over competing alternatives, providing advantages in terms of reduced fees, privileged access, driving facilitations. These policies focus to the support of EV ownership and use, and consequently must be developed in a municipal level and adapted to the unique local conditions of each urban area.

- Exemptions from reinforced regulations limiting the availability of license plates for ICE vehicles
- Exemptions from access restriction in urban areas
- Exemptions from road toll
- Exemption from parking fees
- Dedicated parking areas
- Access to publicly available charging infrastructure
- Permission to EV users to access bus lanes and high occupancy vehicle lanes.

Public Fleet procurement

The public authorities as well as the private sector can contribute significantly to the deployment of EVs by providing the market with demand signals, while exploiting their societal role; thus, they could act as advocates of EV promotion through their staff and customers. Mandates from local authorities and their private contractors can boost EV uptake through the deployment of large fleet of vehicles, such as municipal cars, shared vehicles, service vehicles and vehicles public transport [3]. Moreover businesses can substitute their corporate vehicles with EVs of the same class exploiting smart charging schemes and charging agreements with their employees.

Policy influence on EV deployment

As mentioned above, the deployment of EVs this early in such a premature EV market stage is policy driven. In this stage market sales are volatile and directly influenced by the annual developments of financial support policies applied in local markets. Policy strategies are also uncertain, as policy makers try to identify the transition to higher market maturity and consequently higher financial sustainability. Miscalculation in this identification might lead to local EV market crashes derived from the neutralization of vital for the market support policies and incentives. On the other hand, market experience showed that more fiscal incentives can revitalize an unresponsive market.

Table 8 BEV and PHEV incentives developments in a selection of countries 2016 (source: IEA)

Country	2015 vs. 2016 policy developments		2015 vs. 2016 sales growth		2016 sales	
	BEV	PHEV	BEV	PHEV	BEV	PHEV
China	~		75%	30%	257 000	79 000
United States	~		22%	70%	86 731	72 885
Norway	~	↗	6%	164%	29 520	20 660
United Kingdom	~		4%	42%	10 509	27 403
France	~		26%	36%	21 758	7 749
Japan	~		48%	-34%	15 461	9 390
Germany	~		-6%	20%	11 322	13 290
Netherlands	~	↘	47%	-50%	3 737	20 740
Sweden	~	↘	0%	86%	2 951	10 464
Canada	~		19%	147%	5 220	6 360
Denmark	↘		-71%	-49%	1 218	182
Korea	~		75%	-40%	5 099	164

Moreover, as shown in table 8, the influence of applied policies and incentives reflect directly on the EV sales. Significant is the example of the EV market development in Norway, which shows a very high growth of PEV sales in 2016, with preference being the PHEVs, as a result of higher purchase rebates and tax waivers introduced for PHEVs in 2016. However, even though there were introduction of an 25% exemption of the car purchase value tax on BEVs as well as waivers on road tolls and ferry fees the market only responded with growth of 6% of BEVs' sales, most probably because of peculiarity of the terrain and the extended driving range needs of vehicle owners. Japan's new policy, which introduced subsidization of the electric range of vehicles, upon purchase, lead to a shift of the EV market from PHEVs towards BEVs. In the Netherlands, the application of the differentiated CO_2 based taxation scheme, with gradual annual increase of taxation rates affected the market of PHEVs shifting the market towards BEVs [3]. On the contrary to other markets, Sweden, while reducing the purchase rebate offered to PHEVs it has seen the sales of PHEVs growing rapidly to 86%, probably due to the large amount of PHEVs sold as company cars exploiting the still valid monthly "fringe benefit" offered for the use of plug in cars as corporate vehicles [62]. On the other hand, Denmark has seen its EV market collapsing in 2016 after phasing out the 20% registration tax exemption for EVs. On the aftermath of the market collapse, the Danish authorities reinstated the exemption for the next 5000 EVs or the end of 2018 along with a battery capacity-based purchase car rebate on EVs in hope of the EV market's recovery. [3]

Battery Cost and Performance

The rapidly decreasing cost of batteries, which is the most cost intensive EV component, would be the main driver for dropping the price of EVs in the near future. Moreover, towards this development, the cost of an EV battery fell by 73% between 2010 and 2016 (BNEF, 2017). The technological development comprising the increasing volumetric energy densities of EV batteries and battery chemistry improvement, which combined with the rapidly decreasing manufacturing cost caused by the achievement of economies of scale in manufacturing, and aggressive pricing strategies by large scale producers, drives the battery cost reduction. These developments are expected to help EVs reach parity with conventional vehicles. To achieve this the EV manufacturers along with government agencies set attainable goals, which will lead the EV technology to longer driving ranges at lower costs and consequently to higher cost-effective competitiveness to lower the barriers of adoption.[4]

Research and development had lead into the formation of a competitive EV battery market, in which various battery technologies are present or under development, with the most utilized and expected technologies being: Conventional lithium-ion, Advanced Lithium-Ion, Intermetallic anode (eg. Silicon alloy-composite), Beyond lithium-ion (lithium metal, including lithium Sulphur and lithium air).The five largest battery manufacturers control 64% of Lithium-ion battery capacity production for EVs. Specifically, Panasonic supplies batteries to at least 18 models, LGChem to 12 and Samsung to 6 (Nov. 2017).

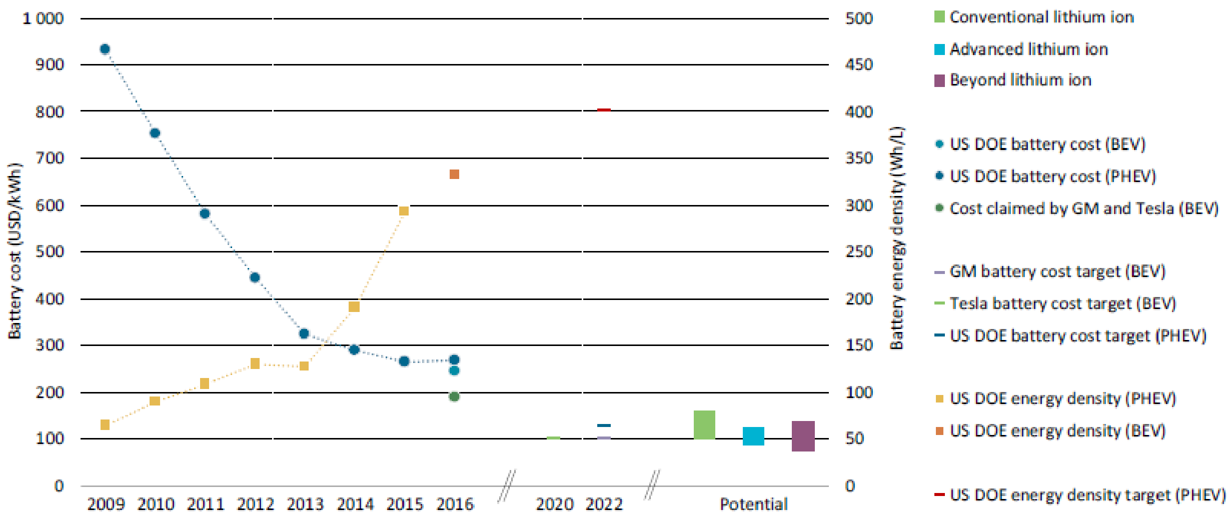


Figure 19 Updated assessment of battery cost developments (source: IEA 2017).

A battery technology assessment by renowned researchers and the US Department of Energy (US DoE) shows the rapid decrease in battery cost from 2009 till 2016 [5].

Moreover, the US DoE's estimation of the current (2016) battery cost, which ranges from 250 – 270 USD/kWh, and can be interpreted as projections for the high-volume production of technologies currently being researched and is significantly higher, than the cost announced by GM and Tesla (180-200 USD/kWh) for conventional lithium-ion technologies [6]. The current battery technology (Figure 19)(2016-2017) refers to a battery for extended (320km) all-electric range for BEVs, and it is an advanced lithium-ion technology (with silicon alloy composite anode), which is currently (2017) deemed to have a greater cost but also a larger potential for cost reductions compared to conventional lithium-ion technologies.

Recent research states, Scaling up production and increasing battery pack size can lead to battery unit cost reduction [5]. According to US DoE, increasing production of a 100 kWh capacity BEV battery pack from 25,000 to 100,000 units allows a reduction in production costs of 13% per kWh. According to recent research, battery pack production comprising of over 200,000 units/year are estimated to cost 200USD/kWh or less, which is 33% less than the 300 USD/kWh estimated for production volumes ranging between 10,000 and 30,000 units in 2015 [14]. In addition, increasing the battery pack size from 60 kWh to 100 kWh would consequently lead to a manufacturing cost reduction of 17% per kWh of EV battery storage capacity [5].

The projected battery costs for 2020 (Tesla), 2022 (GM), are optimistically below the forecast made by US DoE. While the alternative battery technologies (advanced lithium ion, beyond lithium ion) show promise with projected costs that are well below 100 USD/kWh. The battery energy density increased from 100 Wh/L in 2009 to 600 Wh/L in 2015 for BEVs and reached 670MWh/L for PHEV. That is a very crucial development to eliminate the limited range disadvantage of the EV technology. The technology development in energy density shows that it's possible to reach the energy density target (PHEV) for 2022 set by US DoE.

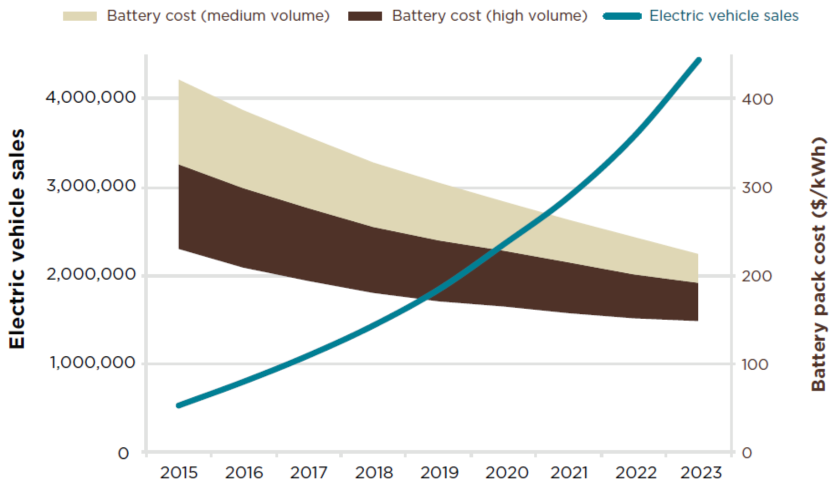


Figure 20 Scenario for estimated vehicle and battery pack cost (source: ICCT)

As shown in figure 20 the predictions that ICCT made in 2015, for the decrease of EV battery cost and global EV sales are verified for 2016. However, based on the most recent battery technology assessments and the targets and mandates of the industry these predictions are proven quite conservative. The reason is that research and development, conducted by key stakeholders in the industry, aiming for cost parity with conventional vehicles, has pushed forward the battery technology introducing technological advancement in leading lithium-ion chemistries, and has steepened the manufacturing learning curve to achieve economies of scale, reducing the manufacturing and consequently the marginal battery cost ($/kWh) to unexpected levels. However, the increasing need for battery capacity in the EV industry might lead to future average battery cost values similar to the ones predicted by ICCT, diversifying the production.

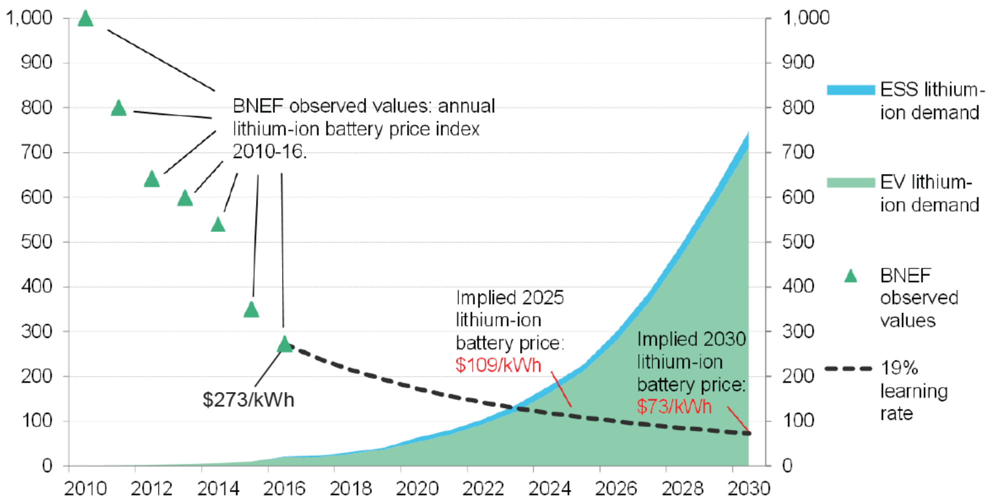


Figure 21 Lithium- ion historical and forecasted battery prices (source: BNEF 2017)

**Prices are for cells plus packs and are an average of BEV and PHEVs. Cell-only prices will be lower. Historical values are nominal; forecast values are in real 2015 US dollars*

In recent study Bloomberg New Energy Finance (BNEF) estimated that the EV battery cost will decrease below $100/kWh by mid-late 2020s, reaching an average price of $73/kWh in 2030. The learning rate of 19% on battery manufacturing cost reduction that BNEF used in its study accounts from historical data derived from the period 2010-2016, which coincides with the scaling up of battery manufacturing, driven by the PV industry overgrowth. The same study predicts that economies of scale of an average up to date battery production unit of 3GWh/year production capacity potential, will have an effect in battery price reduction of 2.5% while technological advancement will lead to a battery pack capacity increase of 5% per annum, achieving a twentyfold production of 60GWh/year by 2030. The battery price reduction development will lead to a steady decline of EV cost, with expected acquisition cost equivalence with ICE vehicles expected to be achieved in 2025. In addition, the overall progress of EV battery development is expected to drop the battery cost to prices below a quarter of their current value (2030), leading the EV cost to an average price of 65% of the 2016's value by 2030.

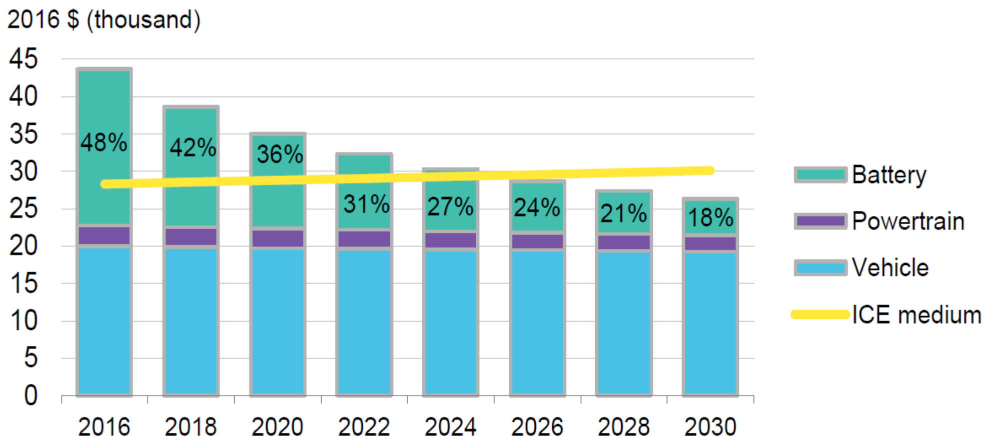


Figure 22 U.S. medium BEV pre-tax price breakdown, ICE pre-tax price and share of battery costs (source BNEF 2017)

Battery Cost formulation

A new analysis by MIT researchers indicates that without proper planning there would be short-term shortages of some metals required for the rapidly increasing lithium-ion EV battery manufacturing [22]. The study, by Olivetti et al, focuses on the availability of the five most essential ingredients needed by the current EV battery industry: lithium, cobalt, manganese, nickel (cathode) and carbon in the form of graphite (anode).

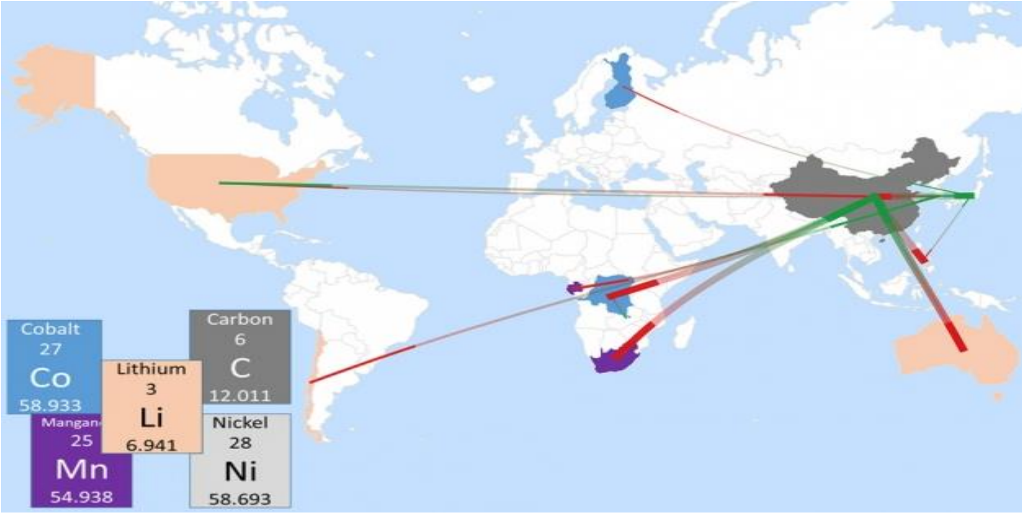


Figure 23 trade flows of key ingredients for battery production (source: MIT Department of Materials and Engineering)

The study shows that apparently nickel and manganese, being materials used much more widely in other industries, are not affected even if the battery production ramps up in very high levels the next decade because the corresponding material amount, dedicated to battery production is only a very small portion of the global supply [23].

Figure 24 Major Lithium deposits by type (sources: Deutsche Bank, USGS, BNEF)

However, short term scarcity could appear in Cobalt and Lithium supply. Moreover, according to BNEF the global reserves of lithium are not close to depletion even with the consideration of the great growth of the EV market, which is expected to increase more than thirtyfold by 2030 dragging upwards the battery manufacturing and the lithium demand. It's characteristic that in the next decade, taking into account the great increase of the EV market, it's expected that less than 1% of the known lithium reserves will be extracted. Deutsche Bank estimates that even if the market triples there are 185 years' worth of known reserves in the ground. However, in 2015 fear and speculation of a probable scarcity almost tripled the prices of the battery grade lithium to more than $20,000 a ton, in just 10 months. This increase was reflected on an instant rise in the price of EVs, propelling the EV market in competing with other markets for lithium resources [25].

The lithium supply is either originated from hard rock mining or processing of brines. The lithium production from brine, which accounts for half of the global production of lithium, can ramp up much more rapidly, within a short period of six to eight months, in comparison to the fairly slow process of establishing new underground lithium mines [22]. Mining companies have announced the addition of 20 lithium production sites to the 16 currently operating (2017b), the first of which is scheduled to open in 2019, but the concern remains that they won't be finished in time to satisfy rising demand [22]. Study by Deutse Bank predicts that beyond 2018 the lithium industry will be directed towards implementing projects of lithium extraction from brine, which account to 76% of the global reserves, and despite being more capital intensive, exploiting their inherently lower costs and greater economy of scale will offer lithium abundance and push the marginal cost of lithium down in the long term [30]. In agreement to these predictions, Oliveti states, that even though there might be disruptions in the supply of lithium, it's improbable that these will majorly disrupt EV battery production [23].

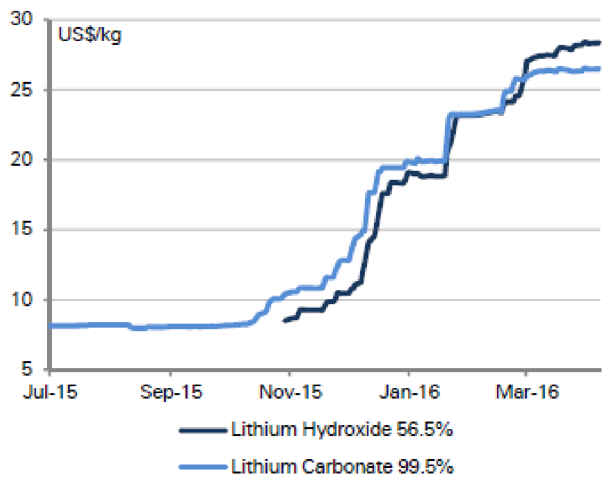


Figure 25 Chinese domestic battery-grade lithium prices 2015-2016 (source: Deutse Bank & Asian Metal [29])

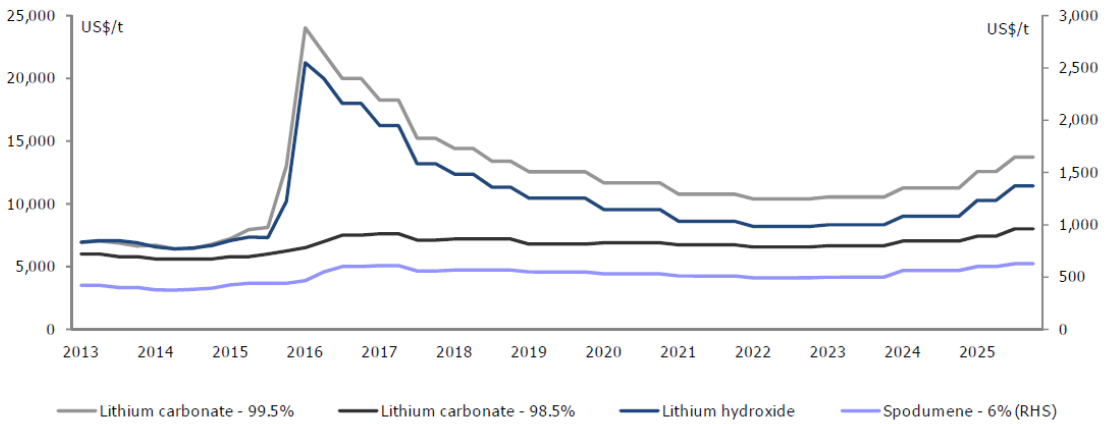


Figure 26 Price forecasts for 99.5% & 98.5% lithium carbonate, lithium hydroxide and 6% spodumene concentrate (sources: Deutse Bank & Asian Metal company data)

Cobalt supply is a more complicated case since one of its main sources is the Democratic Republic of Congo, which has a history of violent conflict and corruption. Cobalt is typically a byproduct of other mining activity, typically nickel and copper extraction [22]. The main problem that disrupts the cobalt supply is focused on the inability to initiate new mining operations, since higher prices induced by scarcity won't stimulate new supply in the way they would in other commodity markets. Even so, the market of cobalt has doubled from the end of 2016 to the end of 2017 reaching a market value of $8 billion, but its value is expected to be stabilized or even drop by 5.3% (to $68,200/ton from $72,000/ton) in 2018, as projected by BMO Capital Markets, while Glencore Plc and Eurasian Resources Group ramp up major new cobalt projects in 2018 and 2019 [28].

The, beyond expectation, expansion at Glencore's Katanga project in Democratic Republic of Congo, seems to delay the onset of a cobalt shortage that many analysts see emerging as the use of EVs is beginning to spike toward the end of 2010s. The cobalt extraction industry is expected to grow further with the integration of three major planned projects but also numerous potential ones. The recent increase in cobalt price has also sprouted an increase of cobalt recycling industry's volume, which is expected to reach 22,500 tons in 2025 from 8,700 tons in 2017 according to Creation Inn, a London-based research firm focused on energy storage and recycling [28].

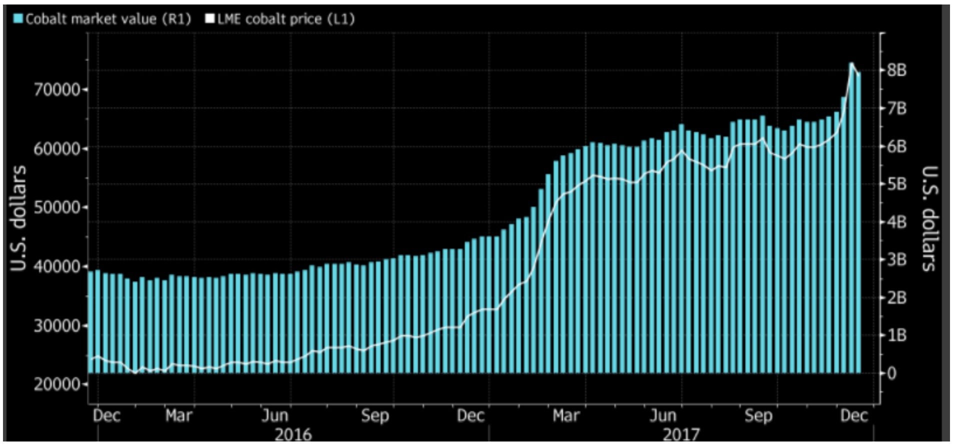


Figure 27 value of global cobalt market and cobalt price development in 2016 -2017 (sources: LME; 2016 output data from Darton Commodities retrieved by Bloomberg)

According to Colin Hamilton, managing director for commodities research BMO Capital Markets, the automakers are expected to push the battery industry for cobalt substitution, given the increased cobalt prices and its projected scarcity. This can be confirmed by the projected cobalt mining operations, as shown in figure 28, which are not expected to follow the EV battery market growth beyond 2025, when to counteract on potential cobalt scarcity the battery industry will be directed towards less cobalt dependent cathode materials for lithium-ion batteries.

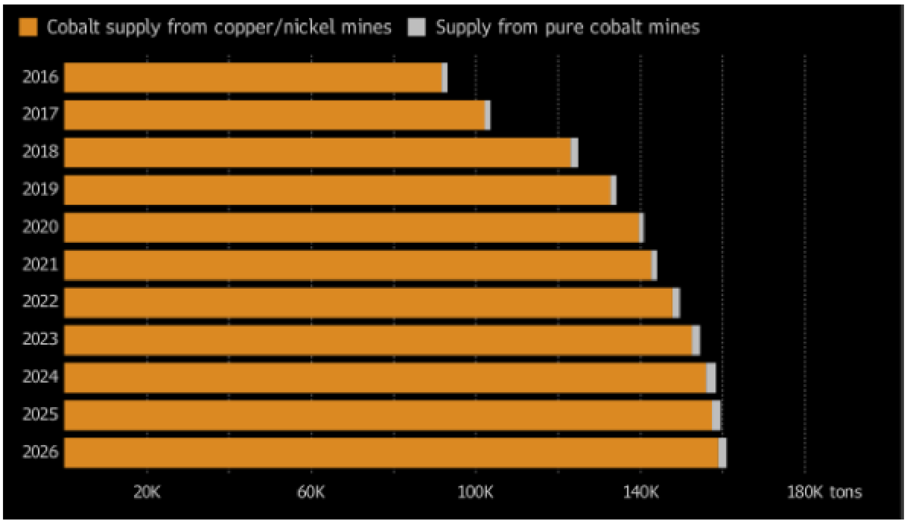


Figure 28 Projections of Cobalt supply from copper nickel mines (sources: CRU, Bloomberg)

A study conducted by BNEF shows the impact of the price fluctuation of various metals in lithium-ion battery price. Important findings of this study, as seen in figure 28, are that analyzing a typical NMC (111) lithium-ion battery, used amongst others by BMW and Chevrolet, showed that cobalt has the biggest price leverage of total battery pack cost increase of 4.3% per doubling of its price, which occurs due to its already high price of $75/kg (figure25) [28]. This leverage of the cobalt in battery packs is also more impactful because of the volatility of cobalt's price caused by short term bottlenecks in supply , which as mentioned above are caused by the inability of the mining industry to constantly adapt to the continuously increasing demand originated in the EV battery industry.

Even though the price of lithium has skyrocketed reaching approximately $22/kg (02.2018)[30] it is still relatively low to significantly affect the battery pack price since indicatively the NMC(111) battery pack contains only 12% Lithium compared to the 30% of the expensive cobalt. Even if the price of lithium soars up to 300%, the reference battery pack (NMC(111))costs would rise only by about 2%. Also nickel's price shows a significant leverage for the price of NMC(111) battery pack reaching 1,5% per 100% increase. However, it seems that nickel's price is unaffected by the rapidly expanding EV battery market with its main volume still being used in the steel industry.

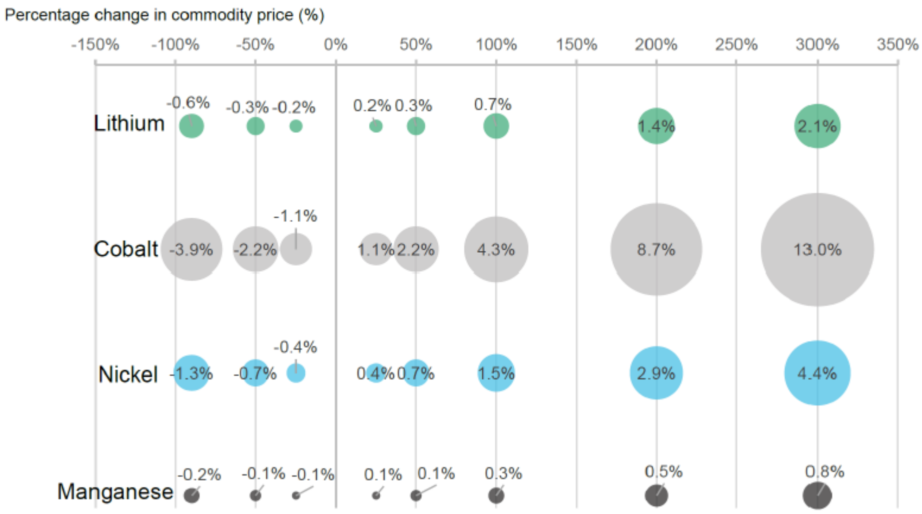


*Figure 29 Impact of raw material price fluctuations on NMC battery pack costs (%) (source: BNEF 2017) *Note: NMC chemistry modelled here is NMC (111); NMC battery pack cost is $223/kWh)*

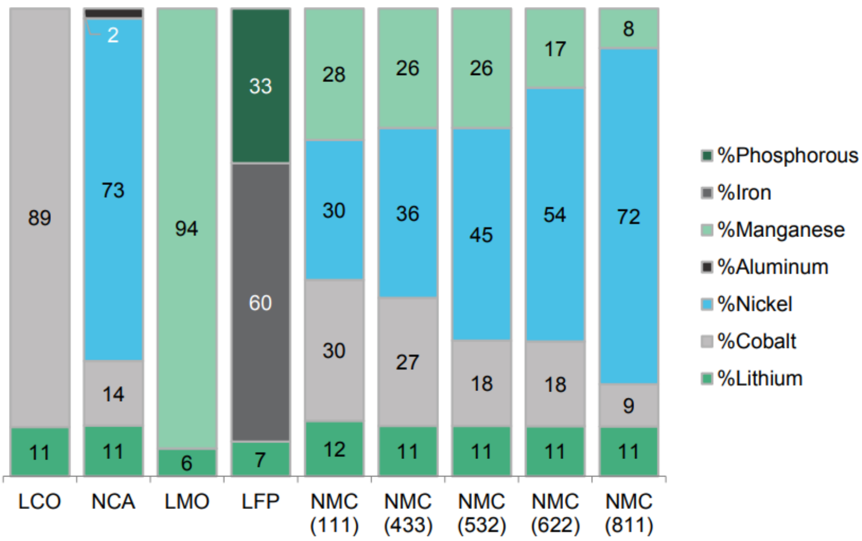


*Figure 30 Metal content of lithium-ion batteries by cathode chemistry, % of total metal content by weight per kWh (*Source: Bloomberg New Energy Finance), Note: The numbers associated with NMC represent the ratio of Nickel : Manganese : Cobalt in each particular blend.

The uncertainty in the price of lithium-ion battery metals is significant, mainly because of prior historical price manipulations. A significant reference case was the sever nickel market price manipulation in 2007, which skyrocketed the nickel price over $52,000/ton from $12,000 [34] in a period of a year, induced by its scarcity resulting from its mass use in the newly introduced production of the metallic alloy NPI (nickel pig iron) [31, 33]. This raises concerns of whether li-ion battery metals' prices will ever undergo such manipulation, how long will this crisis be and how will the battery industry, and by extension the EV industry, be affected by it. The market overcame the Nickel crisis by ramping up its production, which gradually adapted to the demand of NPI production, securing abundance and market price stabilization while the effect of the economic crisis also contributed in the drop of the price to values prior to 2007. To overcome such bottlenecks, battery producers and global automakers are trying to stock up raw materials for their foreseeable needs taking into account the scaling up of production. As such, Tesla is currently in talks with Chile's SQM to invest in lithium. SQM's lithium production from brine is one of the cheapest globally and thus Tesla is examining the viability of the investment in processing technology to produce the battery grade Lithium hydroxide, used by its car batteries, directly from the ground. Furthermore Toyota agreed to buy a 15% stake in Orocobe which produces lithium in Argentina [32]. Cobalt is the most sensitive metal in terms of price volatility due to its scarcity and thus it is a potential target for market manipulation. This fact leads EV manufacturers and battery producers to invest in battery technologies with low cobalt dependency. Such an example is Tesla, which produces and utilizes NCA Lithium-ion batteries containing 14% Cobalt in comparison to NMC (111), (433), (532), (622) Lithium-ion batteries, which contain 30%, 27%, 18% and 18% respectively. [61]

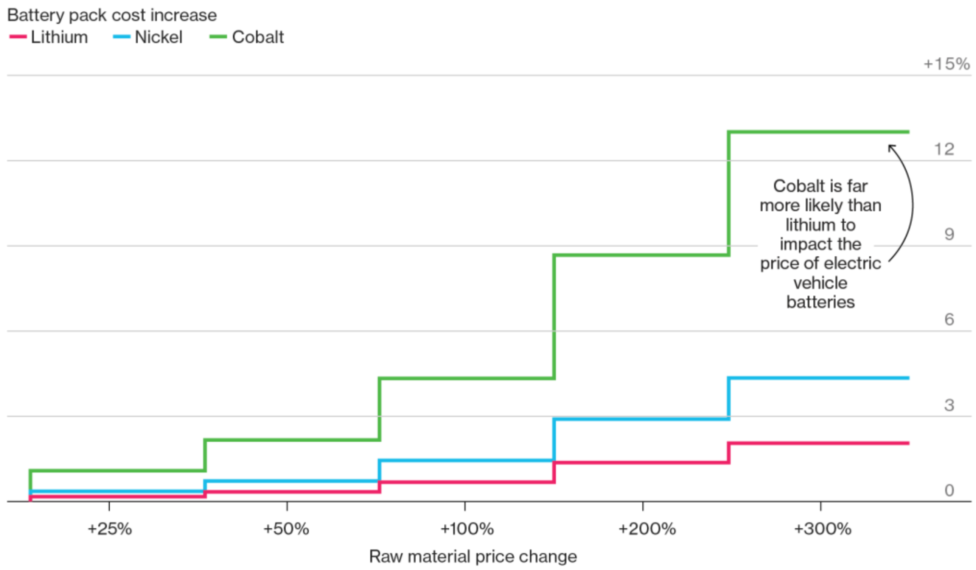


Figure 31 Raw material price influence over battery pack cost (source: BNEF)

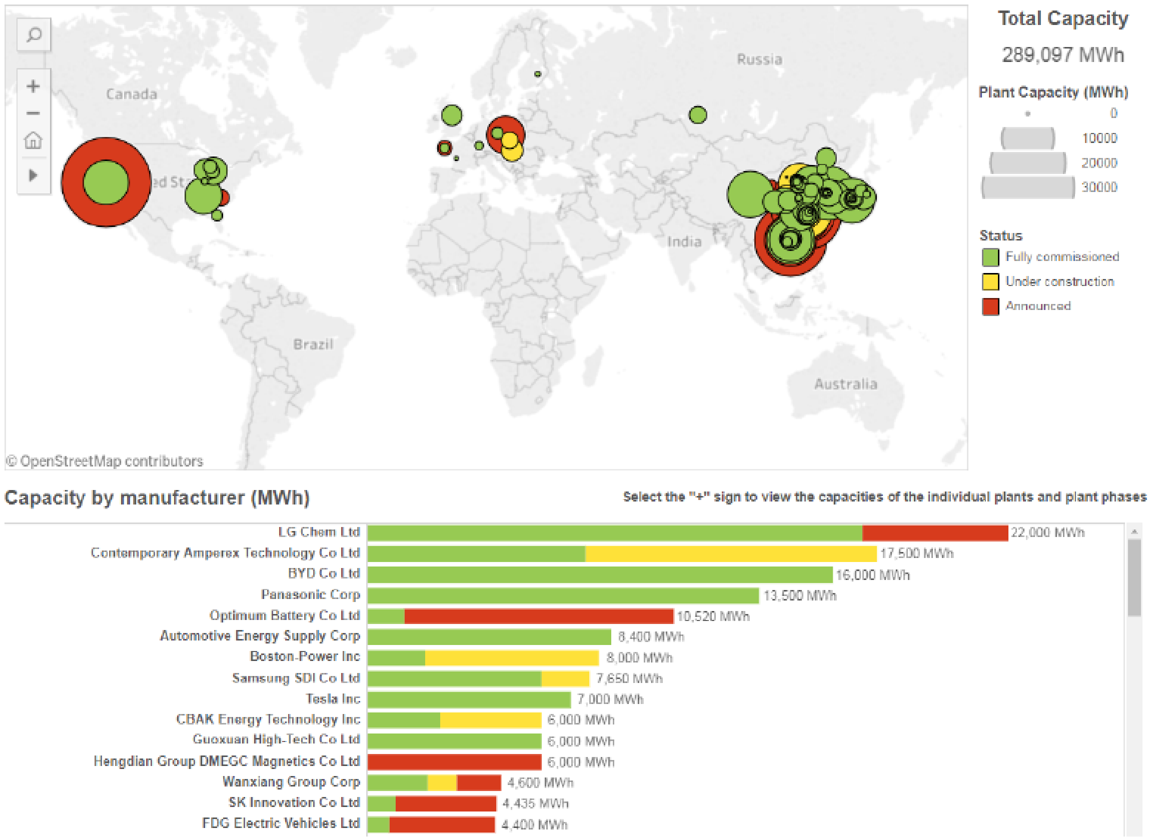


Figure 32 Global EV lithium-ion battery manufacturing capacity (BNEF 2017a [24])

Moreover, the battery industry has seen a transformation since 2014 with the introduction of larger facilities with producing capacity on a multi gigawatt scale, being the dominant trend in today's industry (2017), with26 battery cell plants that are either in production and due to expand capacity or new operations due to be in production by 2021 with a combined operational and planed capacity of 344.5GWh [26]. The industry is ramping up production rapidly to satisfy the future battery demand resulting to an increase of 11% (10GWh) of the total installed production capacity during 2017 and an increase 19% of the total announced planned production capacity for 2021 (from 289 GWh to 344.5GWh)[24,26] .

Also the need to localize production to support the local EV industry is also one of the highlighted trends in the battery industry. China is the dominant force in the industry with 49% of the planned capacity totaling 169 GWh followed by Europe with 23% consisting of 78.5 GWh, while the US is 3rd with 53GWh corresponding to 15% of the total capacity. It is notable that Tesla has announced that beyond 2021 its battery producing plant, known as "Gigafactory" should be able to propel the production to 150GWh/year to meet the demand caused by the mass market scale of production of its EV, Model 3, feat which deemed significant, as such capacity would represent a significant portion of the global battery production [26].

A forecast from Benchmark Mineral Intelligence foresees that new plant announcements would be likely made during 2018. Tesla is expected to announce more details on its planned production unit in Shanghai, China, which is expected to be a vertically integrated battery facility, where it is possible to be the ground for collaboration and joint ventures with other auto manufacturers to build foundations for EV industry development. Securing lithium and cobalt for the future production has been one of the major concerns of the industry with VW and Great Wall Motor (China) being two of the most active actors in ensuring the raw materials for their future production. Europe is a few steps behind in introducing new battery production capacity that will assist the local auto producers while North America is reliant to a successful rump up of Tesla's "Gigafactory" which's production will be mostly committed to the EV manufacturer's own operation [26].

Moreover, many large battery production units are announced expecting to triple the size of the industry by 2021, but these announcements in a rapidly growing market create volatility in market predictions as the implementation of all the announced projects is far from settled. This fact is expected to create uncertainty amongst the auto manufacturers, posing a major challenge and risk for the EV industry in the next 5 years, given the fact that the total announced battery production capacity is deemed necessary to satisfy the production ambition of the autoproducers.

Major World Markets

Asia

China, the biggest EV market worldwide (2017), with a market share that exceeds 49% of total sales [55], examines its future policies for the promotion of electric mobility, even possibly a complete ban for petrol fueled vehicles in major cities [57]. China, by following its industrial policy, "Made in China 2025" is already transforming the activity of its industry towards quality optimization, sustainable development, manufacturing optimization and excellence and promotion of innovation and entrepreneurship [56]. Following this framework, the Chinese authorities announced new directives that bind automakers to gradually increase their battery production in order to meet the constantly increasing demand for EVs. In addition, authorities announced a sale target of 2 million EVs in 2020, which is expected to amount to 1/5 of the country's annual vehicle production and sales. Following this pace, China is expected to reach a fleet of 5 million EVs by the same year [58].

Towards this direction the government already announced a draft legislation requiring car makers to meet EV sales quotas of 8% by 2018, 10% by 2019 and 12%

by 2020 and while this has been met with strong resistance from the industry for being too overly ambitious, the government appears to firm in wanting to uphold its proposal [17, 39]. These targets can be misinterpreted as they include weighting factors in the carbon credit scheme. Logan Manufacturing Company (LMC) and BNEF have estimated that 10% and 12% translate to 2.9% to 3.3 % for 2019 and 3.4% to 3.9% for 2020 in real market share terms, which is certainly achievable in a total market level considering the current annual development of the local market [55]. Up Until 2017 China's policy in promoting EVs has been proven successful providing strong financial and non-financial incentives. These policies included, exemptions from acquisition and excise taxes ranged between CNY 35 000 and CNY 60 000 ($5,000 to $8,500), while local and regional authorities can complement these within the limit of 50% of the central subsidies. Large Chinese cities also allow total or partial waivers from license plate availability restrictions [52]. The combination of imposing license plate restrictions, encouraging consumers to buy electric cars, and offering financial incentives, making electric cars financially accessible, explains the high volume of sales (336,000 cars) and growth rate (40%) in 2016.

The Chinese authorities are in the midst of implementing a change in its policy for EV promotion by reducing the subsidies for EVs by 20% from the beginning of 2017 and onwards, as a necessity to adjust and improve its policies for an optimized market response [53], which didn't seem to halt the Chinese EV market in 2017 [54, 55] as presented in the Figure 33. On the contrary PEV sales have exceeded all expectations in 2017 reaching 630,300 plug-in passenger vehicles of which 605,500 were produced in China and 24,800 were imported. In addition China has to exhibit 198,000 commercial EV sales, which include mostly large electric buses.

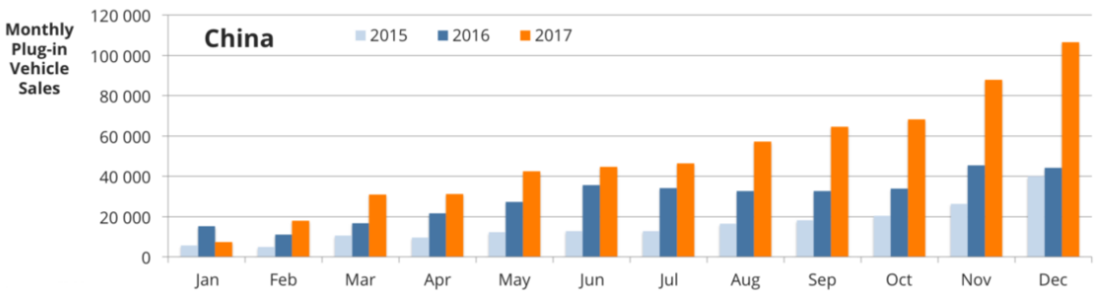


Figure 33 Monthly PEV (PHEV& BEV) sales in Chinese market in the period 2015-2017 (source: EVvolumes [55])

The extend of China's EV market reaches as far as the battery industry, where China is by far the dominant force with 49% of the global (installed and planned) capacity totaling 169 GWh, which is expected to be available in 2021, with the most recently Chinese project being Great Power's planned 10GWh plant in Guangzhou [26]. China has also made important steps towards the decarbonization of the electricity mix powering China's EV fleet. Specifically for the year 2020, the country has set a goal to install 150–180 GW of wind power and 20 GW of PV solar power farms. Such a large RES penetration will require large energy storage systems (ESS) to smoothly support electric grids, so that the electrical power demand and operating standards are met at all the times, further prompting the battery industry to expand its operation [38], which is expected to create a feedback loop of battery cost reduction.

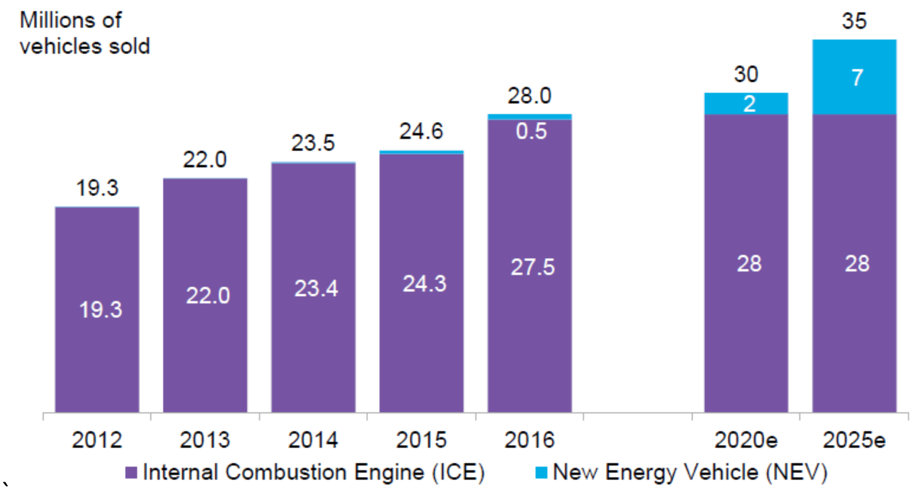


Figure 34 China's vehicle sales according to the recent 2025 plan (sources: China Automotive Information Net, BNEF)

For 2018, EV market analysts expect that Chinese EV market growth will continue at a high pace, with a 1,2 % share increase to 3,6 % for the complete year. This is based on a conservative volume growth estimate of 50 % over 2017. There is still an upside to this number; as during 2018 Chinese EV sales could surpass one million passenger PEVs. Moreover, the BEV / PHEV mix is trending towards pure electric since 2016, with 81 % of sales in 2017 being BEVs, while for 2018 it is expected to reach 82% [55].

Japan: In Japan EV sales after remaining stable in 2016 has showed some decline in the beginning of 2017. Specifically in January 2017 only 1,800 units were sold which accounts for Japan's automotive market share of only 0.46%. Even though Japan has achieved the installation of an extensive network of charging stations [64] the market is dictated only by Nissan Leaf, which is the first EV of its class to have a 30 kWh battery providing an extended driving range, while, being produced in the country, it can be obtained in lower prices than its competitors. Nissan is expected to release its new Leaf model during 2018 with a driving range of 250 km (150 miles) which is expected to further convince the local market to invest in the EV transition [63]. Some important actions have been made in a municipal level for the adoption of EV technology, such as the example of Toyota city, which, following the HA-MO project proceeded to the placement of various Electric Vehicles in the city's transport system (passenger cars, trains, buses, taxis, electric bicycles) and a vehicle sharing network constituting by more than 100 vehicles. [12]

Europe

In Europe, the second largest EV market globally, electrification of the transportation sector is moving forward rapidly. At a central policy level, the European commission is considering the introduction of a zero emission vehicles (ZEV) mandate. If this consideration is translated into legislation, it could lead the European automakers to remodel their production planning to comply with induced the minimum quotas for the production and sales of ZEV [17]. This regulation is expected to tighten the CO2 standards for light duty vehicles with the inclusion of a targeted mechanism, mandating quotas for the sales of ZEV. Significant are the pressures from the Nordic Ministries of Climate (May 2017) to the European Commission, to revise ambitiously its fuel economy standards in order to promote Europe's transition to electro-mobility. This motion is aiming also in disincentivize the diesel use in heavy duty vehicles (HDVs), which account for a significant 30% of the road transport CO2 emissions [17]. It is important to mention that such legislation is deemed required by many European organizations in order for EU to reach its target of reducing CO2 emissions from transport by 60% and eliminate the use of fossil fuels in cars by 2050 especially EU's CO2 legislation falling short on the aftermath of the exposed inadequacy of the EU vehicle emission testing regime.

However, the restructuring of the automaker industry has already been initiated in a policy level with the introduction of decentralized policies of various member states, like UK and France that announced a ban of conventional Vehicles in their cities in 2040 [50, 51]. The bans have prompted intense skepticism and criticism by analysts with regards to their way of implementation. In particular, there is criticism on the long-term horizons of completion and of the lack of central planning, which raises questions about the future development of support infrastructure, as well as the uncertainty of implementation of such plans by future governments.

Despite the concerns, the European motor industry has made a turn towards this direction, with biggest European automakers already having made big steps towards prioritizing manufacturing of zero emissions vehicles. Specifically, the Alliance of Renault-Nissan-Mitsubishi is set to produce 12 all electric cars within the period 2018-2022 and is also planning a funding program that is expected to direct funds of $1 billion to various startups involved in vehicle electrification, autonomous driving systems, connectivity and artificial intelligence [40, 41]. Daimler-Mercedes will offer at least one electrified alternative in every one of its model series by year 2022 [42]. VW is set to build 50 all-electric models by 2025 and electrify 300 models by 2030. The adaptation of electric vehicles is within reach, but it is driven by policy rather than demand. Demand and consumer behavior is expected to shift as the sales of diesel/gasoline vehicles are banned by member states in the near future (UK, France 2040).

In addition EU is major producer of lithium-ion batteries for EVs, second only to China, with planned capacity of 78.5GWh (2017) . Prior to 2017, the EU was falling behind, having inadequate capacity to support its local EV industry, with just one plant planned by LG Chem in Poland with 5GWh capacity. However, the EV battery production activity was accelerated by two facilities, the 34GWh plant of Terra E in Germany and Northvolt' s 32GWh facility in Sweden, with the 7.5GWh plant of SK Innovations in Hungary also playing an important role in the region [26].

Norway: In Norway, electro-mobility has already become a reality with EVs in circulation exceeding 110, 000 in 2016, accounting for roughly 20% of the country's new car sales [17]. While during the period of January-September 2017 light duty EV sales reached 43,700 from 33,900 units sold during the same period in 2016 showing growth of 29%. PEVs' penetration in Norwegian market reached 32% in 2017 from 24% in 2016 [59]. In fact, roughly 72% of EV buyers in Norway quote 'cost savings' as their primary motivation for choosing electric models [17].

Norway first introduced big incentives for electric cars in the 1990s mostly to help local car makers, "Think" and "Buddy", which got bankrupt in 2011 selling accumulatively only 5000 models during their lifespan. With the release of Nissan Leaf and Tesla Model S in 2012 the number of EVs in Norway doubled in each of the five following years. In 2017, 35% of the new cars are Electric (BEVs 18%, PHEV 17%) with plans to achieve a target of zero emissions for all new cars by 2025 [8]. Although Norway seems like the EV market of the future, its success is subject to strong incentive policies and controversial subsidies that enforced and solidified the EV market. Such policies including the zero emissions incentive are [10]:

- No purchase/import taxes (1990)
- Exemption from 25% VAT on purchase (2001)
- Low annual road tax (1996)
- No charges on toll roads or ferries (1997 and 2009)
- Free municipal parking (1999)
- Access to bus lanes (2005)
- 50 % reduced company car tax (2000)
- Exemption from 25% VAT on leasing (2015)

Zero emissions incentives became controversial in the country, as the EV subsidies operate in competitiveness with the development of the public transportation. Specifically, it was estimated that the public revenue loses annually are Nkr300m - NKr350m on tolls and NKr16m on free charging (new infrastructure NKr12m, NKr4m operating costs). Free parking amounts to NKr12m annually with the most escaping public revenue originated from the EV exemption from purchase taxes and VAT of 25%. These policies give a driver for consumers to buy EVs mainly for economic (72%) rather than environmental reasons (26%). Policy makes face challenge on when to halter the extremely generous subsidies that have assisted the outburst of the EV market growth. Such consideration will involve the cost decrease of batteries and the rising demand of EVs. The Norwegian policy makers are examining an increase in taxation but with the intention to maintain very clear incentives for the EV market. The new program is expected to be revised after 2018 according to market development. Such policies could be the implementation of toll prices for EVs in parallel with an increase in toll prices for petrol cars, applying a “polluter pays principle”, as well as the introduction of a transitional model to end free charging.[9]

Germany: Germany has grown into an important market for EVs in 2016, achieving a market penetration of 1.88% [43]. This has been made possible by Germany’s application of an extended incentive programme, with the financial contribution of the automaker industry, which was approved by Germany’s Federal Government in April 2016, following a disappointing performance of the EV market of the previous period. This programme includes a capital injection of 1 billion € from the state budget for the subsidization of the EV market (60%) with the financial contribution of the automotive industry (40%), which is expected to last until 2019 (when funding will be exhausted) [44]. Germany's local governments’ policies follow those of Norway including free parking, access to bus lanes and public charging stations.

Germany intends to play a leading role in developments in the electric mobility industry as a major vehicle supplier, manufacturer and developer of integrated infrastructure solutions. On May 2017, the head of Germany’s Federal Environment Agency (Umweltbundesamt), Maria Krautzenberger, called for the introduction of minimum EV sales quotas in Germany arguing that achievement of the country’s climate targets would be impossible without the implementation of these. Germany, being home to Europe’s largest car making industry, sends an important sign that business-as-usual for the fossil car industry cannot continue [17]. After the emissions scandal in 2015, the German automotive industry made a dynamic appearance in the field of electric mobility in an attempt to improve their public profile. Specifically, VW announced its sales goal of 25% coming from EVs by 2025, while Daimler and BMW are aiming to 15-25% of their total sales in 2025 to be coming from EVs.

UK: UK makes a dynamic entrance to the EV market announcing that it will ban the sales diesel and gasoline powered vehicles by 2040. UK's ministry of Environment also announced a £200m subsidization to local authorities for implementing restrictions of access for diesel powered cars in streets that show high air pollution. Currently, demand for EVs is estimated to be lower than 5%, as the consumers are reserved in concern of their purchase cost and the limited availability of charging stations.

The municipality of London is set to introduce in 2019 or 2020 at the latest an Ultra-Low Emission Zone, within which all vehicles of all categories will have to meet certain exhaust emission standards or pay a daily fee to travel. This measure comes to further upgrade the value proposition of EVs which already enjoy a 100% discount on the London Congestion Charge [3]. The existing EV support policies include, purchase subsidies, registration tax benefits, ownership tax benefits, company tax benefits, local incentives and infrastructure fiscal incentives promoting the installation of domestic or publicly accessed chargers.

Sweden: Sweden follows a far more conservative policy for EVs in regards to tax exemptions and fiscal incentives in comparison with neighboring Norway leading to a respectively lower market penetration.[12] Volvo, the once Swedish automaker, announced that all cars produced after 2019 will be either plug in hybrids or battery electric vehicles (BEVs), development which might sprout some increase of the EV penetration in local market [51].

Netherlands: In the Amsterdam's Schiphol airport there are approximately 8000 EVs in operation serving as the automotive fleet of the airport. The airport's vehicle fleet was gradually replaced beginning in 2013 with the acquirement of 35 pure electric buses with range of up to 250km.

France: French Government announced a sales ban of diesel and gasoline cars by 2040 [51], while the biggest auto producer in the country, Renault-Nissan undergoes a manufacturing transformation aiming to integrate with the global plan for electrification of the transport sector. In 2009 had announced a budget for 4 billion Euros for the purpose of developing the market for electric vehicles.

USA

US is made very important progress during 2017 in increasing the deployment of EVs, the sales of which almost reached the 200,000 mark, showing an increase of 27% in comparison to 2016, with 53% of them being BEVs. The PEV share of the total light duty vehicle sales reached 1.2% showing a significant increase from the 0.9%, achieved in 2016. The growth can be attributed to the markets success of Chevrolet Bolt EV and the new Toyota Prius Prime PHEV. [67]

Even though the present administration doesn't practically support the electrification of the transport sector, various states have proceeded in implementing EV adoption measures. As such California pioneered zero-energy vehicle (ZEV) mandate [65], which was adapted and enforced by several cities in the state, like Los Angeles, Seattle, San Francisco and Portland, and now signed by 30 cities to start a partnership to mass-purchase EVs for their public vehicle fleets aiming to integrate up to 114 thousand vehicles, a magnitude that is comparable with the 160 thousand EVs sold in the United States in 2016 [66].

Moreover, US is the third biggest producer of lithium-ion batteries, with 53GWh which account to 15% of global production capacity share, while the much expected ramp up of Tesla's production unit, aiming to provide battery capacity for the mass scale production of its "Model 3", is expected to be the pillar of supporting the local EV transition [26]

Figure 35 Annual PEV sales and PEV sales' growth is USA in period 2010 – 2018

The future of electro-mobility is promising for the US as analysts expect significant market growth in 2018 approaching the 100% (doubling of the market), with the circulation of EVs reaching the 1 million units. The scaling up of the production of Tesla's Model 3 and the expectation for an increase of publicly available charging infrastructure to over 1.1 million plug-ins, are expected to be the main drivers behind this EV adoption acceleration. [67]

South America

Colombia: In 2013 the capital city of Bogota, was among the first the municipalities that launched initiatives for the adoption of EVs. The municipality's initiative aimed at the development of the largest fleet of electric taxis in The American Continent, knowing that the specific vehicles were the main source of CO_2 emissions in the capital. In continuation of this radical measure Bogota's municipality proceeded to total electrification of the public transportation of the city. The most recently achieved goals of the city towards this direction was the replacement of 2.250 buses with pure electric ones by the end of 2016, while the taxi-fleet's electrification initiative had already amounted to 800 vehicles in 2013. [12]

B. Global Trends and the Future of EV Market

Increased Diversity of Electric Vehicle stock

During 2017 Manufacturers have introduced in the market various battery electric vehicles (BEVs) and plug-in electric vehicles (PHEVs) in most vehicle classes. Over 50 different BEV models are available worldwide [16], while 36 new models are expected to enter the market during 2018 [15]. Moreover, a large variety of PHEVs are available in the market providing a longer driving range alternative. Variety also include china, where the OEMs achieved a 43% of EV production worldwide (2016), introducing 25 new EV models in the market. Survey study by McKinsey & Company in 2017, revealed that Chinese consumers can choose from 75 EV models, more than any other country. [27]

The diversification of the EV stock also highlights the differentiated mobility services each vehicle can provide. One of the dominant product differentiations, which emerge in the EV market, points to either increased Driving range or to energy efficiency to be the key characteristics in market options for BEVs, while the market of PHEVs is, in addition, oriented towards fuel efficiency as well.

Survey by BNEF, based on automakers' stated electrification targets, showed that we can expect more than 220 EV models to be available in the market as soon as 2021. This fact in combination with the rapid development in EV battery technology would lead to further diversification to the global EV stock due to rapid aging of technology. This can be confirmed by the projected energy density for EV batteries as shown in figure 19 [24]

McKinsey & Company, in its study, identified also that Chinese EV owners show increase likelihood to purchase EVs again. This fact, combined with the Chinese policies and incentives for withdrawal of aging EVs would dictate the future diversification, caused by technology aging, of the Chinese EV fleet.[27]

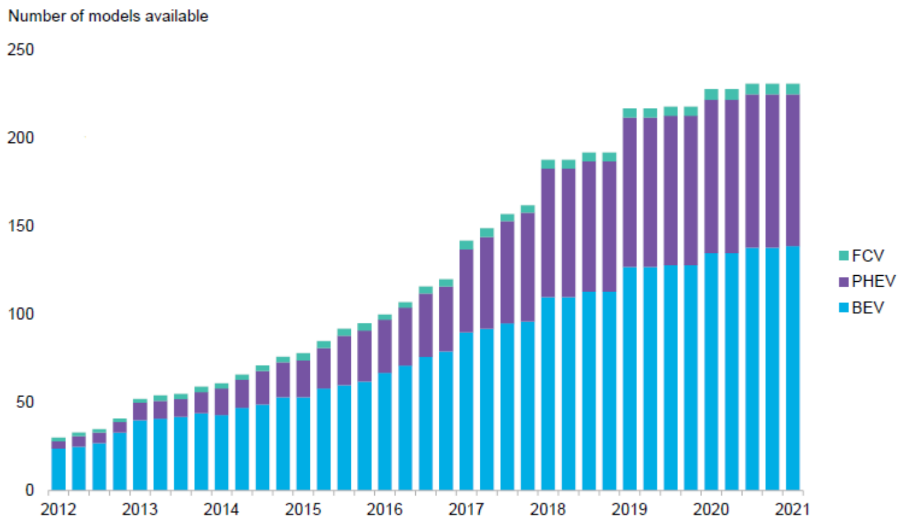


Figure 36 EV model availability (source: BNEF 2017)

A shift from buying cars to buying mobility

The automotive future might be far different than its recent past. Disruptive technologies, government policies and new business models converge to the popularization of mobility as service (Maas) as opposing to car ownership, such as smart ride hailing and the much anticipated autonomous self-driving vehicles. A study by IHS Mark it [7] is forecasting the automotive future of 2040 outlining bizarre changes on the transportation sector. Moreover, it is forecasted that more travel by car will occur with fewer cars

The MaaS industry is expected to purchase more than 10 million cars in the key markets of the future (2040) compared to just 300,000 in 2017. MaaS companies will be key adopters of EVs and driverless cars with a trend to buy their own fleet as opposed to drivers providing their own cars. Already, various schemes of car/bike sharing had already flourished and penetrated the market of various European urban areas. The vehicle sharing system of “Autolib” is the most popular amongst these programmes worldwide. It began in in 2011 in Paris filling in for the bike sharing system of the city (which began in 2007), while now it extends as far as Lyon and Bordeaux. It operates with a fleet of 3980 BlueCars, EVs developed by Bollore group, for public use while having approximately 120.000 registered members (July 2016) and maintaining an extended network of charging and parking stations (5935 and 1084 in Paris respectively). Autolib’s scheme operates as well in London aiming to reach 3000 vehicles for sharing during 2018. Moreover, Autolib’s business model is thoroughly described in chapter 4.E. Similarly, “EV DriveNow”, is also one of the most successful car sharing business models, which began in Munich, Germany in 2011, now operates in 13 cities across Europe with a fleet of 6000 vehicles [68]

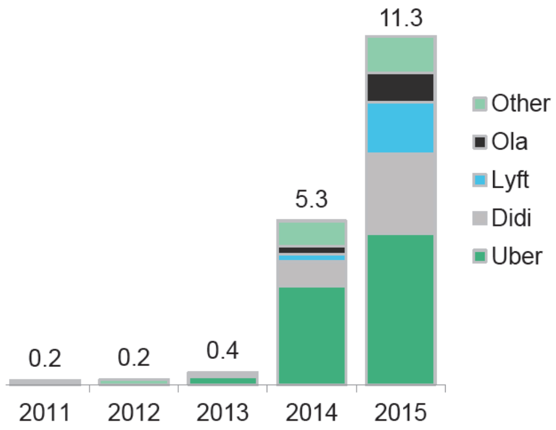


Figure 37 Investments in ride-hailing companies 2011-2015 ($billion) (source: BNEF 2017)

The new mobility business models have promoted the success of various stakeholders in the mobility market. The most successful mobility business models are: (a) Peer to peer ride sharing, which is well represented by “Blabla car” and “Scoop”, (b) Peer to peer car sharing, in which the major players are “Easy Car club” and “Flight Car”, (c) On-demand ride-hailing, in which the most success is realized by “UBER” and “Di Di Chuxing” (China) and (d) Operator car sharing, in which major players are “Zipcar”, “CAR2GO” and “KANDI” [7]

The main concept of peer to peer ride or car sharing and car hailing on demand is based on the sharing economy idea. Sharing economy is an economic phenomenon which besides transport it has expanded to more sectors like accommodation and have received more than $32 billion in overall investment funding (Collaborative Economy Spreadsheet, 2016) [36], but the nature of peer to peer economy bypasses the tax systems and therefore the financial statements of these platforms haven't either been reported or proven their profitability. In contrast with the other MaaS business models, a car sharing operator, can operate more in coordination with the traditional business models, as its activity can be monitored and regulated. Sharing economy is disrupting traditional markets [60], but constitutes an ecological landmark by substituting more carbon intensive practices. In case of the promotion of mobility as a service (MaaS) through sharing economy is easily self-explanatory that this practice is much more environmental friendly in all its manifestations since it is expected to further disconnect vehicle ownership with mobility service, reducing ultimately the total number of cars in circulation [35] and therefore the carbon footprint of the motor vehicle industry. The growth of such business models with the use of EVs could potentially lead to huge developments in the decarbonization of the transportation sector. The concern for the MaaS industry is whether it can adapt and get integrated in a regulated system, coexisting in the same framework and competing with traditional business models.

The most successful MaaS platform is Uber, a car hailing on demand platform, which has spread to 71 countries since 2009. However, the influence of such models in global markets bare many risks since they pose distraction for local economies and thus can be marginalized in various cases, baring the heavy cost of adaptation failure. In contrast to such business models, some sharing economy transport companies operate in one national market for many years having much more adaptation and financial success than those ones that become highly internationalized. For example, local companies such as the Chinese “Didi Chuxing”, founded in 2012 and “Lyft”, founded in 2012 in San Francisco, California, have raised $4,4 and $2 billion in capital respectively [36] There are also various initiatives in the automotive industry promoting MaaS business models. The paradigm of Daimler’s business activity as a mobility provider could prove market changing, considering the resources and knowhow that the automotive giant can provide. As a result its Daimler mobility services are deemed a successful business operation counting 15 million customers in more than 100 cities across Europe, North America and China. Specifically its subsidiaries “car2go”,(global market leader in free-floating sharing), “mytaxi”, (European market leader in car hailing on demand services) and “moovel” more than doubled in the first half of 2017, while since late 2016 Daimler has also been providing private car sharing through “Croove” [42]

Future of EV market

Various economic studies have attempted to predict the future of electric vehicles. Bloomberg New Energy Finance in one of its studies (2016) predicts that the rapid development and cost reduction in battery technology during the 2020s will make EVs a more economic option than gasoline or diesel cars in most countries [19]. Moreover, the study forecasts 41 million EV sales by 2040 corresponding to 35% of new light duty vehicle sales. In that scenario EVs account for a quarter of the total vehicle stock leading to a replacement of 13 million barrels of crude oil per day with 7.4 TWh/day or 2,700TWh of electricity annually which accounts to 11% of electricity produced in 2016 [18]. The study is based on the crude oil price prediction, assuming a recovery to $50 and trending up to $70 per barrel or higher by 2040. An alternative scenario considering the oil price falling to $20 would lead to a delay to mass adoption of EVs to the early 2030s.

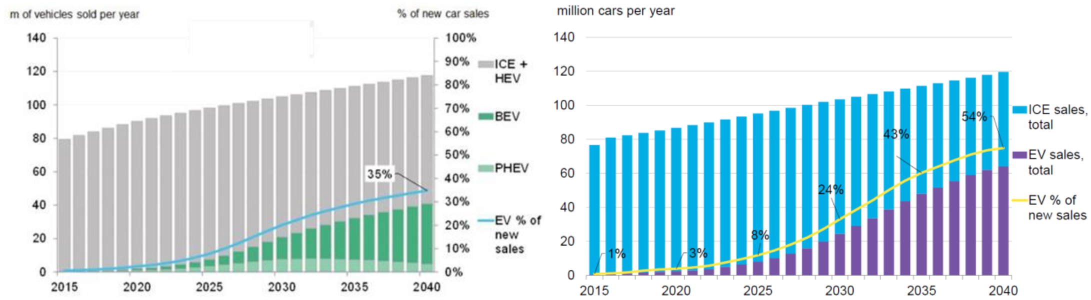


Figure 38 BNEF's predictions (a:2016, b:2017) for the new EV sales till 2040 (source: BNEF)

A new more optimistic scenario for the penetration of EVs in the market is presented in a similar study, conducted also by BNEF in 2017, which predicts 60 million new EV sales by 2040 corresponding to 54% of new light duty vehicle sales. Such a development would displace the use of 19 million barrels of crude oil per day on the transport sector, substituting it with 10.82 TWh of electricity per day which would account to a consumption of 3950 TWh annually, equivalent to 16% of the electricity consumption of 2016. According to this study the major characteristics dictating the optimism of the scenario is the rapid decrease of battery prices in period 2016-2017 and the commitments made by the automakers in the same period. Furthermore the study predicts a global fleet of 7% and 33% EVs in 2030 and 2040 respectively, pinpointing a change in rate of EV introduction, which is translated in an inflection point in the EV deployment curve. Such development is based on a prediction that EVs will become more economical on an unsubsidized total cost of ownership basis across mass-market vehicle classes.

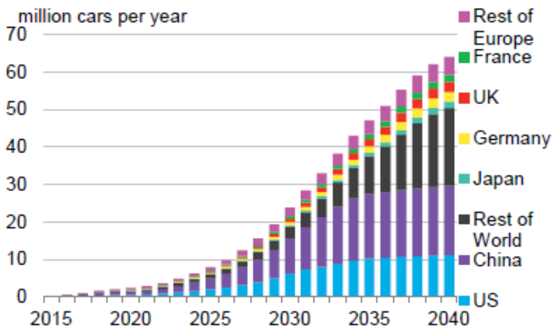


Figure 39: Forecast of Annual new EV registrations per region

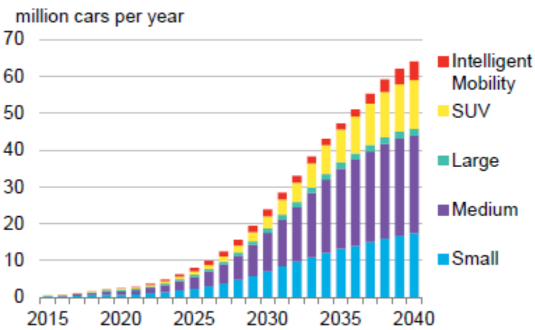
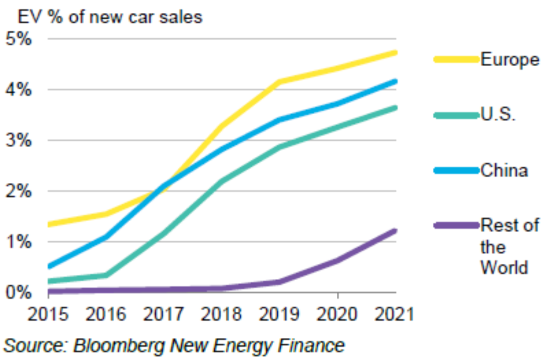


Figure 40 Annual forecast of new EV registrations by class



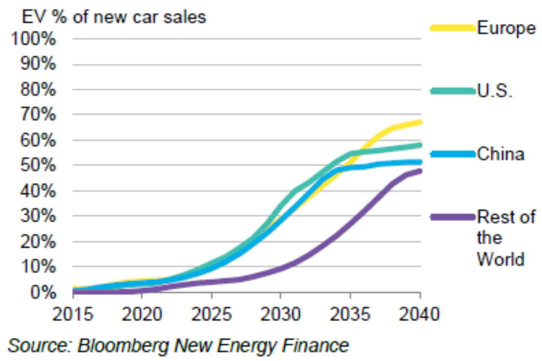


Figure 41 Short Term EV sale penetration by country prediction Figure 42 Long term EV sale penetration by country prediction (source: BNEF)

Other studies that focus in the EU, based on the recent and expected developments in the EV industry, are expecting a 10-20% total market share of EVs by 2025. The share of EV in new vehicle sales could approach 100% as in major European markets, including Norway, the Netherlands, and Germany, the governments and local autoproducers are collaborating towards the implementation of phasing out gasoline and diesel cars within 2025-30. [17]. Mandates set by governments could quickly incentivize the industry leading to economies of scale which could drag production volume to many hundreds of thousands of EVs per year in the time frame of 2020-2023. As a result, leading companies' battery pack costs would decrease to $150-$175 per kilowatt-hour in the same period of time [14]. However, predictions of various organizations for the performance of EV industry are contradicting to each other, mainly because of the high complexity which such estimations require, with many parameters in place influencing the future development of EV industry as seen in figure 43.

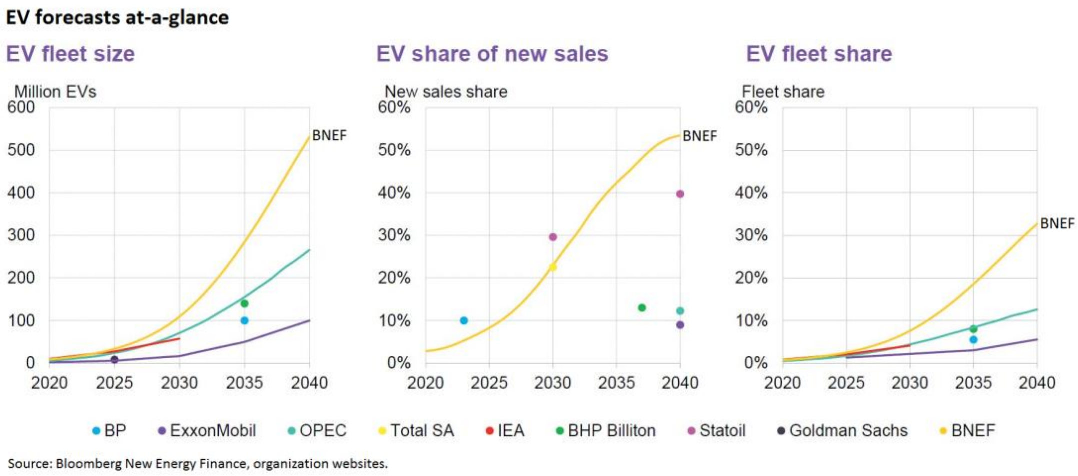


Figure 43 EV market forecasts by various organizations (source: BNEF)

The EV market's performance will be heavily influenced as mentioned above by the oil industry's rally towards an imminent peak demand, which Royal Dutch Shell predicting it could be one decade away. This prospect will collapse the oil prices as the market shifts away from the oil products [1], halting temporarily the rally of EV market expansion. The price of the oil low and the coinciding phase of the EV market are going to determine the duration of the bottleneck of the EV market expansion. A study by IHS Markit, which takes into account alternative fuels, is assuming that cars that solely powered by gasoline and diesel will have fallen below 50% by the year 2031, while EVs will account to more than 30% of the cars sold in major markets by the year 2040 [7]. Moreover the market overtake of EVs is expected by BNEF to happen at 2038 while acquisition cost will reach parity with gasoline and diesel ICE vehicles will be achieved by 2025 [46].

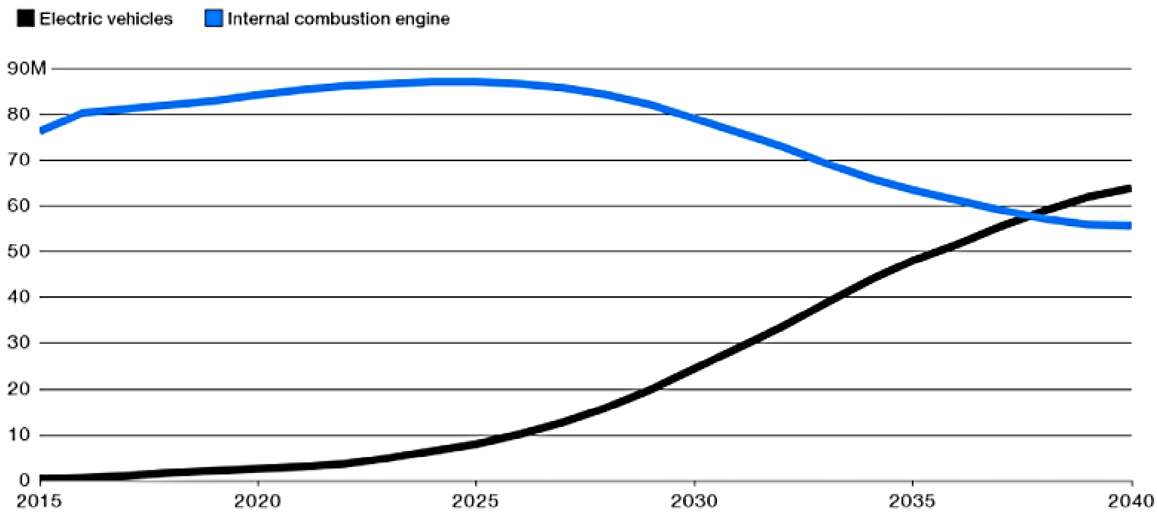


Figure 44 Overtaking Lane – EV sales will surpass ICE vehicles sales by 2038 (Source: BNEF[46])

Conclusion on future of the EV market

Concluding, EV market has shown promise and it seems that, unlike the market failures of the past, the renewed interest in EVs is backed by a rapidly developing industry. Research and development coupled by massive awareness campaigns with the support of global leadership through policies and mandates has solidified the EV market, which is trending upwards with staggering growth rates of 40% to 50% per annum. The trend of EV sales could only be reversed with a U turn in policy in major markets like EU, US or China or if the mass market interest o EVs falls flat. Less likely is an event that EV market growth stops due to a slowdown in lithium-ion battery price declines, which is projected to reach even as low as $109/kWh by 2025 (BNEF 2017). Also unlikely is a development in which a major technology failure would make the current EV technology obsolete, while autoproducers reassure for their proven technology. The only realistic scenario that would significantly delay the mass deployment of EVs is a mass drop of oil prices which would temporarily refocus the interest in ICE technology and delay the EV technology overtaking its market competitors to the late 2030s. In addition a significant uncertainty is concentrated on the key players in battery industry and their ability to provide the automakers with the battery capacity capable for supporting their manufacturing volumes.

C. Greek EV Market

C (i) Present Condition

Greece is an energy depended country, with a net import (import-export) of 18.8 Mtoe in 2015, of which 80% was referred to petroleum and 14% to natural gas [69]. The domestic energy generation in Greece amounted to 8.4 Mtoe, from which the 67% was solid fuel (mostly lignite) and 31% was RES. The electricity consumption in 2015 amounted to 4.37 Mtoe [71] of which approximately 18% was imported. The transport sector consumed only 0.8% [69] of the total electricity consumption, most of which came from rail transport. The market for EVs in Greece is in its infancy accounting for only 334 passenger PEVs in circulation in 2017 [72], while the local fleet includes also 113 passenger tricycles, 124 electric motorbikes and 14 electric trucks (2016) [69]

In Greece the use of alternative fuels in the transport sector is limited, reaching 6,7% of total fuel consumption in 2015 excluding electricity, which amounted to 0,5% of the total energy consumption. LPG is the alternative fuel that is mostly used today for transport reaching a consumption of 257 ktoe in 2015. The increment of the use of LPG has been significant the past 7 years. Moreover, significant ascending trends are observed in the use of biodiesel, another alternative fuel that has significant presence in the transport market after 2005 [69].

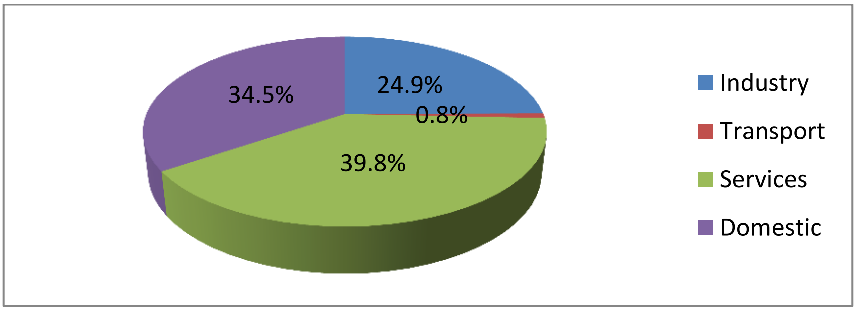


Figure 45 Share of Electricity Consumption per sector in 2015 [69]

2017 has been a significant year for electric mobility in Greece as the EV market share jumped up from 0.06% to 0.19 % with the market almost tripling in volume, achieving a market growth of +243%. The most significant trend is the turn of the consumers towards PHEVs which accounted for 80.1% of the total sales (+821%). This turn is prompted by the new PHEV models that were introduced in the Greek market in 2017 mainly offered by BMW and Volkswagen (BMW 330e, BMW 225xe Active Tourer, BMW XE 40e and Volkswagen Passat GTE), providing 20 – 50 km electric driving range, which offers capability to provide cheap electric mobility within urban areas in a daily driving schedule. On the other hand, the sales of BEVs remained stable (-3%), indicating a market stagnation due to lack of fiscal incentives and supporting infrastructure.

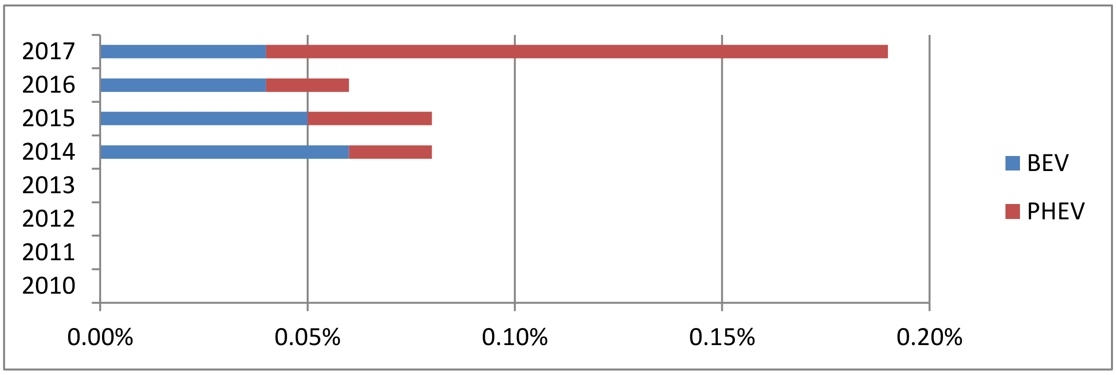


Figure 46 EV market share in Greece 2010-2017 (source: EAFO) [72]

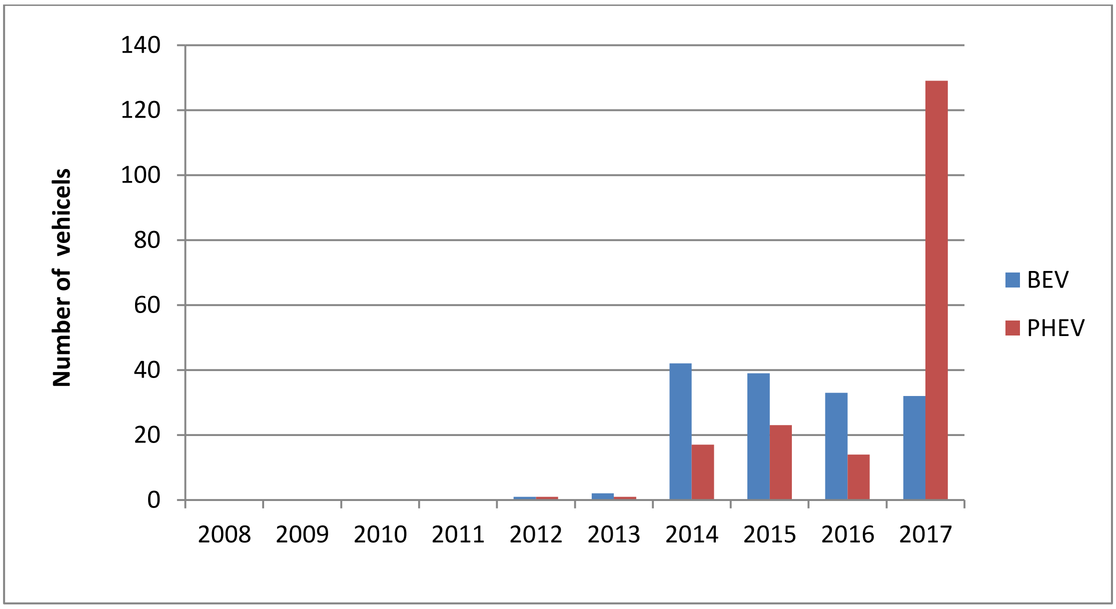


Figure 47 New sales of BEVs and PHEVs in Greece for the last decade (2008-2017) (source: EAFO) [72]

The EV market in Greece is majorly controlled by German OEMs with BMW being the major player with a market share of 65% and 70% on BEVs and PHEVs respectively. The commercial availability of EV models is limited in comparison to the biggest EV markets in the EU. Specifically, in the Greek market in 2017 there were 7 BEVs and 19 PHEVs available [85].

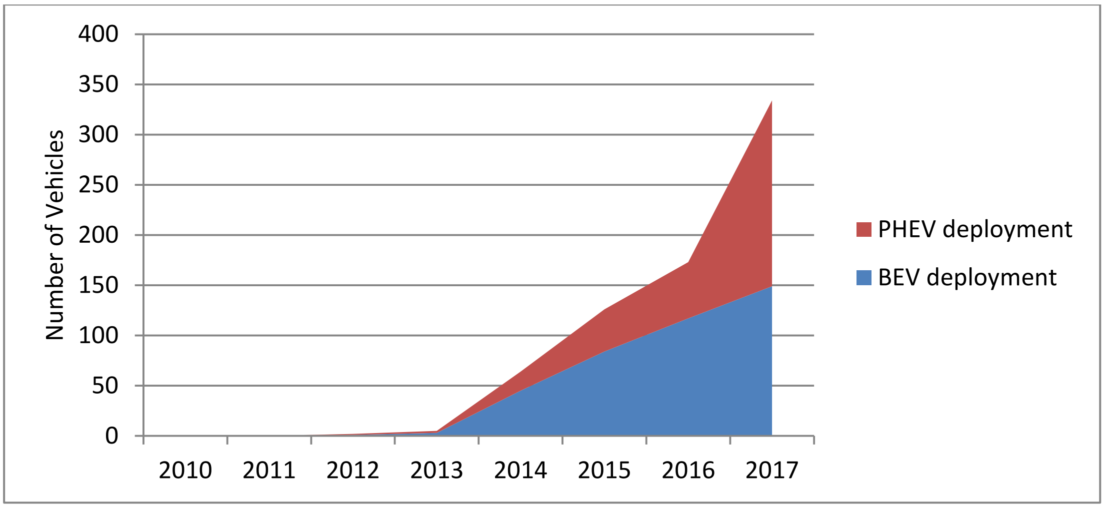


Figure 48 Plug-in Electric Vehicle Deployment in Greece. (2010-2017) (source: EAFO) [72]

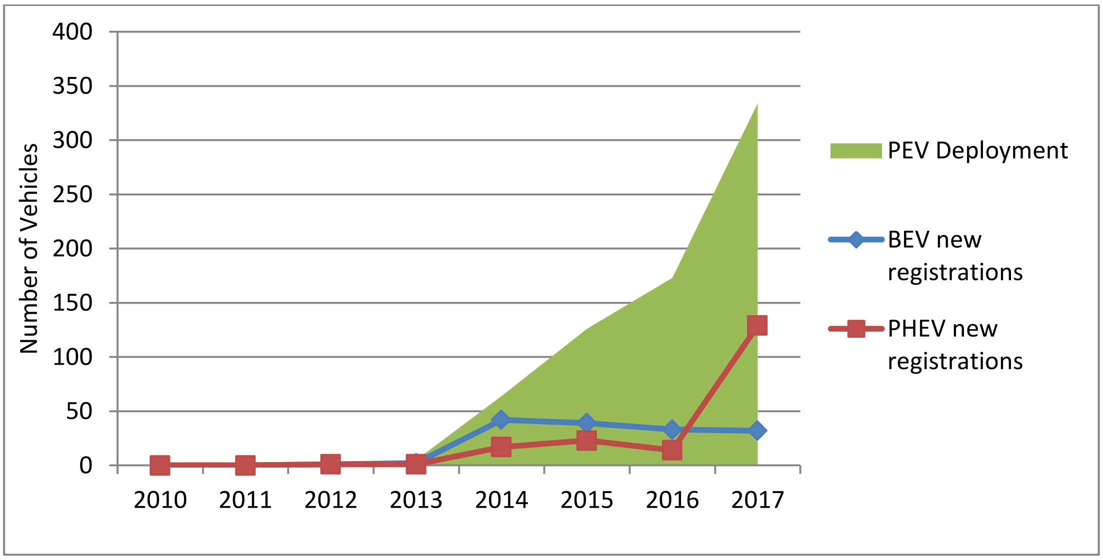


Figure 49 New registrations of plug in electric vehicles in Greece. (2010-2017) (source: EAFO) [72]

Moreover, EV solutions are provided by various small companies, with limited market share with most of them offering utility vehicles or small cars, motorcycles and tricycles.

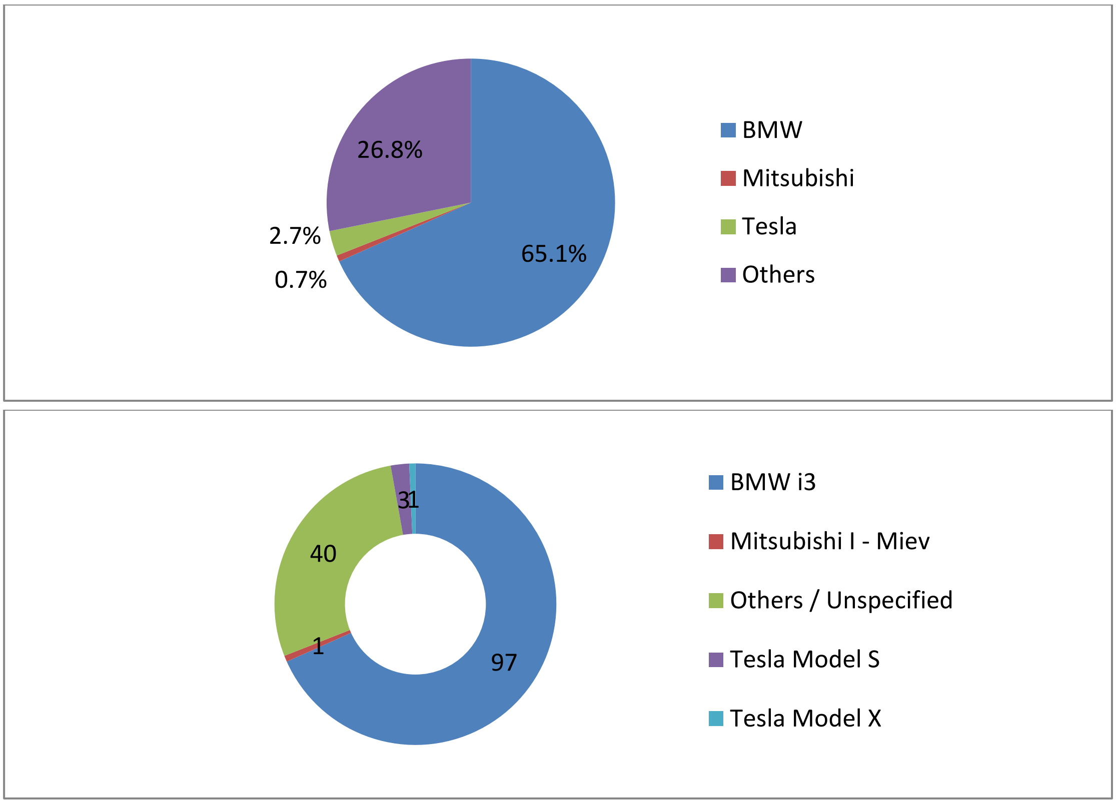


Figure 50 Market Share of BEVs licensed the last decade (2008-2017) in Greece per manufacturer and per model (source: European Alternative Fuels Observatory)

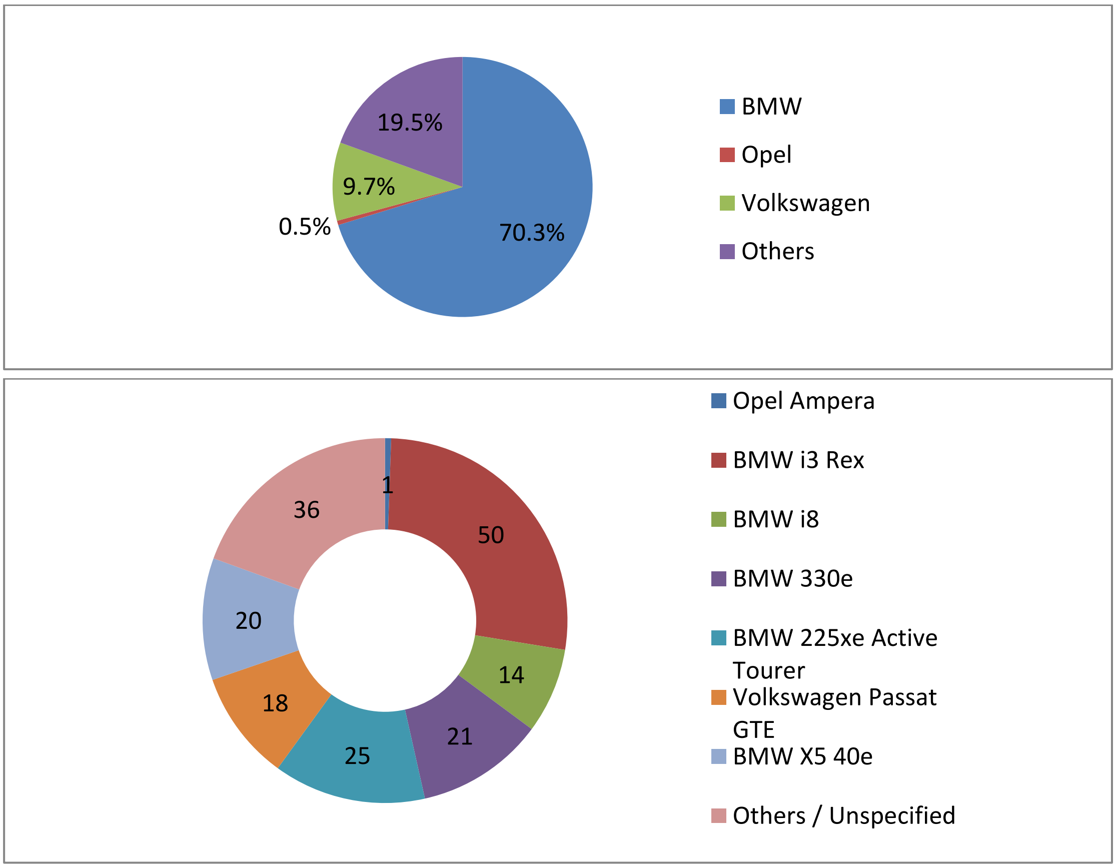


Figure 51 Market share of PHEVs licensed the last decade (2008-2017) in Greece per manufacturer and per model (source: European Alternative Fuels Observatory)

Charging

Electric mobility is at an early stage of development in Greece, primarily because of the lack of charging infrastructure and the lack of education about the advantages of electric vehicles. As for the lack of charging options, they can be developed either privately or publicly. International experience has shown that 85% of electric car users charge them in their own residence. Another percentage of users charge their car in the workspace and fewer of them in public spaces. According to Dr. Ageridis[6], a wide network of public charging points could remain unused and proved economically unsustainable. However, a small percentage of public charging is a crucial parameter in order to get rid of 'electric range anxiety' related to the use of electric cars. [70]

EKO ABEE, a Hellenic Petroleum (HELPE) Group company, has first initiated an attempt to introduce EV charging infrastructure in Greece in 2011. Its charging stations had been placed in three private owned fuel stations in technical collaboration with the utility of the group, Elpedison [97]. Currently, executives of HELPE have expressed the intention of following up the group's prior attempt to introduce EV charging infrastructure, with plans of introducing an extensive network of charging ports nationwide [98]. Such an action will diversify the group's energy portfolio further towards alternative fuels and electric mobility.

Currently, in Greece according to the Hellenic Institute for Electric Vehicles (HELIEV) there are in total 45 public charging stations in operation, providing 64 charging ports [81]. Moreover, 27 charging points are available through the 17 stations participating in Fortizo private charging network [76]. The publicly available charging power sources, which are mostly located in the capital region of Athens, provide AC power at power levels varying from 3.5 kW to 22kW, utilizing Mennekes (type 2) and Wall Outlet (Europlug) connections, with only one charging port providing fast DC charging, utilizing either the standardized CHAdeMO or Combined Charged System charger (CCS) DCFC connection.[72] (The Charging technology is thoroughly described in Chapetr 4)

[6] Director of Energy Efficiency at the Center for Renewable Energy Sources and Saving (CRES) and Chairman of the Greek Institute of Electric Vehicles (ELINIO or HELIEV)

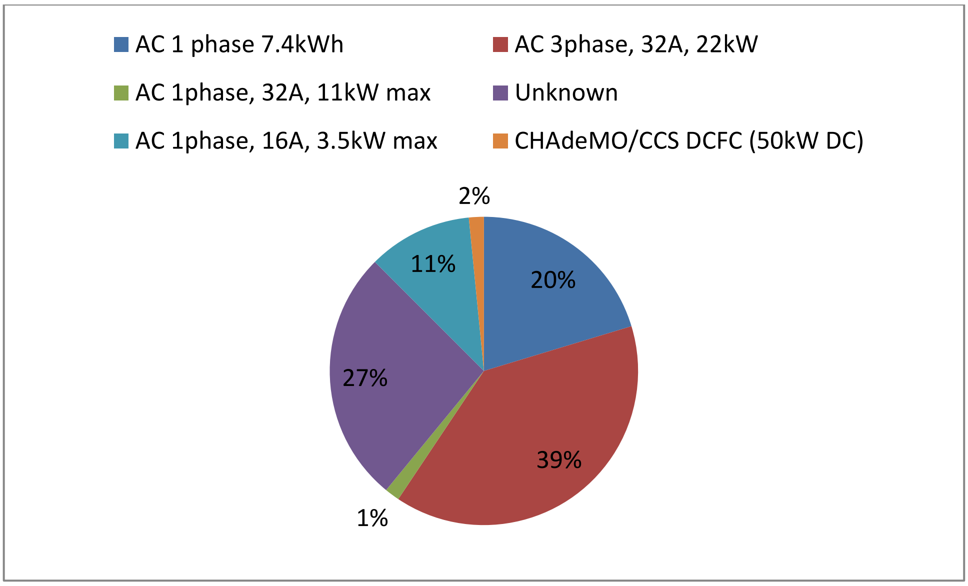


Figure 52 Charging Power Sources in Greece (2017) (source: HELIEV)

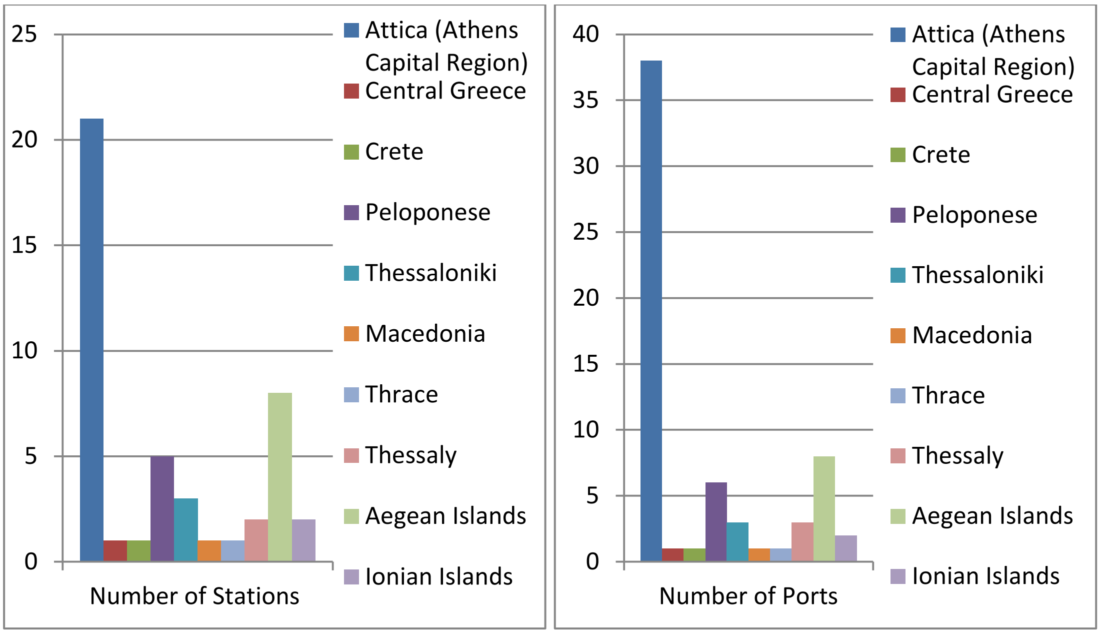


Figure 53 Number of publicly available a) charging stations Figure 54 charging ports throughout Greece

The publicly available charging infrastructure in Greece has reached 1.1MW of installed capacity with 650kW being installed in the Athens Metropolitan Area. The majority of the public available chargers are also located in Attiki and the extended capital region of Athens. There are also three charging Stations available in Thessaloniki and very few scattered in the rest of the Greek continental territory with the most being in Peloponnese (5). Moreover, in the islands of the Aegean Sea there are 8 recorded charging stations provided by local Hotels and accommodation services, which operate during the tourist season, serving the charging demand of seasonal visitors [76][83].

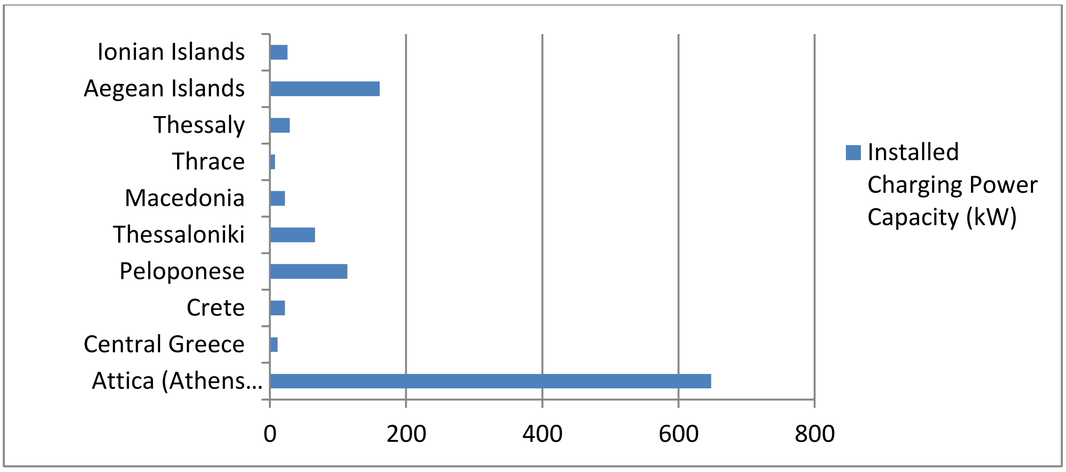


Figure 55 Installed Charging Power Capacity in Greece per region

The charging position availability in Greece is 5.2 EVs/charging position, which is following the European average ratio of 6.7 [72][83]. This indicator cannot describe well the adaptation of EVs or success of the support infrastructure in such an immature market as the Greek one[7]. However, such an indication prompts the challenge to maintain this ratio towards rates that maintain a functional proposition for EV users. Greece due to its geomorphological terrain has long distances between regions and thus requires an extensive range of charging network to support electric mobility for intercity transportation. On the other hand Greece is highly urbanized, with 78.6% of its population living in the largest cities [84], which creates the need of a more centralized approach in the development of the national EV charging network, in order for this to fit in with the urban transportation needs of Greek drivers. This fact, raises the need for development of an urban driving behavior study adapted to both the Greek driving conditions and each city's urban planning, which would determine the real spatial needs for charging infrastructure.

[7] This indicator should be leveled accordingly to include the charging time of the available infrastructure to indicate more clearly the charging service availability as described further in chapter 4.F.

Figure 56 EV Charging Station in the parking area of Athens International Airport

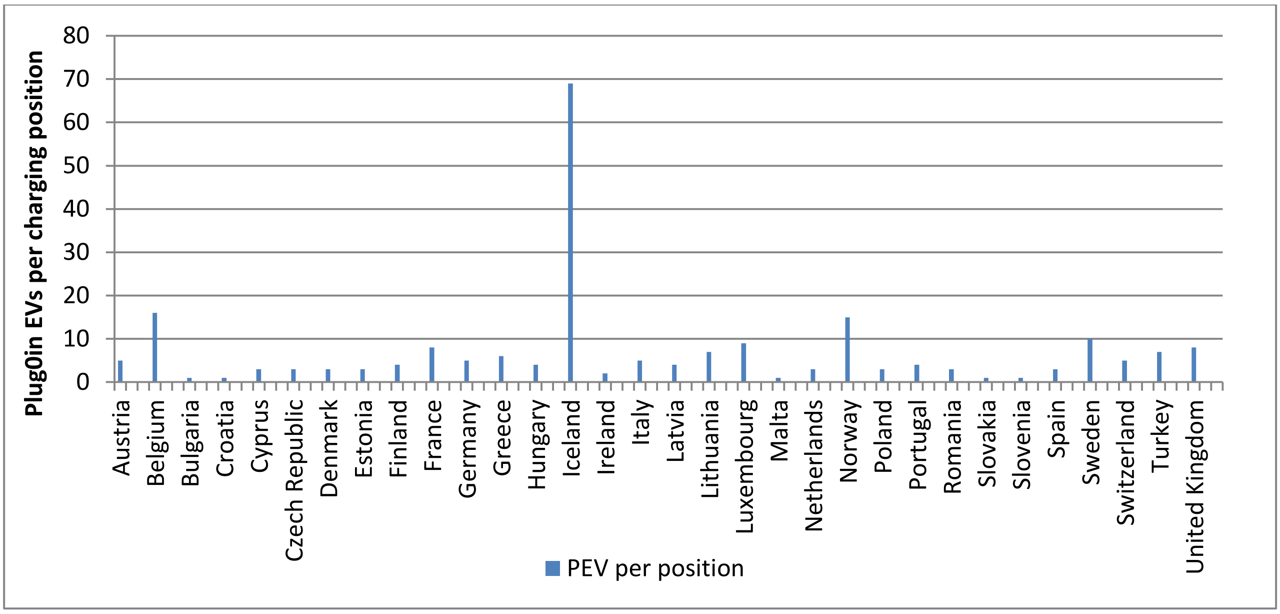


Figure 57 Electric vehicles per charging position per EU country (source: European Alternative Fuels Observatory) (Data available until July 2017)

The charging services are available under various different conditions, which are identified by this study. Specifically paid charging under Fortizo Network charging scheme is one of the options, while the majority of this charging stations, (32% of the publicly available charging stations), which offer these services are located in private parking areas or in parking areas of large Hotels. Also agents in the tourist industry offer services of free EV charging for their guests providing 25% and 17% of the total publicly available charging stations and charging ports respectively. Some agents are also providing free charging with most of them being municipalities and commercial stores that provide free charging to their customers for promotional reasons. The charging station and charging ports that are freely available comprise the 23% and the 29% of the national totals respectively and are mostly located in the Athens Metropolitan Area. Also some private parking areas offer free charging to their customers (9% & 10% of total charging stations and ports respectively).

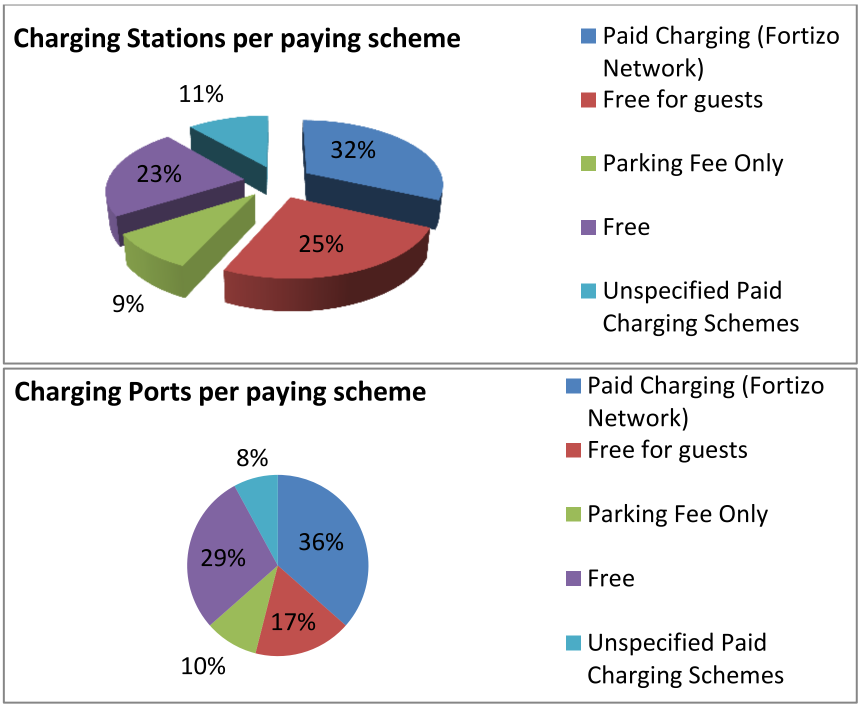


Figure 58 Charging Stations and Charging ports per paying scheme

C (ii) Applied and proposed incentives for the EV adaptation in the Greek market

Applied Market Incentives for EVs

One of the most important recent developments towards adoption of electric mobility in the country's legal framework was the implementation of the package for the support of EVs' penetration in the Greek market in 2010, according to which, electric vehicles and low engine capacity hybrid and fuel cell cars registered before November 2010 were exempt from the annual circulation tax.

Following November of 2010 the vehicle circulation tax was reformed to support green mobility and thus became CO_2 emissions based. Accordingly, Vehicles are taxed based on CO_2 g/km which ranks all EVs in the lowest category of 90 g/km which are exempt of circulation taxes. All-Electric Vehicles are also exempt from luxury and luxury commodity tax charge since 2013, while hybrids received a 50% discount respectively.

National Goals

The first coordinated attempt to study the prospect of electric mobility in Greece began in 2011 with assembly of a scientific commission under the Ministry of Environment, Energy and Climate change (20/09/2011) for the research of development and penetration of electric vehicles in the country's transport sector. (ΥΑ: Δ6/21612/20.09/2011, Α.Δ.Α: 4Α8Κ0-80Β). Its goal was to analyze prospect policies and financial actions to support the initial phase of the penetration of electric vehicles in Greek market as well as the development of an implementation proposal of a holistic schedule of incentives for the promotion of EVs. The technical study of the commission, which was concluded in January 2012, indicated that the initial subsidization of the EV market is deemed necessary during the initial phase of EVs' penetration in Greek market [92]. The environmental benefit of the operation of EVs was found to be significant as the EVs would replace more carbon intensive transportation leading to lower CO_2 emissions, which would be further reduced as Greece moves to a less carbon intensive electricity mix after 2013, phasing out of old lignite el. generation stations, while increasing of the annual electricity Generation from RES. [69]

However, Greece's national goals in regard to electric mobility are conservative due to the recent economic instability. The targets set are according to the EU directive on deployment of alternative fuels infrastructure (2014/94/EU), according to which Greece must reduce its oil dependence in the transport sector. In addition Greece must increase the share of RES in the transport sector by 10% by 2020. Following this direction electricity use is expected to rise significantly in the transport sector in the following years, but this rise won't be due to the use of EVs which is expected to be limited [69].

Further Actions to Support the Penetration of Electric Vehicles in the Greek Market

According to CRES and HELIEV, that support electric mobility in Greece, there are certain actions to support the market for electric vehicles:

- Investment in development of required infrastructure in the fields of electric power generation and distribution, charging positions etc.
- Political action and measures for support: subsidization of new technologies, coordination of the competent and local authorities for the development of new infrastructure etc.
- Development and evolution of the available technology from the car manufacturers: new attractive models offering convenience and security, in reduced production and operational cost.

- The standardization and validation of the available technology, generation of common rules for quality and adaptation. EU must accept the role of the coordinator, setting the direction for all involved parties.
- The familiarization of the users with the characteristics and specification of the new vehicles and the potential of this vehicle technology to cover the consumers' needs
- The configuration of the cost for purchase, operation (energy cost), and maintenance of these vehicles.

Investment Infrastructure

According to the current legislation (N. 4439/2016 p.1) by the end of the year 2020 there must be a secure number of charging positions available for the country's emerging fleet of EVs, which must be accessible for the public in order to facilitate the circulation of EVs in the road network. This availability must follow a certain plan indicated by public surveys, which will show the urban/rural crucial road networks that should be covered. In addition such planning would take into account the number of EVs in circulation as well as up to date relevant practices and indications.

The current legislation (N. 4439/2010 p.7), also predicts the connection of public charging infrastructure with intelligent smart meters (N. 4342/2015, A' 143) accordingly (Secure the appropriate technical specification for the correct operation of the metering devices, in regard to information security and consumer privacy), to achieve the control and recording of the of the energy consumption, data that should not only be available for consumers and charging station operators but also available for the electricity network operator. The access to this data by the distribution network operator would be important for the security of supply and balancing of the electricity distribution network taking into account the predicted electricity demand from EVs' users. It would be also important for the charging station operators and the consumers for data availability/accessibility reasons, which would also enable the roaming of EV charging service operations. Furthermore, the estimation of the number of EV charging locations cannot be easily elaborated, while the data used for such studies usually emerge from simple estimations without further documentation. Such estimations usually derive from the development of electric mobility technology and foremost from the performance of the biggest EV markets worldwide. Moreover, the mechanisms behind EV market expansion is thoroughly described in chapter 4.F.(ii).

Legislative measures

Greece, in order to support the penetration of EVs in the market, must revise and upgrade the existing institutional framework so as to predict fast developing needs.

Specifically the ministry of Environment and Energy has outlined a package of legislative actions that are directed towards the enforcement of the emerging market for EVs. Analytically this framework predicts:

- Regulation of the current institutional framework for the development of EV charging infrastructure (N. 4439/2016, 2014/94/EU)
- Regulation of the institutional framework for the description and the outline of the role of charging infrastructure operators. (The legislation is still pending)
- Inclusion of el. chargers for EVs in new built and renovated buildings (in the direction of 2010/31/EU)
- Implementation in the Greek framework of the standards for CO2 emissions in and the clean energy in the transport sector.

The Greek authorities are also examining possible measures that could also support the development of the EV market in Greece, such as:

- Creation of an institutional framework for financing research projects and programmes for electric mobility, such as standards for coalition of the public and private sector ex. "European Green Vehicles Initiative Association", (EGVIA).
- Direct or indirect fiscal incentives, such as more tax reliefs for EVs and other "low carbon" vehicles and charging infrastructure.
- Favorable regulations for, parking of EVs, the use of Bus/taxi lanes by EVs or the financing of charging infrastructure.

Important Moves towards EV adoption

Important steps have been made towards the adaptation of EVs in a local level in Greece. Below some very important moves are pointed, which create a status quo in regards to the EV adoption.

The Greek authorities have set National targets for the public transport sector, based on which Greece aims to renew its bus fleet gradually introducing clean alternative fuels. The first step will be the induction of 90 new alternative fuel city buses in the fleet of OASA, the Organization for urban public transport of Athens, which will be using as energy source mainly natural gas and electricity. Towards this direction, the Ministry of Infrastructure, Transport and Networks, based on its strategic planning has bound 80 million euros in the framework of the European Partnership Agreement 2014-2020 to further renew the bus fleet of OASA with bus also utilizing alternative fuels, mainly electricity and natural gas (CNG) [69].

In a municipal level local communities are promoting electric mobility through their local authorities. Important moves actions for EV adoption have been done, among others, in Rethymno City, Crete, where by the initiative of the local municipality and PPC, three public charging stations are set to be operational during March 2018 [80]. Important also towards the adaptation of electric mobility in the Greek non-interconnected islands is the implementation of the European program “TILOS-Horizon 2020” which includes the installation of a solar powered charging station in the Island of Tilos, offering charging ports for 3 vehicles (1 car and 2 motorcycles or 2 cars and 1 motorcycle)[88]. Also, the Municipality of Kozani in Western Macedonia region, in continental Greece, procured three EVs to introduce to its fleet of municipality cars, while Dr. Stimoniaris, associate professor in the University of western Macedonia announced the availability of 8 charging stations in the city [89]

In the industrial level, Eco Sun, an active company in the energy systems, sector has released a Greek designed 2 seat EV manufactured in China, with electric range of 120- 150 km, max speed of 45-80 km/h which is among the cheapest EVs worldwide with consumption of 6kW/100 km while operating in full load [90]. Also, very important is the inauguration of Tesla Motors’ R&D hub in Athens Greece. The main source of attraction for the automotive company towards the Greek market was the Greek scientific workforce. With already three of its top designers being graduates of National Technical University of Athens, Tesla aims to attract at least 50 engineers to run a research and development center out of the state-run Demokritos Center for Scientific Research, focusing on electric motor research.[91]

C (iii) Scenarios and predictions for the development of the Greek EV market

The future for electric mobility in Greece until 2030 as forecasted by CRES, HELIEV and The ministry of Environment and Energy doesn’t look very bright. Various scenarios have been considered for the forecast of the penetration of electric vehicles to the Greek transport market, which take into account: (a) The development of vehicle and battery technology, (b) The development of charging infrastructure and technology for faster service (c) The vehicle market trends under the pressure of environmental and public health agenda. (d) The electric vehicle market assessment in the developed European markets and to other European countries that have lower economic growth ratios. (e) The normalization of the economic conjuncture

This analysis which illustrated the worst case scenario for the penetration of EVs in the Greek transport sector, CRES and HELIEV predicted that the number of electric vehicles in circulation will be:

- By the year 2020, 3,500 vehicles in circulation.
- By the year 2025, 8,000 vehicles in circulation
- By the year 2030, 15,000 vehicles in circulation [69]

Such a prediction was made, according to market experts, based on the market limitations of a recessed economy and also based on the urban design limitations of the Greek cities and does not depict the expected penetration rate of EVs in Greece under economic recovery. Moreover, electric mobility experts expect better market performance results for a market as large as the Greek one, with 8.1 million vehicles in circulation, of which approximately 5.1 being light duty passenger cars [69][78]. Furthermore the Greek ministry of Energy announced that the applied program for public transportation will have 90 electric buses introduced in the Greek public transport system by the year 2030, which is also a conservative prediction and more accurately depicts the Ministry's commitment than attempts to predict the on-road electrification of the public transportation. Furthermore, it is possible that external markets will put extra pressure on Greek market to adapt to the new mobility trends. Important is that probably after 2025 the inclination of the global EV deployment curve proposed by competent analysts predicting a rapid decrease in the EV acquisition cost will probably drive also the Greek EV market to maturity. Furthermore Greece has to work towards the formulation of an operational framework for EV adoption, which would include the regulation of the EV charging market and possible incentives prompting consumers towards electric mobility. Furthermore, Greece's authorities must secure the availability of public charging infrastructure that would make such a transition possible.

In regards to the latter, the Greek EV market is currently experiencing a vicious cycle fed by the inability of the market to provide sufficient publicly accessible charging infrastructure to halt the electric driving range anxiety of the consumers. To break this cycle, in order to initiate the market expansion, the Hellenic Electricity Distribution Network Operator (HEDNO), the local DSO, made a proposal to the Greek Regulatory Authority for Energy (RAE) for the development of Greece's first country scale charging network, composed of 1,200 to 1,500 EV charging stations connected to the national grid [82]. RAE has to make a crucial decision assessing HEDNOS proposal as the acceptance would mean that the charging network investment costs will be passed over to the consumers via their electricity bills. This is an important disadvantage of the DSO model since it will add further socioeconomic costs to Greek consumers who have to confront a continuous economic recession. However the corresponding authorities might consider the DSO model since is the only option for the EV market initiation. Furthermore the Greek EV market's future is tightly connected with such a decision as HEDNOS proposal includes, in addition to the urban stations, 100-150 charging stations installed at the Greek islands and multiple fast charging stations placed in the Greek highways enabling the electro mobility for intercity transportation in the continental part of Greece. It is also expected that the installation of such a charging network will initiate an interest by investors in further expanding it, encouraging the transition of the EV charging market from the DSO to the market model. Such an event coupled by the consequent increased interest for EV acquisition by consumers, is expected to lead Greece's catch up in the global electric mobility race.

Based on the predictions of CRES and HELIEV for the future of the Greek EV market in urban and suburban areas, charging stations, in their majority private, are estimated to reach approximately 2000 in 2020. Moreover, the charging locations in urban and suburban areas based on the same prediction are estimated to be approximately 12,000, comprising of 8,000 private and 4,000 public ones in 2025, while in 2030 their number will increase to approximately 35,000 stations publicly accessible nationwide. These numbers are significantly overestimated, reasonably, based on Greece's congestive urban planning and consequently the unavailability of adequate urban parking space. This prediction indicates that in 2030 the ratio of charging position availability will be 0.43 EVs per position for Greece[8], which in comparison to the current EU average of 6.7 indicates an excess of publicly accessible charging stations. Therefore, this prediction is further alarming for the significance of the driving range limitation as a barrier of EV adoption in the Greek market.

An indication of the impact that a possible introduction of a regulatory framework for the subsidization of charging equipment purchases, can be found by analyzing the market results from other mature markets such as the US, where state incentives were applied for electric vehicle service equipment EVSE subsidization [73]. Specifically, the market experience from LPG adoption, as an alternative transportation fuel, showed that on the aftermath of the implementation of regulatory framework (3710/2008) that allowed the construction of LPG stations in areas within urban planning zones, there was a rapid increase of LPG use in private vehicles in the period 2010 – 2011 which followed (almost eightfold increase) [69]. Thus, similar results could be expected from such incentivisation initiatives for other cost competitive alternative-fuel mobility infrastructure, such as the EV charging infrastructure installation in the case of electric mobility.

[8] In regards to the worst case scenario for EV introduction in Greece.

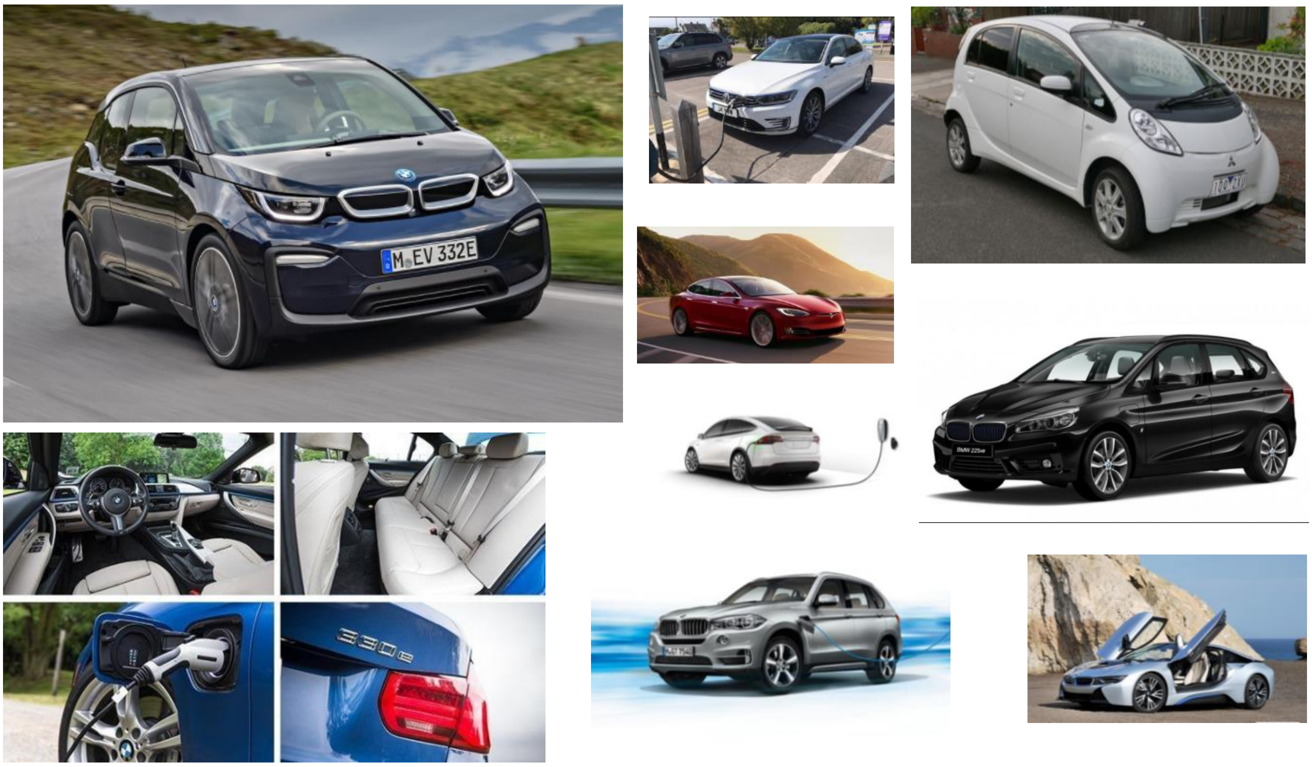


Figure 59 Battery Electric Vehicles and Plugin Hybrid Electric Vehicles already in circulation in Greece

D. Regulations for Electric Vehicles in Greece

Efficient, quick and environmental friendly transportation is a fundamental prerequisite in order to achieve the Freedoms introduced by the European treaties. Freedom of movement, freedom of services and freedom of goods all equally dependent on the available means of transport at the European market. Thus, European Union is constantly aiming at creating a long-term security required for private and public investment in vehicle and fuel technology, and infrastructure build-up, in order to serve the dual purpose of minimising dependence on oil and mitigating the environmental impact of transport[i].

Directive 2014/94/EU is creating certain obligations for Member States to develop the necessary infrastructure and to create the necessary conditions so that the free market and the free economy will be able to use alternatives fuels for transportation needs for vehicles, airplanes and vessels. Due to the big number of different transport modes available, the specific needs of each transport mode shall be taken into consideration, when planning the deployment of means of transport that use alternatives to fossil fuels sources and during the elaboration of national policy frameworks, in general.

It is worth spotting the fact that the policies related to transport are general and do not intent to benefit any specific means of transport, as long as it uses alternative sources as fuel. This is the reason that explains the fact that European legislation for transport is regulating the EVs, as part of Europe's broader policies targets.

More specifically, the Trans-European Network for Transport (TEN-T) guidelines recognize that alternative fuels serve as a substitute for fossil fuels in the energy chain to transport to facilitate the environmental performance of the transport sector. Electricity is such an alternative source which can power electric vehicles (hereinafter "EV") which are listed in the L-category, pursuant to the European legislation[ii].

EVs carry many advantages: they may assist in the effort to improve air quality and reduce noise in urban or suburban areas. However, EVs need special locations to connect to the power grid, the charging stations. In order to deploy and operate a large fleet of EVs in the European continent, the charging stations shall be constructed within a specific network.

The EVs in Greece are being deployed in the local market, through a twofold state effort: firstly, the national government is aiming to achieve the goals that the European Union has set; and secondly, by developing a framework that regulates the ownership and the use of the EV, both by enforcing European Regulations, by implementing European Directives and by adopting legislation, ministerial decrees and regulations that would clarify and simplify all issues related to EVs.

Neither the European nor the national legislation are defining and regulating directly only EVs. Instead, they are dealing with the development of the infrastructure needed to build a better transport network for the common market. So, in the next chapters, we are going to present the applicable European and Greek legislation, while we will try to make some useful remarks for the current situation for EVs in Greece and suggest possible improvements for the successful and quick adoption of EVs as an alternative means of transportation.

D.(i). European Legislation

Directive 2014/94/EU of the European Council for the on the deployment of alternative fuels require MS to determine the network and maintain the appropriate infrastructure by December 2020, in order to ensure that EVs in the EEA may circulate and be recharged at least in urban/suburban agglomerations and other densely populated areas.

Directive 2007/46/EU defines as “*hybrid motor vehicle*” the vehicle that has at least two different energy converters and two different energy storage systems (on-vehicle) for the purpose of vehicle propulsion; Thus, a “*hybrid electric vehicle*” means a hybrid vehicle that, for the purpose of mechanical propulsion, draws energy from both of the following on-vehicle sources of stored energy/power: firstly, a consumable fuel, and secondly, an electrical energy/power storage device (e.g. battery, capacitor, flywheel/generator, etc.).

Many types of EVs exist, depending on the type of connection they need to recharge. May cars may use more than one charging point categories.

Charging Points categories

- Public extremely quick charge: 400 A, power 240 kW.
- Quick High Power Charging : range 32 to 250 A, power range 22 to 95 kW
- Public Slow Charging: range 7,4 t0 12 kW
- Slow Low Power – Home charging: max 16 A, max power 6 kW
- Low Power – Home charging: max 16, max power 3,6 kW
  Note: TESLA uses its own separate charging specifications.

EVs are defined as a motor vehicle equipped with a powertrain containing at least one non-peripheral electric machine as energy converter with an electric rechargeable energy storage system, which can be recharged externally[iii]. However, for the Directive’s scope as EVs are defined all cars that may be charge, irrespective of the fact that electricity is the sole or just one of many sources of supply of this vehicle. European Union is not only interested in supporting the purchase of EVs, but its policies are aiming as well for the development of publicly accessible charging infrastructure, in general. While current recharging interface just included cable connectors, in the near future new interface technologies, such as wireless charging or battery swapping will be common in the EVs market.

Furthermore, the Directive is categorising the recharging points as: privately owned recharging points; devices accessible to the public through registration cards or fees; recharging points of car-sharing schemes allowing access for third party users by means of subscription; and recharging points in public parking. It incorporates an advantage for privately owned recharging points which allow private users physical access with an authorization or a subscription, as the Directive categorize them as recharging points accessible to the public. To that direction, Directive 2012/27/EU[iv] for energy efficiency sets the standards that not publicly available charging points owners or operators shall comply with. However, it is up to the national legislator to describe the additional advantages that a publicly accessible charging point may have in comparison to a charging point dedicated just for the private use.

Members States shall take the follow measures for the development and operation of charging points:

- Establishment of a national regulatory framework, pursuant to the provisions of L. 4439, implementing Directive 2014/94/EU
- Establishment of a national regulatory framework for the operators of the Charging points available for EVs.
- Specification of the technical details to realize the requirements set for new or totally renovated buildings to construct Charging Points facilities.
- Implementation and enforcement in each Member State of the European Directives for the CO_2 emissions standards for clean energy at transportation.

Other potential measures that could help the quicker maturity of the EVs market:

- European Green Vehicles Initiative Association (EVGIA) is an exemplar cooperation between private and public sector and could be used as a guide in order to create the missing framework for financing research projects.
- Direct or indirect tax benefits for purchase of clean vehicles or the construction and operation of charging points.
- Parking benefits for EVs or circulation benefits for the use of buses lanes and financing of charging points related infrastructure works.
- Purchase of electric or hybrid public buses.

Upgrading existing buildings to a higher efficient category is part of the plan to use more alternative fuels and depend less on fuels imports outside the EU. Despite the fact that Directive 2010/31/EU is about to be amended, the increase of energy efficient buildings was an essential goal of the EU since then and now EVs are just added as additional measure to increase the energy efficiency of the buildings. Thus, after the amendment of the aforementioned Directive, financial support could be provided for the installation of Charging Points in newly constructed or totally renovated buildings.

Electric vehicles are closely related to EU's goal for a 20% of total energy production to be from renewables by 2020. Not only, the carbon print used for transportation purposes will be lower due to the higher use of renewables to recharge EVs, but the EVs may assist the stability of the grid system by feeding power from their batteries back into the grid at times of high electricity demand.

EU's goal it that by the end of 2020, EVs will be able to circulate in urban /suburban agglomeration, in networks determined by each MS. What's more, ANEXX II of the

Directive[v] sets out certain technical specifications for the recharging points, so that the producers may follow certain standards at their vehicles which not only comply with EU regulation, but those standards shall be followed in the new charging points that will soon be deployed around the EU.

D.(ii). National Legislation about EVs

National legislation concerning EVs is not only implementing European legislation, but it is also realising European policies to assist the deployment of charging points infrastructure in the country by specifying common technical details and by providing benefits to the purchase, use and ownership of EVs. L. 4439/2016 and JMD 77226/2017[vi] implement the aforementioned Directive 2014/94/EU.

What should be carefully be researched is the value chain of the batteries that EVs are using, the initial purchase cost, the range they provide to EVs, the connection to the grid and mostly the cost of the purchase and operation of the EVs in comparison to the purchase power the consumers.

Member States are planning not only to extend the Railway transport, which now mostly uses electricity, but they are also trying to find solutions that will allow for trains that need lower consumption of energy, because they use hybrid engines or other alternative fuels.

Other piece legislation for EVs is presented hereinafter:

Tax benefits

National framework on EVs has implemented the European legislation and European policies, all aiming to assist the deployment of the largest possible EV fleet. To this direction, the legislators has provided many benefits, such as: the average consumer EVs are excluded from the special consumer levy[vii]; exclusion from circulation fees[viii]; from luxury levy [L. 4211/2013, art. sixth art. 17(3)(a) N. 4172/2013, art. 31 & MD/1041/2016, L. 3833/2010, art. 17]; and from registration tax for privately owned vehicles (L. 3986/2011, art. 35**,** L. 2960/2001, art. 121; L. 2459/1997, art. 5 & 6). The guidelines issued for L. 4389/2016 on private cars, excluded EVs from any registration fee, but reinstates 50% registration fee for hybrid vehicles.

In order to measure the power of the EVs, which are calculated in KWs, for the purposes of taxation law is considered equal to 1200 c.c. and the annual income that the owner of the card is deemed to have is up to the amount of € 4.000, irrespective of the actual power of the car.

Circulation Benefits

Furthermore, circulations controls that are generally applicable in the capital centre (known as circulation ring) are waived for EVs, in order to provide a competitive advantage to their owners[ix].

Charging stations

L. 4001/2011, as amended, defines the agencies that are operating in the EVs charging industry, as electric power end-users. Those end-users are operating in the EVs charging business, thus they purchase energy in order to be able to provide EVs charging services. Furthermore, pursuant to art. 134(2) L. 4001/2011, entities that provide charging services are not required to acquire any special license for the energy traded.

However, the national independent agency for energy issues (RAE) shall determine the terms and conditions for the establishment and operation of EVs charging services, such as the notifications requirements to other agencies, information release, especially upon their power and energy needs on an annual basis and an estimated cost, the compliance of entities which are already operating in this field and any other details on the EVs charging infrastructure[x].

Pursuant to L. 4070/2012, art. 114 (7)(b) a common ministerial Decree of the Ministers of Transport, Environmental affairs and energy, Internal affairs, Financial affairs, Development, Tourism, Shipping and Islands affairs, shall determine the terms and conditions and the technical specifications for the installation of EVs charging stations at existing gas stations, existing or new parking services[xi], existing or new agencies for the technical vehicles control, publicly available charging spots across the city, suburban and national roads network, private or public building parking lots or transportation terminals.

The charging spots shall comply with the minimum requirements set out in Directive 2014/94/EE and the Joint Ministerial Decree 712/2015 (GG B’ 50/2015). Existing gas stations enjoy the same benefits[xii] when deploying infrastructure for charging points. Not specific benefits are already provided to the existing gas stations, in order to invest in this technology. As both European and National legislations allow such benefits to be provided, in order to facilitate such a niche market, it is a political question if more benefits will be provide to enhance the operation of more charging stations in the years to come.

Pursuant to art. 4 par. 7 L. 4439/2010, publicly available charging points will be connected via intelligent - smart systems in order to provide information not only to the operator for the energy consumed in order to provide the charging service, but useful data to the TSO, whose corporate name is DEDDHE in Greece, in order to ensure better stability for the electric grid or to allow users who are not supplier's clients to have access to the charging point.

Charging Stations and Energy Communities

In order to assist the creation and operation of Energy Communities, certain benefits are provided to communities which maintain and operate EVs charging stations[xiii].

C. Conclusion

While the public consultation of RAE's suggestions has already been concluded, it remains to see RAE's regulations and how they will affect or assist to the deployment of charging points in Greece, when they are issued. During this public consultation many concerns have been expressed on the exact space that it would be allowed to use to create charging stations outside existing buildings. Building any fixtures necessary for the charging of the EVs is not only prohibited pursuant to the applicable law, but it would also raise many safety issues.

Furthermore, no specific benefits are provided for the development of charging stations that are powered by RES and the TSO is claiming that cannot install the smart meters RAE that the national plan for the use of alternative fuels provides for. Other energy producers or sellers are suggesting the implementation prepaid cards for the use of public charging stations, but fail to provide the specific technical data for the introduction of such a system.

Municipalities are suggesting, following their experience on shared bicycles that the biggest difficulty and they highest cost they have to undertake is not the building of this system per se, but the creating and maintenance of the necessary information system.

National framework does not provide for charging stations that are defined for each category of fuel they use to recharge the EVs. For example, in the public consultation there is a suggestion to create a hybrid charging station, which will be powered by energy produced by RES located inside the charging station.

Another issue that needs to be resolved, especially in Greece, where we have still operating many isolated electric grids, especially in the islands, is the ability to foresee the needs to charge EVs in each different location, in order to timely dispatch the necessary units to inject into the national or the local independent grid the necessary power for the stability of the system.

Problem is that there not a plethora of information for the everyday issues they may arise from the daily operation of Charging Points. While the legislator has defined the technical details for charging only 43 are already operating in Greece and most of them are privately owned and operated[xiv]. According to some projections for the number of EVs that will be circulating in Greece will be around 3.500 by 2020 and will reach the number of 15.000 by 2030.

As more EVs will circulate in the country and more charging stations will be deployed and used for every day transportation, a clear picture will be created on the EVs position in the market and possible improvements that would be needed to assist successful their successful integration in the different national transport markets. However, it is expected that the majority of the charging stations will be deployed in households or will be privately operated. This is due to the fact that the deployment of charging points along national roads cannot be accomplished, until the upgrade of the energy grid, in order to allow the concurrent use multiple high speed charging points.

E South East Europe's EV Markets [9]

Bulgaria: In Bulgaria the EV market has been initiated slowly with many obstacles. The lack of incentives does not facilitate the adoption of EVs and thus the market performance has been low, with the consumers being reluctant in purchasing EVs

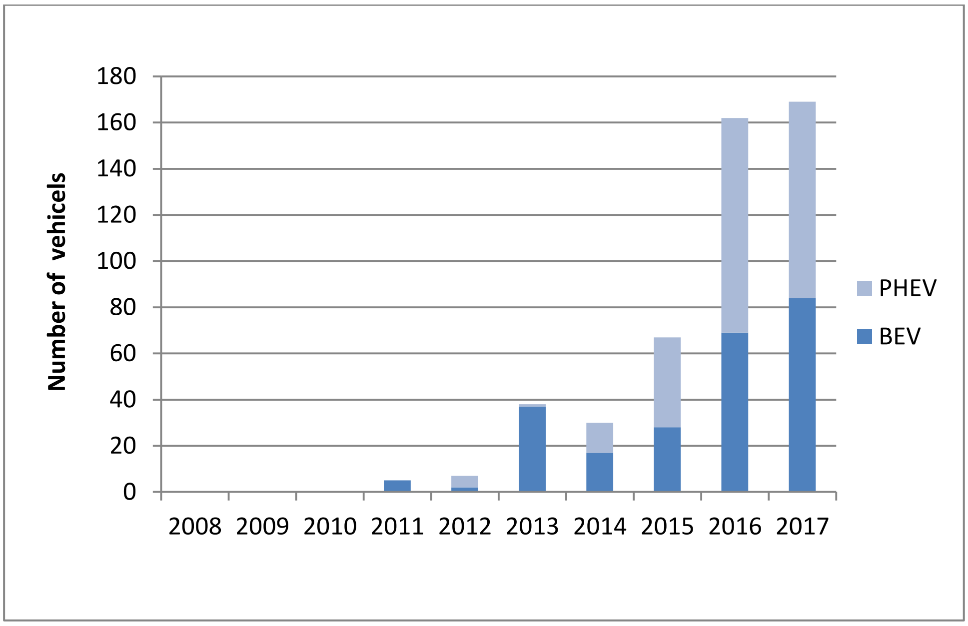


Figure 60 Figure Number of Vehicles (Source: EAFO)

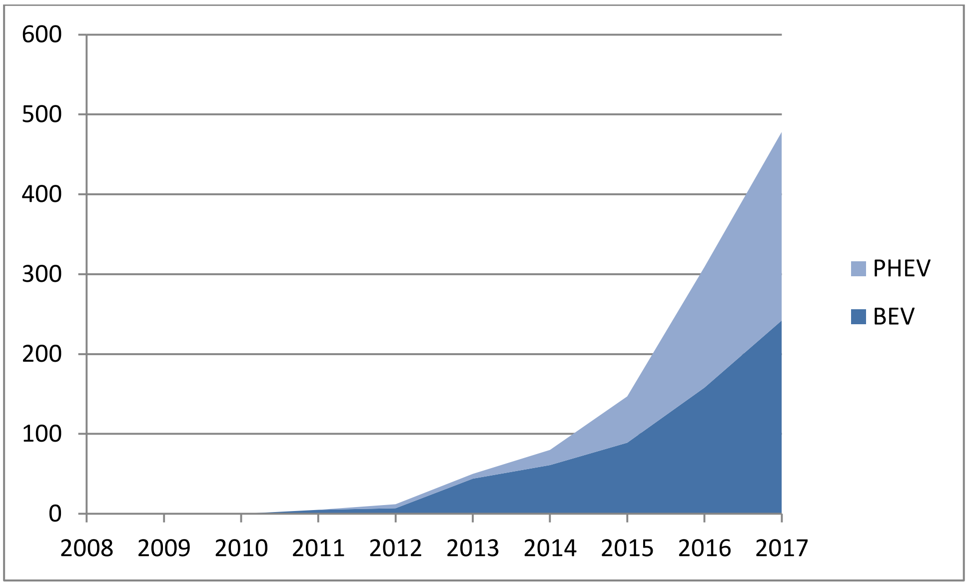


Figure 61 Figure Number of EVs in circulation in Bulgaria (Source: EAFO)

[9] Due to the fact that the EV market of SE Europe is at an early stage of its development, IENE decided to approach indicatively only the markets of Bulgaria and Romania, whereas the rest of SE EV markets are subject to further ongoing observation, monitoring and research. Such observations are expected to be released in future research material of IENE.

Furthermore, the circulation of EVs has exceeded the 450 vehicles in the beginning of 2018. Some of the adoption has been due to corporate initiative as “Spark”, a car sharing service company, currently has deployed more than 50 EVs in the greater metropolitan area of Sofia [93], with goals of reaching the 200 vehicles deployed by the end 2018. Moreover, Electro mobility provider “eMobility International” operates a fleet of 110 rental and rideshare EVs in Bulgaria, as well as a network of charging stations [94]. The company has deployed a network of ABB Terra 53 fast charging stations, operating under the brand Eldrive, which covers the international routes from Sofia to the Greek border. It plans to extend the network to include all the country’s major roads and highways by the end of Q1 2018. ABB’s Terra 53 CJG is compatible with all EVs on the Bulgarian market, using the CHAdeMO, CCS and Type 2 AC standards [94]. The activity of ABB in Bulgaria has been the main reason they were chosen for the infrastructure development of the country. Furthermore, the overall charging infrastructure availability has been ramping up its development to facilitate potential EV introduction in the country. Specifically, according to EAFO, a total of 63 normal power charging points and 31 high power charging points have been deployed in the country by the end of 2017, which have been further developed by the initiative of eMobility International in the beginning of 2018.

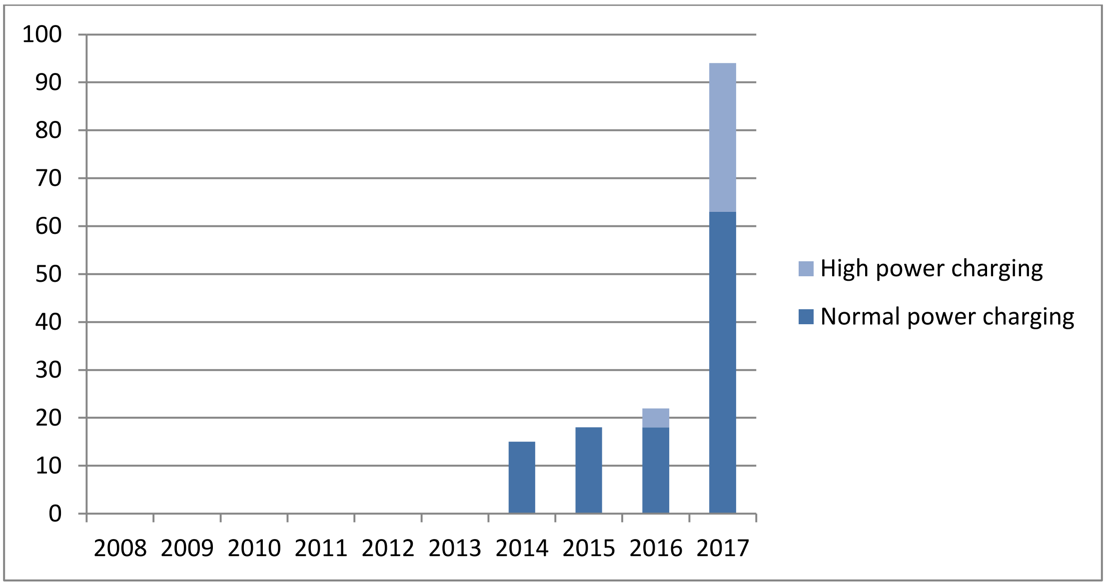


Figure 62 Figure Introduction of power charging points in Bulgaria (Source: EAFO)

Romania: The EV market of Romania has received a significant boost in 2017 both by declaration of Dacia for manufacturing a low cost EV [96] and by the implementation of fiscal incentives by the Order no. 955/2016 (eurotickets) for BEVs and PHEVs. Specifically the incentives reach as much as 4450 Euros (20.000 RON) for BEVs and 1,100 (5,000 RON) for hybrids (The Official Monitor of Romania no. 397/25.05.2016)[95].

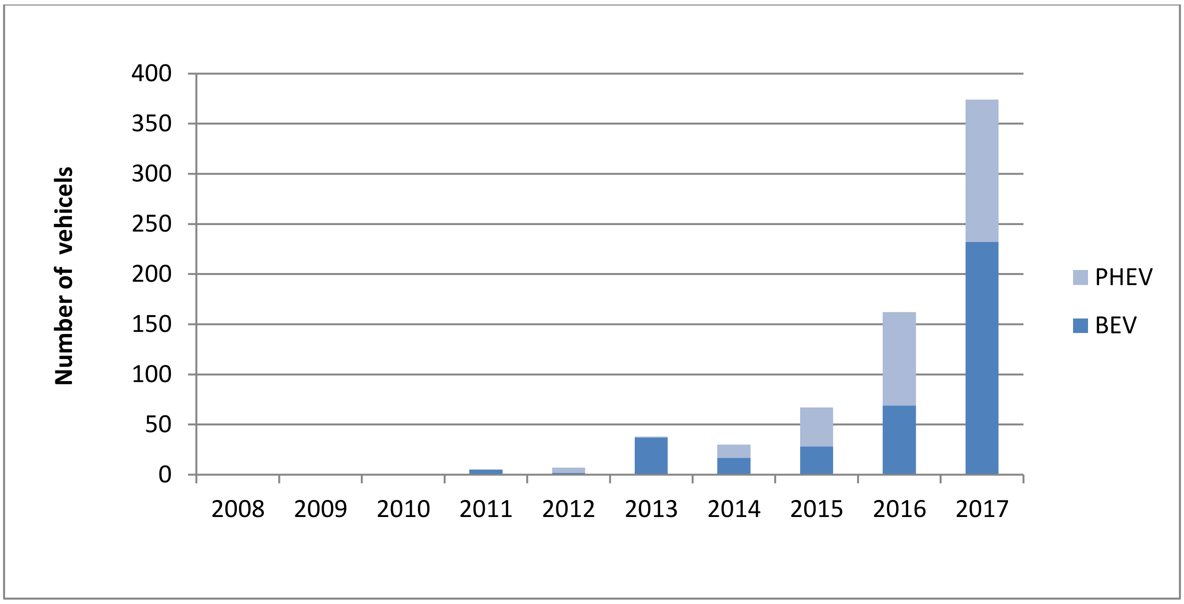


Figure 63 Figure Sales of EVs in Romania in period 2008-2017 (Source: EAFO)

The deployment of PHEVs and BEVs has peaked in 2017 with the introduction of a large volume of BEVs. BEVs reached a market share of 0.22% with deployment of 232 vehicles while PHEVs reached a market penetration of 0.14% with 142 Vehicles. In the end of 2017 the deployment of PEVs had exceeded the 650 vehicles, while charging infrastructure have been steadily under development adding 14 fast charging points and 37 normal charging points publicly available for the Romanian drivers reaching a total of 19 and 95 respectively.

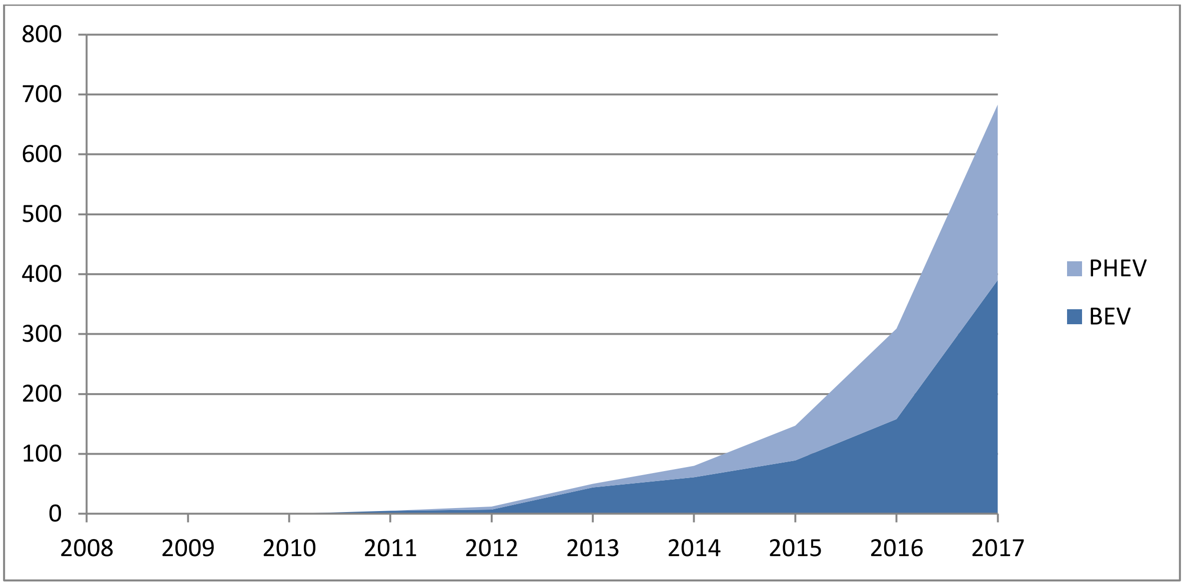


Figure 64 Figure Development of the Romanian PEV fleet (2008-2017)(Source: EAFO)

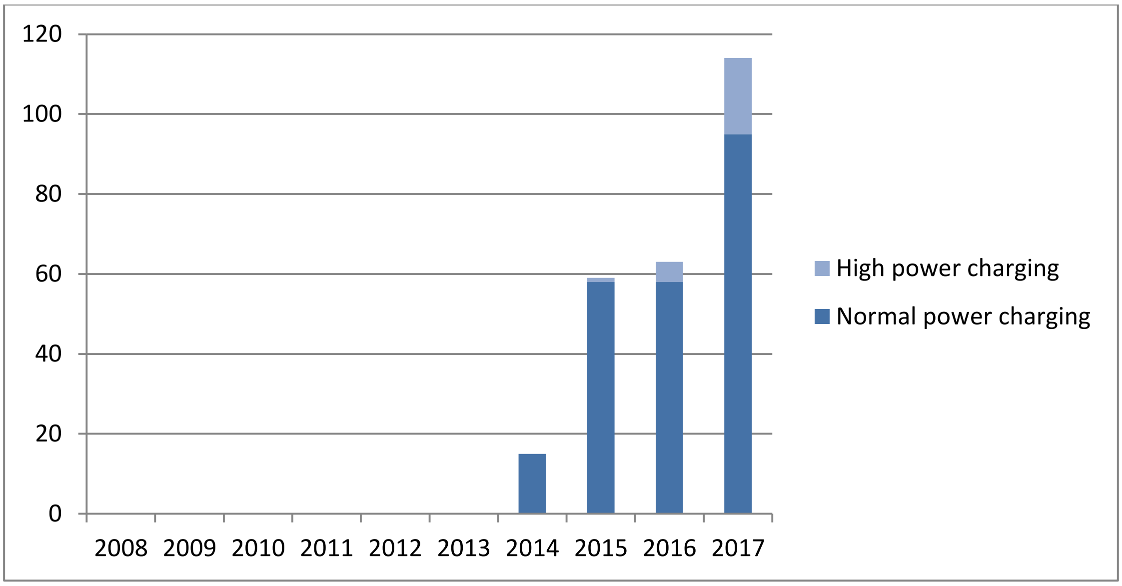


Figure 65 Figure Deployment of PEV charging points in Romania (2008-2017) (Source EAFO)

Moreover, German and French OEMs have been the most active brands in Romanian market Specifically, BMW with its model BMWi3 has achieved the most sales in the BEV market segment, reaching in the span of 2014-2017 with a total sales of 113 vehicles amounting to 29% of the total sales for the same period, while the Dacia owner, Renault, with its models ZOE and Fluence has achieved 23% of the total BEV sales (16% and 7% respectively).

In regards to the PHEV market segment the most successful vehicles are again by the major German OEMs, BMW (X5 40e, 225xe Active tourer, i8) and Daimler (Mercedes C350e, Mercedes S500e) reaching 22% (65 vehicles) and 19% (56 vehicles) market segment penetration respectively.

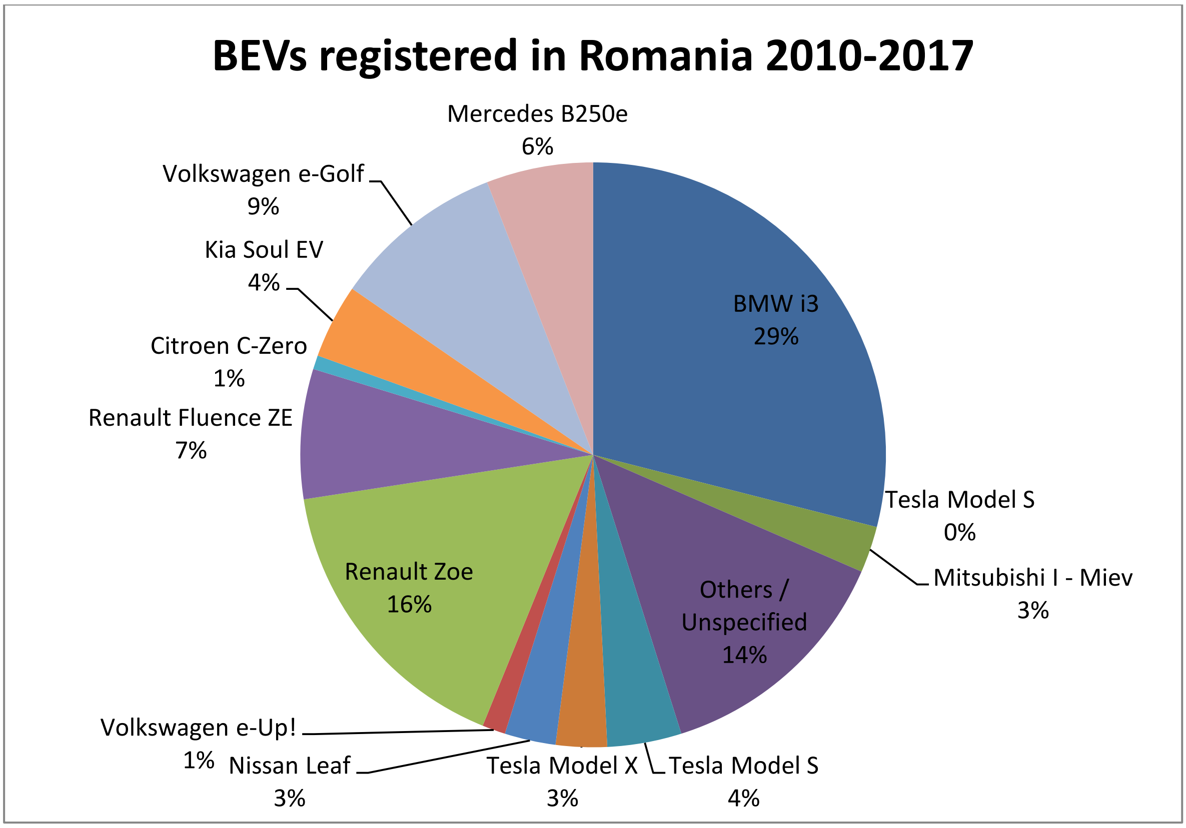


Figure 66 Figure BEVs registered in Romania 2010-2017 (Source: EAFO)

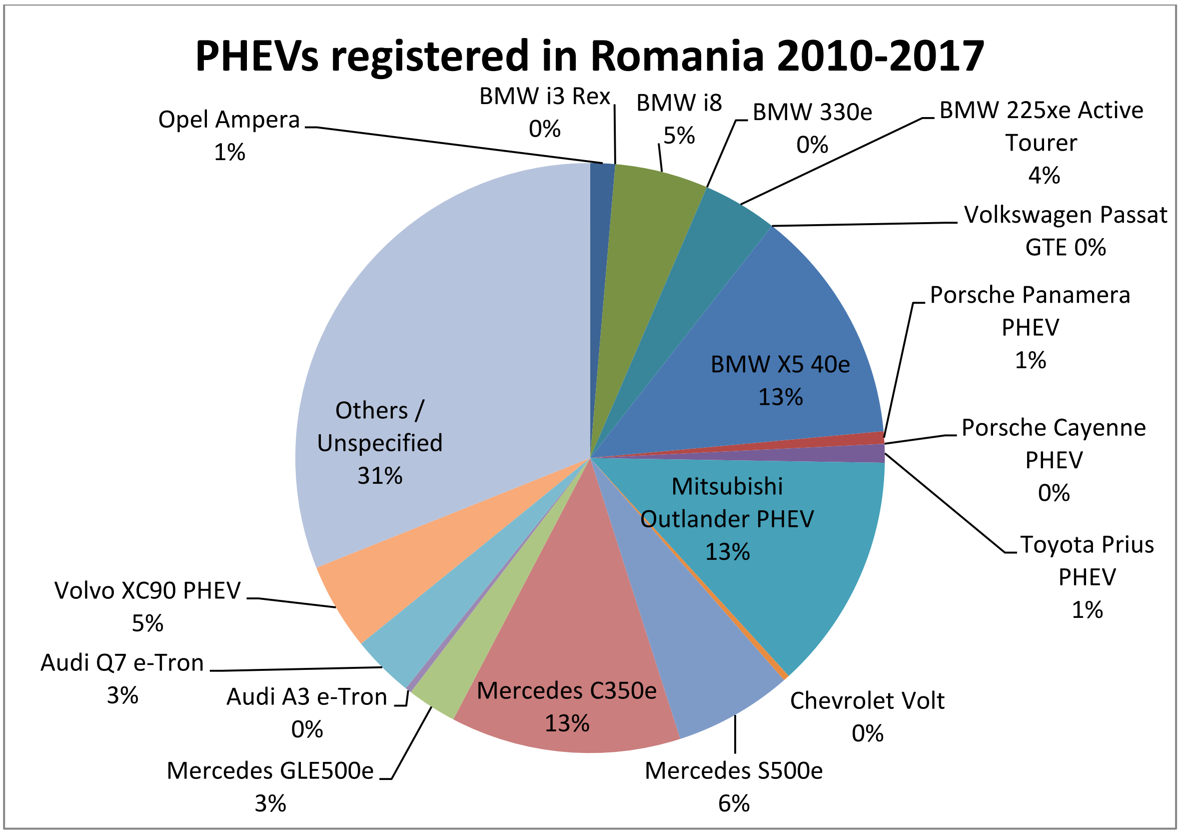


Figure 67 Figure PHEVs registered in Romania 2010-2017 (Source: EAFO)

References

[1] *The Economist Leaders* – "Roadkill", issue August 12th 2017

[2] *The Economist*, (2017), "After electric cars, what more will it take for batteries to change the face of energy?", *The Economist*, issue: August 12th 2017, "Briefing Batteries – Electrifying everything."

[3] *International Energy Agency (IEA)*, (2017), "Global EV outlook 2017", *OECD/IEA 2017,* Available online at: https://www.iea.org/publications/freepublications/publication/GlobalEVOutlook2017.pdf

[4] *International Energy Agency (IEA)*, (2017), "Energy Technology Perspectives 2017 - Catalysing Energy Technology Transformations"

[5] D. Howell, (2017), "personal communications of the authors on the status and projections for EV batteries RD&D.", *March and April 2017*.

[6] J. Ayre, (2015), "$145 kWh battery cell costs at Chevy Bolt launch, GM says", Available online at: http://evobsession.com/gm-145-kwh-battery-costs-bolt-ev-launch.

[7] *IHS Markit*, (2017), "The Future of Cars 2040: Miles Traveled Will Soar While Sales of New Vehicles Will Slow, New IHS Markit Study Says", *Press Release*, Available online at: http://news.ihsmarkit.com/press-release/energy-power-media/future-cars-2040-miles-traveled-will-soar-while-sales-new-vehicles-

[8] *Financial Times,* (2017), "THE BIG READ. NORWAY – Electric Dreams, subsidized reality", Available online at: https://www.ft.com/content/84e54440-3bc4-11e7-821a-6027b8a20f23

[9] *European Alternative Fuels Observatory* (EAFO), "Countries – Norway", [Accessed Jan 2018], Available online at: http://www.eafo.eu/content/norway

[10] *Norsk elbilforening*, (2018), "Norwegian EV policy", Available online at: http://elbil.no/english/norwegian-ev-policy/

[11] https://www.ft.com/content/ca850f68-9a0a-11e7-b83c-9588e51488a0

[12] E. Bekiaris, (2017), "Evidence and perspectives for On-Road and Naval Electric Mobility in Greece" (in Greek), "Energy and Transport in Greece, Conditions and Measures for Clean and Sustainable Energy for Transport", *Committee for Energy, Academy of Athens.*

[13] D. Fickling, (2017), "Electric Cars Reach a Tipping Point Prediction of electric vehicle take-up", *Bloomberg*, Available online at: https://www.bloomberg.com/gadfly/articles/2017-09-11/electric-cars-reach-a-tipping-point

[14] P. Slowik, N. Pavlenko, N. Lutsey, (2016), "White paper: Assessment of next-generation electric vehicle technologies", *The international council for green transportation (ICCT)*, Available online at: https://www.theicct.org/sites/default/files/publications/Next%20Gen%20EV%20Tech_white-paper_ICCT_31102016.pdf

[15] *evrater*, The "Electric Vehicle List - An up-to-date list of current and future full-electric cars.", [Accessed Jan 2018], Available online at: https://evtide.com/evs

[16] European Alternative Fuels Observatory (EAFO), "Database: Fuels – Vehicles: BEVs", [Accessed in Jan 2018], Available online at: http://www.eafo.eu/fuels-vehicles/bev

[17] *Bellona Europa,* (2017), *"*EU contemplates introduction of minimum quotas for the sales of electric vehicles"

[18] *Enerdata*, (2017),"Global Energy Statistical Yearbook 2017"

[19] J. Mac Donald, (2016),"Electric Vehicles to be 35% of global new car sales by 2040", Bloomberg New Energy Finance, Available online at: https://about.bnef.com/blog/electric-vehicles-to-be-35-of-global-new-car-sales-by-2040/

[20] S. Morsy, (2017), "BNEF Long Term EV Outlook – NGA EV Webinar", *Bloomberg New Energy Finance*, Available online at: https://www.nga.org/files/live/sites/NGA/files/pdf/2017/Salim%20Morsy-1.pdf

[21] A. Zamorano, (2017), "Global EV trends and forecast – IEPR workshop on Light Duty Vehicle Transportation Electrification", *Bloomberg New Energy Finance*, Available online at:

https://efiling.energy.ca.gov/GetDocument.aspx?tn=217132

[22] D. L. Chandler, (2017), "Will metal supplies limit battery expansion? Rise of electric vehicles and grid storage may cause bottlenecks, but no showstoppers, analysis suggests.", *MIT News Office,* Available online at: http://news.mit.edu/2017/will-metal-supplies-limit-battery-expansion-1011

[23] E. A. Olivetti et al. (2017), "Lithium-Ion Battery Supply Chain Considerations: Analysis of Potential Bottlenecks in Critical Metals" *Joule* , v. 1 , issue 2 , p. 229 - 243

[24] C. McKerracher, (2017), "EV market trends and outlook – Shift up a gear". *Bloomberg New energy Finance*, Presentation available online at: https://www.transportenvironment.org/sites/te/files/EV%20market%20trends%20and%20outlook%20%28by%20Colin%20McKerracher%29.pdf

[25] J. Shankleman, T. Biesheuvel, J. Ryan, and D. Merrill, (2017), "We're Going to Need More Lithium-There's plenty in the ground to meet the needs of an electric car future, but not enough mines.", *Bloomberg,* Available online at: https://www.bloomberg.com/graphics/2017-lithium-battery-future/

[26] *Benchmark Mineral Intelligence* (2017)"Rise of the lithium-ion battery Megafactories: What does 2018 Hold":, Available online at: http://benchmarkminerals.com/where-is-new-lithium-ion-battery-capacity-located/

[27] P. Hertzke, N. Müller, and S. Schenk, (2017),"China's electric-vehicle market plugs in", *McKinsey & Company, Article: McKinsey Quarterly*, Available online at: https://www.mckinsey.com/global-themes/china/chinas-electric-vehicle-market-plugs-in

[28] M. Burton, (2017)"How Batteries Sparked a Cobalt Frenzy and What Could Happen Next", Bloomberg – Markets, Available online at: https://www.bloomberg.com/news/articles/2017-12-18/how-batteries-sparked-a-cobalt-frenzy-and-what-could-happen-next

[29] M. Hocking et al, (2016), "F.I.T.T for investors: Welcome to the lithium-ion Age", *Deutche Bank - Markets Research, Industry: Lithium 101, M&M-Other Metals*, Available online at: https://www.scribd.com/document/353840445/Lithium-Report

[30] *Lithium Today*, "Lithium prices retrieved in 25.02.2018", [Accessed in Feb 2018], http://lithium.today/

[31] A. Evans-Pritchard, (2007), “Nickel price 'loses touch with industrial reality'”, *The Telegraph: Finance*, Available online at:
http://www.telegraph.co.uk/finance/2806898/Nickel-price-loses-touch-with-industrial-reality.html

[32] Sanderson, H. (2018), “Tesla in talks with Chile’s SQM over lithium investment”, *The Financial Times*, Available online at: https://www.ft.com/content/5df19f04-01c7-11e8-9650-9c0ad2d7c5b5

[33] *International Nickel Study Group (INSG)*, ”About Available online at: http://www.insg.org/prodnickel.aspx

[34] *InfoMine – InvestmentMine,* “Historical Nickel Prices and Price Chart”, *Metal Prices: Nickel,* [Accessed on Jan 2018], Available online at:
http://www.infomine.com/investment/metal-prices/nickel/all/

[35] C. J. Martin, (2016), “The sharing economy: A pathway to sustainability or a nightmarish form of neoliberal capitalism?”, *Ecological Economics*, v. 121, p. 149-159, Available online at:
https://www.sciencedirect.com/science/article/pii/S0921800915004711

[36] A. Kosintceva, (2016), “Business models of sharing economy companies: Exploring features responsible for sharing economy companies’”, *Master Thesis, Norwegian School of Economics, Bergen*, Available online at:
https://brage.bibsys.no/xmlui/bitstream/handle/11250/2403861/masterthesis.pdf

[37] J. Hamari M. Sjöklint A. Ukkonen, (2015), “The sharing economy: Why people participate in collaborative consumption”, *Wiley Online Library*, *Journal of the Association for Information Science and Technology*, v. 67, issue 9, p. 2047-2059, Available online at:
http://onlinelibrary.wiley.com/doi/10.1002/asi.23552/full

[38] *International Electrotechnical Commission (IEC)*, (2012), “Grid integration of large capacity renewable energy sources and use of large-capacity electrical energy storage”. *IEC White paper 3*, Available online at:
http://www.iec.ch/whitepaper/pdf/iecWP-gridintegrationlargecapacity-LR-en.pdf

[39] M. Martina, N. Shirouzu, (2017), “China Upholds Strict Electric Car Sales Quotas Despite Industry Protests”, *U.S.News*, Available online at:

https://www.usnews.com/news/technology/articles/2017-06-13/china-upholds-strict-electric-car-sales-quotas-despite-industry-protests

[40] *Nissan*, (2018), "Renault-Nissan-Mitsubishi launches a venture capital fund to invest up to $1 billion over five years", *(Press Release),* Available online at:
https://newsroom.nissan-global.com/releases/release-4a75570239bf1983b1e6a41b7d01e4f0-180110-01-e

[41] *InsideEVs*, (2018), "Renault-Nissan-Mitsubishi To Invest $1 Billion Into Battery Tech, Electric Car Development: New venture fund looks outside of Alliance boxes for breakthroughs", Available online at:
https://insideevs.com/renault-nissan-mitsubishi-invest-1-billion-battery-tech-electric-car/

[42] *Daimler*, (2018),"Plans for more than ten different all-electric vehicles by 2022: All systems are go", Available online at:
http://media.daimler.com/marsMediaSite/en/instance/ko/Plans-for-more-than-ten-different-all-electric-vehicles-by-2022-All-systems-are-go.xhtml?oid=29779739

[43] K. Field, (2017), "Electric Cars Up 137% In Germany, Approaching 2% Market Share", CleanTechnica, Available online at:
https://cleantechnica.com/2017/09/10/electric-cars-are-up-137-in-germany-with-plug-in-vehicles-approaching-2-market-share/

[44] *Agence France-Presse*, (2016), "Germany to give €1bn subsidy to boost electric car sales", *The Guardian*, , Available online at:
https://www.theguardian.com/world/2016/apr/28/germany-subsidy-boost-electric-car-sales

[45] D. Carrington, (2016), "Electric cars 'will be cheaper than conventional vehicles by 2022'", *The Guardian*, Available online at:
https://www.theguardian.com/environment/2016/feb/25/electric-cars-will-be-cheaper-than-conventional-vehicles-by-2022

[46] J. Shankleman, (2017), "The Electric Car Revolution Is Accelerating", *Bloomberg Businessweek*, Available online at:
https://www.bloomberg.com/news/articles/2017-07-06/the-electric-car-revolution-is-accelerating

[47] *ACEA*, (2016), "CO2 based motor vehicle taxes in the EU in 2016", Available online at:

www.acea.be/uploads/publications/CO2_tax_overview_2016.pdf.

[48] *Global Fuel Economy Initiative (GFEI),* (2017), "International Comparison of Light-Duty Vehicle Fuel Economy: Ten Years of Fuel Economy Benchmarking", *GFEI Working Paper 15, OECD/IEA*, Paris, Available online at:
www.globalfueleconomy.org/media/418761/wp15-ldv-comparison.pdf.

[49] K. Hoy, and H. Weken, (2017), "I-CVUE Final Results", *I-CVUE*,
http://frevue.eu/wp-content/uploads/2016/03/I-CVUE-.pdf.

[50] A. Asthana and M. Taylor, (2017), "Britain to ban sale of all diesel and petrol cars and vans from 2040", *The Guardian*, Available online at:
https://www.theguardian.com/politics/2017/jul/25/britain-to-ban-sale-of-all-diesel-and-petrol-cars-and-vans-from-2040

[51] A. Chrisafis and A. Vaughan, (2017), France to ban sales of petrol and diesel cars by 2040, *The Guardian*, Available online at:
https://www.theguardian.com/business/2017/jul/06/france-ban-petrol-diesel-cars-2040-emmanuel-macron-volvo

[52] *Electric Vehicles Initiative (EVI),* (2016a), "Global EV Outlook 2016: Beyond One Million Electric Cars", *OECD/IEA*, Paris, Available online at:
www.iea.org/publications/freepublications/publication/Global_EV_Outlook_2016.pdf

[53] *Ministry of Finance, China (MoF),* (2017), "Notice on adjusting the financial subsidy Policy for the Promotion and Application of New Energy Vehicles", Available online at:
http://jjs.mof.gov.cn/zhengwuxinxi/tongzhigonggao/201612/t20161229_2508628.html.

[54] Pontes, J. (2017), "China electric car sales keep soaring – March 2017", Available online at:
https://evobsession.com/china-electric-car-sales-keep-soaring-march-2017/.

[55] *EV-volumes*, (2018), "China Plug-in Sales for 2017-Q4 and Full Year – Update", [Accessed on Mar 2018], Available online at:
http://www.ev-volumes.com/country/china/

[56] S. Kennedy, (2015), "Made in China 2025", *Center for Strategic and International Studies (CSIS),* Available online at:

https://www.csis.org/analysis/made-china-2025

[57] *Agence France-Presse*, (2017), "China to ban production of petrol and diesel cars 'in the near future'", *The Guardian*, Available online at: https://www.theguardian.com/world/2017/sep/11/china-to-ban-production-of-petrol-and-diesel-cars-in-the-near-future

[58] *Reuters*, (2017), "China's electric car output to hit one million next year: BAIC chairman", Beijing, Available online at: https://www.reuters.com/article/us-china-baic-motor/chinas-electric-car-output-to-hit-one-million-next-year-baic-chairman-idUSKBN1CN10A

[59] *EV-volumes*, (2018), "Norway Plug-in Sales Q3-2017 and YTD", [Accessed on Mar 2018], Available online at: http://www.ev-volumes.com/country/total-euefta-plug-in-vehicle-volumes/

[60] M. J. Olson and S. J. Kemp, (2015), "Sharing Economy: An In-Depth Look At Its Evolution & Trajectory Across Industries", *PiperJaffray: Investment Research*, Available online at: https://collaborativeeconomy.com/wp/wp-content/uploads/2015/04/Sharing-Economy-An-In-Depth-Look-At-Its-Evolution-and-Trajectory-Across-Industries-.pdf

[61] S. Gandon, (2017), "No cobalt, no Tesla?", *Tech Crunch, Oath Tech Network, WordPress*, Available online at: https://techcrunch.com/2017/01/01/no-cobalt-no-tesla/

[62] P. Kasche, (2017), "Personal communications of the authors on the status and projections for the deployment of electric vehicles in the Sweden, March and April 2017."

[63] A. Krok, (2017), "2018 Nissan Leaf already in production in Japan", *CBS, CNET: Road/Show,* Available online at: https://www.cnet.com/roadshow/news/2018-nissan-leaf-already-in-production-in-japan/

[64] J. McCurry, (2016), "Japan now has more electric car charge points than petrol stations", *The Guardian*, Tokyo, Available online at: https://www.theguardian.com/world/2016/may/10/japan-electric-car-charge-points-petrol-stations

[65] *California Air Resources Board (CARB)*, (2017), "Zero emission vehicle (ZEV) program", Available online at: https://www.arb.ca.gov/msprog/zevprog/zevprog.htm

[66] F. Lambert, (2017a), "US cities' massive electric vehicles order increases to 114,000 vehicles, 40 companies competing", *electrek*, Available online at: https://electrek.co/2017/03/15/electric-vehicle-order-114000-vehicles-40-companies-competing/

[67] *EV-volumes*, (2018), "USA Plug-in Vehicle Sales for 2017 Q4 and Full Year", [Accessed on Mar 2018], Available online at: www.ev-volumes.com/country/usa/

[68] *DriveNow*, "DriveNow Car Sharing & Car Club", Available online at: https://www.drive-now.com/en

[69] *Greek Government Gazette*, (2017), "National Policy Framework on alternative fuels - Newspaper of the Greek Government 31 of October 2017, v. 3824, 2nd issue p. 46463 – 46550. [Retrieved on 05.02.2018], Available online at: https://www.maritimes.gr/news/uploads/YEN/171115%20National%20Policy%20Framework%20on%20alternative%20fuels.pdf

[70] *EnergyWorld Magazine*, (2017) "New Infrastructure for electric vehicles in Greece", issue 18, Available online at: https://www.energyworldmag.com/new-infrastructure-electric-vehicles-greece/

[71] EuroStat, "Database: Final energy consumption by product", [Accessed Dec 2017], Available online at: http://ec.europa.eu/eurostat/tgm/refreshTableAction.do?tab=table&plugin=1&pcode=ten00095&language=en

[72] *European Alternative Fuels Observatory (EAFO),* "Database: Countries: Greece", [Accessed Nov 2017], Available online at: http://www.eafo.eu/content/greece

[73] *Charge Point Inc*, (2017), "Take Credit for Going Green", [Retrieved on 28-11-2017], Available online at: https://www.chargepoint.com/products/station-incentives/

[74] *European Parliament - European Council*, (2014), "Directive 2014/94/EU of the European Parliament and of the Council of 22 October 2014 on the deployment of alternative fuels infrastructure ",Available online at:

https://publications.europa.eu/en/publication-detail/-/publication/d414289b-5e6b-11e4-9cbe-01aa75ed71a1/language-en

[75] *Greek Government Gazette*, (2010), "3888/2010 – Chapter C: Circulation fees and depreciation of licenses, for heavy duty vehicles for public use", Available online at:
https://www.taxheaven.gr/laws/law/index/law/258

[76] *Fortizo Network*, [Accessed Nov 2017], Available online at:
https://www.fortisis.eu/fortizo-network/#the-network

[77] *Autotriti*, (2014), "Everything you need to know for Electric Mobility" (in Greek), Available online at:
https://www.autotriti.gr/data/news/preview_news/Ta-panta-gia-thn-hlektrokinhsh_119728.asp

[78] *Eurostat*, (2017), "Passenger cars in the EU update 2017", [excel file extracted by Eurostat in Apr 2018]

[79] *Hellenic Institute for Electric Vehicles (HELIEV)*, (2016), Info available online at: http://heliev.gr/

[80] *RethemnosNews*, (2018), "Rethimno gets "electrified": Charging stations for passenger electric vehicles and electric public buses" (in Greek), Available online at:
http://rethemnosnews.gr/2018/02/%CF%84%CE%BF-%CF%81%CE%AD%CE%B8%CF%85%CE%BC%CE%BD%CE%BF%CE%B7%CE%BB%CE%B5%CE%BA%CF%84%CF%81%CE%AF%CE%B6%CE%B5%CF%84%CE%B1%CE%B9-%CF%83%CF%84%CE%B1%CE%B8%CE%BC%CE%BF%CE%AF-%CF%86%CF%8C/

[81] *Hellenic Institute for Electric Vehicles (HELIEV)*, (2017), "Publicly Accessible charging points in Greece", *Plugshare,* Available online at:
http://www.heliev.gr/%CF%83%CE%B7%CE%BC%CE%B5%CE%AF%CE%B1-%CF%86%CF%8C%CF%81%CF%84%CE%B9%CF%83%CE%B7%CF%82/

[82] *World Energy News*, (2018), "Planning of of 1,500 charging stations for EVs from HEDNO, RAE's approval pending" (in Greek), Available online at:
http://worldenergynews.gr/index.php/%CF%80%CE%B5%CF%81%CE%B9%CE%B2%CE%AC%CE%BB%CE%BB%CE%BF%CE%BD/item/18452-schedio-dhmioyrgias-1-500-stathmwn-fortishs-hlektrikwn-ochhmatwn-apo-ton-deddhe-%E2%80%93-ekkremei-h-egkrish-toy-apo-th-rae

[83] *Plugshare application*. [Database accessed on 10.02.2018], Available online at: https://www.plugshare.com

[84] *worldometers*, "Greece's Population", Available online at: http://www.worldometers.info/world-population/greece-population/

[85] *Chania Post*, (2017), "The new Greek urban electric vehicle Ecocar", Available online at: http://www.chaniapost.eu/2017/10/12/the-new-greek-urban-electric-vehicle-ecocar-video/

[86] *Fortisis*, (2018), "Electric and hybrid electric vehicles in Greece" (in Greek), [Accessed on Jan 2018], Available online at: https://www.fortisis.eu/information/electric-cars/

[87] *International Energy Agency (IEA),* (2014), "Energy Technology Perspectives 2014: Harnessing Electricity's Potential", Executive summary available online at: https://www.iea.org/publications/freepublications/publication/EnergyTechnologyPerspectives_ES.pdf

[88] *ANA-MPA,* (2018), "Solar electric vehicle charging station to be installed on Tilos", Available online at:

http://www.amna.gr/en/article/233281/Solar-electric-vehicle-charging-station-to-be-installed-on-Tilos

[89] D. Amarantidou, (2017), "Kozani: Electric vehicles deployed on the municipal fleet" (in Greek), *ERT*, Available online at: http://www.ert.gr/perifereiakoi-stathmoi/kozani/kozani-ilektrika-aftokinita-ston-stolo-tou-dimou/

[90] *ECO//SUN,* "The Electric car ECO-CAR by ECO//SUN" (in Greek), Available online at: http://www.ecosun.gr/ecocar-2/

[91] H. Smith, (2018), "Elon Musk to open Tesla R&D plant in Greece", *The Guardian,* Available online at: https://www.theguardian.com/technology/2018/mar/02/elon-musk-to-open-tesla-rd-plant-in-greece

[92] *Ministry of Environment Energy and Climate Change* (2012),“Investigation of the Development and Penetration of Electric Vehicles in the Greek Market - Technical Report.”, (in Greek), Available online at:
http://www.opengov.gr/minenv/wp-content/uploads/downloads/2012/01/texniki-ekthesi.pdf

[93] I. Mihaylov, (2017), “Latvia's Spark, Bulgaria's E-mobility launch e-car rental service in Sofia”, *SeeNews*, Available online at:
https://seenews.com/news/latvias-spark-bulgarias-e-mobility-launch-e-car-rental-service-in-sofia-589945

[94] C. Morris, (2017) “Bulgarian charging network deploys ABB fast chargers”, *Charged – Electric Vehicles Magazine*, Available online at:
https://chargedevs.com/newswire/bulgarian-charging-network-deploys-abb-fast-chargers/

[95] Ziare.com, (2016),“What the Government is doing to boost clean car sales - The "Rabla" program in a straight line” (in Romanian), Available online at:
http://www.ziare.com/auto/masini-electrice/ce-face-guvernul-pentru-a-stimula-vanzarile-de-masini-nepoluante-programul-rabla-in-linie-dreapta-1418158

[96] *Energia16*, (2018),“Dacia working to build the cheapest EV in the market”, Available online at:
https://www.energia16.com/dacia-working-to-build-the-cheapest-ev-in-the-market/?lang=en

[97] *HELPE – information center*, (2014), “Electric Vehicle Charging Stations”, Press release, Available online at:
https://www.helpe.gr/media-center/news/news-sta8moi-fortishs-hlektrokinhtwn-oxhmatwn-01

[98] M. Piou, (2017), “Electricity and Natural Gas will be sold in EKO’s fuel stations” , Available online at:
https://www.businessenergy.gr/articlenews/15850/%CE%B5%CE%BB%CE%BB%CE%B7%CE%BD%CE%B9%CE%BA%CE%AC-%CF%80%CE%B5%CF%84%CF%81%CE%AD%CE%BB%CE%B1%CE%B9%CE%B1-%CE%B7%CE%BB%CE%B5%CE%BA%CF%84%CF%81%CE%B9%CE%BA%CE%AE-%CE%B5%CE%BD%CE%AD%CF%81%CE%B3%CE%B5%CE%B9%CE%B1-%CE%BA%CE%B1%CE%B9-%CF%86%CF%85%CF%83%CE%B9%CE%BA%CF%8C-%CE%B1%CE%AD%CF%81%CE%B9%CE%BF-%CE%B8%CE%B1-%CF%80%CF%89%CE%BB%CE%BF%CF%8D%CE%BD-%CF%84%CE%B1-

%CF%80%CF%81%CE%B1%CF%84%CE%AE%CF%81%CE%B9%CE%B1-
%CE%B5%CE%BA%CE%BF

Appendix

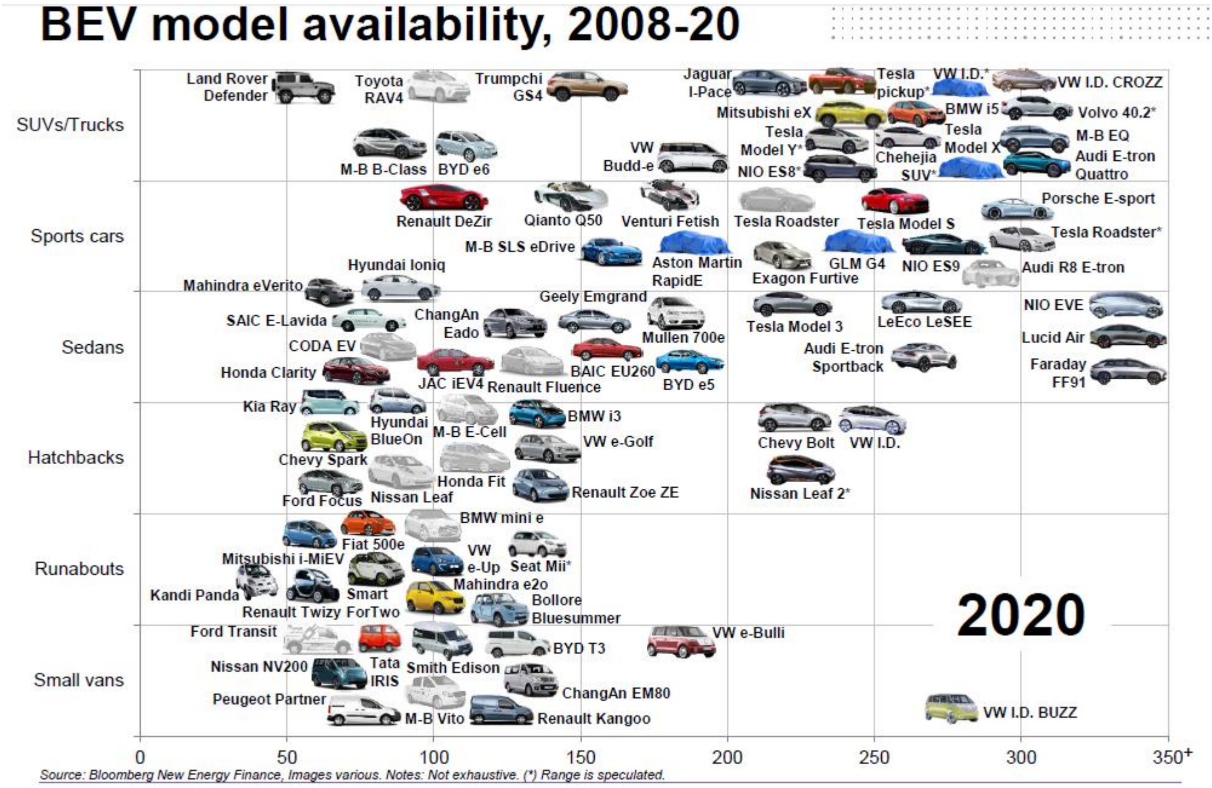


Figure 68 Illustration of the Development of BEV model availability in the period 2009-2020

Table 9 China’s Top Sales – New energy Vehicles for 2017 (Source: EVvolumes)

	EVVOLUMES.COM	Segment	2017 Qtr-4	Change YoY	2017 Total	Change YoY
1.	BJEV EC180/200 EV	Car-B	40 203	+874%	78 079	+1791%
2.	Zhi Dou D1/D2 EV	Car-A	9 751	+25%	42 342	+108%
3.	BYD Song PHEV	SUV-C	11 074	-	30 920	-
4.	Chery eQ EV	Car-A	11 018	+51%	27 444	+71%
5.	JAC iEV6S EV	SUV-C	9 450	+314900%	25 741	+774%
6.	BYD e5 EV	Car-D	5 338	-18%	23 601	+51%
7.	Geely Emgrand EV	Car-D	7 076	-28%	23 324	+36%
8.	BYD Qin PHEV	Car-D	12 903	+271%	20 738	-5%
9.	SAIC Roewe eRX5 PHEV	SUV-C	6 061	-	19 510	-
10.	Zotye E200 EV	Car-A	7 488	+2%	16 751	+27%
11.	JMC E100 EV	Car-A	5 074	+46%	15 491	+43%
12.	BYD Tang PHEV	SUV-D	4 131	-11%	14 592	-54%
13.	Changan Benni EV	Car-B	4 025	+4275%	14 549	+15714%
14.	BJEV EU-Series EV	Car-D	4 914	-43%	13 158	-30%
15.	JMC E200 EV	Car-A	6 760	+175%	12 347	+162%
16.	Hawtai EV160	Car-A	8 467	-	11 823	-
17.	SAIC Baojun E100 EV	Car-A	9 184	-	11 420	-
18.	Zotye Z100 / Cloud EV	Car-A	5 474	-37%	11 038	-33%
19.	SAIC Roewe eRX5 EV	SUV-C	5 609	-	10 436	-
20.	BYD e6 EV	MPV-D	6 250	-19%	10 023	-51%
21.	Kandi K12 Hawk EV	Car-A	5 321	+294%	9 347	+524%
22.	SAIC Roewe i6 PHEV	Car-D	5 067	-	8 925	-
23.	Tesla Model X	SUV-E	1 695	+37%	8 339	+264%
24.	Lifan 320 EV	Car-B	5 110	+508%	7 075	+75%
25.	Horki 300E EV	Car-C	1 792	+35740%	6 666	+133220%
26.	Changan Benni Mini-e EV	Car-A	3 316	-	6 498	-
27.	Tesla Model S	Car-E	1 831	-38%	6 490	+49%
28.	Dongfeng Jun Feng ER30 EV	Car-B	2 190	-23%	6 085	+75%
29.	Zotye E30 EV	Car-A	2 185	+31%	5 716	-6%
30.	BJEV E-Series EV	Car-B	1 611	-52%	5 380	-71%
	Others (84)		52 210	+93%	101 677	+6%
	Total		**262 578**	**+113%**	**605 525**	**+73%**

4. Electric Mobility Infrastructure and Charging Stations

A. Current Charging Technology and Available Charging Infrastructure Worldwide

Electric mobility is an essential part of the solution to the global transport and energy challenges, including the objectives set by the COP21, Paris Agreement, for reducing carbon dioxide and other greenhouse gas emissions. The components needed for a successful adoption of large scale electric mobility are identified mostly on the concepts of funding, standardization, interoperability and deployment of charging infrastructure [10]. Even though the EV market is expanding rapidly, still the biggest obstacle in EV adoption is identified in the limited availability of charging infrastructure, including lack of widely utilized adequate business and financial models.

EV Charging Methods

Charging of EV batteries is majorly accomplished by three methods: Conductive charging method using plug connection, which is the most utilized method today [18-19], Inductive charging method [20-21] and battery swapping technique [22-23]

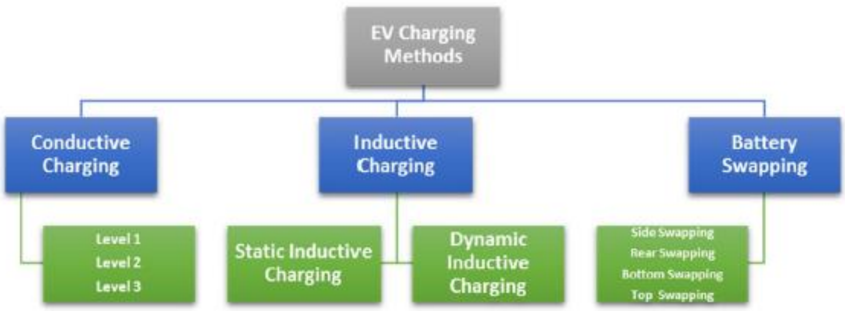


Figure 69 Different EV charging techniques.

Conductive Charging

Conductive Charging suggests direct connection of charger and vehicle. The charging is achieved through cable connection that allows contact between the power supply and the battery. It consists of a rectifier and converter with some power factor correction and it is classified as on-board and off-board charger. The on-board charger, which is embedded in the vehicle, contains the rectifier and the battery regulation system, whereas on the off-board charger these systems are placed on the charging station or the EV supply equipment (EVSE). The conductive charging is segregated in various types of charging which are defined by the voltage and the current of the power supply as well as on the type of connection. Although the conductive charging is the dominant form of charging it has however disadvantages identified in the constant need for available charging infrastructure and planning of charging.

Inductive Charging

Inductive power transfer allows battery charging using a varying magnetic field. The power is transferred inductively form the primary coil in the ground (transmitter) to the secondary coil in the vehicle receiver without any galvanic connection [17]. This simplifies the charging process and reduces the risk deriving from the use of electrical equipment also reduces the requirements for safety for the same reason. The absence of mechanical parts for charging promotes the charging operation as an integrated process in the operation of the vehicle, making charging easier, given also the fact that there would be available infrastructure to support this technology. Such an ease in charging/discharging would minimize the battery depth of discharge enabling the charging process in operating in the most cost effective battery SOC for the battery's lifetime.

The process of wireless power transfer is divided into three different steps: (a) Conversion of power supply, (b) resonance between the coils to transfer power and (c) conversion for battery charging [101]. Initially the supply current is converted to high frequency AC which circulates the transmitting coil generating an alternating magnetic field. The alternating magnetic field induces AC voltages in the receiver coil. Finally the AC power is rectified to charge the battery.

There are two types of inductive charging the static and the dynamic. The static aims to be used in parking areas while the dynamic one enables the charging of the vehicle while in motion, which if established, as a practice, would revolutionize electric mobility, since it would reduce radically the need for electricity storage onboard the vehicles.

Charging Infrastructure, Standardization and Interoperability [10]

The promotion of common open standards, data interoperability and efficient data exchange is one of the most important steps towards facilitation of the EV adoption. Energy and electric mobility service providers should work together with the EV industry in order to create technological language in the field of EV charging that will shape the new e-mobility behavior and culture. Towards this direction the international standardization organizations have issued a series of standards that

[10] Charging infrastructure refers to conductive charging as other types of infrastructure are not commercially utilized.

study, suggest, regulate and coordinate the EV charging technology development worldwide.

Table 10 charging standards issued by the major standardization organizations (source: [17])

IEC	SAE	UL	ESO	NTCAS	JARI	JIS	ARAI
• IEC 61851-XX-1X Ed. X • IEC 62982 Ed. 1.0 • IEC 62196-X Ed. X • IEC 61980-X Ed. X • IEC 62840-X Ed. X • IEC 62983 Ed. 1.0	• J 1772 (RIP) • J 1773 • J 2954 (WIP)	• UL2202 • UL2251 • UL2734 • UL2871 • UL9741	• EN 61851-X-XX • CLC/TS 50457-X:2008	• GB/T 18487.X-2001 • GB/T 20234.X-2011 • QC/T 895-2011 • QC/T 841-2010	• C601: 2000 • G105-1993 • G106:2000 • G107:2000 • G108:2001 • G109:2001	• TS D 0007: 2012 • JIS D 1304: 2004 • JIS D 61851-23/24:2014 • JIS D 62196-3: 2014	• AIS-138/D1

Note: X in the table symbolizes that exists multiple standards in that particular series and are denoted by series number.

Table 10 shows the EV charging standards issued by the major Standardization Organizations. Specifically, the IEC 61851-1 Ed. 2.0 (2010) was designed to provide all the required information to the construction of charging infrastructure.

Charging modes

Important step towards the standardization and interoperability direction was made by IEC in 2010 and 2014 by publishing the IEC 62196 standard (IEC 62196-1,2 and IEC 62196-3 respectively), which along with IEC 61851 has set the foundation of today's EV charging terminology. In this document EV charging is segregated to 4 modes which are defined by the limitations of the power supply and the type of connection.

Mode 1: The EV charging Mode 1 is an uncontrolled AC charging utilizing a 1 or 3 phase circuit and socket (250V 1-phase or 480V 3-phase). The maximum charging current and power output that IEC predicts for this charging mode is 16 A and 11 kW respectively. In this type of charging the charger is built into the vehicle while it predicts no communication between the charging infrastructure and the vehicle. There is not a specific connector for the EV and the electricity supply in such a type of charging, so the EV connection to AC network is achieved by using standard power connections. In addition there are locking mechanisms of the plug and socket outlet in the vehicle. This type of charging is slow. The installation requires earth leakage and circuit breaker protection, while this type of charging is not recommended, since it is not guaranteed that a residual current device (RCD) is included in the building installation [1 - 4]

Mode 2: The EV charging Mode 2 is an uncontrolled slow AC charging utilizing a 1 or 3 phase circuit and socket (250V 1-phase or 480V 3-phase). The maximum charging current and power output that IEC predicts for this charging mode is 32 A and22 kW respectively. In this type of charging the charger is built into the vehicle. There is not a specific connector for the EV and the electricity supply in such a type of charging, while the EV connection to AC network is achieved by utilizing a special cable with intermediate electronic device with pilot control function and protection. In addition there are locking mechanisms of the plug and socket outlet in the vehicle. The installation requires earth leakage and circuit breaker protection; however a protective device/pilot function is provided embedded in the cable [1 - 4].This protection includes protective earth presence detection and monitoring; ground fault, over-current, and over-temperature protection. In addition, functional switching is provided, depending on vehicle presence and charging power demand. Some protections must be provided by an SPR-PRCD plug connector in accordance to IEC 62335[5].

Mode 3: The EV charging Mode 3 is a controlled, Slow or semi-quick AC charging utilizing 1 or 3 phase circuit, type-tested, supply units for electric vehicles. The maximum charging current and power output that IEC determined for this charging mode is 63 A and 43.5 kW respectively and must be in accordance with the connector used. In this type of charging the charger is built into the vehicle. There is a specific connector for EVs, whereas the EV connection with the AC power supply is done through a specific device (SAVE), while locking mechanisms are present on both sides of the plug and socket-outlet. The safety of the system is identified in the protective device/pilot function integrated into the special EV charging station.[1 - 4] The connection between EVs and charging infrastructure allows their integration into smart grids.

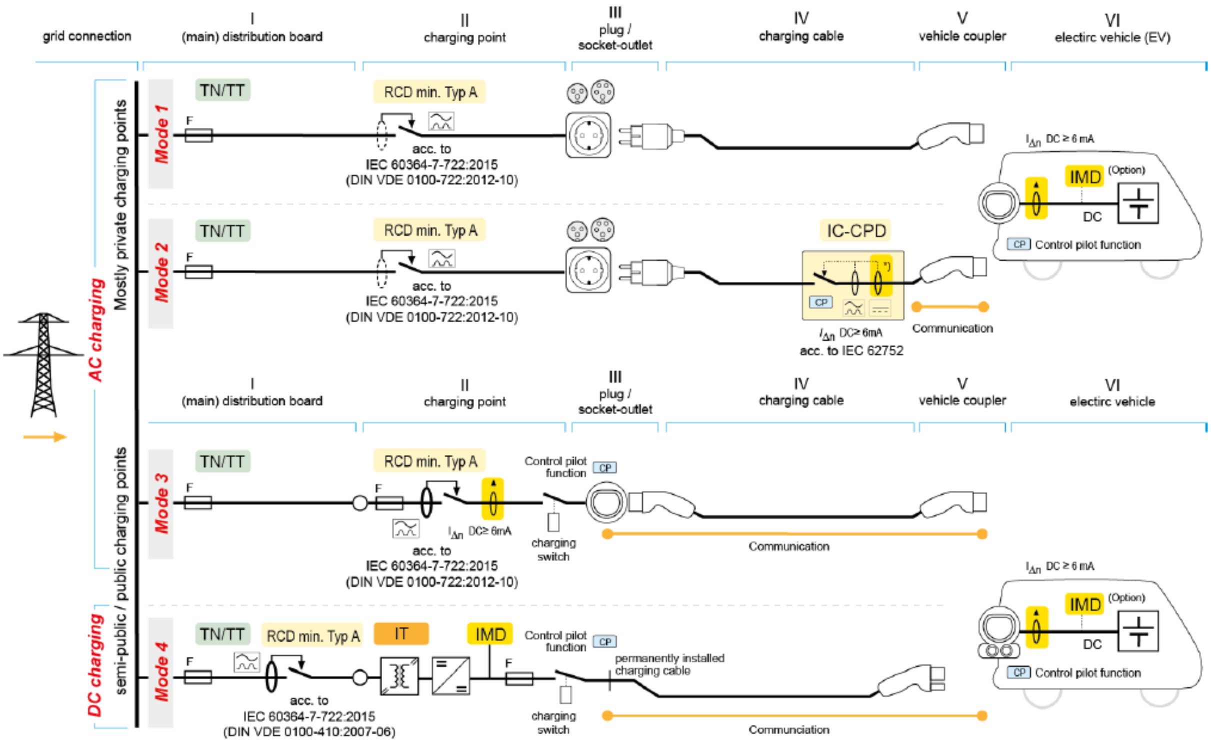


Figure 70 Charging Modes and technical characteristics of the corresponding charging infrastructure

Mode 4: The EV charging Mode 4 is controlled, type-tested, utilizing a DC circuit, fast DC charging stations for electric vehicles. The maximum power supply for charging as determined by IEC for DC low voltage and DC high voltage are 38 kW and 170 kW respectively (maximum permitted current and voltage of 400A and 1000V respectively [1]), while the actual charging voltage and current is depended on the system. The charging cable is built into the charging station. In addition, the system utilizes a specific connector fixed on the external charger, while a locking mechanism of the plug and socket-outlet is present on the vehicle. The vehicle communicates with the charging station utilizing a monitoring and protective device/pilot function, integrated into the charging station.[1 - 4]

SAE – Charging Methods: The Society of Automotive Engineering (SAE) (USA) has also defined through its standard, SAE J1772, charging methods based on limitations in the nominal AC Supply Voltage, the maximum current and maximum power, which are applied by the industry in various global regions including North America. [3]

- for Level I, the charger is on-board and provides an AC voltage at 120 or 240 V with a maximum current of 15 A and a maximum power of 3,3 kW;
- for Level II, the charger is on-board and provides an AC voltage at 240 V with a maximum current of 60 A and a maximum power of 14,4 kW;
- for Level III, the charger is off-board, so the charging station provides DC voltage directly to the battery via a DC connector, with a maximum power of 240 kW.

Table 11 Electrical Ratings of Different Charge Method in North America

Charge Method	Nominal AC Supply Voltage [V]	Maximum Current [A]	Maximum Power [kW]	Charger Location
AC Level 1	120	12	1,44	On-board 1-phase
AC Level 2	240	32	7,7	On-board 1 or 3 phase
DC Level 3	208- 600	400	240	Off-board 3-phase

Charging Plug Types and signaling

The standard IEC-61851 has described the general requirements for EV charging onboard systems for conductive charging. It also defines the limitations and requirement for both AC/DC power supply and the DC EV charging stations (described in IEC 61851-21-1 and IEC 61851-23 respectively). This standard in combination with IEC-60309, which refers to the specifications of plugs and sockets for industrial purposes can contribute to a complete description of EV charging systems for every charging mode described above.

Charging Connectors

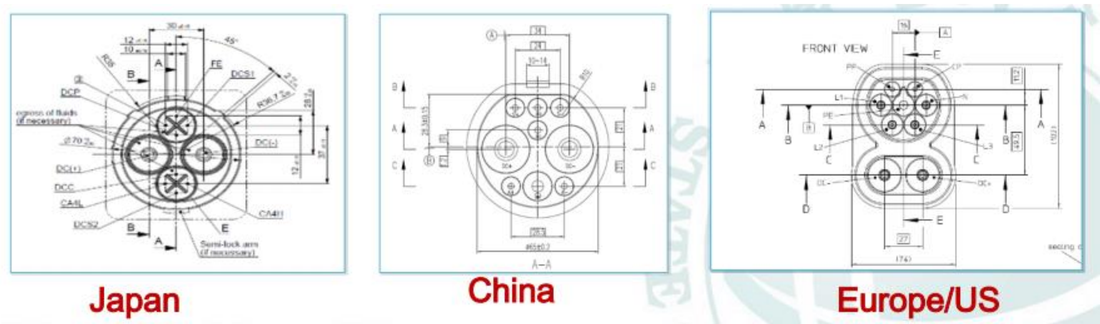


Figure 71 Charging Connector Proposals worldwide

The first step towards connector standardization was made on October 2011 by ETSI and CEN-CENELEC with the publication of IEC 62196-2 and later with IEC 62196-3 (2014), which adapted the infrastructure described in previous publications (IEC 61851) for automotive use. The list of IEC 62196 socket outlet types includes:

1. For AC Charging (IEC 62196-2) [6, 16]:
   1.1. Type 1 – single phase vehicle coupler (vehicle connector and inlet), for example Yazaki or SAE J1772 (Japan, North America)
   1.2. Type 2 – single and three phase vehicle coupler and mains plug and socket-outlet without shutters, for example VDE-AR-E 2623-2-2 otherwise known as Mennekes connector (Europe)
   1.3. Type 3 – single and three phase vehicle coupler and mains plug and socket-outlet with shutters, for example SCAME plug developed by the EV Plug Alliance (Italy, France)
2. For DC charging: IEC 62196-3 [6]
   2.1. Type 4 – Direct current coupler reflecting the Japan Vehicle Standard (JEVS) G105-1993 specifications proposed by the Japan Automobile Research Institute (JARI)

Another classification can be made in terms of type of outlet used in the charging station. The American standards define three types for the three levels [3] (similar to the corresponding electrical ratings proposed by SAE):

Level 1 charging method, the slowest one, uses a standard 120V/15A single-phase grounded outlet, such as NEMA 5-15R. The connection may use a standard J1772 connector into the EV AC port. For home or business sites, no additional infrastructure is necessary;

Level 2 charging method, the primary one for dedicated private and public facilities, requires dedicated equipment for home or public charging;

Level 3 charging method, the fastest one and used for commercial application, typically operates with a 480 V or higher three- phase circuit and requires an off-board charger to provide regulated AC-DC conversion.

AC Charging Connectors

Type 1 (SAE J1772-2009) Yazaki : The SAE J1772-2009 connector, known colloquially as the "Yazaki" connector (after its manufacturer), is commonly found on EV charging equipment in North America. In 2001, SAE International proposed a standard for a conductive coupler which had been approved by the California Air Resources Board for charging stations of EVs. The SAE J1772-2001 plug had a rectangular shape that was based on a design by Avcon which was revised in 2009's SAE J1772 standard update including a new design by Yazaki featuring a round housing. The SAE J1772-2009 coupler specifications have been included to IEC 62196-2 standard as an implementation of the type 1 connector for charging with single-phase AC. The connector has five pins: 2 AC wires, earth, and 2 signal pins, compatible with IEC 61851-2001 / SAE J1772-2001 for proximity detection and for the control pilot function. While the original SAE J1772-2009 standard describes ratings from 120 V at 12 A or 16 A to 240 V at 32 A or 80 A, the IEC 62196 type 1 specification covers only 250 V ratings at 32 A or 80 A.

Figure 72 SAE J1772-2009 coupler Type 1 "Yazaki" connector (photo by Michael Hicks)

ACEA's position paper (June 2010) has ruled out the type 1 connector, position that is based on the requirement of three-phase charging which is abundant in Europe and China but not in Japan and the USA.

Type 2 (VDE-AR-E 2623-2-2) Mennekes: The connector manufacturer Mennekes (Germany), had developed a series of 60309-based connectors that were enhanced with additional signal pins– these "CEE plus" connectors have been used for charging of electric vehicles since the late 1990s. With the resolution of the IEC 61851-1:2001 control pilot function (aligned with the SAE J1772:2001 proposal), the CEE[11] plus connectors were set to replace the earlier Marechal couplers (MAEVA / 4 pin / 32 A) as the standard for electric vehicle charging [86] Volkswagen's and Daimler's requirements inputs on the automakers side as well as the inputs of RWE on the utility side we incorporated to the new design of the Mennekes connector. Mennekes connector, which was presented at the start of 2009 [87], would become accepted by various European automakers as a standard connector [88]. The proposal is based on the observation that standard IEC 60309 plugs are rather bulky (diameters of 68 mm and 83 mm for 16 A and125 A respectively) for higher current, while Mennekes to ensure easy handling by the consumers designed the plugs significantly smaller (55 mm) and flattened on one side (physical protection against polarity reversal). Unlike the Yazaki connector, there is no latch, meaning consumers have no exact feedback that the connector is properly inserted. The lack of a latch also puts unnecessary strain on any locking mechanism. [6] The Association of Electrical, Electronic and Information Technologies standardized the connector in 2009 with VDE-AR-E 2623-2-2 [89] and later was included in IEC 62196-2 as "type 2".

In Central Europe, in countries like Netherlands, Belgium, Germany, Switzerland, Austria, Poland, Hungary, Slovenia and Croatia Mennekes type 2 connector is broadly utilized for charging mode 3, highly influenced by the widely available 400 V three-phase domestic power grid.

[11] "CEE plus" connectors are defined by IEC60309 and the systems which comply with it.

Figure 73 Type 2 coupler, Mennekes (source Hadhuey)

Type 3 EV plug Alliance Connector – SCAME: The EV Plug Alliance was formed on March 28, 2010 by electrical companies in France (Schneider Electric, Legrand) and Italy (Scame).Within the IEC 62196 framework they propose an automotive plug, specified as "type 3", which was derived from the earlier Scame plugs that were already in use for light electric vehicles [90]. Gimélec joined the Alliance on May 10 and a number of more companies joined on May 31 (Gewiss, Marechal Electric, Radiall, Vimar, Weidmüller France and Yazaki Europe) [91]. The proposed connector is able to provide 3-phase charging up to 32 A. Schneider Electric emphasized in the design the use of shutters on the plug over the socket side pins, which is required in 12 European countries and neither of the other proposed EV charger plugs were featuring. Another feature was the limitation of the plug to 32 A, which made the plugs cheaper and with lower installation costs.

The EV Plug Alliance points out that the future IEC 62196 specification will have an annexe categorizing electric vehicle charger plugs into three types (Yazaki's proposal is type 1, Mennekes' proposal is type 2, Scame's proposal is type 3) and that instead of having a single plug type at both ends of a charger cable one should choose the best type for each side, with "Scame EV Plug" being the best option for the charger side wall box, leaving the choice for the car side open. (On 22 September 2010, the companies Citelum, DBT, FCI, Leoni, Nexans, Sagemcom and Tyco Electronics joined the Alliance). As of early July 2010 the Alliance has completed the test of products from several partners and the plug and socket-outlet system are made available on the market. [92]

The ACEA position paper (March 2011), following a previously released position paper with the same content, recommends to use only type 2 mode 3 (with IEC 60309-2 mode 2 and standard home socket outlets mode 2 being still allowed in Phase 1 up to 2017) being the EU uniform solution by 2017. Car makers should equip their models only with type 1 or type 2 sockets – existing type 3 infrastructure may be connected with a type 2, or type 3 cable in Phase 1 for basic charging (up to 3.7 kW). Fast charging (3.7–43 kW) and ultra-fast DC charging (beyond 43 kW) may only use a type 2 or combo 2 connector. There concerns expressed by Schneider Electric that some countries require a mechanical shutter for electrical outlets which the original VDE proposal did not include were resolved by a proposal by Mennekes for an optional shutter solution in October 2012.

In October 2015, after the 2 position papers published by ACEA recommending type 2 mode 3 charging (2011) and the European Commission decision to support the specific connector and plug for EU's uniform solution by 2017 (2013) in order to end interoperability uncertainty across the union, it became known that Schneider Electric (a founding member of the EV Plug Alliance) only manufactures charging stations with type 2S connectors (type 2 with shutters).[94] In November 2015, Renault started selling its electric vehicles in France with a type 2 connector cable instead of the previously used type 3 [95], marking the abandonment of the production of type 3 connectors and the end of the Alliance.

DC Fast Charging Connectors

DC Fast charging is the fastest (with the highest power supply) EV charging system currently available. The charging station provides high power DC current which reaches up to 120 kW directly to the EV's battery bypassing any other charging equipment of the EV. Most EVs support DC fast charging or as called "DC level 2" charging at power rates up to 90 kW.

IEC, through the standard IEC 62196-3, published in 19th June 2014, proposed the way of operation of charging mode 4/ DC charging. However, the specification on DC charging has been researched and promoted on national level. Such processes have formatted the landscape of worldwide infrastructure on plugs and DC fast charging systems. A number of plug types are under consideration for DC charging worldwide.

Figure 74 Charging systems illustration (Source: IEC)

Characteristic of DC Fast charging is that the vehicle communicates with the charging station through vehicle bus port which is embedded to the charger plug. This aims to optimize and automate the charging process and provide safety. The vehicle utilizes a communication protocol for the data transfer, with the most commonly used ones being the CAN Bus protocol utilized in CHAdeMO and GB/T, while Home Plug Green PHY PLC protocol is utilized in CCS type 1 and type 2 charger

CHAdeMO (Japan): The Japanese developed CHAdeMO (CHArge de MOve) plug has been in use in a number of years and has been adopted widely due to its success in the country of its origin and of course as a result of the success of the compatible Nissan Leaf worldwide, with the Japanese CHAdeMO charging stations forming one of the most extended DC, fast EV charging network on a national level in the world, counting 5484 chargers, while a total of 5974 are installed in Asia, 2,755 in Europe and 1400 in the US [7]. CHAdeMO was formed as an association, aiming to increase quick-charger installations worldwide and to standardize EV charging, by The Tokyo Electric Power Company, Nissan, Mitsubishi and Fuji Heavy Industries, while Toyota later joined as its fifth executive member. [9] CHAdeMO certified chargers deliver 50kW charging power in high Voltage up to 500V and high current up to 125 A [8][9]. The connector includes two large pins for DC power, plus other pins to carry CAN-BUS connections. CHAdeMO ports do not support AC charging. As a result EVs must have two charging ports – one for AC mode 2 charging (power level II), the other for CHAdeMO.

Figure 75 CHAdeMO plug and socket.

CCS (EU): The Combined Charging System (CCS), is a charging system proposed by SAE and European Automobile Manufacturers Association (ACEA) in 2011 following the idea of introducing DC wires to the existing AC connector types. Thus, CCS combines a single connector pattern on the vehicle side with enough space to accommodate a “type 1” or a “type 2” connector along with a two pin DC connector, designed to sustain electric DC current of up to 200 A. In that way only a single charging inlet is required supporting both slow and fast charging (versus two required in CHEdeMO standard). The CCs connector utilizes the Home Plug Green PHY communication protocol, which support smart grid application for charging control [9].CCS is widely utilized by many EVs with the most prominent automakers supporting it being BMW, Volkswagen, General Motors, Daimler, Ford and Porche. The first vehicles using the SAE Combo plug were the BMWi3 released in 2013 and Chevrolet Spark EV released in 2014.

The CCS charger has been implemented in 2 Versions. CCS 1.0 was firstly released in 2011, enabling DC charging of up to 80kW with maximum voltage 400V and maximum current 200 A. It enables load balancing, charge authorization and charging station-vehicle communication, which is compliant to DIN SPEC 70121:2014 [83]. CCS 2.0 Enables Charging of up to 350kW with voltage ranging from 200 to 1000 V. Charging stations communication while charging at 0-350kW is supported by ISO15118-2:2014 and ISO15118-3:2015, and at 0-80kW by DIN SPEC 70121:2014. In addition there are plans of developing and releasing a CCS 3.0 version that would enable wireless inductive charging which could enable reverse power transfer.

Figure 76 SAE Combo plug (CCS) and power inlet

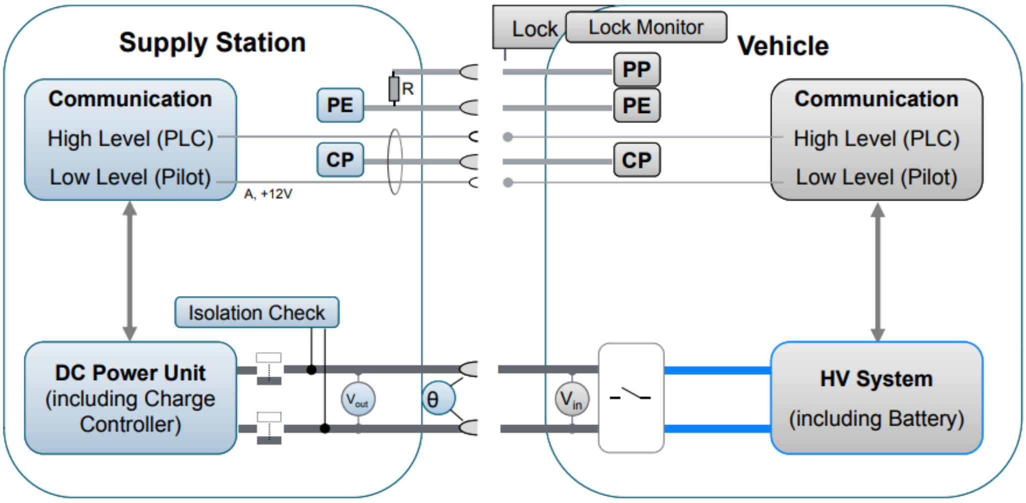


Figure 77 Illustration of CCS charging connection (communication and power ports) (source [84])

Table 12 Overview of CCS 1.0 safety features

Description	Relevant Standard
Protection against direct contact and De-energization of unmated connector	ISO 17409 IEC 61851-1 IEC 62196-3
Basic insulation	IEC 61851-1
Locking of Connector by vehicle in dc supply mode	ISO 17409 IEC 62196-3 IEC 61851-23
Grounding, PE connection	IEC 60364-5-54
Continuity of connection between station and vehicle	IEC 61851-1 IEC 61851-23
Touch current limitation	IEC 61851-23 ISO 17409
Aging /environmental conditions to apply for the Combined Charging System	IEC 61851-1 IEC 62196-1
Adoption of measures from IT-systems	IEC 61851-23
Voltage measurement at vehicle inlet in combination with disconnecting device (unintended connection of AC/DC)	ISO 17409
DC Input resistance against damage due to AC voltage	ISO 17409
Temperature monitoring of connector	IEC 61851-23
De-energisation function of mated connector	ISO 17409
Exit strategies based on specified control (Charge sequence, communication)	IEC 61851-23
Prevention of unintended power supply from vehicle	IEC 61851-23
Overvoltage Category at Vehicle Connector	IEC 61851-23

NOTE: The overview on the Safety Features in Table 6 does not claim completeness.

GB/T (PRC)

The Chinese charging standard GB/T 20234-2011 is, according to “EV Infrastructure and Standardization in China” [96] similar to the IEC 62196 proposing a similar connector to the type 2 Combo charger, supporting both level 2 and level 3 AC charging of 250 V, 16 A and 400 Volt,32 A, as well as DC charging (250/400V). GB/T similarly to CHAdeMO is utilizing the CAN BUS communication protocol unlike CCS utilizing PLC. However the pinning is similar to the type 2 combo charger featuring 7-pin mechanical lock with an optional electronic lock (with type-2-features-only electronic lock). The standardization of the Chinese charging infrastructure are complied with the corresponding international ones, with the Chinese authorities issuing a correlation memorandum

Communication protocol

Type 1-3 - SAE J1772 signaling

Originating with the type 1 connector, SAE J1772 signaling is used in all but the type 4 connector. The signal pins and their function were defined in SAE J1772-2001, which was included in IEC 61851. All plug types of IEC 62196-2 have the two additional signals: the “control pilot” (CP; pin 4) and “proximity pilot” (PP; pin 5) over the normal charging power pins line 1 (L1; pin 1), line 2 or Neutral (N, or L2; pin 2), and protective earth (PE; pin 3)

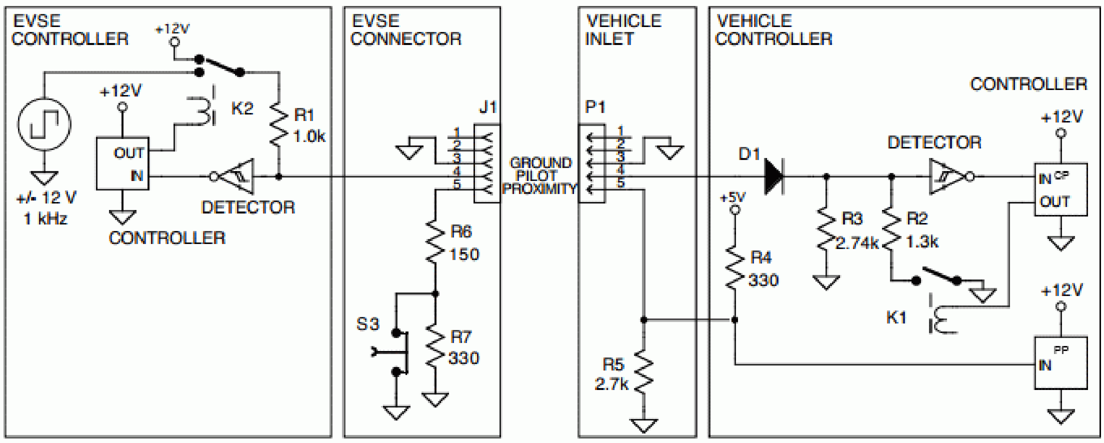


Figure 78 J1772 signaling circuit

The signaling protocol has been designed so that it can supply equipment signals for the presence of AC input power. The design also predicts that the vehicle plug is detected via a proximity circuit (thus the vehicle can be prevent driving away while connected in an energized cable). The control pilot functions begin when (a) supply equipment detects a plugged in electric vehicle (PEV), (b) supply equipment indicates to PEV readiness to supply energy, (c) PEV ventilation requirements are met and (d) when supply equipment’s current capacity is provided (dedicated) to the PEV. The signaling protocol provides the PEV with the command of the energy flow and continuity of PEV-parameterized charging process. The signaling protocol also ensures that the PEV and supply equipment continuously monitor the power transfer in regards to safety. The charging protocol also ensures that the charge will be interrupted by disconnecting the plug from the vehicle.

The technical specification was described first in the 2001's version of SAE J1772 and subsequently to the later IEC 61851-1 and IEC TS 62763:2013. The control pilot signal is designed to be easily processed by analog electronics, eliding the use of digital electronics, which can be unreliable in automotive settings. The charging station puts 12 V on the contact pilot (CP) and the proximity pilot (also, plug present; PP) measuring the voltage differences as indication of the connection and charging process changes. This protocol, unlike other protocols, doesn't require integrated circuits, making the SAE J1772 robust and operable through a temperature range of −40 °C to +85 °C.

Type 4–CAN BUS signaling

The Type 4 charging system, Japanese CHAdeMO and the Chinese GB/T, utilize the CAN bus communication protocol for charging control. One of its main advantages is that is aligned with the operation of other vehicle control functions in the vehicle, meaning that the charging signaling can be integrated to a known and trusted environment while utilizing the CAN communication protocol.

CAN is a multi-master serial bus standard for connecting Electronic Control Units (ECUs) also known as nodes. Two or more nodes are required on the CAN network to communicate. The complexity of the node can range from a simple input/output device up to an embedded computer with a CAN interface and sophisticated software. The node may also be a gateway allowing a standard computer to communicate over a USB or Ethernet port to the devices on a CAN network.

Vehicle to Grid (V2G) Charging

Vehicle-to-grid (V2G) describes a system in which there is bi-directional electrical energy flow between plug-in electric vehicles and the power grid. This is done through selling demand response services by throttling the charge rate, shifting the charging time or returning electricity to the grid. Studies show that most vehicles are idle for up to 95% of the day, so electric vehicles could potentially act as dispatchable energy pool, ready to support the energy system by providing load leveling and temporary energy storage [13]. The main principle according to which the V2G system operates is identified in the fact that when the grid requires energy, electric power flows in the opposite direction facilitating the power distribution. Thus, EVs act as spinning reserves during the peak demand hours. In that way V2G technology can support load-sharing with the power grid. The technology can include subsets of

V2G like vehicle-to-home (V2H) and vehicle-to-building (V2B), both of which draw power directly from the EV, when needed, rather than from the power grid.

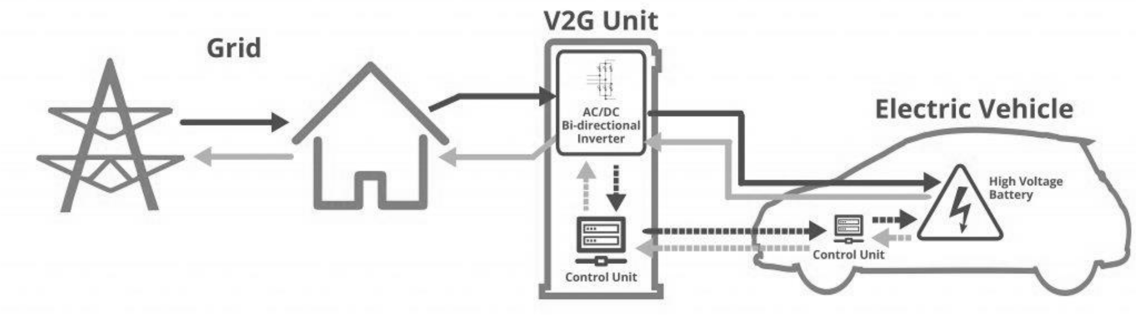


Figure 79 V2G Charging schematic

The Benefits of V2G

Owning an electric vehicle already has a variety of benefits from tax breaks to rebates and grants, but in addition to that with the introduction of V2G technology, it can also be used to power the domestic electric appliances. The following are some of the biggest advantages to V2G technology:

- **Financial Benefits**: According to a recent study by the National Grid (UK) and global engineering firm Ricardo, V2G could provide £600 to £8,000 of income each year for Britain's electric vehicle owners [11]. Energy stored in the vehicle can be used to avoid peak tariffs at times of high demand and an extra strain on the power grid. V2G can also optimize the value of energy generated from domestic power generation by renewables (like solar panels) to reduce monthly bills**.**
- **Home Energy Storage**: According to the RAC Foundation, a 4 kWh Electric Battery has the power to provide a third of the energy needs for a typical home in the UK [11]. Currently the BEV batteries can reach capacities of 20 - 90 kWh, energy capable to cover entirely the daily energy needs of a household. Products for home battery energy storage, in addition to EV battery technology, are currently being developed to offer the opportunity to scale-up dispersed energy storage capacity. Optimizing energy use through a fully connected home energy network can help homeowners reduce their energy cost annually. Additionally, low cost energy can be saved from the power grid by EVs during their idle time, which can be used to power other demand in a distance as part of a new grid infrastructure.
- **Green Impact:** V2G is intended to increase EV deployment in an attempt to give back to the power grid and save from any lapses in the power supply. The V2G through EVs batteries can save less carbon intensive energy produced by RES and reduce the dispatching of carbon intensive power generating units in energy

demand periods. Inevitably, this can have an incredibly positive impact on the environment [12].

The Drawbacks of V2G

The V2G towards adoption, as a disruptive technology, it needs to overcome obstacles and learning curves. The main drawbacks of the V2G in the current state of technological and market development are the following:

- **The Energy Cost:** A typical EV battery pack has a capacity of around 25kWh and a life time of 2000 cycles and has an average cost of $273/kWh (2017) or a total average cost of approximately $7,000 or €5500. With a limited depth of discharge reaching a maximum 80% of its total capacity and taking into account a 10% efficiency charging loss, the total amount of energy required to fill the reference battery pack would be 22kWh. Extra charging would be required for maintenance of the required state of charge with the V2G operation, which should be appropriately compensated by the DSO.
- **Battery Depreciation:** The increase of the daily charge/discharge ratio that comes with the V2G system can be identified as an important cause for the cycle life reduction of an EV battery. Each charge-discharge cycle of the battery consumes one of the battery’s 2000 cycles, which accounts to 0.05% of its life time. With an average EV battery pack costing up to €5500, each cycle costs €2.75 which is a significant value in reference to an average power system. With the average price of electricity as much as €0.15/kWh[12] (source: LAGIE) a complete EV battery pack charging of 25kWh (22kWh energy needed) would cost €3.3, making the battery depreciation value a significant additional cap of 83.3% over the price of the charging cycle. To mitigate the battery depreciation caused by charging cycles dedicated to V2G ancillary services, the power electronics industry is focusing on automations embedded in charging protocol that will only extract the cost effective depth of discharge, since not all discharge has the same impact on cycle life reduction based on the non-linearity of the relation, as it was described in chapter 2. Moreover, the cost of EV battery packs has been declining rapidly the past years, with projections reaching to values below $100/kWh by the end of next decade [14]. This means that the battery depreciation cost will become less and less significant in the foreseeable future.
- **Battery Capacity reduction:** As thoroughly described in Chapter 2, charging-discharging cycles are reducing the total battery capacity of EV battery packs. V2G further contributes to the depreciation of EV batteries storage capability

[12] Refers to the low voltage consumer price while marginal price of electricity varies between €0.04/kWh and €0.07/kWh during the time period 2017Q1-2018Q2

and can be cost effective only if the value proposition of the capacity reduction is included in the compensation for ancillary services, provided by the DSO.

- **Maintaining the required SOC:** The EV users must plan their daily charging and discharging (V2G), in order to maintain the required daily state of charge (SOC) for their vehicles. This can be achieved with the assistance of power electronic automations embedded in the charging systems.

The Current Models That Offer V2G

Nissan and Mitsubishi are currently the leaders in manufacturing EVs with V2G capabilities. The following are some of the models and companies that offer V2G capabilities: Nissan Leaf, Ford F-Series Pickup Trucks, Tesla Mitsubishi, BMW, Honda etc. However, not all companies are building their own models. BMW and Honda are pairing with commercial partners and research development hubs to ensure the technology is well evaluated when released. Tesla has also announced that will enable also for its models V2G capabilities which are currently under development [].

Future of V2G

Business cases for V2G still need to be made in a variety of local economies and governments. In the UK, domestic-based charging applications can become an obstacle. In summary, although V2G is vital to close the energy gap in some countries, there are still quite a few issues to overcome before the technology can be implemented in large scale. Commitments by the industry and the authorities to cooperate in the framework of developing a cleaner energy infrastructure, advancing the related research and providing strong economic incentives for consumers are all benchmarks that must be in place for V2G to come to full fruition. A holistic and smart approach to EV use, storage, and energy generation will ensure that the supply and demand gap is filled before an energy crisis is even formed on the horizon. Towards this direction V2G along with smart charging would have significant success.

B. Charging and Safety Issues

Electric and hybrid vehicles represent a totally different technology compared to internal combustion engines. This means that new safety issues arise, which are mainly related to the high voltage electrical equipment that is present in the vehicle. Standards already exist for the construction of such vehicles in terms of reducing potential risk of the charging operator and the electrical system. Risks involve human exposition to hazards such as corrosive chemicals, toxic gases, fire and electric shock and system failures that can potentially result to short circuit, electrical current leakages and fire [31].

Figure 80 results of electrical fire caused by batter malfunction on EVs - Chevrolet Volt (left), Tesla model S (right) (source: S Kjosevski et al.)

Charging Safety

With the increase in deployment of EVs more and more people require access to charging infrastructure in the premises of their home. Thus, access to a private home level 2 charging station is considered a common commodity for EV users. However, the diffusion of the Electric Vehicle Supply Equipment (EVSE) technology, commonly called charging stations, contains risks in regard to safety issues. Since the primary function of a plug-in electric vehicle charging station is to provide electrical safety for the operator and the electrical infrastructure throughout the charging process, safety should not be compromised by all means, especially in such processes that contain risks of fire and electric shock. An EVSE “charging station” implements several layers of redundant safety features to protect the user from potential electrical and fire hazards while connecting, disconnecting, and charging the vehicle. Once connected to the vehicle, the station informs the vehicle that power is available and on what level. The vehicle then takes over, initiates and takes full control of the power transfer. If an electrical fault occurs the station will stop the power transfer immediately and de-energize the cable [24, 30].

To avoid the hazards entailing potential battery damage, which happens more frequently by inappropriate charging, than by any other cause, a utilization of battery management system BMS for charging control is proven necessary. The Battery Management System (BMS) is tightly integrated with the battery. It monitors the key battery operating parameters of voltage, current and temperature and controls the charging rate to provide the required constant current / constant voltage (CC/CV) charging profile and it triggers the protection circuits if the battery's operating limits are exceeded, isolating the battery if needed [33]. The battery protection is further enhanced by the utilization of data exchange between the vehicle and the charging station in the framework of smart grid application with the utilization of a communication protocol (chapter) which aims in monitoring and improving the quality of the electric current utilized for charging.

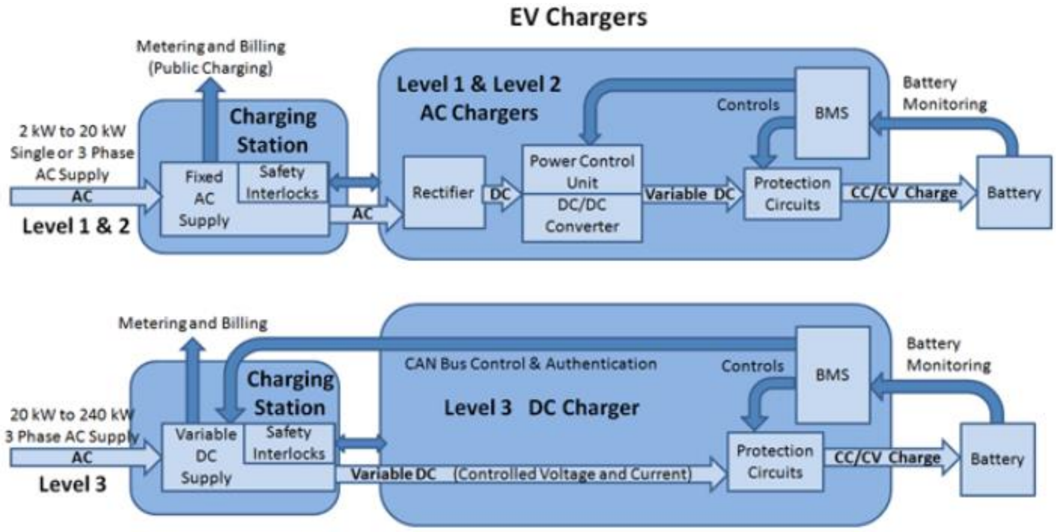


Figure 81 Charging Safety and Control features in AC and DC charging (source Woodbank Communications Ltd [33])

In regards to the charging infrastructure, the Underwriters Laboratory, a multinational organization dedicated on promoting safety, security and sustainability of products, has circulated the UL2202 [24], UL2251 [25], UL2594 [26], UL2734 [27], UL2871 [28] and UL9741 [29] standards to address the EV charging issues. The UL2202 sets the requirements for the Conductive Charging System equipment required for recharging EV batteries. Amongst others, the standard contains safety measures for access internal charging circuit with description of the feature of the relevant technology and the access cover specification. It also sets the limits for the thickness of various type, material and surface of internal circuit enclosures, as well as specifications for a various types of openings for wiring purposes. It also establishes the minimum requirements for the EVSE defining the type and the length of the charging cable, describes protective interlock for the connectors and other means which must de-energize the cable if the connection isn't coupled with the EV [24]. The UL2202 safety standard is being implemented by a number of industries like Delphi (120 V/15A, Level 1 Charger) among others in their charging equipment's.

Also IEC 60364-7-722: 2015 [32] contains safety specifications for low voltage electrical installations required for power supply for electric vehicles. Specifically provides specifications for devices for protection against indirect contact (fault protection) by automatic disconnection of supply and overcurrent. It also provides specifications for isolation, switching and control devices, earthing arrangements and protective electrical separation. In addition, it provides insight on proper installation, structure, inspection and testing of the proposed equipment.

EV charging is a safe procedure when done using proper independently safety certified equipment. However, in the rapidly expanding EVSE market the challenge is that not all equipment is proven and certified [30]. The certification procedure involves the testing of the new or updated EVSE product by a Nationally Recognized Testing Laboratory (NRTL), where extensive safety testing is conducted, which the products must pass in order to become available to the public for sale. To secure the EVSE quality further after certification the producer can be randomly inspected by the corresponding authority that issued the certificate, where the inspection staff ensures that the products being sold are constructed in the same manner as the samples that were tested. Such inspections are conducted four times a year in the EVSE industry in the US, in which the equipment is graded. After certification the Electric Code and Fire Protection Standards' minimum regulatory safety requirements must be met in order for the EVSE to be installed. In most countries installing EVSE requires a building permit, which also ensures that equipment and the infrastructure are inspected by an expert upon installation. Equipment that must be avoided in the installation are: (a) self-certified equipment of all kind which bear the CE mark but not a Recognized Testing Laboratory's mark (b) Non grounded plugs etc.

C. The Impact on Power Generation on the Grid from the Gradual EV Adoption

The Electric vehicles (EVs), which are developing rapidly the in recent years, when connected to the grid, may be considered both as active loads and energy storage devices, which both have different but significant impact on the distribution system. In this section the impact of EV charging on the grid is addressed, with the main issues focused on power quality compromisation, voltage drops due to congestion and power losses.

C. (i) Harmonic Distortion and Power quality

When connected to the electricity distribution network for charging, EVs need the charger as interface. Battery chargers are power electronics devices, which due to their nonlinear nature can produce deleterious harmonic effects on the electric utility distribution system [57]. Specifically, harmonics lead to non-sinusoidal load currents which cause abnormal increases in transformer temperature beyond rated operation. Because of this, transformers can suffer age reduction and premature failure due to resulting thermal stresses in the windings and core structure [66]. Moreover, higher levels of harmonics might result in erratic, sometimes subtle, malfunctions of the equipment that can, in some cases, have serious consequences including its unpredictable performance [63].

Figure 82 Harmonic Distortion in electrical current waveform after rectification

A study has identified the magnitude of the total harmonic distortion (THD) of the charger device's actual current (THDi), to vary from 2.36% to 5.26% in the begging of charging and could reach up to 28% at the end of charging [58], while other researchers claim lower THD values ranging between 1 and 2% with a power factor very close to unity (i.e. 1) [60].[13][14][15]

At full load **TDD(I)=THD(I).** So, **TDD** gives us better insight about how big impact of harmonic distortion in our system. For example we could have very high THD but the load of the system is low. In this case the impact on the system is also low. [64]

In order to prevent harmonics from negatively affecting the utility supply, standards such as IEC 61000-3-12 [76] and IEC 61000-2-4[77] or IEEE Standard 519-1992 [75], have been established with the goal of developing recommended practices and

[13] THDV: Total Harmonic Distortion of the voltage waveform, is the ratio of the root-sum-square value of the harmonic content of the voltage to the root-mean-square value of the fundamental voltage

$$V_{THD} = \frac{\sqrt{V_2^2+V_3^2+V_4^2+V_5^2+\dots}}{V_1} \times 100\%$$

[14] THDI Total Harmonic Distortion of the current waveform. The ratio of the root-sum-square value of the harmonic content of the current to the root-mean-square value of the fundamental current

$$I_{THD} = \frac{\sqrt{I_2^2+I_3^2+I_4^2+I_5^2+\dots}}{I_1} \times 100\%$$

[15] TDDI Total Demand Distortion of the current waveform. The ratio of the root-sum-square value of the harmonic current to the maximum demand load current

$$I_{TDD} = \frac{\sqrt{I_2^2+I_3^2+I_4^2+I_5^2+\dots}}{I_L} \times 100\%$$

requirements for harmonic control in electrical power systems[16]. These standards, which are widely adopted by the industrial and research communities, describe the problems that unmitigated harmonic current distortion may cause within electrical systems, as well as the degree to which harmonics can be tolerated by a given system. Utilities are supposed to provide power quality limited on the voltage level of the connection, while EV users are responsible of not degrading the voltage of the utility by drawing significant nonlinear or distorted currents. However, the harmonic impact on points of common coupling (PCC) is interesting both for the consumer's and utility's perspective for example, IEEE STD 519-1992 proposes voltage harmonic limits on low voltage systems of 5% for total harmonic distortion (THD) and amplitude of 3% of the fundamental voltage for any single harmonic. These limits, which can be observed in the tables (13-16), aim to prevent end-users from causing harmonic distortion and degrade the power quality of the supply for other end-users and the utility.

Table 13 Voltage distortion limits set in IEEE 519-1992. (source : Lucas et al.)

Bus voltage at PCC	Individual voltage distortion (%)	Total voltage distortion THD (%)
69 kV and below	3	5
69.001 kV through 161 kV	1.5	2.5
161.001 kV and above	1	1.5

Table 14 Maximum harmonic current distortion in percent of IL set in IEEE 519-1992. (source : Lucas et al.)

Individual harmonic order (odd harmonics)						
I_{SC}/I_L	<11	$11 \leq h < 17$	$17 \leq h < 23$	$23 \leq h < 35$	$35 \leq h$	TDD
<20	4.0	2.0	1.5	0.6	0.3	5.0
20<50	7.0	3.5	2.5	1.0	0.5	8.0
50<100	10.0	4.5	4.0	1.5	0.7	12.0
100<1000	12.0	5.5	5.0	2.0	1.0	15.0
>1000	15.0	7.0	6.0	2.5	1.4	20.0

Table 15 Maximum harmonic current distortion in percent of IL set in IEC 61000-3-12.

Minimum RSCE	Admissible individual harmonic current I_h/I_{ref} (%)				Admissible harmonic parameters (%)	
	I_5	I_7	I_{11}	I_{13}	THC/I_{ref}	PWHC/I_{ref}
33	10.7	7.2	3.1	2	13	22
66	14	9	5	3	16	25
120	19	12	7	4	22	28
250	31	20	12	7	37	38
≥350	40	25	15	10	48	46

The relative values of even harmonics up to order 12 shall not exceed 16/h%. Even harmonics above order 12 are taken into account in THC and PWHC in the same way as odd order harmonics. Linear interpolation between successive R_{SCE} values is permitted. R_{SCE}—short-circuit ratio; I_h—harmonic current component; I_{ref}—reference current; THC—total harmonic current; PWHC—partial weighted harmonic current.

[16] K-factor is a weighting of the harmonic load currents according to their effects on transformer heating, as derived from ANSI/IEEE C57.110. A K-factor of 1.0 indicates a linear load (no harmonics). The higher the K-factor, the greater the harmonic heating effects. [65]

Table 16 Voltage distortion limits set in IEC 61000 2-4.

Harmonic order n (non multiples of 3)	Class 1 µn [%]	Class 2 µn [%]	Class 3 µn [%]
5; 7	3; 3	6; 5	8; 7
11; 13; 17	3; 3; 2	3.5; 3; 2	5; 4.5; 4
THD_V	5%	8%	10%

Class 1: compatibility level lower than public (laboratory instrumentation, some protection equipment, etc.). Class 2: compatibility level equal to public (any equipment designed for supply from public networks). Class 3: compatibility level higher than public (equipment in the presence of welding machines, rapidly varying loads, large converters, etc.).

Harmonics Theory is a well-established field of study. However, it is a complex problem, to assess the phase angle from each harmonic order and consequently to make accurate assumptions on how they add up when multiple loads are online, similarly to the charging of multiple EVs, which is usually subject for probabilistic estimation [59].

Studies showed that even for relatively low EV penetration levels distribution infrastructure can have limitation on EV charging supply. Specifically, a study by F. Musavi et al, pointed that, in order to mitigate the effects on the grid, specific ideal topologies for residential, power level 2 (Mode 2), EV charging are proposed to be distribution systems with system voltage of 240/250V and power level of 8 kVA. However, for power level 1 EV charging a typical supply which is limited to 120 V and 1.44 kVA or 1.92 kVA (reference system in US) is proven sufficient with no significant disruptions caused by THD and TDD effects [61]. The electricity industry on the other hand has recommended Mode 3 EV charging as the preferred solution for all types of topologies (IEC 61851)[1].

In a condition of high EV penetration, when an event of simultaneous charging of a large number of EVs occurs, these harmonic effects are substantially enhanced. Most importantly, studies that are done to investigate the magnitude of THD effect in conditions of multiple simultaneous EV charging showed that, where multiple different chargers were present, in contrast with simple summing of magnitudes, 10% smaller harmonic current magnitudes were observed [78]. A similar study showed that the diversification of SOC and the charging start time results to a reduced estimate of harmonic currents in the system [79]. Therefore researchers with similar results argue that from the point of view of the substation transformer the impact of EV charging is mainly one of power and energy as it is observed a cancellation effect of the system's harmonics.

However, another study by Lucas et al. showed that simultaneous fast charging with the same type of charger showed neither synchronization nor random behavior in the phase angles. The study's paradigm results for the difference in the same harmonic order suggested that there is an upper limit to the number of EVs to be considered allowable in the system, since the number of EVs, hence the maximum demand load current I_L , is observed to be inversely connected to the standard harmonic limits .[59]

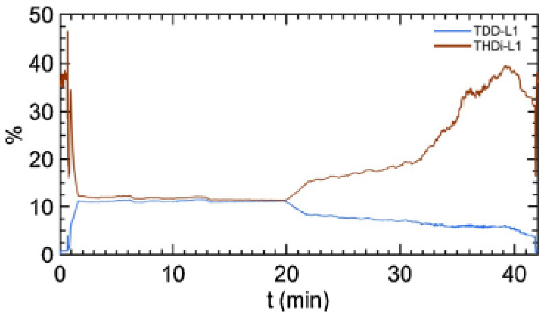


Figure 83 THDI and TDD during a complete charging cycle

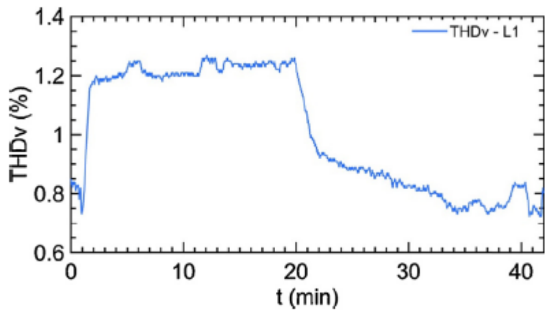


Figure 84 THDV during a complete charging cycle as researched by Lucas et al,.

Lucas et al. showed that the primary limitation of the number of fast chargers/vehicles in a cluster is not the power capacity of the upstream power transformers, but the harmonic limits for electricity pollution. The same study also pointed out that limit analysis of the TDD should be applied instead of the THD since there is a variation of the current during the cycle, and hence an opportunity for the European standards to improve in future versions [59].

C. (ii) Voltage Drops and Power losses

A significant impact of EV introduction is the Voltage drop caused by system congestion induced by simultaneous EV charging. A typical charging load is between 10 to 30 kW, so a simultaneous charging of multiple vehicles in the same distribution branch might cause congestion. Under these circumstances, the voltage at customer premises might drop below acceptable and/or statutory limits. Moreover, in the case of severe overload, the distribution conductors might get damaged due to overheating [82].

In addition, academic literature pointed at the impact of EV charging in the aging of the transformers of the power distribution system. Moreover, the more significant the peak load, generated by the EV charging, to the overall daily load profile, the more significant the impact to the transformers operation and lifetime reduction [81]. Calculating the absolute life span of a transformer is almost impossible. However, it is possible to determine the relative loss-of-life of a transformer. The aging of a transformer is mainly related to the aging of the LV/HV wiring insulation which is a function of the hottest spot temperature of a transformer [98, 99]. The hottest spot temperature T*H*, for any specific transformer, is calculated from the absolute and change of load, and the ambient temperature T*A*. The two main parameters are defined by IEEE Std C57.91-1995 [100]. Following this method M. Rutherford et al. found that the most effective way to reduce the unnecessary life loss of the distribution system's transformers was to introduce intelligence coordination in the charging schedule.

Extended research focused on the impact of fast constant power charging has been recently commenced. Dharmakeerthi et al showed that the EV loads can be better represented as combination of constant power and negative exponential loads, in which the constant power component has greater magnitude when voltage is regulated around the nominal value at the point of common coupling (PCC). Main findings of this research is that when the voltage drops, the influence of the negative exponential load component increases. This increase depends on the lead resistance between the charging unit and the PCC, the parasitic resistance of the filters and the turn on resistance of rectifier switches [80]. This means that the system's voltage drops due to congestion by simultaneous charging could further introduce variation of the charging load.

Also increasing EV charging could multiply feeder losses, which would affect the distribution system based on their relation to the load factor and load variance as illustrated by Sortomme et al [62] in their model. Specifically this study uses the paradigm of an electric 9 bus system and utilizes Monde Carlo simulations to depict the relations of power feed losses (charging losses) as a depended variable of the load factor, the load variance of the system and the EV penetration. Interestingly enough the foundings show that the system optimized for charging loss minimization bears a similar result of total average losses with the load variance minimization one, while the system, operating with a maximum load factor, will have slightly more losses 1.2%, with uncoordinated charging option bearing the most losses (7%) for a 10% EV penetration. This shows again that an effective strategy for mitigating power losses is to minimize the load variance, even more so than charging in a maximum load factor.

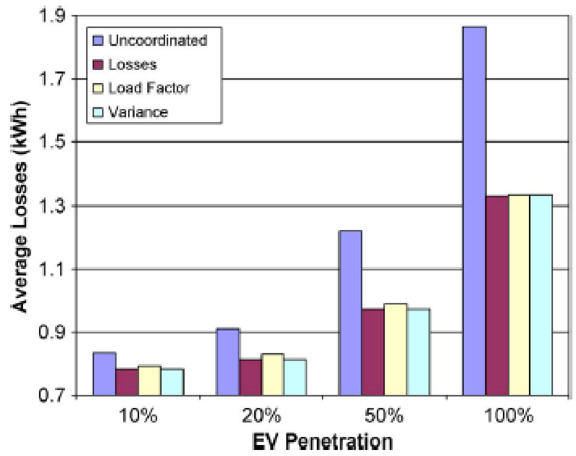


Figure 85 total power feed losses for charging profile over a 24h period of 9-bus system as illustrated by Sortomme et al [62]

Long-Term Threats – Congestion and Exceeded Capacity

The growing number of EVs will eventually drive peak demand higher, which, in turn, might compromise the overall reliability of the grid. Insufficient generation and transmission, commonly referred to as blackouts and rolling brownouts, will be the impact of imbalance to the system. The grid must be capable of delivering the power necessary to charge electric cars, even on the most congested days. Because of that, the peak capability serves as the limiting factor for EV adoption under the current grid constraints. Moreover, even without increasing peak demand, the amplified level of transmission utilization can affect the cost of electricity delivery by adding the extra cost of congestion in transmission lines, which will occur as a result of the EV adoption increase [67].

To mitigate the effects on the distribution system the distribution system operator (DSO) may upgrade the network infrastructure by installing bigger transformers and thicker conductors, but such an upgrade could be very costly, especially, if the durations of overloaded periods are short and hence will result in underutilized assets for most of the time. Recent study in the Metropolitan area of London estimate that the cost of the required upgrades of the local distribution network in order to sustain the future EV penetration is estimated to be between £6 and £16 billion until 2050. Ofgem, the power market regulator of the UK has published a study which examines the way the cost of such a distribution system upgrades will be passed on consumers through electricity bills with fairness [68]. In contrast to distribution network upgrade, it is suggested in the literature that the DSO can install software components in the recharging sockets that will enable the coordination of EVs' recharging activities and consequently minimize power losses and voltage deviations by flattening the system's peak demand [82, 97]. Other methods like

Vehicle to Grid (V2G) and smart charging in which the DSO's role is substituted by a PEV Aggregator are described in the 4.F.(ii) chapter of this study.

D. Smart Charging Strategies

With global power market aiming to achieve high penetration of RES to reach the COP21 climate goals, the electrification of the transportation sector has been an important piece to the strategy for Climate Change mitigation. The large scale integration of variable renewable energy resources (RES) such as wind and solar which are directly depended on local weather conditions would add uncertainty in keeping the balance between electricity supply and electricity demand. This real-time balance between power generation and demand is indicated by the grid frequency which is required to be maintained around a certain level (50 or 60 Hz globally). The fluctuating power generation of the system with the integration of RES reduces the system inertia. Such a system would encounter faster and more severe frequency deviations in cases of sudden changes in supply or demand [39]. Therefore, the system operator should seek immediate response to frequency changes either on the demand or the power generation side. The introduction of EVs to the power system, even though it constitutes a significant load introduction to the power demand with all the impact on the power distribution that this implies [40], could provide such response, which would enforce grid support by providing frequency and voltage regulation services through smart charging strategies and vehicle to grid discharging services [52].

Such a response to the imbalance of electricity supply and demand is possible in the Demand side and could be implemented with strategic coordinated EV charging, which would utilize smart grid systems to carry out load shifting of EV charging operations accordingly. Thus, transition to electric mobility in combination with the application of smart charging strategies could potentially positively influence power generation in a large scale [34].

Smart charging and discharging of EV fleets could help power plants produce in a more steady pace by shifting the electricity demand for charging to time periods of either overall low electricity demand or high power supply mainly due to the variable nature of power generation from renewables. This means that power plants could avoid unnecessary output load adjustments (ramp-ups, ramp-downs) and minimize the number of start-ups resulting in a low marginal cost of electricity that benefits the consumers. That implies that the EV owners can participate in power market regulation by bidding capacities either in up- or down regulation. To coordinate such a strategic participation of EVs in the power market the actors must participate as either very large EV fleet operators or as consumers applying the same smart charging strategy. Ideally the optimal impact of smart charging could be achieved by an aggregator that could act as a capacity bidder for the whole EV fleet participating in a power market [34]. PEV Aggregators are power market entities [50] that can either act as electricity providers by estimating the charging load they cover and bid for it in the day-ahead electricity market, or as charging service providers, as which they plan the whole charging process including possible discharges to the grid (V2G) while they participate in the wholesale electricity market including the intraday and balancing power market. Moreover, the PEV Aggregator's charging strategies are driven by both profit and grid stability purposes [41]. In power market, such aggregators would bid for themselves while passing on partially their economic benefits to the consumers. Many researchers have focused their research on optimal biding in power markets [35,36,37] developing various optimization models. These models study power markets defined by price-taking electricity producers while considering technical boundaries such as start-up costs, ramping restrictions and storage balances.

Moreover, balancing the power distribution system is also possible by power supply response side actions, with the utilization of large energy storage systems (ESS), which are required in a system with a large scale introduction of RES, to support appropriately the smooth operation of the grid in a way that electrical power demand and operating standards are met at all times [53]. A large fleet of EVs could act as such an ESS, which that would operate as a dispatchable unit to discharge immediately power to the grid when needed, using a vehicle to grid mechanism (V2G), acting as a spinning reserve to balance power supply and demand. Such response from an EV fleet integrated to the power system becomes imperative due to the high demand for grid regulating solutions, since an average 95% of all time EVs are idle and thus, assumingly connected to the grid, available for charging/discharging.

However, because a fleet of EVs as a charging load on the demand side and as Dispatchable battery power capacity on the supply side is a complex system, that is bound by the charging/discharging availability, which in turn is a subject to in the diverse driving behavior of each EV user and the technical characteristics of each vehicle's battery, battery management system and power electronics, it's imperative to approach it as an aggregation. Moreover, such a system is controlled and modeled as a virtual power plant [39] and managed by plug-in EV (PEV) Aggregators following various charging strategies.

D. (i) Charging Behavior and Charging Strategy

EV Charging behavior has spatial and temporal characteristics. Data from mature EV markets indicate that the charging behavior of the EV users does not resemble similarities with refueling internal combustion engine vehicles' habits. In accordance with that, study of the EV charging behavior in Norway revealed that electric car owners charge mainly their vehicles at home. More over 40% of the EV user population never charge their vehicles at work providing concrete spatial indication of the Charging load [38].

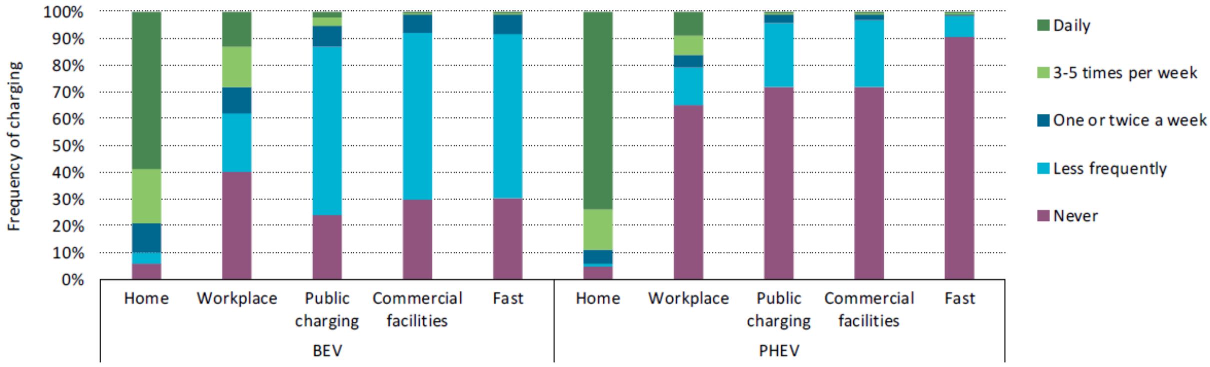


Figure 86 Charging habits for a sample of Norwegian electric car users, 2016 (source IEA)

In addition, the need to minimize deployment costs suggests that the deployment of charging infrastructure should be tailored to the evolution of the electric car stock growth and the charging behavior.

The Charging behavior and strategies that can be observed in the academic literature as well the ones that can be identified from the market experience are the following:

Uncoordinated Charging

Uncontrolled charging: Uncontrolled charging is the charging behavior in which the EV owners usually plug in and charge their vehicle as soon as they return from a trip. Furthermore, this behavior is subject to further assumptions on the amount of charge filled in the batteries of the vehicle as this is influenced by its driving pattern hence the availability of the vehicle for charging and the charging speed. In research literature this behavior usually assumes that the users charge the same amount as they have discharge while driving to keep the battery full and be ready for the next trip [34]. Hence no information for this behavior is needed other than the driving pattern. Furthermore, this strategy means that the vehicle owner will not act on the regulating market.

Delayed charging: The delayed charging is similar to uncontrollable charging with the exception that charging of EVs is delayed from when the EVs are plugged in. In this behavior some kind of intelligence is needed, often a timer setting that will shift charging time to late night hours when the marginal cost of electricity is lower. Similarly to the Uncontrollable charging in this behavior there is no participation on the regulating market.

Coordinated Charging

Deterministic charging: In this behavior the EVs optimize their charging based on deterministic future electricity prices. The marginal electricity prices utilized in such behavior are forecasts formulated by projections of historical data (e.g. a 1 year period) for electricity demand and in a smaller timeframe (weekly), accurate weather forecasts that would provide a deterministic input for the variable power generation from RES. The potential for adding extra value to the EV use could be realized through Optimization Models utilizing such charging behavior by allocating charging operations to time periods in which the EVs are available for charging and the marginal cost of electricity based on forecasts is low. This behavioral scenario is subject to a lot of assumptions that aim to describe the deterministic input of power generation and electricity demand in a period of time, often assuming similar price variations over a long period [34]. This type of charging allows the EV user to act both on the up- and down-regulation market. Up-regulation can happen in terms of halting charging operations or down-scaling the already planned electricity demand for charging, as well as discharging to the grid through a Vehicle to grid mechanism (V2G), acting as a virtual power plant. That kind of discharge would add complexity to such models plus would essentially involve a strict deterministic driving service assuming no unpredictable driving needs and thus it is not utilized widely as Juul et al. mentions in relevant research [34]

Stochastic charging: This strategy is similar to deterministic charging taking into account future electricity prices as an input with the exception that in this case the uncertainty of the electricity prices is realized. Thus optimization models are considering multiple scenarios exploring the probabilities of electricity prices going up or down. Even though, Charging decisions are made prior to the formulation of the actual regulating price, by providing more information on value variation in historical development of electricity prices the optimization could extract more benefit from the bidding mechanism [34].

D. (ii) The role of Smart charging in mitigating the impact of the EV adoption on the Grid

The impact of EV charging on the power distribution networks is an issue that highlights the need of spatial planning of the EV charging problem. The rapid development of intelligent (ITS) transportation systems, communication systems, geographic information systems (GIS) and global positioning systems (GPS) enabled the use of historic and real time data to make such a spatial planning possible. The origin-destination analysis (OD) is an important tool towards this direction, which offers detailed input on the spatial and temporal driving profile of EVs [42-45]. Various models have been developed following the OD analysis, such as the spatial-temporal model, which was developed by Y. Mu et al., that addresses the EV charging problem using Monte Carlo simulation to determine the charging load for each individual power distribution branch [42].

In extend, the role of the PEV Aggregators, as charging service providers, is majorly dictated by the need to manage the charging loads in a way to secure the smooth operation of the local distribution network, avoiding the potential voltage drop incidents, transformer and thermal limit violations caused by exceeding the distribution branch's rated capacity. Many studies showed that the absence of coordinated charging can lead to such impact [42, 47-49].

The Framework on which the PEV Aggregators have to Operate

The Aggregators in order to manage the charging of an EV fleet by developing an effective charging strategy they are required to maintain knowledge on the technical characteristics of the EV fleet they serve and the driving behavior of their users, including. Technical and non-technical parameters that would define such a charging strategy are described below.

1) *Technical Characteristic of EVs*

Battery Capacity: The battery of each EV is an energy pool and thus because not all its capacity is required daily, it has become imperative to address the optimal charging to provide the consumer with the needed temporal state of charge (SOC) while providing ancillary services to the grid. Battery capacity determines a large variety of parameters that have a significant influence in the charging strategy such as the driving range of the vehicle, the charging time to reach full SOC as well as the required frequency of charging [74].

Type of Vehicle: The type of vehicle as defined by MERGE project [46] based European EV market survey. This would be valuable information to identify the transport purpose, the driving behavior and a range of technical characteristics of the vehicle.

Electrical Energy Consumption (per km): The rapid developments in the EV technology both in battery technology and EV power management systems has created a diversification of the EV stock leading to vehicles with different capabilities both in daily energy consumption, which affects the average daily available state of charge (SOC), as it is resulting from the strategic charging process. Thus an aggregator, when planning, it is sensible to aggregate, while maintaining an EV technology diversification input, close to real world data, which would provide a better overview of the flexibility of the charging load and consequently would result in less required adjustments on the intraday market.

2) *Driving and charging behavior:*

EV Driving Pattern: The weekly driving pattern followed by each EV would determine the residual/idle time in which each vehicle is plugged in to the grid and thus its availability for charging/discharging. It would also provide sufficient information, along with the type of vehicle and the driving behavior, for the energy consumption of each of its trips. Several articles underline the importance of a predictable driving pattern for the charging behavior [70], [72]. Smart et al. (2013) highlighted the importance of the adaption of the driving pattern to the EV capabilities by showing that in an EV driver sample in North America, 62% of EV drivers were able to accomplish their daily driving needs on one fully charged battery. The same study found that charging frequency and SOC were also influenced by the degree in which EV drivers were considering fuel economy in their daily transportation [73].

EV user behavior: The EV user behavior is a complex parameter that describes the rational and irrational behavior of EV users in regards to their daily charging habits. It is comprised by various other parameters such as (a) Range anxiety, (b) planning of charging, (c) EV experience and others [68]. Range anxiety refers to the fear of the drivers for a possible inability of reaching their destination with their current state of charge (SOC). This fear leads EV users to overestimating their electrical range needs. Studies showed that EV users prefer vehicles with considerable higher electrical range availability than they need. They, also, have a tendency to charge their vehicles more often and for longer periods of time to reach a power excess SOC which would alleviate this range anxiety, affecting significantly their daily charging behavior. Range anxiety is reduced with daily planning or increased accessibility to charging infrastructure [41].The planning factor is referred to the matching of the realized driving pattern with the real daily scheduling conditions, including externalities such as emerging patter-breaking events (emergency events). Studies showed that EV users are only partly able to predict their mobility behavior which negatively affects their friendliness towards electric mobility and add to the uncertainty of the charging behavior [39]. EV experience factor refers to the user experience of EV drivers in regards to the limitations of the EV technology. This experience determines the way these individuals cope with range anxiety, electrical range realization, mobility planning and behavior [68].

3) *Technical characteristics of the charging infrastructure*

The charging infrastructure: The types of charging infrastructure which are available for charging, their power output and the compatibility with the individual EV, along with each EV's battery capacity could provide sufficient information for the charging time (charging rate) and thus the scheduling of charging operations to achieve the required temporal SOC for each vehicle.

4) *Local Distribution Network Boundaries*

Power distribution network branches must not exceed their power transfer capability (rated capacity). The uncontrolled charging of large number of EVs is possible, in the peak load times, to cause network failure resulting to voltage shortages and finally to DSO-imposed blackouts. Due to temporal and spatial variability of EV charging, it is expected that the load demand at a national scale would increase. It is important in rapidly expanding EV markets that the DSO assesses regularly the status of power distribution network to predict future failure and plan the necessary upgrades to secure the operability of the network. Moreover the description of the effect of EV penetration to the distribution network can be observed in chapter 4.C.

In order to provide grid regulation services, it is important for an Aggregator to make an appropriate contract with each vehicle owner. After mapping the vehicle stock it serves, the aggregator must declare the charging load to the grid operator by participating in the day-ahead power market. In case the aggregator is able to and chooses to utilize V2G for grid regulating purposes should make a contract with the Distribution System Operator (DSO). The aggregator should control the sequence, duration and the rate of charging for each vehicle, accordingly to the DSO's boundaries while maximizing its revenue [51].

Typically the way PEV Aggregators approach their charging strategy has to do with the scale of their operations. Typically in small scale of EV introduction the PEV Aggregator is sufficient to just consider the day-ahead electricity prices in its charging strategy. In large scale EV introduction, where the fiscal benefit of more accurate scheduling becomes essential, for a performance measure, an approach, in which intra-day regulation price should be considered. Furthermore, in mature EV markets, with a high EV penetration, a complete simulation of the energy system, including spot price formulation, could be proven beneficiary for both the Aggregator and the DSO.

In practice, there are according to literature two types of EV charging control models, the centralized and the decentralized. In centralized control planning the EV

Aggregator using a central control unit is responsible to manage the charging demand by controlling the charging process of each EV individually. Although this strategy offers a simple way to control charging operations the calculation of the optimal charging schedule of a whole EV fleet requires numerous iterations and thus high complexity, requiring high computational resources to perform, while an advanced communicational infrastructure is required to enable real time operation.

Decentralized charging control strategies are effective when the intelligence is distributed among the power system components [55]. In this approach the charging schedule is formulated by the consumer or as an automated process chosen by each electric vehicle-charging infrastructure system by reflecting the condition of the local power distribution system. The complexity of such decision making is low and consequently the communication cost and computational resources required are low.

In decentralized control strategies, pricing schemes such as Time of Use pricing (ToU) can potentially trigger a shifting of EV charging load as Demand Response, with potential benefits for the system. However in more mature markets, in which the EV stock is larger, and respectively the charging load is proportionally larger, such pricing could potentially lead to peak loads during the low pricing timeframe.

Literature usually approaches the EV charging control as a deterministic problem. However, the nature of EV use implies that a various types of uncertain events may diversify the daily EV operational schedule. An EV charging control strategy and practical implementation was presented by E. Xydas et al. [55], which introduced the terms unresponsive EV agents and emergency event to describe behavioral scheduling faults and an occurring out of schedule power demand, while it effectively deals with them on its scheduling algorithm.

D. (iii) Conclusions on Charging Strategies and the Role of PEV Aggregators

Why a centralized EV charging control strategy run by EV Aggregators? It is shown that coordinated power demand responses are more effective both in providing grid ancillary services and driving down the price of electricity.

In decentralized strategies the smart grid application managing EV charging would be responsible for the demand response with the drawback of not delivering the required SOC in the optimal price. In addition, such strategy fails to provide ancillary services to the grid towards an optimal marginal system price, aiming mostly in providing frequency regulation response. On the other hand, the centralized control of EV charging, approached as a system, would optimize the temporal power load demand for charging both in the day-ahead market and in real time (intraday and balancing market), aiming for balancing supply and demand. The variable, intermittent power supply from RES, when in excess, offers a window of opportunity for a low power system operational cost (low marginal price of electricity), which can be exploited by a centralized charging strategy. Finally, the PEV Aggregators can simultaneously exploit and pass on fiscal benefits of electricity price minimization on the consumer, achieved by such system performance. In addition fiscal incentives should be given to responsive EV agents that reschedule their charging operation to regulate the system or adapt to the rescheduled the temporal charging demand derived by the activity of unresponsive EV agents [55].

In market models that the DSO is participating in the EV charging market it is relevant to examine the feasibility of investment for upgrades in the local power distribution networks in order to support the forecasted future integration of EVs. In addition, V2G functionality must be also examined in the framework of finding the feasible marginal compensation price per kWh of electricity provided to the grid by EVs for stability purposes, taking into account the reduction of the cycling and depreciation costs of their batteries.

E. Use of EVs in an Urban Environment: The Case of Paris and other business models

E. (i) The Case of Paris - Autolib

Anyone who has recently visited the French capital has certainly noticed the growing number of sleek, gray, compact cars, labeled "Autolib", which are the French answer to the challenge of introducing electric mobility in urban environment. These cars, created by the famous designer Pininfarina, are fully electric, manufactured in France by a subsidiary of the Bolore group and are part of a fleet of approximately 4000 electric cars that are exclusively driven in the wider Paris metropolitan area. These standardized electric cars are part of a vast car sharing network with 1400 organized parking and charging points where 6,400 electrical chargers are installed.

Figure 87 Autolib's facilities and fleet in Paris

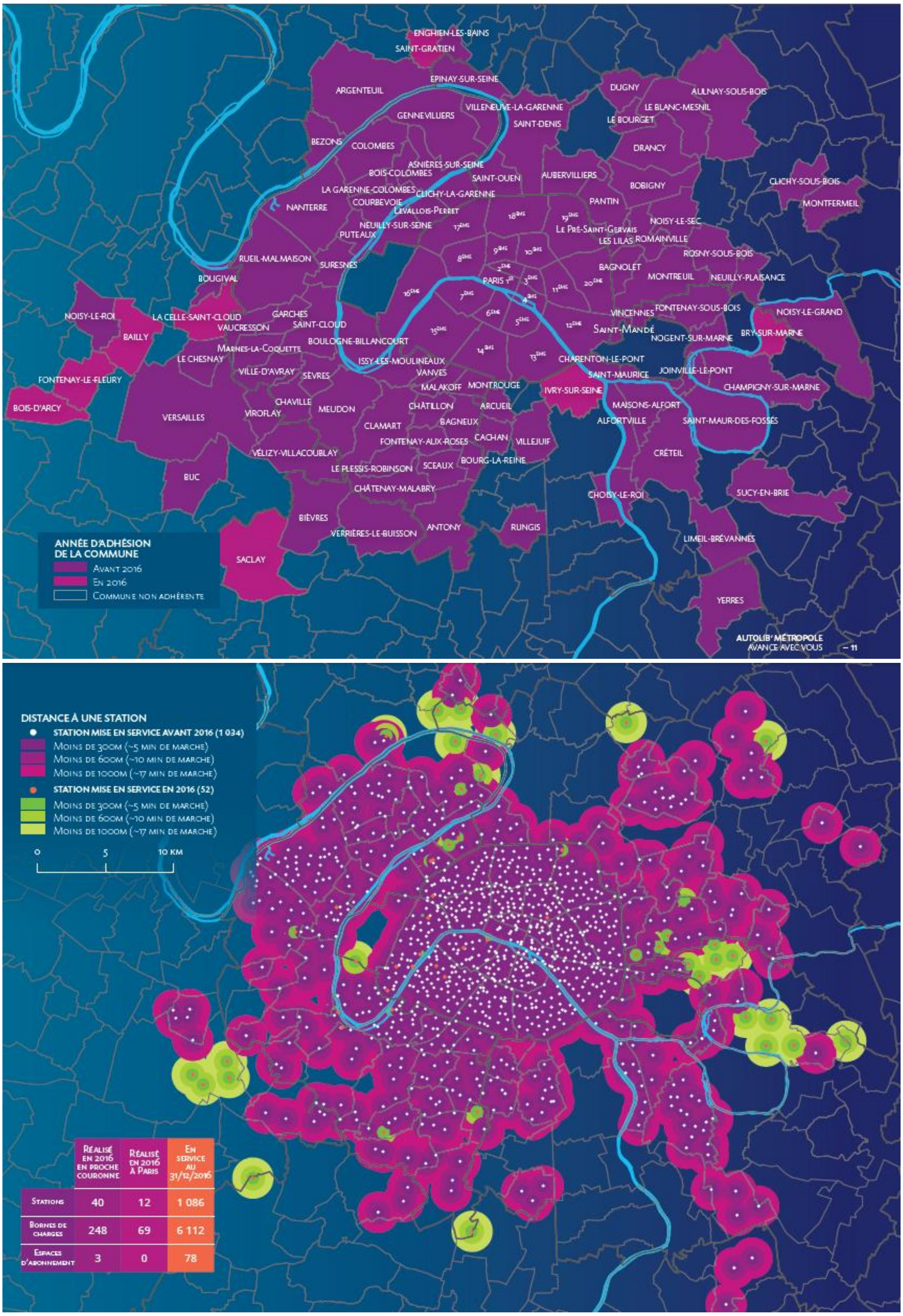


Figure 88 Autolib's Coverage and Expansion in the wider metropolitan area of Paris

"The creation of the Paris-based public electric mobility system started as an initiative of the city of Paris (Ile-de-France) and the 12 contiguous municipalities (12 EPCI), who set the original design and operating conditions, committing at the same time to provide the appropriate facilities and to support in any way this transport service," as stated by Thierry Michel Isoard, elected municipal councilor of Asnières-sur-Seine, and executive director of the Autolib Métropole consortium. "Our approach from the beginning of the whole project," adds Isoard, "was focused on geographic and urban planning, because without the active involvement of the various urban and suburban municipalities, the whole system could never function satisfactorily, in covering the transport needs of an internet-savvy and increasingly mobile audience”.

The joint venture, which was set up in 2009 is a public-private partnership (PPP), which includes the 12 municipalities (EPCI), which are shown in the map illustrated in figure 88, and the Bolore Group, with municipalities controlling 51% and Bolore the remaining 49%. It is managed through Autolib with a long-term contract, which was launched in 2011 and expires in 2023.

The principle of car sharing and organized parking are the basis of the whole system designed to serve the needs of residents and visitors of Paris. Thus, Autolib electric cars are not hired for a week or a day, but for only a few hours or less, since they are only required to serve the needs of going from one point to another within the wider metropolitan area of Paris.

On the basis of a monthly or annual subscription system, the registered driver, who maintains his own code is equipped with a dedicated electronic card, can search through the internet for the nearest car station and available idle Autolib car. The user after boarding and reaching his destination, is obliged to look for free parking space and after parking the car and connecting it to the charger-pillar, leaves the vehicle, which is ready to accommodate the next driver.

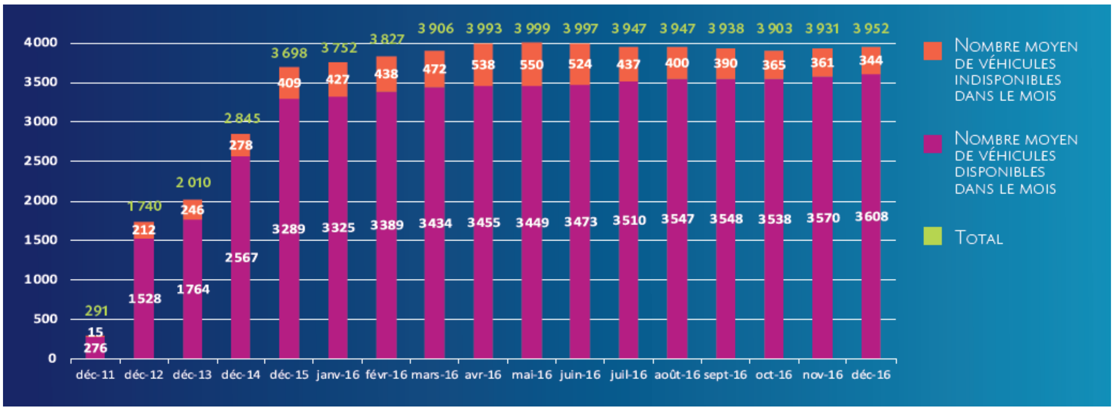


Figure 89 Development of Autolib’s vehicle fleet, Figure shows the monthly average of available, non-available and total vehicles

It should also be noted that car parking/charging stations are also available to non-subscribers of Autolib, who are EV owners and are looking for places for EV charging. However, to make use of the Autolib infrastructure, these 'independent' EV drivers, who are increasing daily, are obliged to subscribe with Autolib, and obtain a special card and thus be free to park and charge their cars as they please.

Autolib' is committed in expanding its fleet as wells as its charging network on a monthly basis. The average availability of EVs per station has reached an average of 3.32 vehicles per station in the beginning of 2017, which secures the flexibility and usability of the car sharing system.

Figure 90 Development of Autolib's vehicle fleet, Figure shows the monthly average availability of vehicles per station.

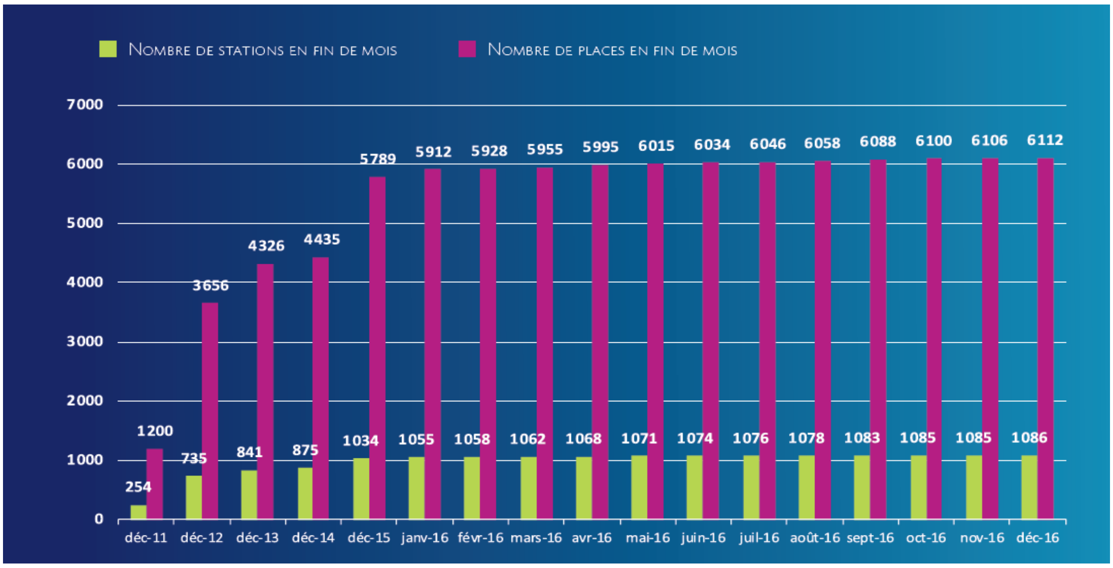


Figure 91 Development of Autolib's parking/charging stations and charging position

With approximately 140,000 registered driver users (2017) [107], the public electric mobility system in Paris is now well established and fully operational and appears to be part of the response to the bottlenecks of moving within European cities. The experience of Paris, with similar organizational structure, has been implemented in two large urban and suburban centers in Lyon and Bordeaux with several thousand subscribers in their urban electric mobility scheme. Significant interest in cooperation and transfer of know-how has been shown by many other European capitals and major cities.

E. (ii) The Virta Busness model

Virta Mobility, Virta Operator and Virta Bundle are an integrated mobile application-based solution of an EV charging system offered by the Finnish company Virta. Virta's mobile application offers a comprehensive and simplified, highly usable platform that connects Electric vehicle Drivers, Charging Point Owners as well as charging network operators.

In regards to EV drivers, the Virta Mobile application provides a real time map showing the nearby available charging stations. The user through the application can initiate and terminate the charging operation, as well as pay automatically with various methods. The application also offers a home-charging service, which enables smart charging by managing charging operations based on the time of the day and energy market signals, as well as it assists the user in keeping track of his EV charging expenses.

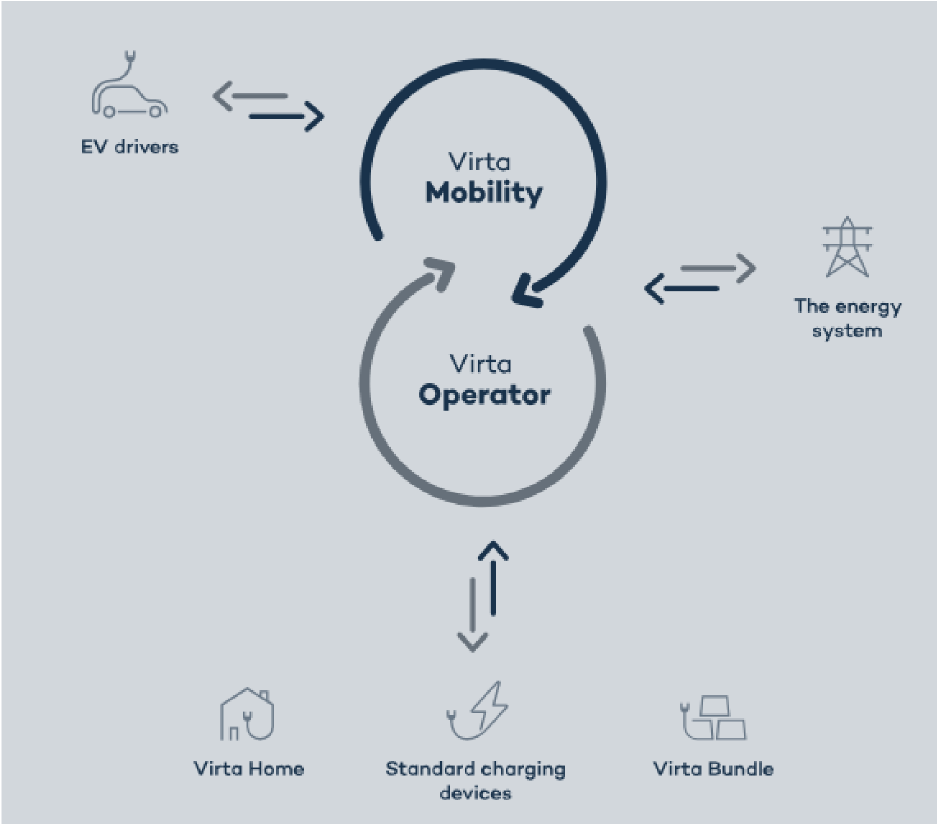


Figure 92 Illustration of the integrated operations of Virta's software

Virta Operator offers a comprehensive EV charging platform for Charging Network Operators that works with any Open Charge Point protocol (OCPP) device. It also enables various payment schemes set by the operator. In addition, it is a very good way for a Charging Operator to promote its brand, and that is because through the white-label mobile and web application the users can engage each company and its products. It also offers a continuously developed interface through which EVs can be utilized as balancing elements in the energy system.

In addition, Virta Bundle application, oriented towards Charging Point Owners offers a charging service with cloud connected charging devices which can be used by EV drivers with either their mobile applications (Virta Mobility) or radio frequency identification cards (RFID), and credit card payments. This system transfers directly the payments to the charging device owner as well as manages the charging loads automatically to protect the electrical grid. The service adapts to both public and private charging needs offering a viable charging solution to all market participants, namely the EV driver, the charging infrastructure and the distribution system operator. Similar applications can be found in many countries worldwide. Similarities with Virta software can be found in : Enel X recharge [112], Freshmile (FRA & GER) and many more.

E. (iii) The case of Sofia - Spark business model

Spark is the Bulgarian answer to urban electric mobility with 26 Charging points in Sofia. It is a car sharing system similar to Autolib but with significant differences. The company offers four types of EVs, (VW eUP!, Nissan Leaf, Nissan eNV 200 Passenger, Nissan eVN 200 cargo), which enables the user in choosing the vehicle of his preference. The company utilizes a mobile application, in which the users can book a vehicle for a specified period of time, based on different availability, and price offers, leaving the choice for a cost effective solution to the user.

El drive charging stations offered by the company are free for all SPARK users, who can recharge their vehicle for about 3 hours. The charging stations are strategically deployed in Sofia close to business clusters, hotels and shopping malls. Each of the charging stations has at least 2 charging points, providing constant access for the SPARK electric vehicles.

The process of utilizing Spark's charging services is illustrated in figure 93. Primarily, the user can find a nearby available charging point through the SPARK mobile application. Afterwards, the user adjusts the charging cable into the charging socket of the vehicle and then he activates the charging process by using the Eldrive card provided by the company.

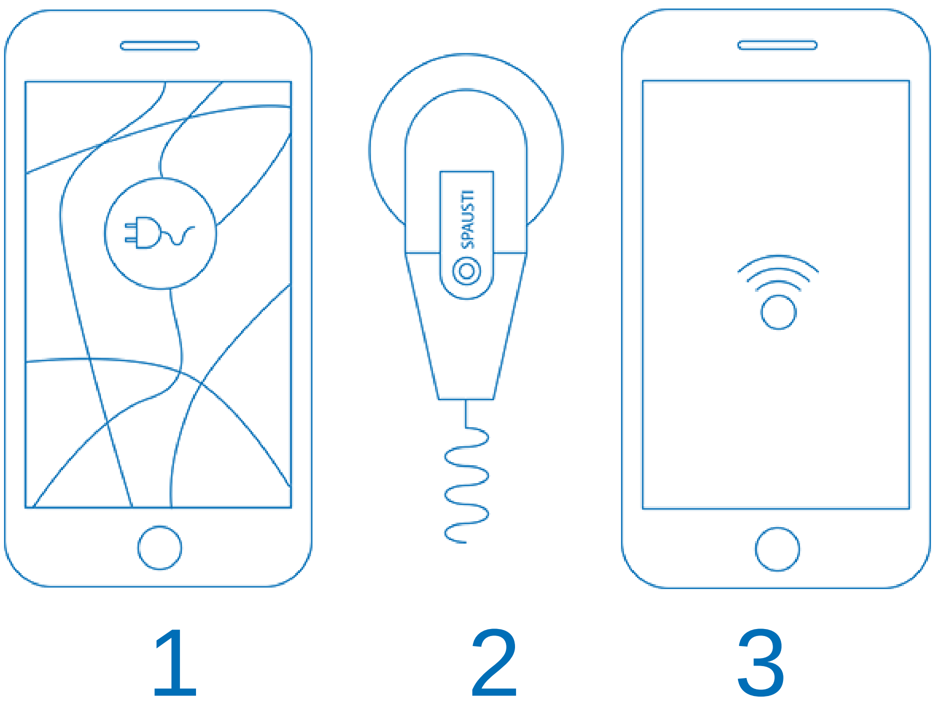


Figure 93 Spark's Charging Services sequence

Spark has announced that it is aiming to offer a total of 250 electric vehicles and have 40,000 active users by the end of 2019. By the end of 2018, Spark Bulgaria will likely have 100 electric vehicles and 10,000 users [110].

E. (iv) Public charging solutions

The main business model, which has been widely adopted in the early stage of the public EV charging market, is the charge card or key fob[17]. Through this system the user is either maintains for free or is charged a small monthly fee for maintaining a card or fob, which can be used for accessing all publicly available charging infrastructures, while extra charging fees are imposed on charging by the charging infrastructure operator.

Such payment systems include EVBOX in The Netherlands, Chargemap in Rotterdam (Netherlands), Freshmile in France and Germany and many more.

F. EV Charging considerations for Greece

F.(i) Considerations for Infrastructure installation

According to the Directive 2014/94/EU of the European Parliament and Commission, Greece should ensure that recharging points accessible to the public are built up with adequate coverage, in order to enable electric vehicles to circulate at least in urban/suburban agglomerations and other densely populated areas, and, where appropriate, within networks of intercity and international transportation. The number of such recharging points should be established, according to the directive, taking into account the number of electric vehicles estimated to be registered by the end of 2020. As an indication, the appropriate average number of recharging points should be equivalent to at least one recharging point per 10 cars, also taking into consideration the type of cars, charging technology and available private recharging points. An appropriate number of recharging points accessible to the public should be installed, in particular at public transport stations, such as port passenger terminals, airports or railway stations. Private owners of EVs depend to a large extent on access to recharging points in collective parking lots, such as in apartment

[17] A fob, commonly called a remote key fob is a small security hardware device with built in authentication used to control and secure access to network services and data. The key fob displays a randomly generated access code, which changes periodically, usually every 30 to 60 seconds. A user first authenticates himself on the key fob with a personal identification number, followed by the current code displayed on the device.

blocks and office and business locations. Public authorities should take measures to assist users of such vehicles by ensuring that the appropriate infrastructure with sufficient electric vehicle recharging points is provided by site developers and managers.

The Greek authorities should also ensure that publicly accessible infrastructure for the supply of electricity to motor vehicles is built up. Greece's national framework does not yet include a concrete plan for the number of EV charging points accessible to the public. Such a consideration which is required by the 2014/94/EU, must consider also the power of each station that indicates charging time and therefore charging point availability. Greece's authorities need to ensure that technological innovation in regards to development and integration of charging infrastructure is facilitated.

Also the directive highlights the need for the recharging of electric vehicles at recharging points to, if technically and financially reasonable, make use of intelligent metering systems in order to contribute to the stability of the electricity system by recharging batteries from the grid at times of low general electricity demand and to allow secure and flexible data handling. In the long term, this may also enable electric vehicles to feed power from the batteries back into the grid at times of high general electricity demand. Intelligent metering systems as defined in Directive 2012/27/EU of the European Parliament and of the Council enable real-time data to be produced which is needed to ensure the stability of the grid and to encourage rational use of recharging services. Intelligent metering systems provide accurate and transparent information on the cost and availability of recharging services, thereby encouraging recharging at 'off-peak' periods, which means times of low general electricity demand and low energy prices. The use of intelligent metering systems optimizes recharging, with benefits for the electricity system and for consumers.

With respect to recharging points for electric vehicles which are not publicly accessible, Greece should aim to explore the technical and financial feasibility of synergies with intelligent meter roll-out plans following the obligation under Annex I.2 to Directive 2009/72/EC of the European Parliament and of the Council. The country's Distribution system operator, HEDNO, should play an important role in relation to recharging points. HEDNO, while may participate to a vertically integrated undertaking owning or operating recharging points, should also cooperate on a non-discriminatory basis with any other owners or operators of recharging points, in particular providing them with the information needed for the efficient access to and use of the system. Moreover, the establishment and operation of recharging points for electric vehicles should be developed as a competitive market with open access to all parties interested in rolling-out or operating recharging infrastructures.

Interface to charge electric vehicles could include several socket outlets or vehicle connectors as long as one of them complies with the technical specifications described in the directive 2014/94/EU, so as to allow multistandard recharging. However, the choice made by EU for union-wide common connector for electric vehicles is Type 2 and Combo 2 plugs and sockets. However, such selection should be realized by the market and should not be considered detrimental where EV market participants have already invested or plan to invest in other standardized technologies, ensuring that EVs already in circulation should be able to recharge.

F. (ii) Considerations for Charging System Operators (PEV Aggregators)

Greece, on the level of operators of publicly accessible recharging points, shall ensure that these market entities are free to purchase electricity from any local electricity supplier, subject to the supplier's agreement. Also by adapting to the EU directive 2014/94/EU Greece should adjust its legal framework to allow the operators of recharging points to provide electric vehicle recharging services to customers on a contractual basis, including in the name and on behalf of other service providers, while all recharging points accessible to the public shall also provide for the possibility for electric vehicle users to recharge on an ad hoc basis without entering into a contract with the electricity supplier or operator concerned. Most importantly, the prices charged by the operators of publicly accessible charging points must be reasonable, easily and clearly comparable, transparent and non-discriminatory.

Greece’s legal framework should adapt in order to enable the separation of the electricity supply for EV charging from the electricity supply to households or premises where such a recharging point is located and therefore distinctively separate the EV charging operator and its role from the Electricity provider.

F. (iii) Charging load predictions

To predict the charging loads it is essential to predict (a) the number of charging stations, (b) the charging rate (charging station’s power capacity) of the future infrastructure determined by the type of the technology and (c) the number of vehicles introduced in the energy system as well as (d) the driving and charging behavior of their users. In regards to the charging market components (a)(b)(c) , Bayram et al. approaches the EV introduction and EV charging market development as two closed cycled problems oriented either as social welfare maximization or as a resource provisioning problem [102]. This approach is a statement that the EV and charging infrastructure deployment are two connected but also independent parameters, the increment of which is based on societal will, societal welfare, environmental awareness and policy planning.

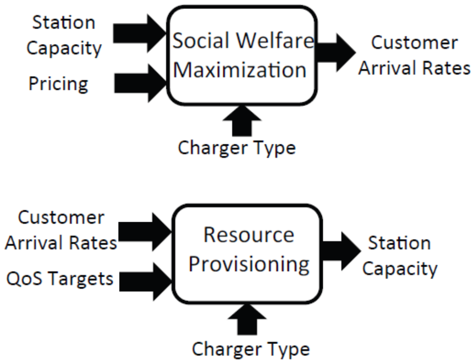


Figure 94 Two design problems for the EV Charging Market of the Future

In regards to publicly accessible charging stations, these in regards to urban and suburban transportation, even though have been deemed crucial for the development of the EV market and therefore necessary for the future of Electric mobility, they widely remain unused due to the preference of the consumers in charging their vehicles privately at home or in their work space [103] [104]. However, when it comes to intercity transportation the role of publicly accessible charging stations is broadly increased and their technical specifications heavily highlighted. Pricing mechanisms are also gaining popularity in academic literature on controlling EV demand [106].

The way the estimation is performed is heavily influenced by the organizational structure of the charging operations. Specifically, Bayram et al overviewing the possible organizational schemes of a charging market identified two major trends. In the first one, there is a central authority (dispatcher) that to a large extent controls and mandates charging rates, start times, etc. Such system level decisions involve selecting the desired state of charge, charging intervals, etc. are taken into consideration in order to finish all charging requests by a prespecified deadline (e.g. 7 am). The main advantage of a centrally controlled charging schedule is that it leads to higher utilization of grid resources, together with real time monitoring of operational conditions across the entire power system, as mentioned on chapter 4.D. The second category examines decentralized decision making by EV owners. Specifically, they select individual charging patterns based on the prevailing price of electricity or on self-imposed deadlines. It eliminates the need for a third party controller (dispatcher) and complex monitoring techniques. Since decisions are taken individually, game theoretic models, such as mean field games, potential games, and network routing games are used in these studies.

Energy storage is a critical component in the system architecture, as it is utilized to smoothen the customers' stochastic demand. The adoption of energy storage technology is heavily based on technology spread, support schemes, private initiative and informative campaigns. However in transitioning markets especially in recently recessed economies like the Greek one which are not capable to implement fiscal incentives for the adoption of Energy Storage Systems (ESS) it is evident that the unpredictability of EV charging loads would be more impactful for the power generation and distribution system.

The charging station technology of the future can be developed and therefore forecasted based on either the principle of power electronics components' performance optimization, which aims to overall minimize the charging time of the infrastructure or based on an overall cost effective charging system which aims in optimizing the system towards system usability, waiting time minimization, societal cost reduction and more [105].

Literature describes that (a) charging needs and (b) price levels generate the requests of charging services which are various. A two dimensional vector of charging price $P_{i,t}$ was utilized by Bayram et al to determine the price of charging service i on a time period t.

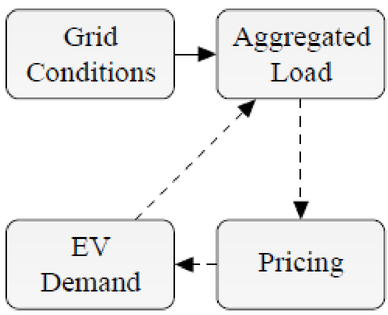


Figure 95 Pricing-based control mechanism for social welfare maximization

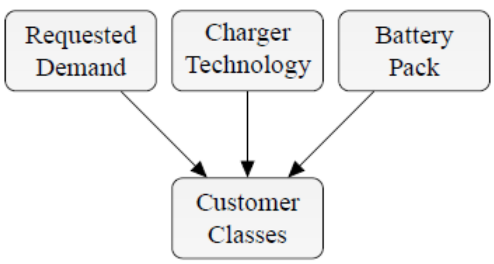


Figure 96 Customer preferences can be determined by EV type, amount of requested demand, and the charger technology.

G. (iv) A rough estimation of Electricity Demand caused by EV charging in Greece

To determine the electricity demand curve caused by the EV charging is imperative to investigate the temporal charging loads based on the driving behavior of the consumers which indicates the idle time of the vehicles, in which they are available for charging and therefore possible for a PEV aggregator to include in a temporal charging plan.

Such driving behavior studies have not been implemented for Greece, therefore we can only estimate the driving behavior of Greek Drivers in urban, suburban and intercity transportation based on studies conducted in other countries. Specifically, driving pattern survey held in Denmark by Riso DTU and Denmark's Ministry of Transport were utilized to determine the temporal EV charging needs of Greece proportionally adjusted to the reduced mobility of the Greek motor vehicle fleet equivalent to a total of 9723km/year/vehicle traveled by the average Greek passenger car [107]. This specific driving pattern is an average schedule of the distance travelled in an hourly basis for a week, in which 20 different driving behaviors are identified and depicted.

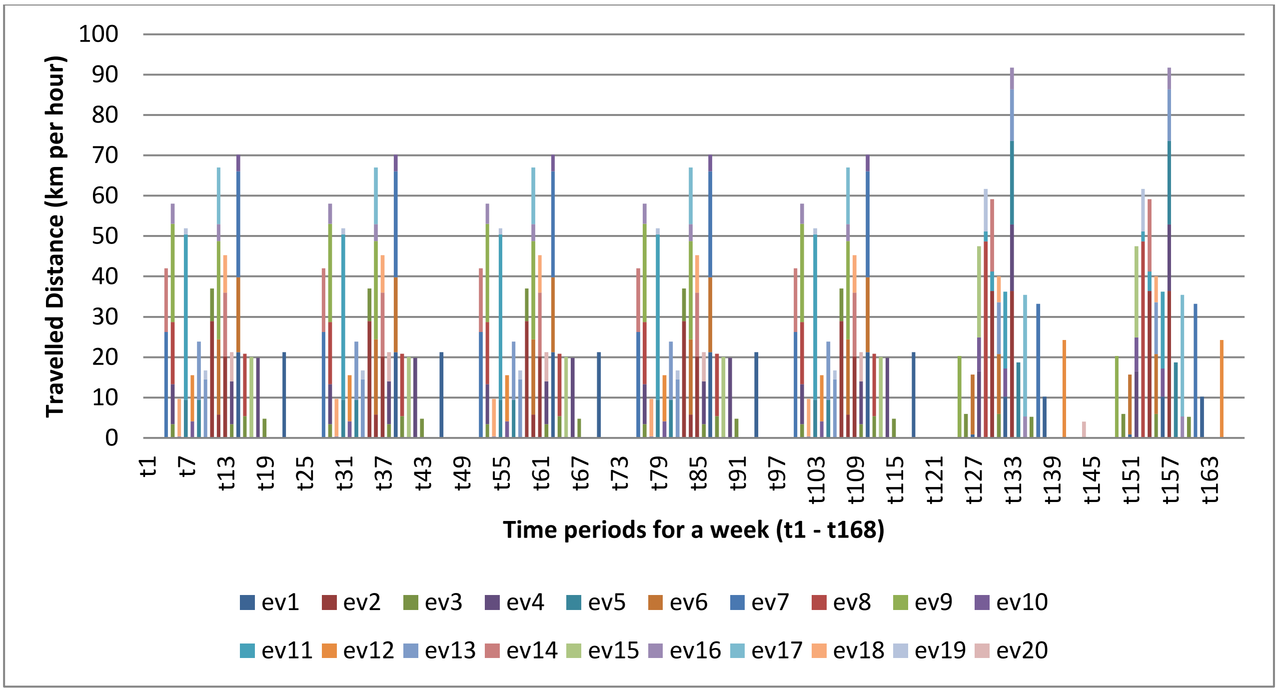


Figure 97 Hourly driving pattern of a typical week (168h) adjusted in the Greek on-road passenger car mobility of 2015 (Source: Riso DTU, Danish Ministry of Transport)

In the calculation of charging needs it was estimated that an average charging rate of a vehicle will be 7.4kW utilizing the widespread Mennekes (Type 2) charging modules. Such a rate resembles a system in which a Type 2 plug is applied at the vehicle and a Type 2 at the charging station, applying one phase AC charging. A reference consumption of 0.150kWh/km was used in the calculation, which refers to an average EV model for urban transportation (Current technology, namely BMWi3 consumes 0.136kWh/km (2018) and Nissan Leaf (2018) consumes 0.206kWh/km), which while being low for an average vehicle, it is roughly estimated to be a reasonable consumption estimation for current and future highly commercial vehicles, based on energy efficiency developments on reducing traction size and the chassis weight. Cumulative average charging losses of 20% in the points of common coupling, on EVSE infrastructure, including transformer losses [111], were also considered in the calculation, which also are expected to be partially mitigated in future EV charging installations.

While in this rough estimation assumes that EVs are charged as soon as they are idle and has been made based on the average reduced mobility of the Greek fleet, assuming the type 2 – mode 1 charging rate, the average trip could be replenished energy wise in less than three hours of charging. Of course such estimation is considered to be rough one, assuming availability of charging as soon as the vehicle is idle plus such estimation doesn't consider the choice of charging time based on the advantages of the fluctuations of marginal price of electricity and the time zone electricity provision contracts, which would be indicative for charging timeframe behavior of the consumers.

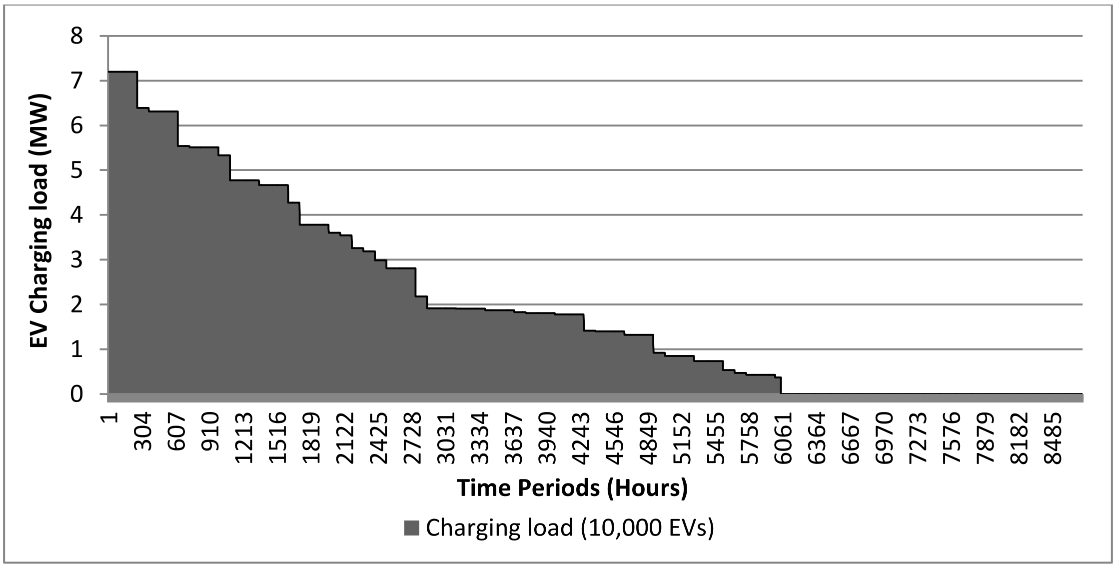


Figure 98 EV Charging Load curve resulting from the introduction of 10,000 vehicles in the Greek power system

Based on IENE's analysis, the introduction of 10,000 EVs in the system are expected to introduce annual energy demand of 17.6 GWh. The peak load of charging operations is expected to be 7.2 MW, while an increase in the annual peak demand of the interconnected system by 0.92 MW is anticipated. The Greek system is prepared to accommodate moderate loads of such proportion; however depending on the spatial distribution of the EV charging load, problems will potentially begin in volumes approximating or exceeding 100,000 vehicles. In such EV introduction in urban areas, like the capital city of Athens, maintaining about 40% of the country's passenger car fleet, peak loads resulting from EV charging could potentially reach as much as 30MW (72 MW in a country scale) and are expected to add 9.2 MW to the annual hourly peak demand of the Greek power system.

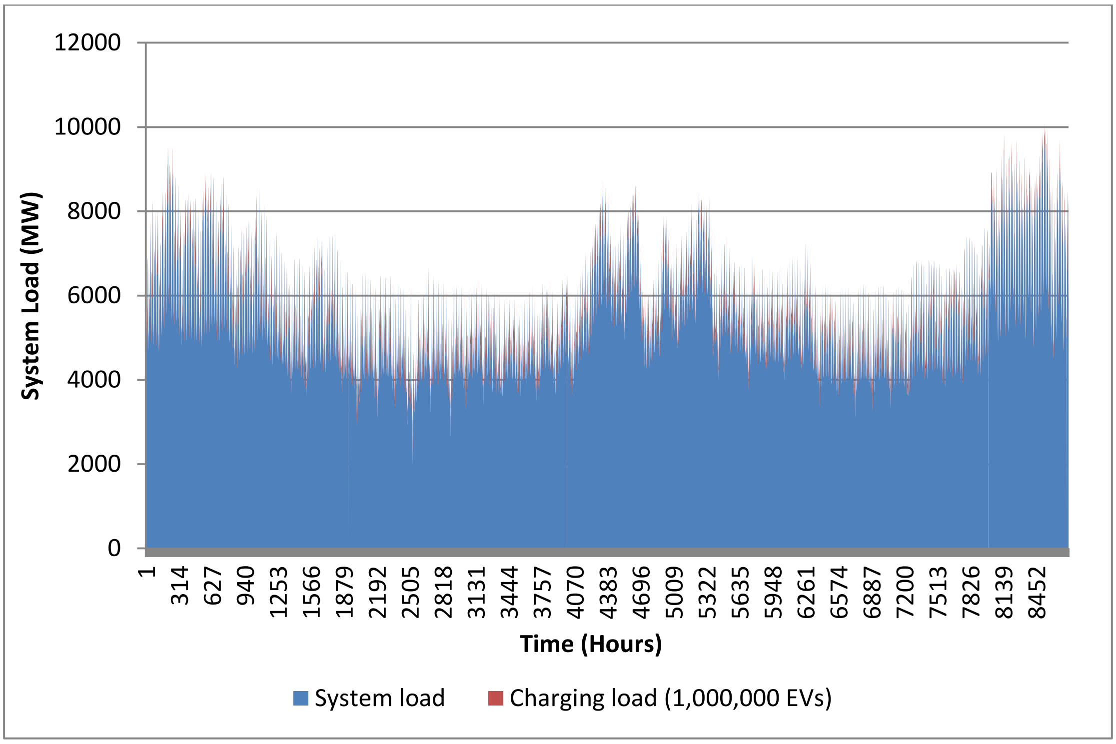


Figure 99 Illustration of the hourly power load demand with the charging load of 1,000,000 vehicles. (The unit's power generation utilized 2017 as a reference year) (Sources: IPTO, ENTSO-E)

Assuming that in the time span of 2018 – 2030 (12 years) the automotive sales in the Greek market will return to volumes prior to the recession of approximately 100,000 vehicles annually and be will remain in that level, while assuming that during that span of years an average of 10% to 15% of the new sales will be EVs (both BEVs and PHEVs), it is roughly estimated that 1 to 1.2 million electric vehicles will be in circulation in Greece by 2040. Moreover, it is important to mention that as the charging load estimation performed in this study is proportional, a number of 1,000,000 electric passenger cars would result in an introduction of 1.76 TWh of annual electricity demand in the Greek power system, while a worst case scenario of 347.2 MW would be added to the annual hourly peak load demand, reaching a total of 10.2 GW. Such a power demand would require the introduction of power generation capacity resources equivalent to approximately 2.5% of the current dispatchable power generation capacity of the country. Assuming that the RES penetration will be significant for the power system to maintain its resilience under such load introduction, probably the installed power generation in Greece would have to increase significantly its capacity by 2040 to accommodate the EV charging load.

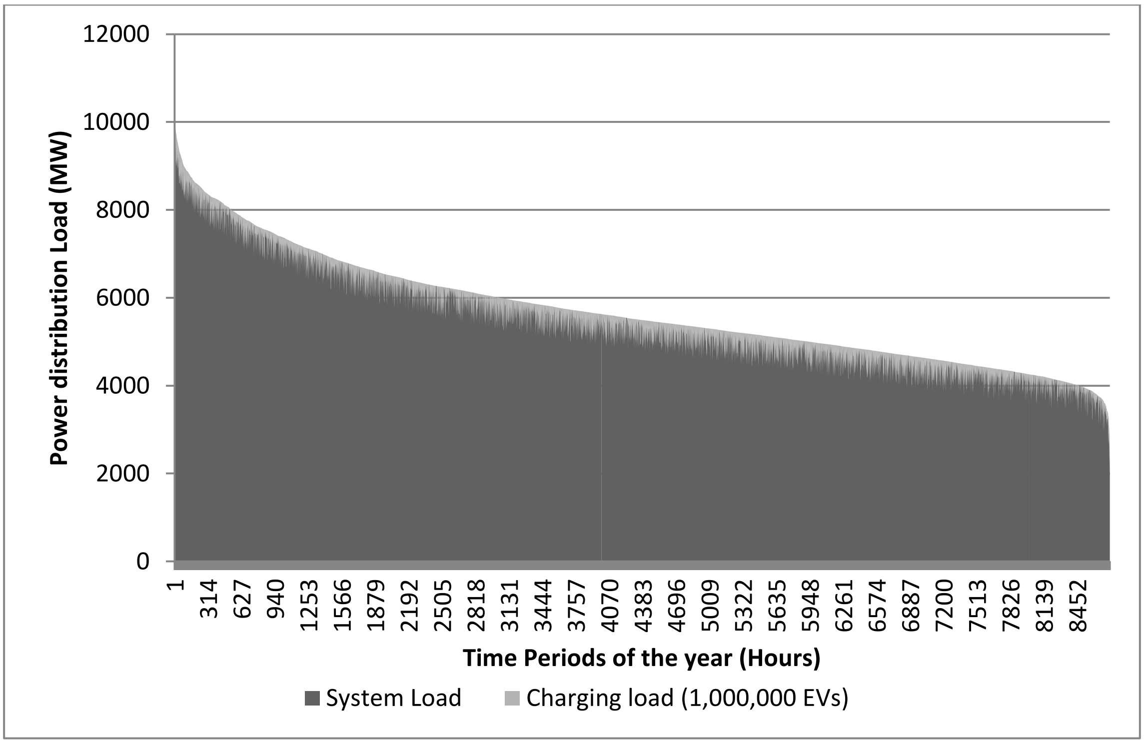


Figure 100 Load Curve of Greek Interconnected power system with the introduction of 1,000,000 EVs
NOTE: [1]The systems refers to the load of 2017 with the addition of the charging load [2]The charging load refers to urban transportation with small size EVs, with reference vehicle BMWi3 (2016)[3]The mobility utilized in this study is equivalent to 9,723 km/year (2015) which is recessed and while the economy recovers it is expected to be higher

Here must be noted that proper temporal load allocation imposed by smart charging managed by PEV aggregators, as well as the improvement of efficiency in EVs would drive these numbers down significantly. Furthermore, in order to achieve a smarter load allocation of PEV charging it is necessary to use optimization tools that approach the power generation and the EV fleet operation as an integrated system allocating the charging load based on the system congestion and the hourly marginal price of electricity. In addition, the calculation is assuming a mobility trend of urban driving with small EVs like BMWi3 and thus, we expect the resulting charging load to be higher once other larger vehicles are substituted with electric ones. Moreover, in order to have a better picture for the Greek fleet, the Greek ministry of transport must perform mobility surveys which should be publicly available and updated regularly to reflect behavioral changes. Such surveys are necessary to depict the actual mobility behavior of drivers per vehicle segment, as the temporal and spatial behavior of a national fleet is both affected by the cultural, societal and labor market peculiarities of each country. Such studies would be able to improve the quality of predictions of both environmental and economic impact of EV introduction and therefore help the authorities to plan for the future and promote policies that are better tailored to their expected result.

References

[1] *International Electrotechnical Commission (IEC)*, (2010),"IEC 61851-1:2010" | IEC Webstore [Online]; [cited2018Jan29]. Available online at: https://webstore.iec.ch/publication/6029

[2*] CIRCUTOR SA* , "Charging modes (IEC-61851-1)", Available online at: http://circutor.com/en/training/electric-vehicle/charging-modes-iec-61851-1

[3] C. Falvo, D. Sbordone, I. Safak Bayram, M. Devetsikiotis, (2014), "EV Charging Stations and Modes: International Standards", *International Symposium on Power Electronics, Electrical Drives*, (*Automation and Motion* 978-1-4799-4749-2/14/2014 IEEE)

[4] *Bender Benelux B.V.*, "Overview of charging modes and protective measures - Charging Brochure", Available online at: https://graphicsurgery.nl/sites/default/files/downloads/Charge%20mode%20overview.pdf

[5] *International Electrotechnical Commission (IEC)*, (2008), "IEC 62335:2008" "Circuit breakers - Switched protective earth portable residual current devices for class I and battery powered vehicle applications"

[6] *International Electrotechnical Commission (IEC)*, (2014), "IEC 62196: (a) IEC 62196-1:2014" "Plugs, socket-outlets, vehicle connectors and vehicle inlets - Conductive charging of electric vehicles - Part 1: General requirements", (b) IEC 62196-2:2016 "Plugs, socket-outlets, vehicle connectors and vehicle inlets - Conductive charging of electric vehicles - Part 2: Dimensional compatibility and interchangeability requirements for a.c. pin and contact-tube accessories", (c) IEC 62196-3:2014 "Plugs, socket-outlets, vehicle connectors and vehicle inlets -

Conductive charging of electric vehicles - Part 3: Dimensional compatibility and interchangeability requirements for d.c. and a.c./d.c. pin and contact-tube vehicle couplers”, Content Analysis available online at: https://wiki2.org/en/IEC_62196

[7] *CHAdeMO Association*, https://www.chademo.com

[8] *CHAdeMO Association*, (2018), “Certified Charger List”, Available online at: https://www.chademo.com/wp2016/wp-content/uploads/pdf/Certified_charger.pdf

[9] D. Herron, “EV DC Fast Charging standards – CHAdeMO, CCS, SAE Combo, Tesla Supercharger, etc”, *Green Transportation info, “Range Confidence: Charge Fast, Drive Far, with your Electric Car”*, Available online at: https://greentransportation.info/ev-charging/range-confidence/chap8-tech/ev-dc-fast-charging-standards-chademo-ccs-sae-combo-tesla-supercharger-etc.html

[10] H.T. Berge, (2016), “Europe's EV infrastructure check list”, *Power Engineering International*, Available online at: http://www.powerengineeringint.com/articles/print/volume-24/issue-10/features/europe-s-ev-infrastructure-checklist.html?utm_source=Daily+News+mailing+list&utm_campaign=72671f22ad-EMAIL_CAMPAIGN_2016_11_18&utm_medium=email&utm_term=0_4eff22fd09-72671f22ad-129411197

[11] S. Irish, (2017) “V2G: The role for EVs in future energy supply and demand”, *Renewable Energy Focus*, *Elsevier Ltd*., Available Online at: http://www.renewableenergyfocus.com/view/45571/v2g-the-role-for-evs-in-future-energy-supply-and-demand/

[12] E. Schmidt, (2017), “The Impact Of Growing Electric Vehicle Adoption On Electric Utility Grids”, *FleetCarma-Electric Utility Segment*, Available online at: https://www.fleetcarma.com/impact-growing-electric-vehicle-adoption-electric-utility-grids/

[13] B. Lawson, “Vehicle to Grid (V2G) Energy Transfer- A seductive idea, but what's in it for me - (or anybody)?”, *Electropaedia, Woodbank Communications Ltd*, Available online at: http://www.mpoweruk.com/v2g.htm

[14] N. Zart, (2017), “Batteries Keep On Getting Cheaper”, *CleanTechnica*, *Sustainable Enterprises Media, Inc.*, Available online at: https://cleantechnica.com/2017/12/11/batteries-keep-getting-cheaper/

[15] S. Hanley, (2017), “European Vehicle-To-Grid Plan Pays Off For Electric Car Owners & Extends Battery Life”, *CleanTechnica*, *Sustainable Enterprises Media, Inc.*, Available online at: https://cleantechnica.com/2017/08/18/european-vehicle-grid-plan-pays-off-electric-car-owners-extends-battery-life/

[16] *International Electrotechnical* Commission (IEC), (2011), “A step forward for global EV roll-out *:* IEC International Standard for EV charging”, *News release – 2011 n. 04,* Available online at: http://www.iec.ch/newslog/2011/nr0411.htm

[17] A. Ahmad, Z. Ahmad Khan, M. Saad Alam & S. Khateeb, (2018) “A Review of the Electric Vehicle Charging Techniques, Standards, Progression and Evolution of EV Technologies in Germany”, (2018), *Smart Science*, v. 6:1, p. 36-53, Available online at: https://doi.org/10.1080/23080477.2017.1420132

[18] *International Electrotechnical* Commission (IEC), (2017), “IEC 61851-1:2017: Electric vehicle conductive charging system – part 1: general requirements”.

[19] C. Toepfer, “SAE electric vehicle conductive charge coupler”, *Soc Automot Eng*. v. 09;1, p. 776–790”.
[20] C. Qiu, H.T. Chau, C. Liu, et al., (2013), ”Overview of wireless power transfer for electric vehicle charging”. *Electr Veh Sym pExhib (EVS27)*, 2013 World, v. 7, p. 1–9.

[21] A. Neves, D.M. Sousa, A. Roque, et al.,(2011), “Analysis of an inductive charging system for a commercial electric vehicle*”. Proc 2011 14th Eur Conf Power Electron* Appl.2011, v. 48(7), p. 1–10.

[22] H-Y Mak, Y. Rong, Z-JM. Shen, (2012), “Infrastructure planning for electric vehicles with battery swapping”. *SSRNElectron J. 2012*.

[23] Sarker MR, Pandzic H, Ortega-Vazquez MA., (2013), “Electric vehicle battery swapping station: Business case and optimization model”. *2013 International Conference on Connected Vehicles and Expo, ICCVE 2013* –Proceedings 2013 p. 289–294.

[24] UL 2202, (2018) “Standard for Electric Vehicle (EV) Charging System Equipment” [Online]; [cited 2018Jan29].Available online at: https://standardscatalog.ul.com/standards/en/standard_2202_2

[25] UL 2251, (2018), “Standard for Plugs, Receptacles, and Couplers for Electric Vehicles” [Online]; [cited 2018Jan29].Available online at:

https://standardscatalog.ul.com/standards/en/standard_2251_4

[26] UL 2594, (2018), "Standard for Electric Vehicle Supply Equipment" [Online]; [cited 2018Jan29]. Available online at: https://standardscatalog.ul.com/standards/en/standard_2594_2

[27] UL 2734, (2018), "Outline for Connectors and Service Plugs for Use with On-Board Electrical Vehicle (EV) Charging Systems" [Online]; [cited 2018Jan29]. Available online at: https://standardscatalog.ul.com/standards/en/outline_2734_3

[28] UL 2871, (2017), "Outline of Investigation for Electric Vehicle(EV) Service and Production Chargers" [Online]; [cited2017 Jan29]. Available online at: https://standardscatalog.ul.com/standards/en/outline_2871_1

[29] UL 9741, (2017), "Outline of Investigation for Bidirectional Electric Vehicle (EV) Charging System Equipment" [Online]; [cited 2017 Nov 30]. Available online at: https://standardscatalog.ul.com/standards/en/outline_9741_1

[30] S. Guinn, (2017), "EV charging stations: Staying safe", *EVobsession*, Available online at: https://evobsession.com/ev-charging-stations-staying-safe/

[31] S Kjosevski, A. Kostikj, A. Kochov, "Risks and safety issues related to use of electric and hybrid Vehicles", *University Mother Teresa in Skopje- Faculty of Mechanical Engineering, Ss. Cyril and Methodius University in Skopje*, Former Yugoslavic Republic of Macedonia

[32] *International Electrotechnical Commission (IEC)* , (2018), "IEC 60364-7-722:2015", "Low-voltage electrical installations - Part 7-722: Requirements for special installations or locations - Supplies for electric vehicles" [Online]; [cited 2018 Feb 26]. Available online at: https://webstore.iec.ch/publication/21884&preview=1

[33] B. Lawson, "Electric Vehicle Charging Infrastructure", Electropaedia, Woodbank Communications Ltd, Available online at: http://www.mpoweruk.com/infrastructure.htm

[34] N. Juul, G. Pantuso, J. E. Banning Iversen and T. K. Boomsma, (2015), "Strategies for Charging Electric Vehicles in the Electricity Market", *International Journal of Sustainable Energy Planning and Management,* v. 07 2015, p.71-78,

[35] T.K. Boomsma, N. Juul, and S.E. Fleten, (2014), "Bidding in sequential electricity markets: The Nordic case", *European Journal of Operations Research,* v. 238 (2014), pa. 797–809. Available online at: http://dx.doi.org/10.1016/j.ejor.2014.04.027

[36] S. E. Fleten, T. K. Kristoffersen, (2007), "Stochastic programming for optimizing bidding strategies of a Nordic hydropower producer", *European Journal of Operational Research,* v.18(2)(2007), p. 916-928, Available online at: http://dx.doi.org/ 10.1016/j.ejor.2006.08.023

[37] D. Ladurantaye, M. de Gendreau, J.Y Potvin JY, (2007), "Strategic bidding for price-taker hydroelectricity producers", *IEEE Transactions on Power Systems,* v. 22(4) (2007), p. 2187-2203. Available online at: http://dx.doi.org/10.1109/TPWRS.2007.907457

[38] *Internation Energy Agency*, (2017), "IEA: Global EV outlook 2017"

[39] M. Cheng et al., (2016)"Benefits of using virtual energy storage system for power system frequency response". *Appl Energy (2016)*, Available online at: http://dx.doi.org/10.1016/j.apenergy.2016.06.113

[40] A. S. Brouwer, T. Kuramochi , M. Van den Broek, A. Faaij, (2013), "Fulfilling the electricity demand of electric vehicles in the long term future: an evaluation of centralized and decentralized power supply systems". *Appl Energy2013*, v.107, p.33–51.

[41] D. Wu, D. C. Aliprantis, and L. Ying, (2012), "Load Scheduling and Dispatch for Aggregators of Plug-In Electric Vehicles", *IEEE TRANSACTIONS ON SMART GRID*, v.3, n.1 (2012)

[42] Y. Mu, J. Wu, N. Jenkins, H. Jia, C. Wang, (2014), "A Spatial–Temporal model for grid impact analysis of plug-in electric vehicles"., *Appl Energy 2014*, v.114(February), p.456–465.

[43] Hu SR, Wang CM., (2008), "Vehicle detector deployment strategies for the estimation of network Origin destination demands using partial link traffic counts". *IEEE Trans Intell Transp Syst 2008*, v.9(2), p.288–300.

[44] Seungkirl B, Hyunmyung K, Yongtaek L., "Multiple-vehicle origin-destination matrix estimation from traffic counts using genetic algorithm". *J TranspEng 2004*, v.130(3), p.339–347.

[45] Y. Kudoh, H. Ishitani, R. Matsuhashi, Y. Yoshida, K. Morita, S. Katsuki, et al. ”Environmental evaluation of introducing electric vehicles using a dynamic traffic flow model”. *Appl Energy 2001*, v.69(2), p.145–159

[46] EU Merge Project, Deliverable 2.1: “Modelling Electric Storage devices for electric vehicles”, 2010, Task. Rep.; 2010

[47] Sharma I, Canizares C, Bhattacharya K. “Smart charging of PEVs penetrating into residential distribution systems”. IEEE Trans Smart Grid 2014;5(3):1196–209

.

[48] J . de Hoog, T. Alpcan, M. Brazil, D. Thomas, I. Mareels, (2014), “Optimal charging of electric vehicles taking distribution network constraints into account”, IEEE Trans Power Syst 2014; vol.Early Access Online.

[49] Masoum MAS, Moses PS, Hajforoosh S. “Distribution transformer stress insmart grid with coordinated charging of Plug-In Electric Vehicles”. In:Innovative Smart Grid Technologies (ISGT), 2012 IEEE PES; 2012. p. 1–8.

[50] K. Fell *et al.*, “Assessment of plug-in electric vehicle integration with ISO/RTO systems,” KEMA, Inc. and ISO/RTO Council, Mar. 2010 [Online]. Available online at: http://www.isorto.org

[51] Sekyung Han*,* , Soohee Han, and Kaoru Sezaki*,* (2010),“Development of an Optimal Vehicle-to-Grid Aggregator for Frequency Regulation”, *IEEE TRANSACTIONS ON SMART GRID, VOL. 1, NO. 1, JUNE 2010 65*

[52] Ehsani M, Falahi M, Lotfifard S., (2012,)“Vehicle to grid services: potential and applications”. Energies 2012;5:4076–90.

[53] *International Electrotechnical Commission* (IEC), (2012) “Grid integration of large capacity renewable energy sources and use of large-capacity electrical energy storage”. White paper 3; 2012.

[54] F. Mwasilu et al. “Renewable and Sustainable Energy Reviews 34 (2014) 501–516”

[55] E. Xydas, C. Marmaras, L. M. Cipcigan, (2016), “A multi-agent based scheduling algorithm for adaptive electric vehicles charging”, *Applied Energy v.*177 p.354–365

[56]Vasirani M, Kota R, Cavalcante RLG, Ossowski S, Jennings NR, (2013),“An agent-based approach to virtual power plants of wind power generators and electric vehicles”, *IEEE Trans Smart Grid2013*; v.4(3), p.1314–1322.

[57] Xin Gong, Tao Lin, Binghua Su, (2011),“Survey on the impact of Electric Vehicles on Power Distribution Grid”, 978-1-4244-9690-7/11/2011 IEEE

[58] F. Lambert, “Secondary Distribution Impacts of Residential Electric Vehicle Charging,” Public Interest Energy Res. (PIER), California Energy Commission, Project no. 373, 1999.

[59] A. Lucas∗, F. Bonavitacola, E. Kotsakis, G. Fulli, (2015), “Grid harmonic impact of multiple electric vehicle fast charging”, *Electric Power Systems Research* v.127 p. 3–21,

[60]D. K. Jackson *et al.*, “A multi rate digital controller for a 1.5-kW electric vehicle battery charger,” *IEEE Trans. Power Electron.*, vol. 12, pp.1000–1006, Nov. 1997.

[61] F. Musavi, M. Edington, W. Eberle, W.G. Dunford, S. Member, Evaluation and efficiency comparison of front end AC–DC plug-in hybrid charger topologies, IEEE Trans. Smart Grid 4 (1) (2012) 413–421.

[62] E. Sortomme, M. M. Hindi, S. D. James MacPherson and S. S. Venkata, “Coordinated Charging of Plug-In Hybrid Electric Vehicles to Minimize Distribution System Losses”, IEEE TRANSACTIONS ON SMART GRID, VOL. 2, NO. 1, MARCH 2011

[63] T. Hoevenaars, K. LeDoux, M. Colosino, “Interpreting IEEE Std 519 and Meeting its Harmonic Limits in VFD Applications” , Available Online at: Interpreting IEEE Std 519 and Meeting its Harmonic Limits

[64] “Total Harmonic Distortion (THD) and Total Demand Distortion (TDD)”, Elnet Fenix-pro. Available online at: http://www.elnet.cc/thd-and-tdd/

[65] “K-Factor Defined” (2000),XiTRON Technologies Manufacturers of Engineering and Production Test Equipment APPLICATION NOTE, Available online at: http://www.xitrontech.com/assets/002/5787.pdf

[66] M. A. S. Masoum, P. S. Moses, and S. Deilami, “Load Management in Smart Grids Considering Harmonic Distortion and Transformer Derating”, 978-1-4244-6266-7/10/$26.00 (2010) IEEE

[67] E. Schmidt, “The Impact Of Growing Electric Vehicle Adoption On Electric Utility Grids”, (2017), FleetCarma, Available online at: https://www.fleetcarma.com/impact-growing-electric-vehicle-adoption-electric-utility-grids/

[68] Ofgem: “Upgrading Our Energy System –Smart systems and Flexibility Plan Systems and Flexibility Plan”, July 2017, Available online at: https://www.ofgem.gov.uk/system/files/docs/2017/07/upgrading_our_energy_system_-_smart_systems_and_flexibility_plan.pdf

[69] J. C. Spoelstra, Master Thesis,“Charging behaviour of Dutch EV drivers - A study into the charging behaviour of Dutch EV drivers and factors that influence this behavior”,(2014), Utrecht University, Available Online at: https://www.rvo.nl/sites/default/files/2014/10/Master%20Thesis%20Charging%20behaviour%20of%20Dutch%20EV%20drivers.pdf

[70] Pearre, N. S., Kempton, W., Guensler, R. L., Elango, V. V. (2011) “Electric vehicles: How much range is required for a day’s driving?”, Transportation Research Part C, Vol. 19 No. 6 (2011) pp. 1171 – 1184.

[71] He, L., Chen, W., Conzelmann, G. (2012) “Impact of vehicle usage on consumer choice of hybrid electric vehicles.”, Transportation Research Part D, Vol. 17 (2012) pp. 208 – 214.

[72] Hahnel, U. J. J., Gölz, S., Spada, H. (2013) “How accurate are drivers’ predictions of their own mobility? Accounting for psychological factors in the development of intelligent charging technology for electrical vehicles”. Transportation Research Part A, 48 (2013) pp. 123 – 131.

[73] Smart, J., Powell, W., Schey, S. (2013) “Extended range electric vehicle driving and charging behaviour observed early in the EV project.”, SAE international technical paper 2013-01-1441.

[74] Franke, T., Krems, J.F. (2013a) “Understanding charging behavior of electric vehicle users.” Transportation Research Part F, 21 (2013) pp. 75 – 89.

[75] IEEE, IEEE 519-1992, “IEEE Recommended Practices and Requirements for Harmonics Control in Electric Power Systems (ANSI)”, IEEE, New York, NY, 1992.

[76] IEC, IEC 61000-3-12: “Electromagnetic Compatibility (EMC)—Part 3–12: Limits—Limits for Harmonic Currents Produced by Equipment Connected to Public Low-Voltage Systems with Input Current > 16 A and ≤75 A per Phase”,(2011).

[77] IEC, IEC 61000-2-4, “Electromagnetic Compatibility (EMC)—Part 2–4: Environment—Compatibility Levels in Industrial Plants for Low-frequency Conducted Disturbances”, (2014).

[78] J.A. Orr, A.E. Emanuel, D.J. Pileggi, “Current harmonics, voltage distortion, and powers associated with electric vehicle battery chargers distributed on the residential power system”, IEEE Trans. Ind. Appl. 20 (4) (1984)727–734.

[79] *Electric Power Research Institute*, (1997) “The Harmonic Impact of Electric VehicleBattery Charging”, TR-108540, Electric Power Research Institute, Palo Alto, CA,August, 1997, pp. 1–184.

[80] C.H. Dharmakeerthi, N. Mithulananthan, T.K. Saha, “Impact of electric vehicle fast charging on power system voltage stability”, Int. J. Electr. Power Energy Syst. 57 (2014) 241–249.

[81] R. Vicini, O. Micheloud, H. Kumar, A. Kwasinski, “Transformer and home energy management systems to lessen electrical vehicle impact on the grid”, IET Gener. Transm. Distrib., 2012, Vol. 6, Iss. 12, pp. 1202–1208

[82] Qazi R. Hamid and Javier A. Barria, Member, “Congestion Avoidance for Recharging Electric Vehicles Using Smoothed Particle Hydrodynamics”, IEEE TRANSACTIONS ON POWER SYSTEMS, VOL. 31, NO. 2, MARCH 2016

[83] “Combined Charging System 1.0 Specification - CCS 1.0”, Coordination Office Charging Interface, c/o Carmeq GmbH

[84] “Design Guide for Combined Charging System Combined Charging System” Edited by Matthias Kübel on behalf of Initiative Charging Interface, 02.06.2015 Date: 2015-06-02

[85] SAE: “Electric Vehicle and Plug in Hybrid Electric Vehicle Conductive Charge Coupler”, Available online at:
http://grouper.ieee.org/groups/earthobservationsSCC/IEEE_SAE_J1772_Update_10_02_08_Gery_Kissel.pdf

[86] *Bundesamtfür Energiewirtschaft* (Switzerland), (2001)"Internationaler Standard für das Laden von Elektrofahrzeugen - Schlussbericht", , (In German), Available online at:
http://www.bfe.admin.ch/php/modules/enet/streamfile.php?file=000000009155.pdf&name=000000210379.pdf

[87] *Mennekes*, ”Ladesysteme für Elektrofahrzeuge”, Specification of Mennekes plugin connectors, (in German) Avaialable online at:
https://www.pedelecforum.de/forum/index.php?attachments/spezifikation_mennekes_ladesysteme_rev10-pdf.100167/

[88] X. Navarro, (2009),”The European standard charging plug for cars is selected after Mennekes design”, Autoblog – Oath Inc.(20/05/2009) Available online at: https://www.autoblog.com/2009/05/20/the-european-standard-charging-plug-for-cars-is-selected-after-m/

[89] DIN EN 62196-2, ”Plugs, socket-outlets, vehicle connectors and vehicle inlets – Conductive charging of electric vehicles”, VDE 0623-5-2:2017-11

[90] Scame Electrical Solutions, ”Scame Infotech, Libera Series - Connectors For Electric Vehicles”. Available online at: http://www.scame.com/doc/info_ser/LIB-GB-10.pdf

[91] *Schneider Electric “EV Plug Alliance announces new members”*, *Press release, 2010-05-31.* Available online at:
http://www2.schneider-electric.com/corporate/en/press/press-releases/viewer-press-releases.page?c_filepath=/templatedata/Content/Press_Release/data/en/shared/2010/05/20100531_ev_plug_alliance_announces_new_members.xml .

[92] *Schneider Electric* “*EV Plug Alliance announces availability of products and new members*”, *Press release, 2010-09-20.* Available online at:
http://www2.schneider-electric.com/corporate/en/press/press-releases/viewer-press-releases.page?c_filepath=/templatedata/Content/Press_Release/data/en/shared/2010/09/20100920_ev_plug_alliance_announces_availability_of_products_and_new_members.xml

[93] *European Automobile Manufacturers’ Association (ACEA), “ACEA position and recommendations for the standardization of the charging of electrically chargeable vehicles”, Brussels, 2011-03-02.* Available online at:
https://web.archive.org/web/20121202043526/http://www.acea.be/images/uploads/files/charging_20110511.pdf

[94] J.P. Beaudet, “Bornes de recharge : un marché en pleine evolution”, Article at www.filiere-3e.fr, 2015-10-06. Available online at http://www.filiere-3e.fr/2015/10/06/bornes-de-recharge-un-marche-en-pleine-evolution/

[95] C. Noya, “Renault abandona el formato de recarga Scame”, www.forococheselectricos.com , 2015-11-08. Available online at:
http://forococheselectricos.com/2015/11/renault-abandona-el-formato-de-recarga-scame.html

[96] State grid Corporation of China, (2013), "EV infrastructure and standardization in China!" (Oct.2013)

[97] P. Richardson, D. Flynn, and A. Keane, (2012), "Local versus centralized charging strategies for electric vehicles in low voltage distribution systems," *IEEE Trans. Smart Grid*, vol. 3, no. 2, pp. 1020–1028, 2012.

[98] *IEEE*, (1995), "IEEE Guide for Loading Mineral-Oil-Immersed Transformers", *IEEE Std C57.91-1995*

[99] R. Walling, G. B. Shattuck, "Distribution Transformer Thermal Behavior and Aging in Local-Delivery Distribution Systems,"19th International Conference on Electricity Distribution

[100] M. Rutherford et al., (2011),"The Impact of Electric Vehicle Battery Charging on Distribution Transformers", *Twenty-Sixth Annual IEEE Applied Power Electronics Conference and Exposition (APEC),* Available online at:
https://www.semanticscholar.org/paper/The-impact-of-Electric-Vehicle-battery-charging-on-Rutherford-Yousefzadeh/22efc46d15a7391595c69524251d70d19ca4a9cd

[101] Diamond D. (2009),"The impact of government incentives for hybrid-electric vehicles: evidence from US states." *Energy Policy* 2009;37(3):972–983.

[102] I. S. Bayram, A. Tajer, M. Abdallah and K. Qaraqe, (2015),"Capacity Planning Frameworks for Electric Vehicle Charging Stations with Multi-Class Customers", *IEEE TRANSACTIONS ON SMART GRID*

[103] "Ontario's electric car charge station 'screw up'" http://torontosun.com/news/provincial/ont-electric-car-charging-program-was-screw-up-ev-drivers

[104] E. Figenbaum, M. Kolbenstvedt, (2016), "Learning from Norwegian Battery Electric and Plug-in Hybrid Vehicle users Results from a survey of vehicle owners", TØI rapport 1492/2016 available online at:
https://www.toi.no/getfile.php?mmfileid=43161

[105] I. S. Bayram, G. Michailidis, M. Devetsikiotis*,* F. Granelli, (2013), "Electric Power Allocation in a Network of Fast Charging Stations", *IEEE Journal on Selected Areas in Communications (2013),* v.31, issue7.

[106] X. Xi and R. Sioshansi, (2014), “Using price-based signals to control plugin electric vehicle fleet charging,” *IEEE Transactions on Smart Grid*, no. 99, pp. 1–15,

[107] Autolib’, (2016), “Autolib’ Metropole Avance Avec Vous – Rapport D’activite 2016”

[108] Virta Global, “Web Portal”, Available online at: https://www.virta.global/news/charge-without-a-wallet-virtas-mobile-app

[109] Spark, “Web Portal”, Available online at: https://spark.bg

[110] *UAB Ride Share Bulgaria*, (2018)“E-car rental service Spark Bulgaria targets 250 cars, 40,000 users in 2019”, *SeeNews,* Available online at: https://seenews.com/news/e-car-rental-service-spark-bulgaria-targets-250-cars-40000-users-in-2019-video-607810

[111] E. Apostolaki-Iosifidou, P. Codani, W. Kempton, (2017), “Measurement of power loss during electric vehicle charging and discharging”, Energy, v. 127(2017), p.730-742, Available online at: http://www.sciencedirect.com/science/article/pii/S0360544217303730

[112] *Enel X*, “Enel X Recharge”, *web portal*, available online at: https://www.enelx.com/content/enel-x/en/electric-mobility/charging-services-description.html

5. Cost Analysis of Production and Use of EVs

A. Acquisition Cost and Cost of Ownership

The cost of EVs in the market is an important indicator for their production costs. That is valid because automakers, as OEMs, are adjusting their production based on the indicated demand. Various analyses showed that, for the automakers, the adaptation phase to the new vehicle production has not yet elapsed. The already matured market of vehicle and powertrain production is expected to marginally push the EV construction cost further downwards.

Expectations for base vehicle cost reduction include body and chassis production cost reductions, which are expected to drop for battery electric cars, due to simpler design and easier manufacturing. For ICEs, these costs will slightly increase, as a result of additional effort of the industry to reduce the vehicle weight aiming in increased fuel efficiency to meet CO_2 emissions and fuel economy requirements. Such Chassis have been developed by various OEMs with the most research and cost efficient material so far been carbon fiber. However, even though there are certain OEMs moving towards reduction cost of the low weight car chassis, like Far-UK [3], so far industry is offering the same category vehicles with the new lightweight carbon fiber chassis in non-cost effective value of more than double the price in comparison to conventional constructions. For example, light weight alfa Romeo 4C is priced at $65,000 in contrast with the conventional $25,000 Mazda MX-5 Miata. Market experts expect that the commercialization of carbon fiber chassis due to the achievement of economies of scale will be achieved approximately in 2025 when the OEMs will include it in large scale production vehicles of more than 100,000 units per year [4].

It is also expected that electric powertrain costs for BEVs, such as motors, inverters and electronics, to drop by about 20-25% by 2030, mainly due to volume manufacturing [1]. A study by the investment bank UBS found out that EV powertrains are $4,600 cheaper to produce than the cost the vehicle industry endures, leaving a lot of reduction potential to be exploited in the future. [5]

The most expensive component of electric vehicles is currently the battery, which we expect to contribute between 18%-23% of the price by 2030, down from around 50% at present. [1] Parameters of battery technology market and development that will lead to such price reductions have been further analyzed in chapters 2 and 3.

BNEF also assumes high production EV volumes in the future for its EV price estimations, describing outputs of more than 100,000 vehicles per year. At the moment, manufacturers do not produce EVs at this scale, so unit costs for body and other parts are currently higher for EVs than ICEs. BNEF estimates that by 2020-22 production capacity of electric vehicles will scale up for the more aggressive car makers, while expecting a premium of 20 - 30% in the next three to four years to the component manufacturing cost of EVs.

Even though that Signs of market parity of ICE vehicles and EVs are evident during 2018 it is estimated that these prices do not reflect economically viable production operations. Specifically, the study by UBS also estimated that the car manufacturers lose a great amount of money due to the lack of optimal production scale ups. Specifically, General Motors is estimated to endure losses $7,400 with every Chevrolet Bolt model sold however the development of the production processes by 2025 though, it should lead to a 5% profit margin, using the earnings before interest and tax (EBIT) measure. Tesla’s Model 3 is also expected to lose $2,800 per vehicle in its base version, which is expected to be marketed at $35,000, but is expected to compensate with its other versions which will exceed the marginal cost per vehicle of Tesla’s production of $41,000 [5].

BNEF estimates that in the US, BEVs and ICEs in all segments will cost the same around 2026. In Europe, medium vehicles should reach price parity earlier – by 2025 – compared to small and medium cars and SUVs. In particular, small BEVs will not be price competitive until late in the decade, due to the low ICE prices in the segment. [1]

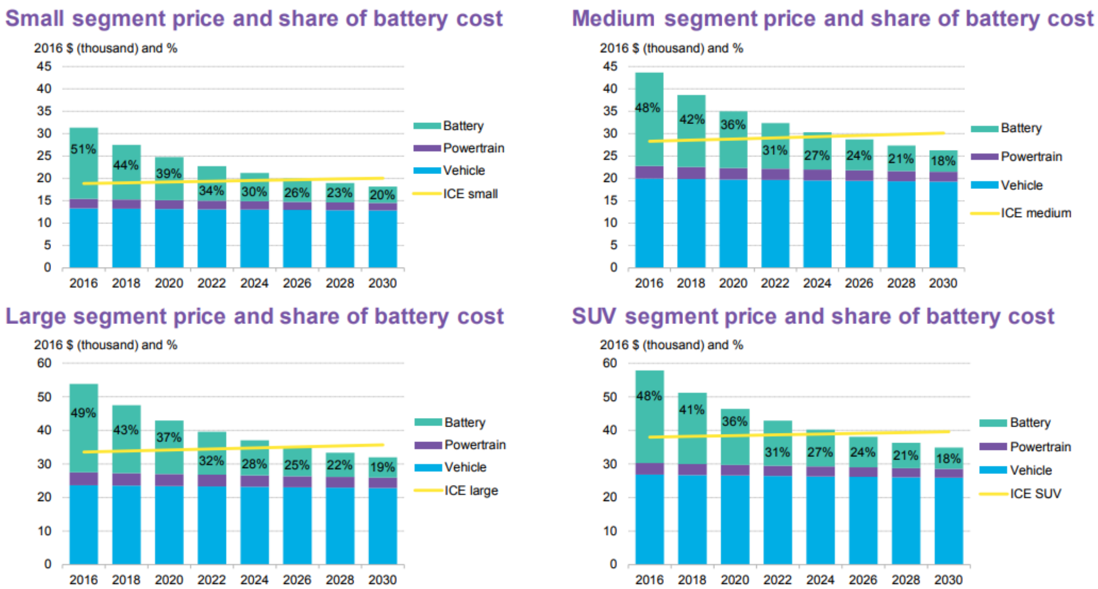


Figure 101 BEV and ICE pre-tax prices in the US and the share of battery costs in the vehicle price (Source: BNEF)

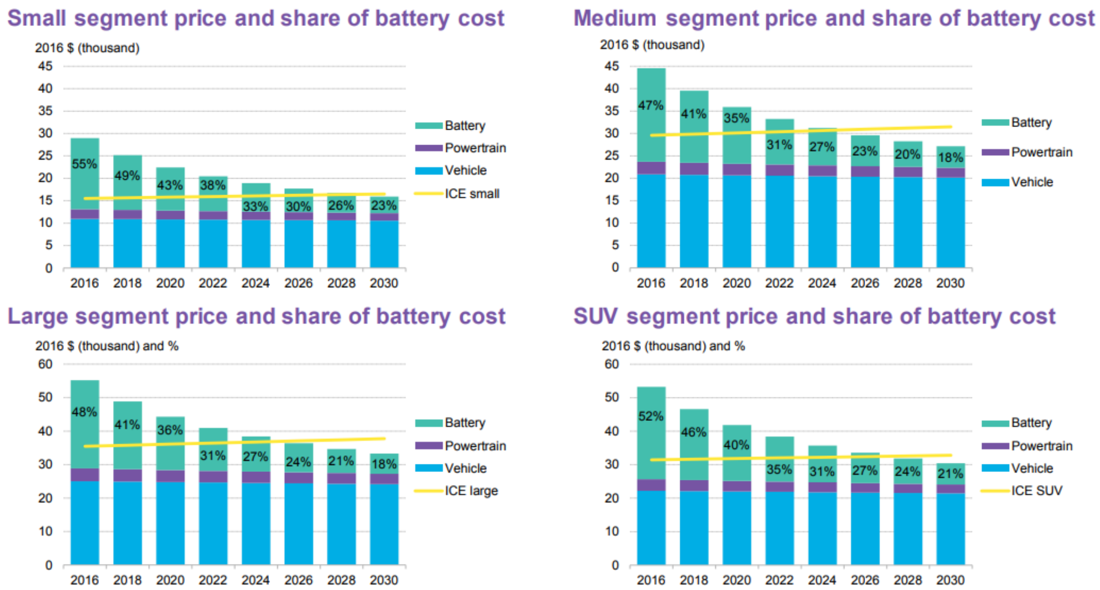


Figure 102 BEV and ICE pre-tax prices in the EU and the share of battery costs in the vehicle price (source: BNEF)

Market Analysts expect battery electric vehicles to reach 15% cheaper than equivalent ICEs by 2030. This comparison, takes into account the assumption that costs for internal combustion engine vehicles will rise slightly in the future to comply with an increasingly stringent regulatory environment. This is supported by analysis from groups like the EPA, NHTSA, and from statements from the car manufacturers [1]. This however as can be observed from figures 73 and 74 is subject to the type of market demand. Markets that are more oriented, based on local demand, towards the production of a specific type of vehicle, would eventually achieve larger price difference between equivalent EV and ICE vehicles. For example, BNEF predicts the difference of EV and ICE vehicle price on the SUV market segment would be 15% ($5,000) in US while in EU would be approximately 7% ($2,000) in 2030. Moreover in both regions, the SUV and large vehicle segments will reach price parity after 2026. This does not seem to have deterred some OEMs, who are planning SUV and crossover BEV launches around 2020. However, several have acknowledged that generating significant profits from EVs will be challenging over the next few years until battery prices drop further. [1]

However, automotive manufacturers could delay this trend by merging or otherwise pooling manufacturing capacity, withdrawing from certain markets and pursuing higher efficiencies in all aspects of their operations. Potential relaxation of fuel economy and emissions regulations could ease these cost pressures and alter the projected pricing dynamics between BEVs and ICEs.

Changing costs will make EVs competitive with their ICE counterparts over the next ten years, but economics alone will not dictate adoption.

B. Operational Cost EVs and Displacement of Conventional ICE Vehicles

The expectations on displacement of Conventional ICE Vehicles by EVs are mainly summarized in BNEF's predictions and can be observed in chapter 3.B "Global Trends and future of EV market". In this section, it is important to identify the operational costs, mainly the cost of energy for propulsion to be the most advantageous benefit that will direct the

EV sales are correlated and should be influenced by petrol prices. As petrol prices declining moving towards a peak oil demand it is evident that the projected ownership cost competition between EVs and conventional ICE vehicles will turn in favor of ICE vehicles. This is due to the fact that EVs are not projected to achieve acquisition value parity with ICE until the mid-late 2020s' and at this point a rapid decline of oil prices driven by the trending electrification of the transport sector would be most probable.

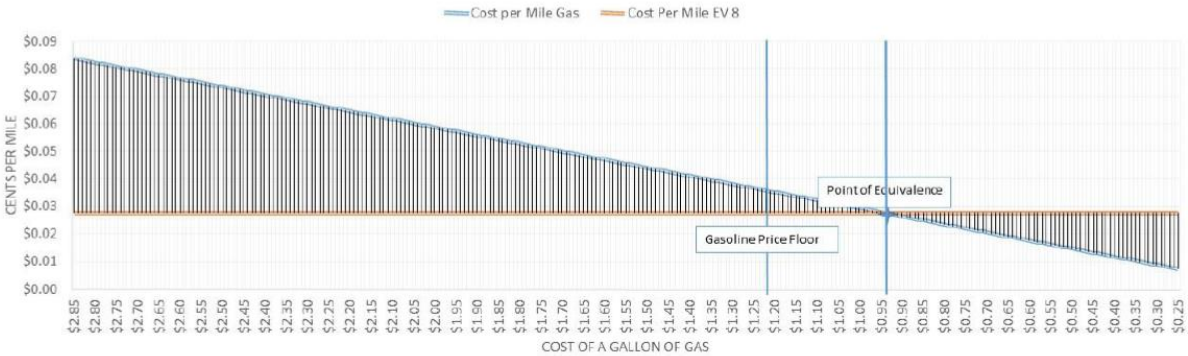


Figure 103 The cost of running a car with electricity vs petrol (source: Cairn ERA)

However, operational cost parity of ICE vehicles with EVs will not be achieved. This can be observed by comparing the operation costs of a Nissan Leaf, which are $0.026 per mile to charge the car (based on US average electricity prices), with the $0.054 per mile worth of petrol consumed by an equivalent size car with excellent mileage like Nissan Versa based on the current petrol price ($1.85/gallon). Petrol would have to reach a price point of $0.93 per gallon before it reaches an equivalent per mile cost to electricity. However, petrol is highly improbable to reach such price levels. This can be observed by decomposing the petrol price, showing that taxes cost $0.49 per gallon (EIA), refining costs $0.40 per gallon (Exxon Mobil) and distribution costs $0.33 per gallon (California Department of Revenue)[2]. Consequently, oil retail vendors cannot offer petrol below $1.22 per gallon because such a transaction would be a loss-making one. However, this petrol floor price could vary due to spatial and micro-economic characteristics of the market, which would formulate a marginal price of oil for which running costs of an ICE vehicle would be competitive to the ones of an EV. In addition this competition between oil/gas prices with electricity could potentially push marginally the electricity prices in retail market upwards as the demand increases and more cost intensive units enter the energy mix.

References

[1] 3. N. Soulopoulos, (2017), “When Will Electric Vehicles be Cheaper than Conventional Vehicles?” Bloomberg New Energy Finance, Executive Summary available online at: http://www.automotivebusiness.com.br/abinteligencia/pdf/EV-Price-Parity-Report.pdf

[2] 15. S. Jaffe, (2016), “EV Transportation Battery Global Overview”, Cairn ERA, - Munich ECarTec presentation, Available online at: https://www.emove360.com/wp-content/uploads/2016/11/Cairn-ERA-Global-EV-Overview-EcoMobility-October-19.pdf

[3] *CW Composites World*, (2014),“Far-UK launches carbon fiber composite automotive chassis”, Available online at: https://www.compositesworld.com/news/far-uk-launches-carbon-fiber-composite-automotive-chassis

[4] B. Berman, (2015), “Where’s the Affordable Carbon Fiber Automobile?-A test drive of the Alfa Romeo 4C reveals what a difference carbon fiber can make in a car.”,MIT Technology Review, Available online at: https://www.technologyreview.com/s/539971/wheres-the-affordable-carbon-fiber-automobile/

[5] N. Winton, (2017), “Electric Car Price Parity Expected Next Year”, *Forbes*, Available online at: https://www.forbes.com/sites/neilwinton/2017/05/22/electric-car-price-parity-expected-next-year-report/#3c5301c47922

6. Environmental impact of EV introduction

Transport represents almost a quarter of Europe's greenhouse gas emissions and is the main cause of air pollution in cities. The transport sector has not seen the same gradual decline in emissions as other sectors: emissions only started to decrease in 2007 and still remain higher than in 1990. Within this sector, road transport is by far the biggest emitter accounting for more than 70% of all GHG emissions from transport in 2014 [13]. Therefore, a high potential of emissions' reduction could be realized by the adoption of electric mobility in EU, given the fact that the energy industry is reducing gradually its carbon intensity and therefore is projected to cover the energy demand of EVs with low-carbon electricity.

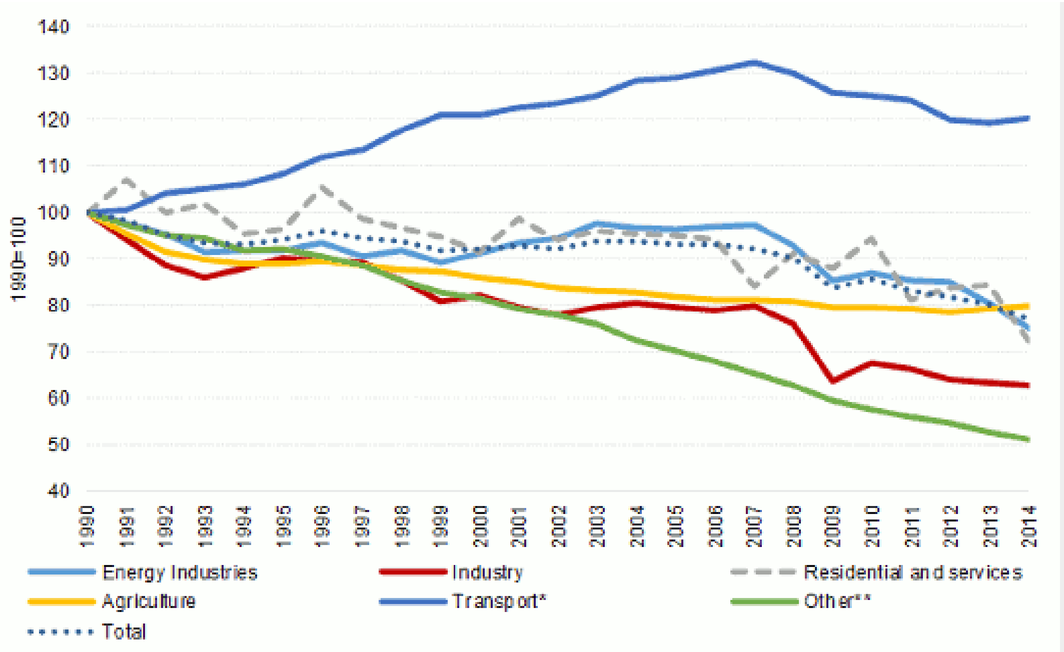


*Figure 104 Sectorial CO2 emissions development in EU in comparison to 1990's levels [13] (Source EEA) Note: Transport includes international aviation but excludes international maritime; ** Other include fugitive emissions from fuels, waste management and indirect CO2 emissions*

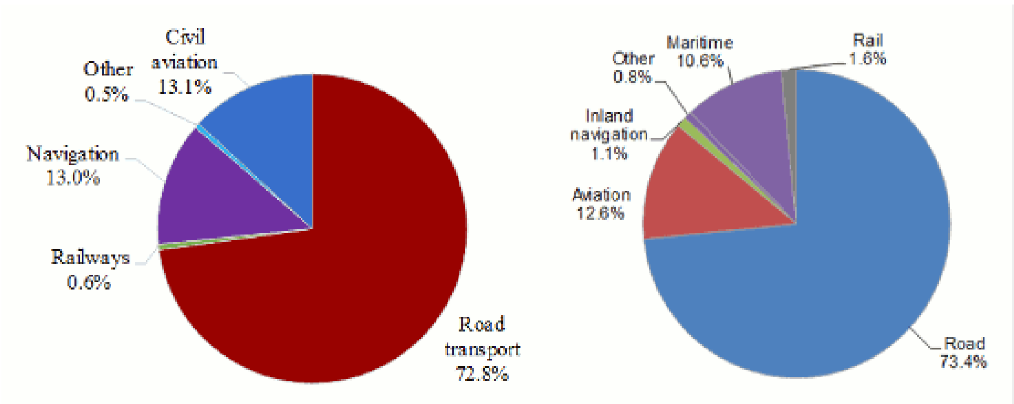


Figure 105 Greenhouse gas emissions from transport by mode in 2014 & Share of transport energy demand by mode in 2014 (%) [13]

Reductions in emissions of local air pollutants from the transportation sector over the past several decades have shown how effective transportation regulations can be. Government regulations worldwide have been responsible for driving the development of emission control technologies for passenger vehicles and heavy-duty trucks that are capable of reducing emissions of local air pollutants by more than 90 percent, assuming test cycle conditions. Developed economies like Europe, Japan, and the United States can lead by example towards the development of world-class conventional pollutant emission standards and technologies. The role of EVs in the emission reduction is expected to be crucial in the near future as the energy system transitions towards renewable energy.

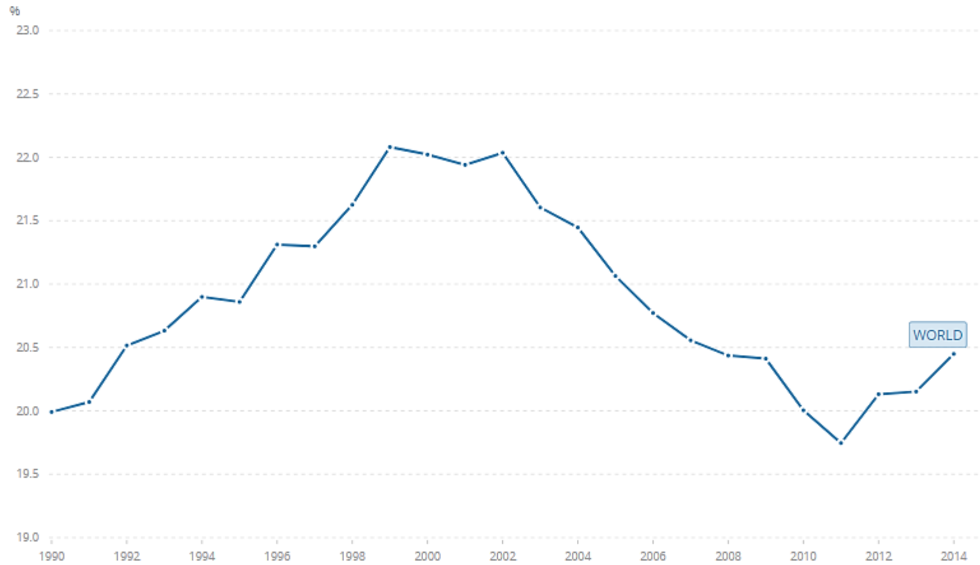


Figure 106 CO2 emissions from transport (% of total fuel combustion), IEA Statistics (Source OECD/IEA 2014)[14]

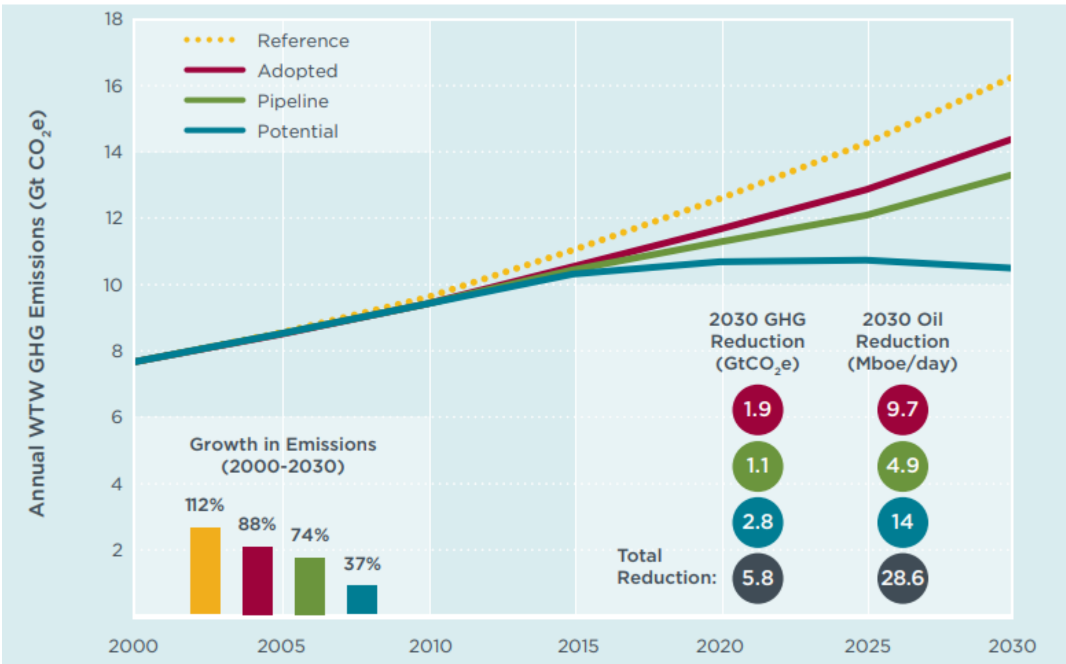


Figure 107 Global Transportation Emission Trajectories based on effect of various policies

Average Age of Vehicle Fleet

In Europe the increasingly tight regulations have resulted in the gradual introduction of more fuel-efficient, less polluting, less noisy and generally safer road vehicles. Hence, a quick replacement of older with new ones, results in an overall improvement of the environmental performance of the vehicle fleet. The average age of the vehicle fleet is therefore an indirect indication of the environmental performance of road transport.

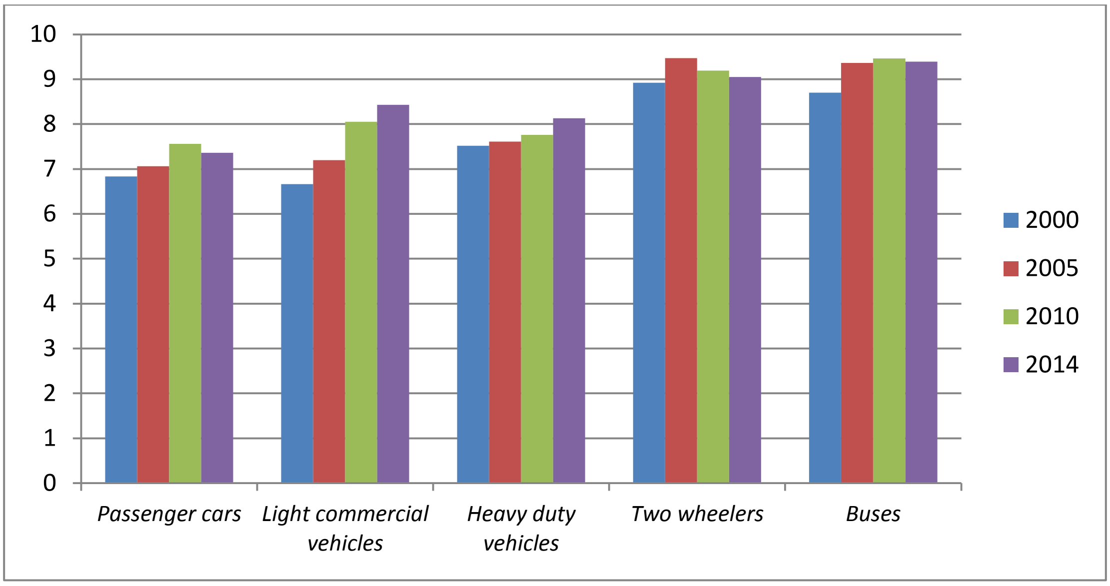


Figure 108 Average age of road vehicles in EU 27. (Source: European Environment Agency)

The average age of Europe's fleet of passenger cars, which indicates their overall efficiency and carbon intensity, after peaking in 2009 with a value of 7.56 years, showed a slight decline (7.36) which depicts in some cases the higher introduction of new vehicles as a result of the recently imposed alternative fuel promotion and transport decarbonization policies. Even though EU is prompting member states to prioritize towards electric mobility which incorporates all these design standards.

In other cases this trend illustrates the higher vehicle scraping rate due to emission penalties passed on consumers through environmentally oriented taxes in combination with the success of public transportation and alternative business models, promoting mobility as a service. However, the analysis of the European Environment Agency showed that the diversification of the consumers is intensified with a large share of them tending to hold on to their vehicles longer than ever before despite the current market development. As a result in 2014 the share of cars aged 10 years or over was generally increasing across Europe's fleet. A report provided by ACEA for vehicle stock in circulation in Europe for 2015 showed that the passenger car fleet is getting even older with an average age of 10.7 years.

However assessing the performance and hence the environmental impact of the vehicle fleet through the average age is not totally accurate and can be regarded only as an indication. This is due to the fact that older vehicles are used less compared to new ones i.e. they have a lower annual mileage. Hence, from an environmental perspective, the performance of the vehicle fleet can be considered somewhat better than the average age suggests.

In addition, the recent development of the Diesel vehicle market shows significant impact on Buses which showed a decline in average age. This decline is expected to intensify in later years with the introduction of alternative fuel solutions mainly CNG and Electricity and the introduction of highly efficient vehicles substituting the national public transportation fleets across the continent. In addition the electrification of the transport sector in combination with the expansion of public transportation is prompting the introduction of more buses which also influences the observed and expected age reduction. However, the ratio of age reduction in the bus segment is not one of substitution of old vehicles but rather one of fleet expansion due to the increased need for buses, as the European public transportation needs has significantly increased, hence the scrappage of old buses in later years have been in some cases suspended. This can be confirmed through the fact that roughly 8% of the EU bus fleet is renewed every year following a typical 8-10 year cycle life for (diesel) buses, while Diesel buses continue to represent the largest part of the urban bus fleet [32]. Thus, the typical life cycle of buses is in many cases exceeded beyond 10 years contributing in the overall HDV age increase as shown in figure 108.

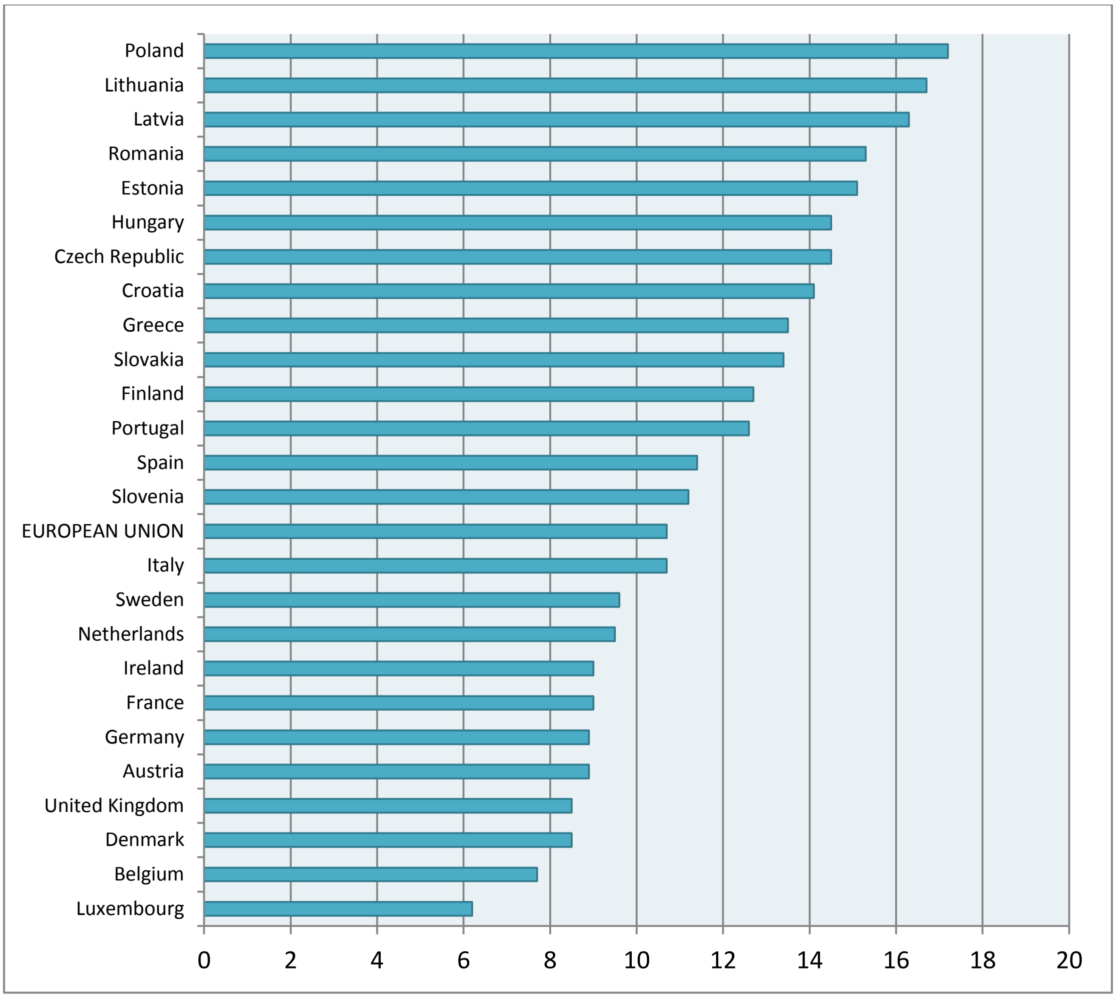


*Figure 109 Average age of passenger cars in circulation for EU Countries (25) (2015) (Source ACEA) [6] * ACEA's data don not include Bulgaria, Cyprus and Malta*

On the other hand the only vehicle categories which showed an increase in vehicle age are commercial and heavy duty vehicles, fact that shows the inability of the heavy vehicle industry to provide the market with a more energy efficient product, while being also effective from a cost-benefit standpoint. Despite the recent effort of automakers to address the development of freight road-transport vehicle technology development, vehicles that will make a market success have yet to be introduced.

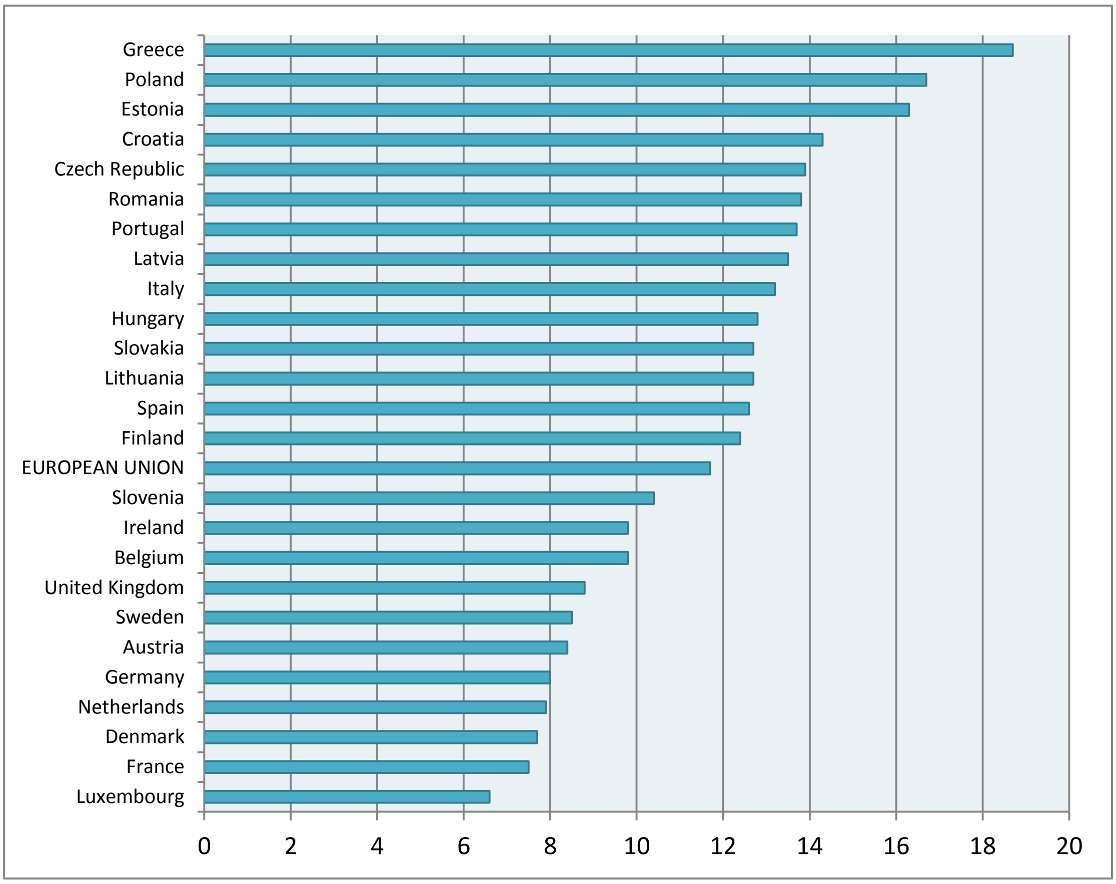


*Figure 110 Average age of medium and heavy commercial vehicles in circulation for EU (25) Countries (2015) (Source ACEA) [6] * ACEA's data don not include Bulgaria, Cyprus and Malta*

Car scrappage schemes, which could potentially prompt the substitution of EU's vehicle fleet and promote electric mobility, have not yet been introduced at EU level. The European Parliament and Council have issued Directive 2000/53/EC on end-of-life vehicles (ELV Directive), which states the need for harmonizing the various measures adopted at country level on the treatment of end-of-life vehicles. In addition, the ELV Directive stresses the need for adopting a Community-wide framework for this purpose, but does not include any specific car scrappage schemes. The ELV Directive, as amended by Directive 2008/53/EC and other Commission Decisions, requires that Member States set up systems to ensure ELVs are treated within authorized treatment facilities, sets progressively higher reuse, recycling and recovery targets and an ultimate recovery target of 95 % by weight by 2015, encourages manufactures to design their vehicles with recyclability in mind, and restricts the use of heavy metals in the manufacture of new vehicles.

Automotive Emission Regulations in EU

Automotive emissions have been regulated in Europe since 1970 with the implementation of the parent European Council Directive 70/220/EEC. This Directive was the result of an intensive period of consultation between member countries of the European Economic Commission (EEC) at that time. At the beginning of the 1970s, the United Nations Economic Committee for Europe (UNECE) established Regulation 15, which, together with its various amendments, delivered the first coherent automotive emissions control policy in Europe for vehicles of less than 3.5 tonnes in mass.

Since the 1970s, the key mechanism by which vehicle air pollutant emissions have been regulated has been through the setting of exhaust emissions limits. As with CO_2 measurements, vehicle conformance with the required limits is checked on the basis of standardized laboratory emissions measurements. The first European Council Directive to specify measures against air pollution from motor vehicles was published in 1970 (EU, 1970). Around 20 years later — in 1992 — the 'Euro' emissions standards were introduced, starting with the 'Euro 1' step, followed, generally, by successively stricter standards: Euro 2 to Euro 6. At present, in 2016, only Euro 6 vehicles can be sold in the EU. At the same time, with all the regulatory improvements in emissions control and specific fuel-efficiency targets, CO_2 emissions targets were set independently for cars and vans (see TERM027 for more information).

Table 17 Table European Emission Standards for Passenger Cars

EU Emission Standards for Passenger Cars (Category M1*)

Stage	Date	CO	HC	HC+NOx	NOx	PM	PN
		g/km					#/km
Compression Ignition (Diesel)							
Euro 1†	1992.07	2.72 (3.16)	-	0.97 (1.13)	-	0.14 (0.18)	-
Euro 2, IDI	1996.01	1.0	-	0.7	-	0.08	-
Euro 2, DI	1996.01[a]	1.0	-	0.9	-	0.10	-
Euro 3	2000.01	0.64	-	0.56	0.50	0.05	-
Euro 4	2005.01	0.50	-	0.30	0.25	0.025	-
Euro 5a	2009.09[b]	0.50	-	0.23	0.18	0.005[f]	-
Euro 5b	2011.09[c]	0.50	-	0.23	0.18	0.005[f]	6.0×10^{11}
Euro 6	2014.09	0.50	-	0.17	0.08	0.005[f]	6.0×10^{11}
Positive Ignition (Gasoline)							
Euro 1†	1992.07	2.72 (3.16)	-	0.97 (1.13)	-	-	-
Euro 2	1996.01	2.2	-	0.5	-	-	-
Euro 3	2000.01	2.30	0.20	-	0.15	-	-
Euro 4	2005.01	1.0	0.10	-	0.08	-	-
Euro 5	2009.09[b]	1.0	0.10[d]	-	0.06	0.005[e,f]	-
Euro 6	2014.09	1.0	0.10[d]	-	0.06	0.005[e,f]	-

* At the Euro 1..4 stages, passenger vehicles > 2,500 kg were type approved as Category N1 vehicles
† Values in brackets are conformity of production (COP) limits
a - until 1999.09.30 (after that date DI engines must meet the IDI limits)
b - 2011.01 for all models
c - 2013.01 for all models
d - and NMHC = 0.068 g/km
e - applicable only to vehicles using DI engines
f - 0.0045 g/km using the PMP measurement procedure

Smoke levels of heavy duty diesel engines were historically controlled using an opacimeter on steady state and free acceleration tests, as specified in Council Directive 72/306/EEC. The legislation imposed maximum limits for the emission of visible smoke. The first gaseous pollutant limits were developed by UNECE in 1982 with the development of Regulation 49, which set the techniques and limits for the control of CO, HC and NOx. The work at UNECE was later taken up by European Council Directive 88/77/EEC, which first established mandatory limits for new types of on-road diesel engines with regard to their gaseous emissions. Directive 91/542/EEC established the first “Euro” based emissions limits for heavy duty engines, including the regulation of particulate matter emissions, as a consequence of the intensive discussions within the activities of Auto Oil I and follow up revisions by the European Council and the Parliament. These two steps aimed at bringing heavy duty vehicle emissions control on a par with their light duty counterparts. These earlier steps were followed by Decision 1999/96/EC which, in total, defined four new steps for heavy duty vehicle emissions control from 2000 to 2014 (i.e. until the introduction of Euro VI). One significant concept introduced was the definition of Enhanced Environmentally friendly Vehicles (EEVs), i.e. a stringent voluntary emissions step introduced as early as in 2000. This step was more stringent even than the much later introduced Euro V.

Inspection and maintenance programmes are of great importance to the environmental performance of the vehicle fleet. Properly maintained vehicles can be of higher age as long as their environmental performance does not differ too much from the newest technologies. The roadworthiness test Directive 2009/40/EC, repealing Directive 96/96/EC, harmonizes the frequency of road worthiness tests and details which parts of motor vehicles must be tested. The directive aims at maintaining emissions at a low level throughout the useful life of a vehicle by means of regular exhaust emissions tests and ensuring that high emitters are withdrawn until they are brought to a proper state of maintenance.

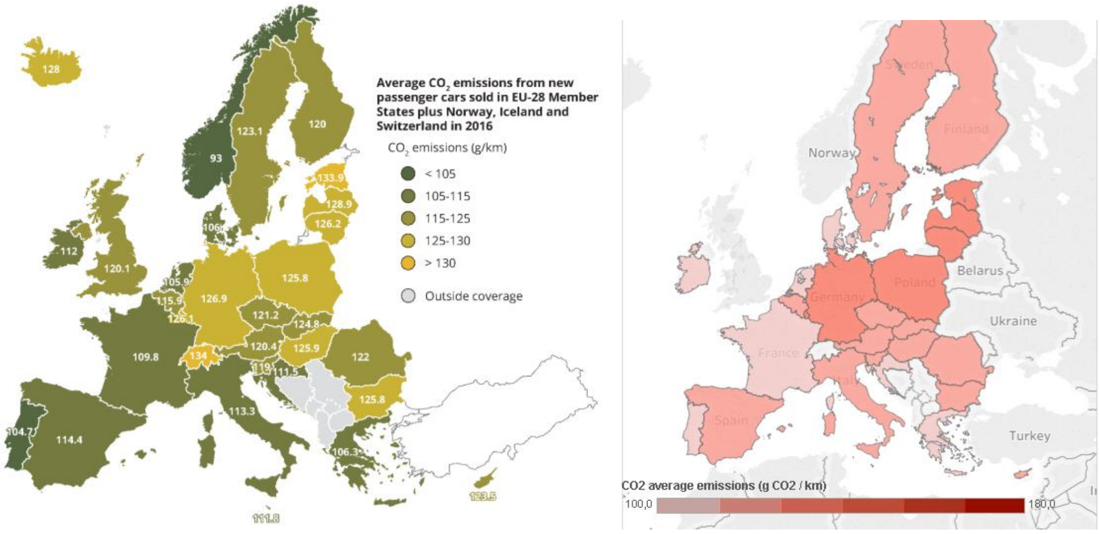


Figure 111 Average CO2 emissions of new passenger cars in EU countries for 2016 & 2017 (Sources: European Environment Agency)

A. Environmental Benefits

A.(i) Avoided CO_2 emissions by the substitution of carbon intensive vehicles

As mentioned in chapter 2, hydrocarbon fuel combustion results in CO_2 emissions. The chemical reaction of combustion of 1 liter of petrol (gasoline), 0.737 kg, of which approximately 0.63 – 0.65 kg are carbon, produces approximately 2.3 – 2.4 kg of CO_2 [29][30]. Analytically, petrol is composed of hydrocarbons, which are hydrogen (H) and carbon (C) atoms that are bonded to form hydrocarbon molecules ($C_X H_Y$). In the combustion process petrol reacts with the oxygen of the air (O_2) in the presence of heat. The combustion process starts with the ignition of the fuel, usually by a spark. A simplified equation for the combustion of hydrocarbon fuels may be expressed as follows:

$$\text{Fuel } (C_X H_Y) + \text{oxygen } (O_2) + \text{spark} \longrightarrow \text{water } (H_2O) + \text{carbon dioxide } (CO_2) + \text{heat}$$

The Diesel combustion is quite similar, with the differences being identified in the ignition process, emitting 2.67 kg of CO_2 per liter [30]. Fuel efficiency and decarbonization are the most effective strategies towards on-road CO_2 emission reduction.

Globally, the first steps of decarbonization of the road transport sector has been set as early as 2000, when relevant policies promoting the substitution of the carbon intensive vehicle stock were adopted, which according to an ICCT study, are projected to reduce global oil-equivalent consumption by 9.7 million barrels per day

(Mboe/day) and GHG emissions by 1.9 metric gigatons of CO_2 equivalent ($GtCO_2e$) in 2030 [15]. Such reductions will be equivalent to 9% of global oil consumption and 4% of global all-sector GHG emissions of 2030, as projected by IEA [16]. Moreover, policies in the pipeline aiming mostly in improving the efficiency of on-road vehicles, marine vessels and aircraft are expected to push CO_2 emissions reduction further down by 14.5 Mboe/day and 2.9 $GtCO_2e$ in 2030, equivalent to a 14% reduction in global oil consumption and a 7% reduction in global economy-wide GHG emissions of 2030 as projected by IEA.

Specifically, regarding the on-road emissions, despite the Light Duty Vehicle (LDV) (including passenger cars and vans) policies pushing forward the technological development of LDVs and thus their market penetration towards doubling in numbers from 2000 to 2030, from 640 million to 1.5 billion respectively, their consumption and GHG emissions are projected to stabilize as soon as 2025 as a result of the introduction of strong fuel efficiency and GHG emission standards in major markets since 2005 [15]. Expansion of world-class policies and cost-effective technologies across the globe, including vehicle efficiency, mode shift, and activity reduction policies, are expected to result in oil and emission reductions of 28.6 Mboe/day and 5.8 $GtCO_2e$ in 2030, equivalent to a 28% drop in global oil consumption and a 13% cut in global economy-wide GHG emissions of 2030 as projected by IEA. This level of reduction would essentially stabilize transportation emissions by the year 2025 [15]. The electrification of the transport sector will be one of the main contributors of such turn because, while vehicles powered by internal combustion engines are far from the limits of efficiency, meeting long-term emission reduction targets while activity continues to grow, will require a switch to true low-carbon energy sources, with one of the most prominent solutions being power generated by renewable energy sources.

But while Electric-drive technology, including plug-in hybrid electric vehicles (PHEVs), battery electric vehicles (BEVs), and fuel cell electric vehicles (FCEVs), could provide substantial energy and GHG benefits over conventional technologies, the boundaries of electric vehicle adoption are heavily affecting their takeover in global market. Both vehicle and charging infrastructure technology development are the main boundaries to be breached as analyzed in chapters 2 and 3. Therefore, the market needs such developments that will reduce the price of electric mobility technology through the development of large economies of scale. Market commercialization will enable the transformation of the vehicle fleet to electric-drive technologies, which when coupled with grid decarbonization would achieve much more dramatic reductions in carbon emissions beyond 2030 [20]. The potential for GHG emission reduction is large but the global community must act fast in order to make timely changes towards a greener transport sector.

Different segments of the global vehicle fleet have significant different contributions in GHG emissions. As shown in figure 112 even though heavy duty vehicles (trucks) comprise only the 9% of the total global fleet their use is equivalent to the 17% of the total global distance traveled resulting in the staggering 39% of the total life-cycle road transport greenhouse gas emissions for 2015.

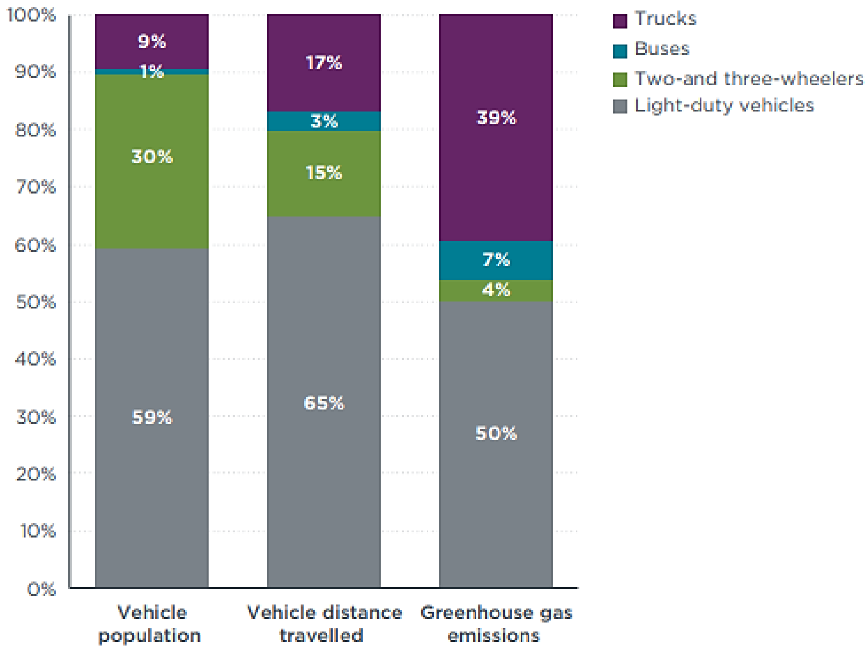


Figure 112 Global vehicle stock, distance traveled, and life-cycle road transport greenhouse gas emissions by vehicle type in 2015 (source ICCT) [20]

In addition to that also buses contribute highly to on road GHG emissions by 7% of the total amount while the specific segment amounts to only 1% of the total global vehicle fleet. Moreover Light duty vehicles amounted to 50% of the total on-road global emissions while two/three-wheelers contributed by 4%. The fact that heavy duty vehicles, namely trucks and buses contribute by 46% on the total on-road GHG emissions makes imperative their immediate substitution with either more fuel efficient ones or with EVs.

But how can the saved CO_2 emissions from the substitution of carbon intensities can be realized? Actual CO_2 emissions of a vehicle fleet can be determined as an approximation, estimated by the fuel consumption of the transport sector. However, because each vehicle is differentiated in use and efficiency, the anticipated CO_2 emissions cannot easily be assumed based on historical data. To understand why this happens, one must consider the fact that the number of vehicles in circulation per fuel, even though it’s one of the most important parameters, is not the only one that affects the GHG emissions of a fleet. The other two important parameters are vehicle energy efficiency under various driving cycles and the driving behavior which consists of the mileage and the driving conditions (type of driving cycle) under which the vehicles perform. The latter two parameters are mostly stable, but in economies under transition can be radically differentiated from year to year. Economies that recently were mostly affected by the economic crisis of 2008 showed radically different results in their motor vehicle market than the ones presented prior to the crisis. Also technological development and the success of differentiated mobility business models, such as mobility as service and public transportation, also affects the driving behavior of the users as the new services are adopted substituting the old mobility preferences. The driving behavior in regards to the average mileage of each vehicle category can be determined in a country scale via the annual fuel consumption per type of fuel. However due to the diversification of the vehicle in regards to age, efficiency and mileage , the substitution of a conventional ICE vehicle provides emission reduction benefits proportional to the mileage and inversely proportional to the efficiency of the substituted vehicle. In estimated the avoided emissions it is important to proceed with an aggregation of the vehicles substituted based on average age since it is the most important factor affecting scrappage by progressively reducing the value of the vehicle in the market and thus the cost effectiveness of repairs after major crashes.

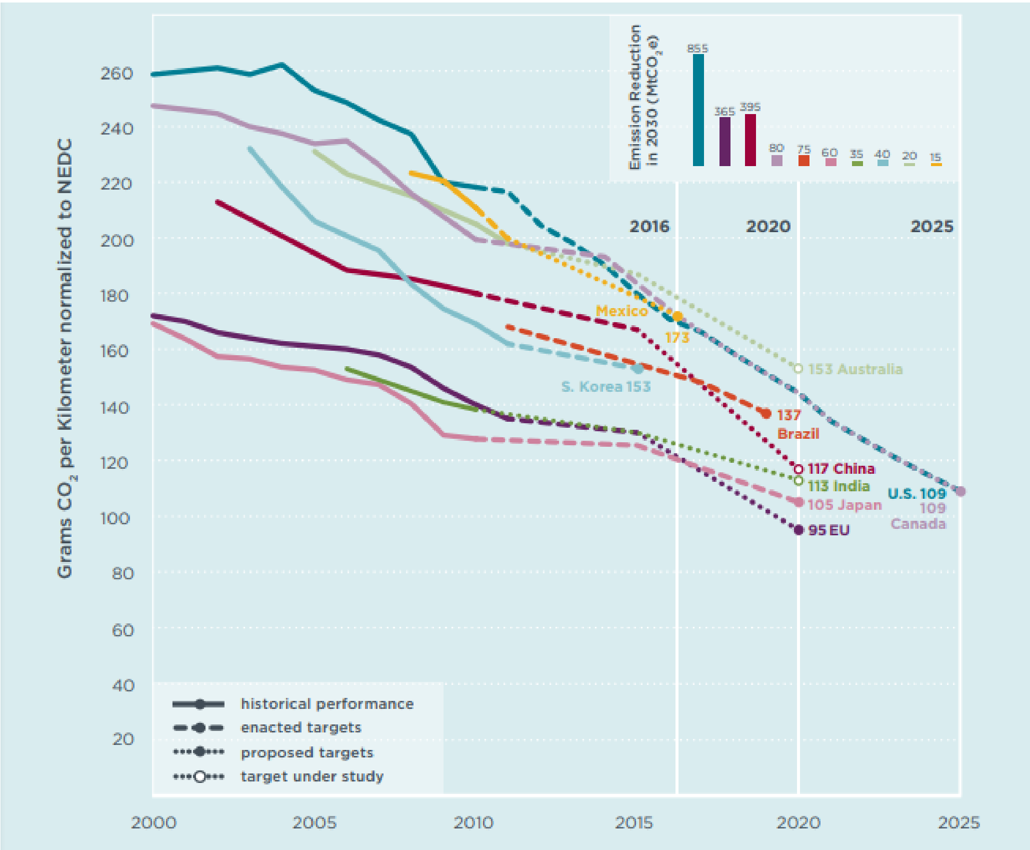


Figure 113 Figure comparison of LDV CO_2 Emission rate development (source ICCT)

EU has set Emission targets for its vehicle fleet for 2021. The targets are set to be 95 g/km for passenger cars. Based on these targets European auto producers are rearranging their production to provide with vehicles with average emissions that comply with the demands of the EU commission. The development of the average CO_2 emissions of the newly registered vehicles in EU can be seen in the following graphs.

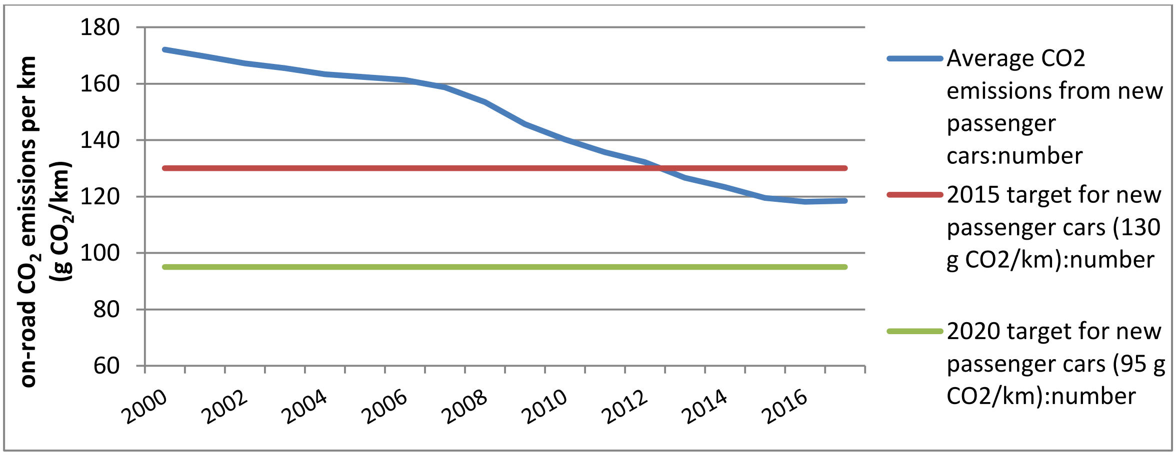


Figure 114 Figure Development of average emissions of newly registered passenger cars in EU (25)

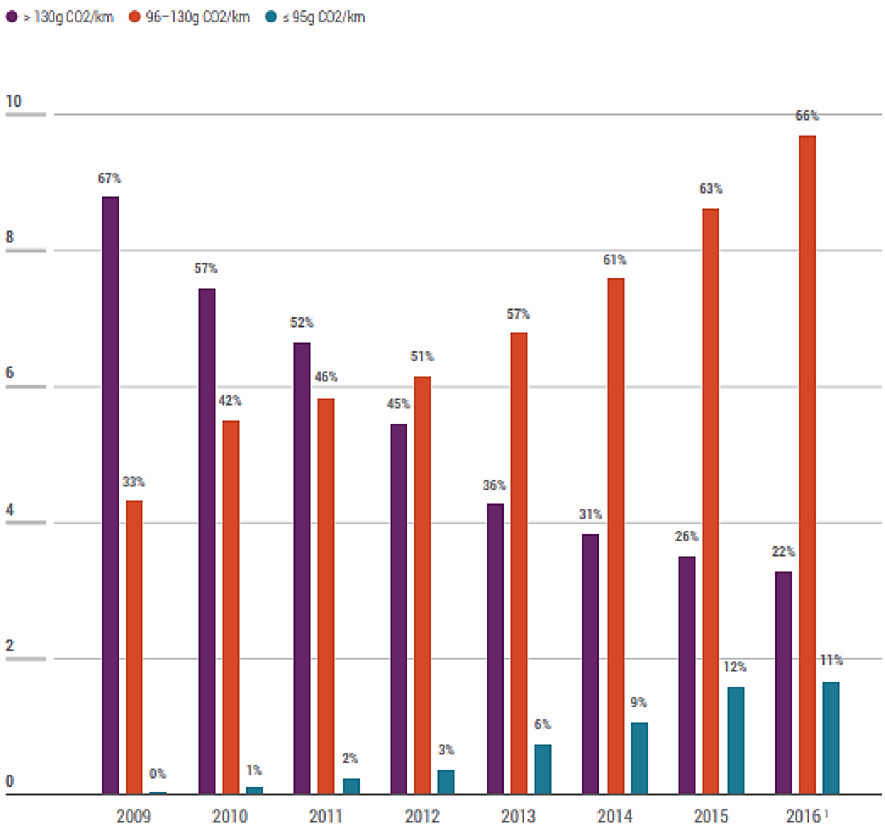


Figure 115 New passenger cars in the EU by emissions classes for period 2009 – 2016 (in million units, % share)[11]

Even though major polluters, medium and heavy duty vehicles haven't been under emissions' restriction. The CO_2 standards which are aiming to be implemented in 2025 and 2030 are currently under debate between the European Automobile Manufacturers' Association (ACEA) and European Commission. The two step approach (2025,2030) is welcomed by the Association, while the validation at a later point of the emission goals of 2030 is a positive measure that allows the inclusion of the latest fuel efficiency technologies in the final 2030 emissions' goal. However, the proposal's aims at CO_2 emission reductions of 15% and 30% from the 2019 average CO_2 emissions for 2025 and 2030 respectively, which has risen strong reactions from the automotive industry, deeming them far too aggressive and without consideration of the nature of the truck market. Also the industry argues that, given the fact that product development of the vehicles, which are going to be sold until 2025, is already under way, it is very hard for the industry to adjust and rearrange its manufacturing operations to meet the commission's targets. Moreover, the proposed 15% additional reduction of CO_2 emissions target for 2030 on the aftermath of the 15% reduction target for 2025 seems to be against a realistic technology ramp-up, as the most advanced fuel saving technologies will take time to be developed [12]. Given the fact that heavy duty vehicles are mostly custom built, aiming to meet the buyers specific requirements, showing variations in the number of axles, the size of the engine, the size of the fuel tank or cab and the height of chassis as well as variations of the size of the rigid body or the trailer, it becomes imperative that the market is quite inflexible in such rapid transitions, and thus it would require CO_2 emission standards that are tailored to fit the diversity of the HDV market [19] .

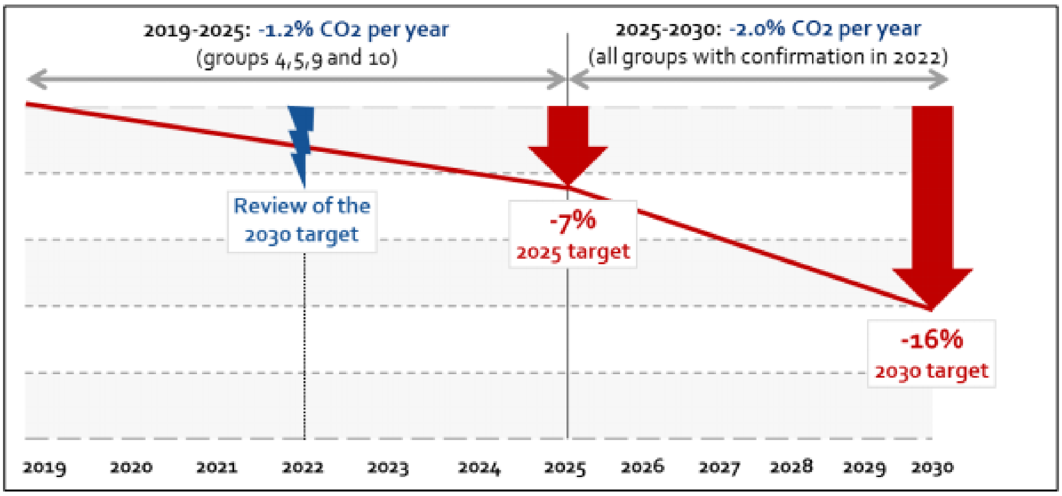


Figure 116 Figure European CO_2 reduction targets of EU heavy duty vehicle fleet as proposed by ACEA [21]

On the other hand ACEA with a position paper proposes a more plausible transition to lower carbon mobility for heavy duty vehicles, which can be observed in figure 116 This timetable includes an emissions reduction target for 2025 of total on road emissions of the HDVs fleet of 7% (ie -1.2% per year), for vehicle groups covered by the scope of the mandatory CO_2 declaration (2019)(vehicle groups 4, 5, 9 and 10 – covering 80% of EU fleet emissions) on the basis of the HDV associated emissions of 2019 calculated according to certified procedures and VECTO. It also includes a proposed 16% CO_2 reduction for 2030 (ie -2% per year from 2025 to 2030) from the HDV on road emissions of the reference year (2019), reduction target which would be updated in 2022 based on the projected evolution of product development and energy efficiency of the newly registered HDVs. The position paper also highlights the need for flexibility for the CO_2 emission targets on the basis of the differentiation of each vehicle group and subgroup by enabling the transfer of proposed CO_2 credits and debits between the groups [21].

Even though that policy-making is prompting the substitution of trucks with electric motor ones, the technology is not fully mature to be adopted for long range operations, with the combined challenges of limited driving range and limitation of publicly accessible charging stations to be significant for their success. However, truck industry, having identified the challenge, has mostly oriented their electric solution towards short-range urban operations [22]. This means that a radical emissions reduction caused by HDV fleet electrification is not likely to happen soon, so the industry has to adjust to the new CO_2 standards by upgrading fuel efficiency and introducing low carbon alternative fuel use. Study of the German market, by Deloitte, shows that about 13% of new vehicles (MCV + HCV) in the key German market will already have an alternative drive system by 2026. In MCVs, there is a trend toward plug-in hybrids (67% vehicles will have alternative drive systems vehicles by 2026). On long distances, nearly 80% of HCVs with alternative drive systems will be running on natural gas (LNG + CNG) [23].

On-road Transport Electrification and avoided CO_2 emissions in Greece

The transport sector is the second-largest emitting sector, accounting for 25.8% of the total energy-related CO_2 emissions in 2015. Emissions from the transport sector decreased from 22.9 $MtCO_2$ in 2007 to 16.7 $MtCO_2$ in 2015 [7]. This occurs mainly due to the shrinking of private transportation activities of the Greek population. Specifically, the average distance travelled by a passenger car per year dropped radically during the years of recession from 69,380 km/year in 2009 [33] to 9,723 km/year[18] in 2015.

[18] The average mileage of Greek passenger car fleet was calculated on the basis of total petrol (gasoline) consumption for 2015, resulting to a total of 9,723 km/year

The passenger car fleet of Greece is one of the oldest in Europe, according to ACEA, numbering more than 3.5 million cars which are more than 10 years in circulation [6]. The average age of Greece's passenger cars was 13.5 years, in 2015, while light commercial vehicles and medium - heavy duty vehicles (including buses) accounted for an average of 16.8 and 18.7 years in circulation respectively. Due to stagnation of the local motor vehicle market as a result of the economic crisis, Greek consumers tend to stick to their vehicles for a longer period of time, so in a span of 2 years (2017) the average age of Greece's passenger car fleet is estimated to have risen significantly to 14.7 years.

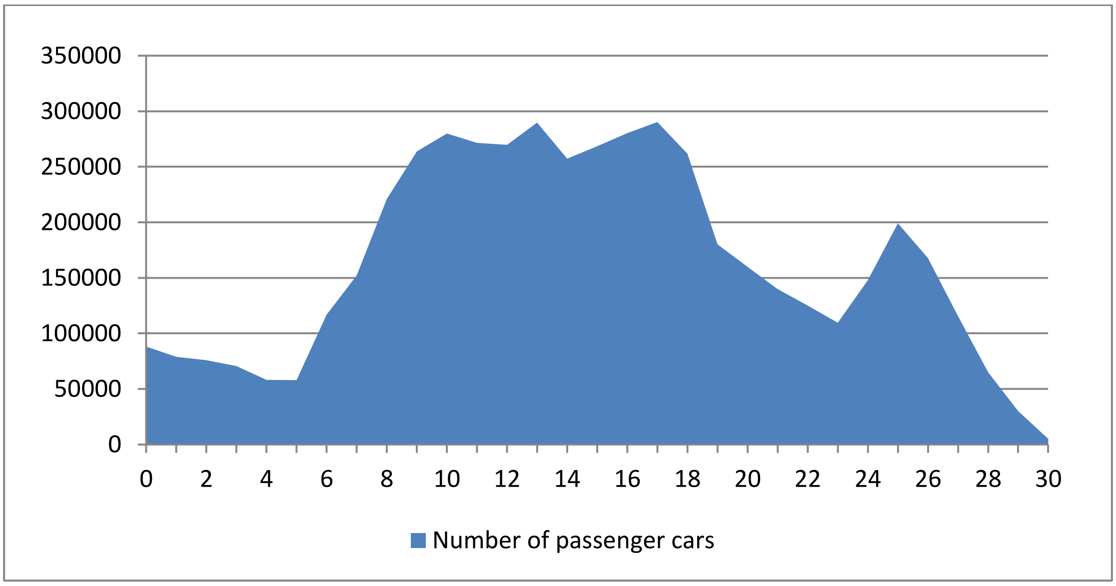


Figure 117 Figure Age of the passenger car fleet of Greece (Sources ACEA, SEAA) in 2017 NOTES: [1] Data are based on ACEA's report for vehicle age in EU (2016) under the assumption that substitutions made in later years were from the older segment of the car fleet. [2] The number of passenger cars older than 28 years (registered prior to 1990) are estimated to be approximately 100 thousand still in circulation (source ACEA), however the analysis and the allocation of these vehicles to age categories is hypothetical.

The following diagram, showing the average CO_2 emissions of the passenger cars registered each year in Greece per km travelled. These data are indicative for the average CO_2 emission of the total Greek passenger car fleet, which according to IENE's analysis is approximately 171 grams of CO_2 per km, although the effective value after taking into account the mileage of the fleet should be lower, due to the fact that older more emitting cars are used less than the new ones. Moreover, the use of passenger cars is estimated to emit approximately 8.15 Mt CO_2 equivalent (2015).

By observation it is evident that the economic crisis manifested in 2009 affected majorly both the new registrations but also the average CO_2 emissions of new cars due to the turn of the consumers towards smaller vehicles. The trend in the market initiated by the economic crisis still holds to up today with a slow growth initiated in 2014. Furthermore the financial crisis has put the motor vehicle market in Greece into a recession, where mobility commodities, like light duty passenger vehicles, has been a reluctant purchase. Hence the remaining consumers have reduced their choices towards smaller efficient vehicles which would primarily satisfy their predicted mobility needs without considering other factors, which prior had been significant in influencing consumer choice in the local motor vehicle market.

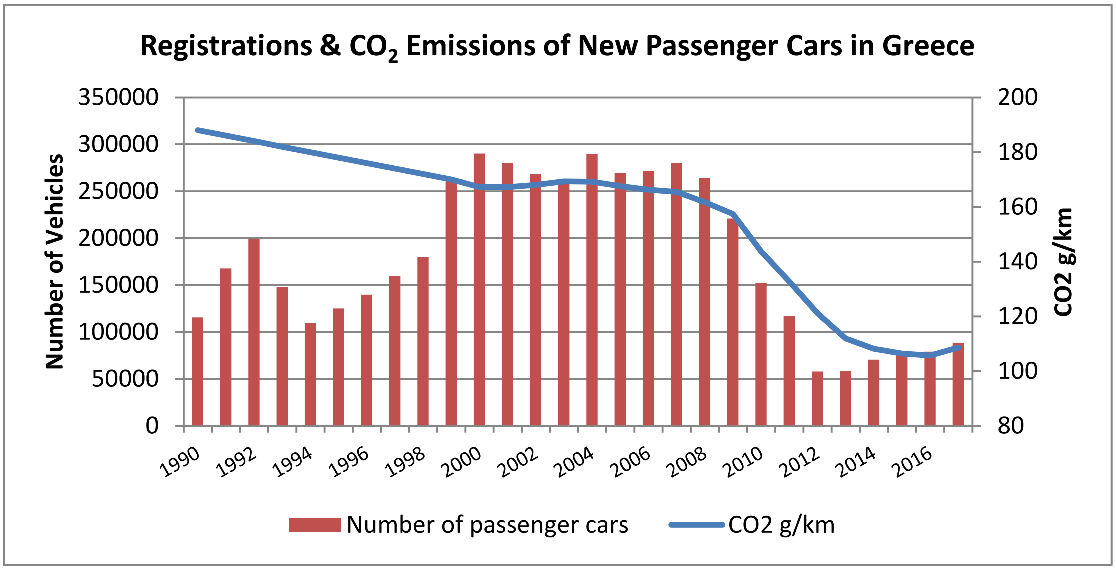


Figure 118 Figure Development of the Average CO_2 emissions emitted by the new passenger cars in Greece and the annual deployment of passenger cars (Sources: SEAA, ACEA).
NOTES: [1] Average CO_2 Emissions of passenger cars sold prior to 2000 are hypothetical based on the technology of the most successful models in the market during the reference year. [2] Cars sold prior to 2000 are found through ACEA databases and might have mismatches with the number of imported vehicles provided by SEAA.

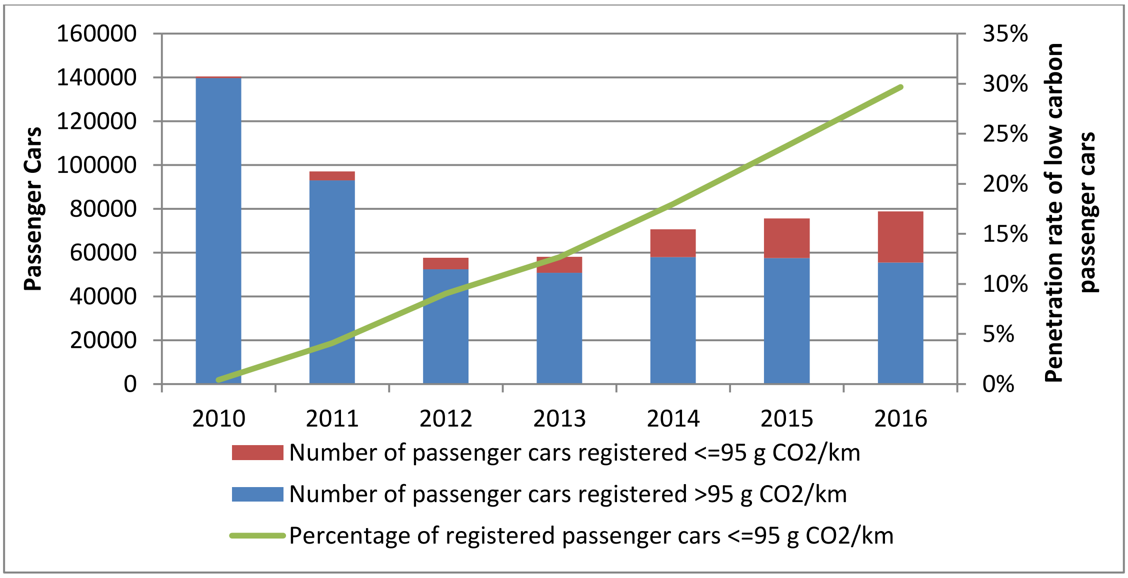


Figure 119 Number of passenger cars registered in Greece per year, which are compliant with the emissions target of 95 CO2 g/km set by EU for 2021

In Greece, the number of light duty passenger vehicles registered, which meet the emissions target of 95g CO2/km for 2021, has been 71,260 in the period 2010-2016 accounting for the total 12.3% of the total cars registered in the same period. While the percentage of vehicles sold that are compliant with the emissions targets keep increasing steadily. Namely the share of emission target compliant vehicles accounted for the 29.7% of the total sales in 2016, which is significantly higher from the 23.8% and the 18% which accounted for in 2015 and 2014 respectively, generating an incremental trend in adoption of vehicles with low carbon intensity in the country.

Given the fact that the motor vehicle market in Greece is expected to bounce back after the severe recession it experienced up until 2013, it is expected that the rate of substitution of carbon intensive vehicles with new Euro 6 compliant ones will increase significantly in the following years.

Table 18 Table CO_2 Emissions of Greece's passenger car fleet.

	Petrol Passenger Cars	Diesel Passenger Cars	Units
Annual Consumption / vehicle	671.976	498.563 [2]	Liters
Combustion CO_2 Emissions / liter[1]	2.39	2.67	CO_2 kg/l
Annual CO_2 Emissions / vehicle	1606.023	1331.163	CO_2 kg
Total passenger fleet emissions	7.939	0.218	Mt COeq

NOTES: [1]CO2 equivalent emissions per liter of fueled combusted as estimated by US Environmental protection Agency [29][30]. [2] The fuel consumption of diesel cars have been calculated based on a ratio of 0.74, which is a market statistics average of consumption ratio of diesel to petrol for the vehicles that have both petrol (gasoline) and diesel version [28]. Here is pointed that driving behavior per vehicle segment is required for more accurate data input.

The total emission resulting from the use of passenger cars are estimated to be 8.16 million tons of CO_2 equivalent, accounting for approximately 48.9% of the total emissions resulting from the activity of the transport sector in the Country. By substituting the older segment of the passenger car fleet with EVs we expect the tailpipe emissions of the total country's fleet to reduce radically. Such introduction, leads to 2.3% of tailpipe emission reduction (0.17 $MtCO_2eq$) for substitution of the 100 thousand most carbon intensive cars with EVs, while substituting the 1 million most carbon intensive passenger Cars with EVs will result to 21.9%

Table 19 Table Tailpipe and Total Emission of Greek passenger car fleet in under various scenarios

	Number of EVs introduced				Units
Scenario	Reference	10000	100000	1000000	EVs
Average CO_2 emissions per km	164.29	163.91	160.56	128.29	CO_2 g / km
Total Fleet Tailpipe CO_2 emissions	8.16	8.14	7.97	6.37	Mt CO_2eq/y
CO_2 Tailpipe Emissions' Reduction (%)	0	0.2%	2.3%	21.9%	%
Total Indirect Emissions of EV segment of the passenger car fleet	0.02	7.70	76.96	769.60	kt CO_2eq/y
Total fleet emissions	8.16	8.15	8.05	7.14	Mt CO_2eq/y
CO_2 Total Emissions' Reduction (%)	0%	0.1%	1.3%	12.5%	%

[1] The calculation of the tailpipe and indirect emissions CO_2 was based on the average mileage of Greek passenger car fleet calculated on the basis of total petrol (gasoline) consumption for 2015, resulting to a total of 9,723 km/year

[2] The reference EV model utilized in the scenario calculations was BMW i3 (2018)

[3] Indirect emissions are calculated based on the carbon intensity of the local power sector of 532g CO2/kWh

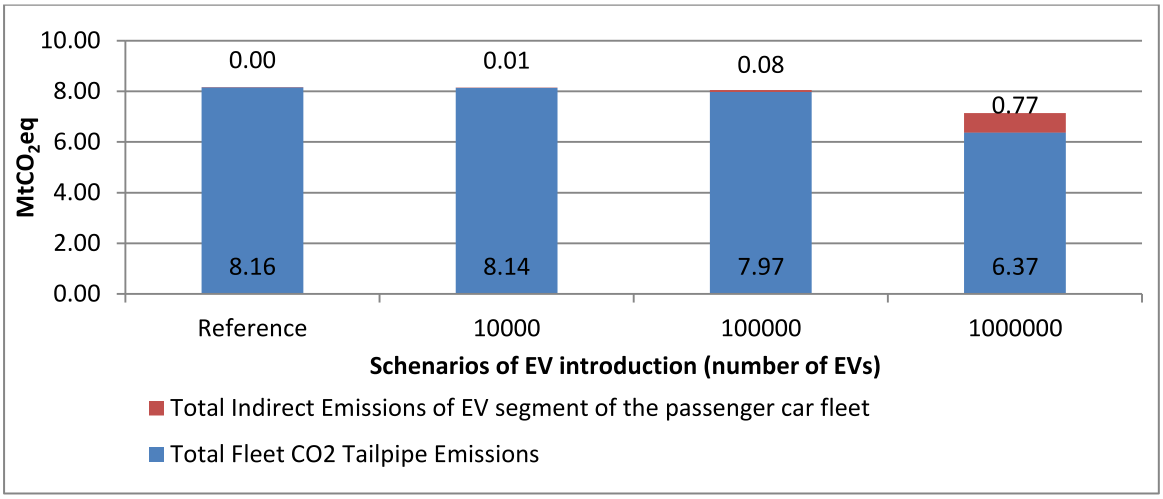


Figure 120 Tailpipe, Indirect and Total Emission of Greek passenger car fleet in under the scenarios presented in table 19

A. (ii) Reduction of carbon footprint of vehicles

Even though car production has been on the rise again since 2013, manufacturers have been able to decouple CO_2 emissions, energy consumption, water usage and waste generation from production growth. Total CO_2 emissions from car production, for example, have remained stable despite a substantial increase in production volume – while CO_2 emissions per car produced dropped by 25.8% between 2007 and 2016 [11].

Full life cycle emissions resembles the total embedded GHG emissions of a vehicle from the extraction and processing of its materials until the assembly and provision of the final product including the energy spend for scrappage in the end of the vehicle's life. Such indicator would be the most relevant to assess the EV technology as the extraction of their battery material as well as the energy intensive recycling operations could potentially add more to the over-all environmental impact of the vehicle.

Even though life cycle assessments and their relevant indicators are well adopted in the scientific and industrial community still the indicator that is mostly observable in environmental policies is the tailpipe emissions of the vehicles. Example of consideration of life cycle emissions of vehicles in new energy policies is the ZEV program in California that used the term to diversify and incentivize the environmental impact of the introduced vehicles [17].

A. (iii) Avoided air pollutants in major cities.

In addition to CO_2 conventional petrol vehicles emit also carbon monoxide when the carbon in fuel doesn't burn completely. Moreover, hydrocarbons, a toxic compound of hydrogen and carbon, can be emitted from the exhaust of the vehicles as a result of unburnt fuel or as a byproduct of combustion.

Table 20 Table Measurements of Carbon emissions of conventional vehicles (Nam et al. 2004 [35])

vehicle identifier	fuel	methane (mg/km)	NMHC (mg/km)	CO (g/km)	CO_2 (g/km)
car A	cert	16 ± 1	63 ± 16	0.84 ± 0.07	293 ± 2
car B	cert	6 ± 1	67 ± 11	0.23 ± 0.02	288 ± 5
car C	CRF	12 ± 1	85 ± 2	1.16 ± 0.02	239 ± 1
car D	CRF	6 ± 4	66 ± 2	0.68 ± 0.02	258 ± 2
car E	CRF	11 ± 1	97 ± 6	0.59 ± 0.04	285 ± 1
car F	CRF	9 ± 1	41 ± 2	0.53 ± 0.02	295 ± 3
car G	CRF	14 ± 1	94 ± 6	0.86 ± 0.02	286 ± 2
car H	CRF	18 ± 9	31 ± 3	0.23 ± 0.02	305 ± 4
car I	CRF	2 ± 1	14 ± 3	0.15 ± 0.05	217 ± 2
car J	CNG	43 ± 4	8 ± 1	0.23 ± 0.02	247 ± 2
car K	M-85	3 ± 1	18 ± 2	0.59 ± 0.05	244 ± 9
car L	diesel	8 ± 1	107 ± 19	0.30 ± 0.02	193 ± 11
car M	diesel	7 ± 3	116 ± 86	0.53 ± 0.23	161 ± 2
car N	E-85	11 ± 6	54 ± 2	0.88 ± 0.06	247 ± 2
car O	cert	12 ± 2	34 ± 3	0.31 ± 0.07	201 ± 8
car P	diesel	23 ± 2	18 ± 2	0.07 ± 0.02	146 ± 2
car Q	cert	3 ± 1	34 ± 2	0.30 ± 0.05	199 ± 1
car R	CRF	4 ± 1	43 ± 11	0.43 ± 0.28	250 ± 2
truck A	cert	6 ± 1	54 ± 11	0.44 ± 0.06	394 ± 3
truck B	cert	20 ± 1	61 ± 2	1.16 ± 0.07	289 ± 4
truck C	cert	21 ± 1	51 ± 3	0.44 ± 0.03	293 ± 4
truck D	CRF	22 ± 1	83 ± 3	2.16 ± 0.06	259 ± 2
truck E	CRF	4 ± 1	43 ± 2	0.48 ± 0.04	268 ± 2
truck F	CRF	7 ± 1	83 ± 6	0.69 ± 0.05	339 ± 2
truck G	CRF	11 ± 1	78 ± 8	0.97 ± 0.06	345 ± 2
truck H	CRF	11 ± 1	61 ± 3	1.36 ± 0.09	381 ± 40
truck I	CNG	97 ± 5	18 ± 2	0.32 ± 0.09	329 ± 4
truck J	E-85	33 ± 2	73 ± 38	0.50 ± 0.05	266 ± 3
truck K	Cert	11 ± 1	93 ± 11	0.54 ± 0.14	351 ± 5
truck L	CRF	13 ± 2	55 ± 12	0.57 ± 0.05	260 ± 17
car	avg	12 ± 2	55 ± 8	0.50 ± 0.07	242 ± 11
truck	avg	21 ± 7	63 ± 12	0.80 ± 0.15	314 ± 14
car	avg non-CNG	10 ± 1	58 ± 8	0.51 ± 0.07	242 ± 12
truck	avg non-CNG	14 ± 3	67 ± 6	0.85 ± 0.16	313 ± 15
car	avg diesel	13 ± 5	80 ± 31	0.30 ± 0.13	166 ± 14

Hydrocarbons emitted by the combustion cycle during vehicle propulsion can either be methane or a mix of non-methane hydrocarbons. Measurements in various vehicles revealed a differentiation of these emissions in regard to the type of fuel, the combustion cycle and the size of the vehicle, as shown in table 20.

Methane (CH_4) is an important greenhouse gas emitted by vehicles. Results of a study conducted in the research laboratory of Ford Motor Company in 2002, which studied the methane emissions using a standard driving cycle for 30 different cars and trucks (1995-1999 model years) from four different manufacturers, showed that an average car emits 10 mg of methane per kilometer while non methane hydrocarbon emissions account for an average of 58 mg/km (taking account CNG vehicles 12mg/km CH4 & 55mg/km Non-methane). The corresponding results for methane and non-methane emissions for trucks were found to be 14mg and 67mg respectively (taking account CNG vehicles 21mg/km CH4 & 63mg/km Non-methane). It was estimated that the contribution of CH4 emissions from vehicles to climate change is 0.3-0.4% of that of the corresponding CO_2 emissions of the same vehicles. Thus, the environmental impact of CH_4 emissions from vehicles is considered to be negligible and is likely to remain so for the foreseeable future [35].

The same study also revealed that the examined vehicles emit an average of 0.5g of CO per kilometer while trucks emit approximately 0.8g/km.

Another study, by Nelson et al., measured the non-methane hydrocarbon (NMHC) compositions of the exhausts from 67 vehicles driven through an urban driving cycle. The major components of of NMHC was found to be ethylene (11.2% w/w of NMHC), toluene (10.2%), acetylene (8.7%), m,p-Xylenes(6.5%), benzene (5.0%), propylene (5.0%) and i-pentane(4.8%). These emissions were found to be insensitive to the mass emission rates of hydrocarbons from ICE vehicle's exhaust except ethylene and propylene, which were affected by engine modifications introduced to satisfy emission control requirements. Moreover, the same study revealed a close relationship between petrol composition and exhaust composition but this did not correspond simply to emissions of unburnt petrol. The aromatics were found to be enriched relative to the alkanes in exhaust when compared with their proportions in the petrol.[36] A study by S. Guo et al. revealed that vehicular e NMHC emissions can induce haze pollution and consequently have a significant negative impact on visibility, human health, and even the global climate [44].

Important pollutants emitted by ICE vehicles also are nitrogen oxides (NO_X), which are formed when during the fuel combustion process the nitrogen and oxygen react with each other. Nitric oxide (NO) and nitrogen dioxide (NO_2) are together referred to as nitrogen oxides (NO_X). The emissions are not dependent solely on the amount of nitrogen in the fuel but also on the air-fuel mix ratio. High temperatures and oxidation-rich conditions generally favor NO_X formation in combustion [40]. A new report from the International Council on Clean Transportation (ICCT), which compared the emissions from trucks and buses in realistic driving conditions with those of cars, found, interestingly enough that heavy-duty vehicles tested in Germany and Finland emitted about 210mg NO_X per kilometer driven, less than half the 500mg/km pumped out by modern diesel cars that meet the highest “Euro 6” standard. However, the buses and trucks have larger engines and burn more diesel per kilometer, meaning that cars produce 10 times more NO_X per liter of fuel. The ICCT analysis showed that manufacturers were able to ensure that heavy duty vehicles kept below NO_X pollution limits when on the road, while on the contrary the smaller engine ones under succeed. Evidence that some diesel cars emitted up to four times more NO_X than a bus was also revealed in 2015 [31].

NO_X contributes to acid deposition and eutrophication which, in turn, can lead to potential changes occurring in soil and water quality. The subsequent impacts of acid deposition can be significant, including adverse effects on aquatic ecosystems in rivers and lakes and damage to forests, crops and other vegetation. Eutrophication can lead to severe reductions in water quality with subsequent impacts including decreased biodiversity, changes in species composition and dominance, and toxicity effects. In many cases, the deposition of acidifying and eutrophying substances still exceeds the critical loads of the ecosystems (see EEA indicator Core Set Indicator (CSI) 005 'Exposure of ecosystems to acidification, eutrophication and ozone'). Further, details concerning emissions of acidifying pollutants are provided in EEA CSI 001 'Emissions of acidifying substances. It is NO_2 that is associated with adverse effects on human health, as at high concentrations it can cause inflammation of the airways. NO_2 also contributes to the formation of secondary particulate aerosols and tropospheric ozone (O_3) in the atmosphere - both are important air pollutants due to their adverse impacts on human health. NO_x is therefore linked both directly and indirectly to effects on human health. Further details concerning the contribution of NO_X to emissions of tropospheric ozone precursors and particulate matter are contained in EEA CSI 002 'Emissions of ozone precursors' and CSI 003 'Emissions of primary particles and secondary particulate precursors'.[40]

A significant pollutant resulting from the use of ICEs are the Sulphur oxides, (SO_x), mainly sulfur dioxide SO_2, and sulfur trioxide, SO_3. SO_2 is a colorless gas with a pungent odor that dissolves in water very easily, forming a weak acidic solution, sulfurous acid. When sulfur dioxide combines with the oxygen in the air SO_3 is slowly formed. SO_3 then rapidly combines with water to produce sulfuric acid. The lifespan of SO_x in the atmosphere is from 4 to 10 days. Sulfur dioxide (SO_2) can harm crops and trees, textiles, building materials, animals, and people, either as a result of exposure to long-term low concentrations or short-term high concentrations. It turns leaves yellow and decreases the growth rate of crops. Sulfur dioxide corrodes metal, and causes building materials and textiles to deteriorate and weaken. Even at low concentrations (approximately 5 parts per million – ppm) SO_2 can severely irritate the throat and lungs and, when SO_2 attaches to fine dust particles in the air, the results can be respiratory system damage as such particles can reach the deepest regions of the lung. The current occupational exposure limits for SO_2 is 5 parts per million (ppm) set by OSHA PELs and 0.25 ppm set by ACGIH TLV [43]. Short-term exposures to high levels of sulfur dioxide can be life-threatening while according to National Institute for Occupational Safety and Health (NIOSH), the immediately dangerous to life and health (IDLH) airborne concentration is 100 ppm. Because SO_2 is readily soluble in water, it is a major contributor to acid deposition. While acid deposition is a broader term than acid rain, the two are often used interchangeably. Most acid rain is caused by emissions of SO_x and NO_x which converts to sulfuric acid and nitric acid (among other products). Diluted forms of these acids, and other substances, can fall to earth as rain, snow, sleet, hail, or fog. When it is not raining, the oxides interact directly with soil, vegetation and water in a variety of ways referred to as dry deposition [42].

Particulate matter, namely small particles of foreign substances, in the air contribute to atmospheric haze and can cause respiratory problems of the local population. “Particulate matter” (PM) is the general term used to describe solid particles and liquid droplets found in the air. The composition and size of these airborne particles and droplets vary. Some particles are large enough to be seen as dust or dirt, while others are so small they can only be seen using a powerful microscope. Two size ranges, known as PM10 and PM2.5, are widely monitored, both at major emissions sources and in ambient air. PM10 includes particles that have aerodynamic diameters less than or equal to 10 microns (µm), approximately equal to one-seventh the diameter of human hair. PM2.5 is the subset of PM10 particles that have aerodynamic diameters less than or equal to 2.5 µm [39]. The Swiss Study on Air Pollution and Lung Diseases in Adults assessed lung diseases in adults from eight Swiss communities in 1991 and again in 2002. Overall exposure to outdoor PM10 estimated at each individual’s residence fell by an average of 6.2 µg/m3 over the study period, to reach a range of approximately 5 µg/m3 to 35 µg/m3 in 2002, depending on the community. This reduction in particle levels was associated with attenuated age-related annual declines in various lung function parameters. The falling PM10 levels were also associated with fewer reports of respiratory symptoms such as regular cough, chronic cough or phlegm, and wheezing and breathlessness. As part of a separate investigation, children from nine Swiss communities were followed between 1992 and 2001 as part of the Swiss Study on Childhood Allergy and Respiratory Symptoms with respect to Air Pollution, Climate and Pollen. Falling levels of regional PM10 were associated with a declining prevalence of various respiratory symptoms, including chronic cough, bronchitis, common cold, nocturnal dry cough and conjunctivitis symptoms. These findings suggest that modest as well as drastic improvements in ambient air quality are beneficial for respiratory health in both children and adults. These examples of successful interventions show that decreased levels of particulate air pollution can substantially diminish total, respiratory and cardiovascular death rates. Benefits can be expected at almost any reduction in levels of air pollution, which suggests that further policy efforts that reduce fine PM air pollution are likely to have continuing favorable effects on public health [41].

While EVs are considered green transport the indirect emissions of NO_x, SO_x and $PM_{2.5}$ resulting from the power generation intended for their use is significant. A study by ICCT on the estimation of indirect pollutant emissions resulting from the use of BEVs in California in 2020 released very interested results. The study was based on the estimations of the future power generation system of the state of California as forecasted by the California ARB staff for 2020, under the achievement of state's 2020 target of 33% RES penetration. Specifically, the study assumes energy efficiency of 0.3 kWh/mi for the reference BEV, while taking into account battery/charger losses [17].

Table 21 Table. Electric Vehicle Electricity Criteria Pollutant Emission Rates in Grams per Mile, 2020, 33% Renewable Electricity Standard (RES) Scenarios

	33% RES—High load		33% RES—Low load		33% RES—Incremental	
	CA	**WECC***	**CA**	**WECC**	**CA**	**WECC**
ROG	0.0030	0.0032	0.0029	0.0030	0.0035	0.0043
NO_x	0.0151	0.0906	0.0157	0.1108	0.0118	0.0141
SO_x	0.0028	0.0279	0.0031	0.0345	0.0012	0.0014
$PM_{2.5}$	0.0044	0.0121	0.0043	0.0142	0.0051	0.0053

**California plus other Western Electricity Coordinating Council (WECC) states.*

ROG = reactive organic gases; NO_x = nitrogen oxides; SO_x = sulfur oxides; $PM_{2.5}$ = fine particulate matter (<2.5 μ).

Note: System-emissions are depicted in three scenarios: (a)in high load, (b) in low load, (c) in an incremental state, where ramping up of power generation is performed

The calculated emission rates are shown in Table 22. In-state and out-of-state incremental NO_X emissions for electricity generation are significantly less than ICCT-estimated upstream refinery emissions, whereas organics are comparable and fine particulates may be slightly higher. Taking into account tailpipe and petroleum distribution emissions, vehicle electrification should have a very positive overall effect on ozone and fine particulates.

Table 22 Table TIAX Estimated Well-to-Wheels Nitrogen Oxide (NOx) Emissions, 2017, Model Year 2010 and Newer Vehicles

	NO_x Emissions, g/mi	
	Total	**Urban**
Light duty auto	.29	.04
Battery electric vehicle	.01	.001
Fuel cell electric vehicle	80–90% < RFG	80–90% < RFG

RFG = reformulated gasoline.

Total light-duty vehicle NO_X emissions for vehicles burning reformulated gasoline were also estimated by the same study at 0.29 grams per mile (g/ mi) on a well-to-wheel basis[19], with 0.04 g/mi urban emissions. Electric vehicles are estimated to result in 0.01 g/mi for electricity from natural gas (including natural gas production and transportation) mixed with state-mandated levels of renewable electricity over that same timeframe, with 0.001 g/mi urban emissions. Urban emissions are defined in this study as fuel cycle emissions that occur in California, assuming that increased power plant emissions are fully offset.

TIAX also estimated significant reductions in other ozone precursors and fine particulates for both BEVs and FCEVs. Per the TIAX report volatile organic compound emissions would be reduced by 90% or more. Hydrogen production NO_X mass emission rates are estimated to be 80% to 95% less than for reformulated gasoline for both total and urban emissions over that same timeframe. Volatile organic compound emission reductions for this pathway were estimated at approximately 40% for total emissions and marginally larger than 90% of urban emissions. Fine particulate emission rates are also estimated to be smaller for electric and FCEVs, except when coal is used as a fuel source (including coal production and transport).. Table 23 shows the emission components included in the TIAX estimates.

19 WTW analysis refers to specific lifecycle analysis applied to transportation fuels and their use in vehicles. The WTW stage includes resource extraction, fuel production, delivery of the fuel to vehicle, and end use of fuel in vehicle operations. Although feedstocks for alternative fuels do not necessarily come from a well, the WTW terminology is adopted for transportation fuel analysis.[18]

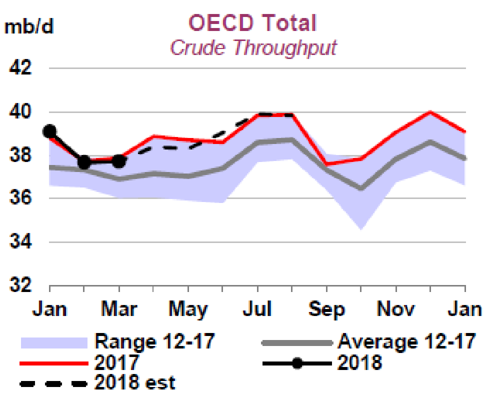
Table 23 Table Emissions Included in TIAX Estimates

Emissions	Urban	Total
Petroleum—NO_x, VOC, fine particulates	Marine vessel emissions within 100 mi of California In-state rail, local truck, pipeline delivery Storage/fueling losses Vehicle tailpipe	Crude production and transportation Refining Total global marine transport Rail, local truck delivery Storage/fueling losses Vehicle tailpipe
Electricity—Natural gas and RPS–NO_x, VOC, fine particulates	In-state production and transportation of natural gas	Global production and transportation of natural gas Natural gas power plant stack emissions
H_2 FCEV—SMR–NO_x, VOC, fine particulates	In-state natural gas production H_2 compression energy usage H_2 transportation	Global natural gas production H_2 compression energy usage H_2 transportation H_2 plant emissions

NO_x = nitrogen oxides; VOC = volatile organic compounds; H_2 FCEV = hydrogen fuel cell electric vehicle; SMR = steam methane reforming.

A.iv Water Pollution

The conventional petroleum vehicles' use is indirectly responsible for the impact of the life cycle of its fuel. Petroleum production, refining, and distribution create significant risk of environmental contamination. For the oil products directed for consumption in the transport sector there is a significant amount lost in oil spills. For 2017 International Tanker Owners Pollution Federation (ITOPF) has recorded two large spills (>700 tons) and four medium spills (7-700 tons). One among the two major incidents occurred in SE Europe in September 2017. Specifically, a tanker sunk off the coast of Greece in Saronicos golf spilling about 700 tons of oil. For 2017 the total volume of oil lost to the environment was approximately 7,000 tons worldwide [24]. In addition, refineries are estimated to generate 76 to 151 liters of wastewater for every barrel of petroleum refined [17]. Taking into account the global average refinery of 81.5 million barrels per day for 2017 [25], would result in 6.2 - 12.3 billion liters of waste water per day.



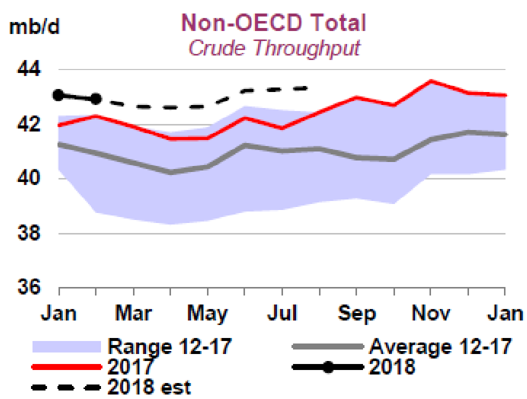


Figure 121 Figure Refinery Crude Throughput and Utilization in OECD and Non OECD Countries (million barrels per day)[25]

Therefore, the annual average gasoline consumption of a petrol passenger car in Greece of 672 liters (495.4kg) (2015) would result in wastewater generation from the refinery process equivalent to 675 to 1,340 liters of wastewater. In extend the whole fleet of passenger cars of Greece is indirectly responsible for generation of 32.2 to 63.95 billion liters of waste water annually (2015) from the oil refinery process.

Table 24 Table Water Pollution During Refinery Process as life cycle pollution of conventional vehicles

Fuel	Water pollution per Unit during refinery process	Minimum	Maximum	Unit
Crude oil	Wastewater / barrel	76	151	liters
Petrol	wastewater per gallon of petrol [3]	36.2	71.9	liters
	wastewater per liter of petrol	9.6	19.0	liters
	Wastewater/ petrol car use in Greece (2015)	6424.46	12764.38	liters
	Indirect wastewater generated by the total end use of petrol passenger cars in Greece (2015)	31.76	63.10	billion liters
Diesel	wastewater per gallon of diesel [3]	19.9	39.5	liters
	wastewater per liter of diesel refinery	5.26	10.45	liters
	Wastewater/ Diesel car use in Greece (2015)	2621.59	5208.69	liters
	Indirect wastewater generated by the total end use of diesel passenger cars in Greece (2015)[2]	428.53	851.43	million liters

[1] The numbers of refinery water pollution are calculated based on the estimations made by ICCT (2012)[17]

[2] The Indirect wastewater generated by the total end use of diesel passenger cars in Greece (2015) were estimated based on the total fleet segment registered during the years 2010-2015, thus the total impact is partially downgraded (IENE estimates that the diesel segment of the Greek fleet could deviate upwards at 5% the most)

[3] The impact of each oil segment on wastewater generation from the refinery process is calculated as a percentage of the quantitative (per kg) analysis of a crude oil barrel to different oil segment products after the refinery. Values of 11gal/barrel and 20 gal/barrel have been used for Diesel and Petrol (Gasoline) for the specific calculation [26][27]

[4] The fuel consumption of diesel cars have been calculated based on a ratio of 0.74, which is a market statistics average of consumption ratio of diesel to petrol for the vehicles that have both petrol (gasoline) and diesel version [28]

Mitigation of the noise pollution, caused by road transport.

One of the important contributions of the electric mobility transition to the betterment of the quality of the urban environment is the mitigation of the noise pollution. Specifically, the noise resulting from the use of internal combustion engines is subtracted from the urban driving environment with the substitution of conventional ICE vehicles with EVs, which maintain soundless electric motors. EVs almost entirely eliminate engine noise, and the relatively high-pitched noise electric motors do emit doesn't propagate as far. They currently tend to have lower coefficients of drag, reducing wind passage noise at higher speeds. However, these contributions are lower than road and tire noise and consequently the deference between EVs and ICE vehicles would not be noticeable all the time. There have been numerous publications focusing in different elements of noise from vehicles.

Moreover, the European COMPETT project, launched by 5 partner institutes in Austria, Denmark and Norway, aiming to shed new light on the appropriate role of the government in the takeoff stage and the creation of a self-sustaining market for EVs, has elaborated a performance survey in regards to noise mitigation achieved by the substitution of conventional ICE vehicles with EVs.

Vejdirektoratet, the Danish Road Directorate, an organization responsible for the state-owned roads in Denmark, carried this survey study, which revealed that after 35km/h the tire noise and road noise overtakes the propulsion noise in ICE vehicles and approximately beyond 40km/h the noise difference of tire/road noise and total vehicle noise drops below 3dB , and thus becomes undetectable to the human ear.

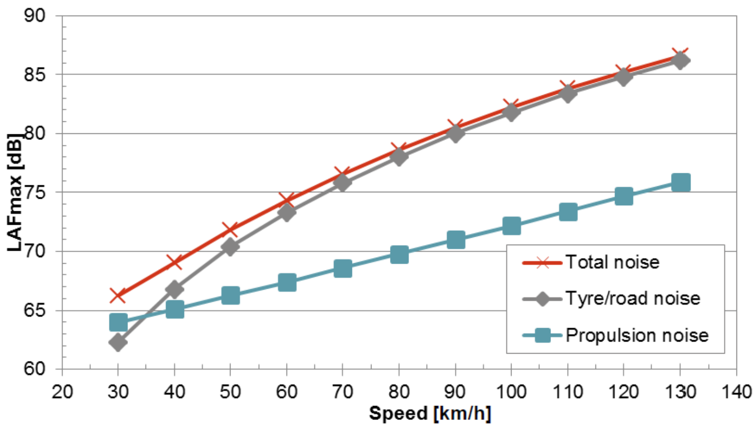


Figure 122 Noise from an average modern ICE passenger car (source: Compett project)

The measurements of the study were carried out on 4 different vehicles, Citroen Berlingo EV, Citroen Berlingo ICE, Nissan Leaf EV and VW Gold Variant ICE. The noise measurements were performed on ambient temperature of 16.6 °C normalized to 20 °C with a correction of -0.05 dB/°C, while the drive was performed on 2-3 years old soft asphalt. The experiment investigated three different driving patterns: (a) constant speed, (b) engine braking, and (c) accelerating.

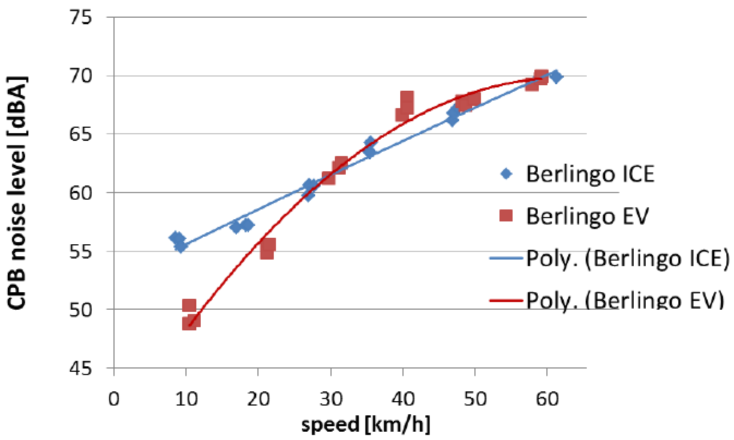


Figure 123 Noise performance results for the pick-up truck Citroen Berlingo's EV and ICE cersions at constant speed

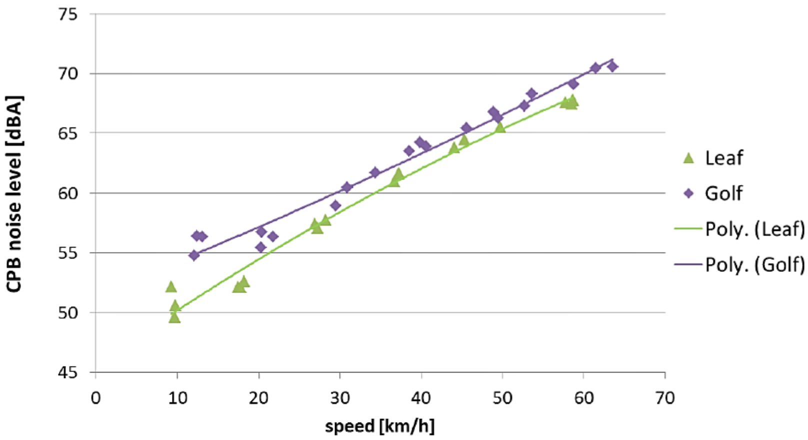


Figure 124 Noise performance results for the passenger cars Nissan Leaf (EV) and VW Gold Variant (ICE) at constant speed.

Moreover, the study revealed that at constant low speeds EVs are 4-5dB less noisy than similar ICEs. In addition to that, at about 30 km/h the difference in emitted noise between the two propulsion technologies becomes insignificant. In deceleration by engine braking EVs are 2-4 dB less noisy than ICEs at low speed. However at higher speeds the difference decrease as the tire/road noise is getting dominant. Analysis of these results showed that in low speeds, ICE passenger cars were more noisy than EVs for sound frequencies between 40 and 50Hz which can reach as much as 15dB difference and for high pitch noise spanning between frequencies of 2500Hz – 10000Hz which varied between 4dB and 10dB. Little different results were shown in the pick-up truck measurement where the difference in breaking noise was more evident in the whole frequency spectrum.

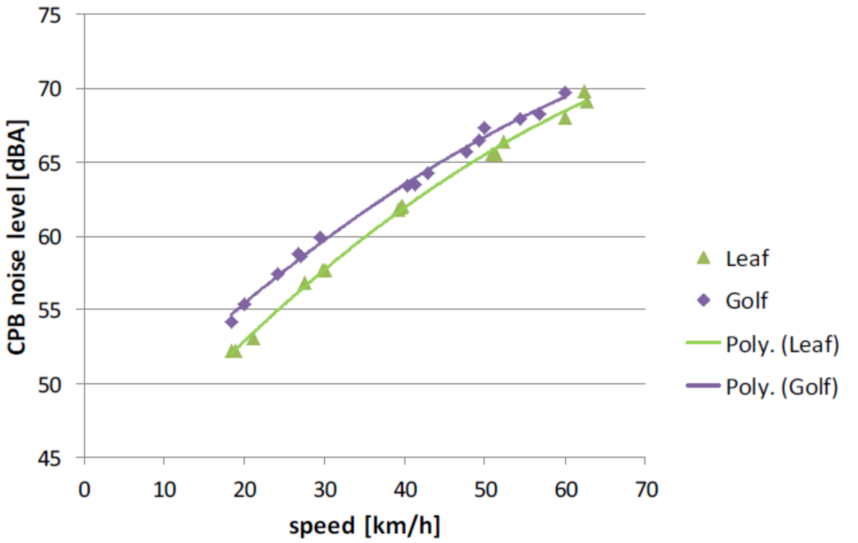


Figure 125 The Nissan Leaf and VW Golf Variant noise levels at deceleration by engine braking

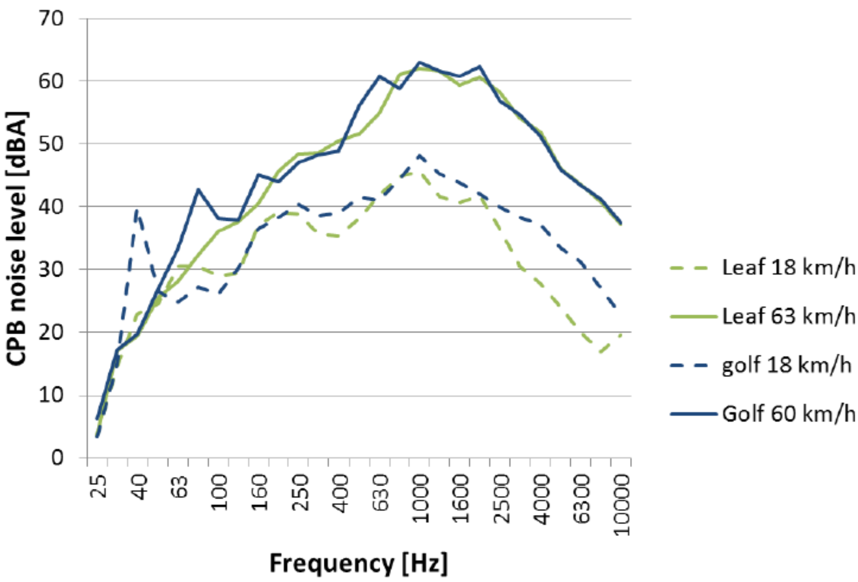


Figure 126 The Nissan Leaf and VW Golf Variant frequency spectra at deceleration by engine braking

Also during acceleration the level of noise emitted were slightly higher for passenger vehicles of approximately 3-4dB with some significantly higher noise levels resulting for the less smooth acceleration of ICE cars' driving behavior. Overall the study's key result is that EVs will have the potential to reduce the traffic noise in carparks and on streets where vehicles travel with speeds under 30 km/h.

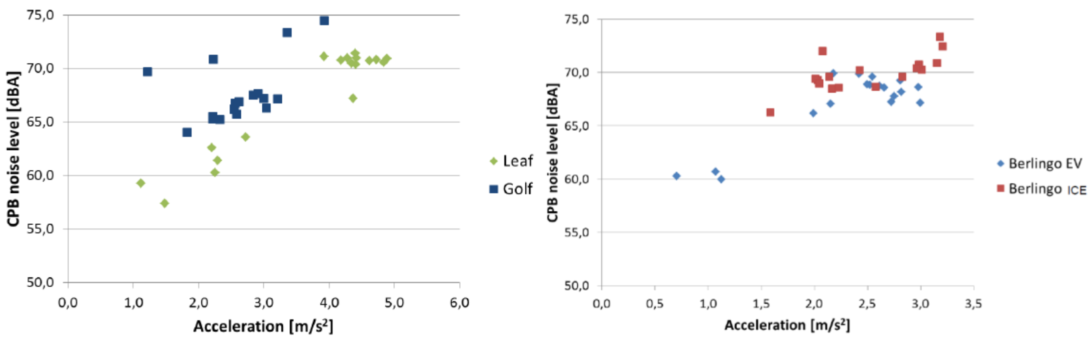


Figure 127 Acceleration Noise levels of Nissan Leaf, Golf Variant and Berlingo EV and ICE at various acceleration levels (Source: Danish Road Directorate DK, COMPETT Project)

Other study carried out by Purdue and the University of Central Florida showed that no significant noise reduction is mitigated by the use of EVs in highway transportation, while it also confirmed the results of Compett project identifying detectable noise reduction in low speeds, below 40 km/h [38].

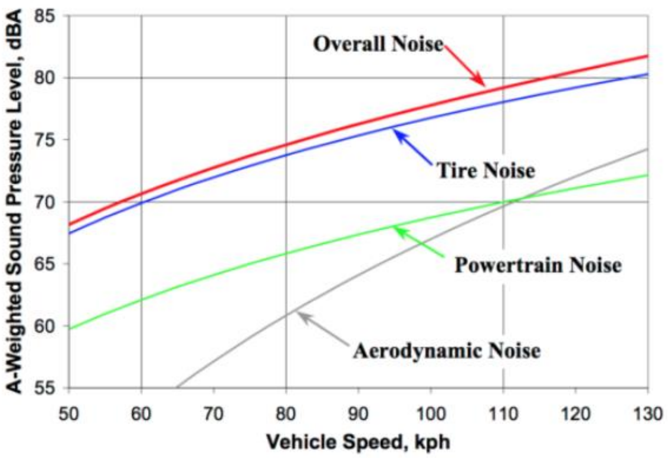


Figure 128 Components of Highway noise pollution (Source: Purdue and the University of Central Florida)

B. Decarbonization through Penetration of RES in the Power Generation and EVs

Even though that Electric Vehicles are promoted as a green solution for the transport sector, it is imperative to be accompanied with power generation by RES. As mentioned in prior Chapters the carbon intensity of its power generation is the main indicator of how "green" are the EVs introduced to each energy system. Moreover, indirect CO_2 emissions caused by the use of electric vehicles can be significant in carbon intensive energy systems.

The Decarbonization of power generation, which is needed to provide EVs "green" charge, is slowly being adopted by the global economy as part of a holistic strategy of mitigating the effects of climate change by reducing rapidly the anthropogenic CO_2 emissions. Various scenarios for the future of the energy sector have been accommodated by IEA with two of them, 2 C° Scenario and Beyond 2 C° Scenario (2DS and B2DS) being the paradigm for the IEA's proposal towards energy transition. These scenarios namely approach all human activity from GHG emission's perspective and propose scenarios for sectorial transformations in order to mitigate the climate change effects towards 2 C° and 1.5 C° of global average temperature raise in 2100 from the 2013 levels respectively. Specifically, the 2DS lays out an energy system deployment pathway and an emissions trajectory consistent with at least a 50% chance of limiting the average global temperature increase to 2°C. The 2DS limits the total remaining cumulative energy-related CO_2 emissions between 2015 and 2100 to 1,000 $GtCO_2$.The shift to electrification in the B2DS increases the pressure on the power sector, not only to accommodate additional generation but to do so while rapidly decarbonizing and becoming a source of negative emissions. This transformation will require a considerable change in the traditional trends in power sector investment, with the carbon intensity of electricity generation declining at an average rate of -3.9% in the next decade for the 2DS or -4.5% for the B2DS, compared with -0.5% over the past decade.

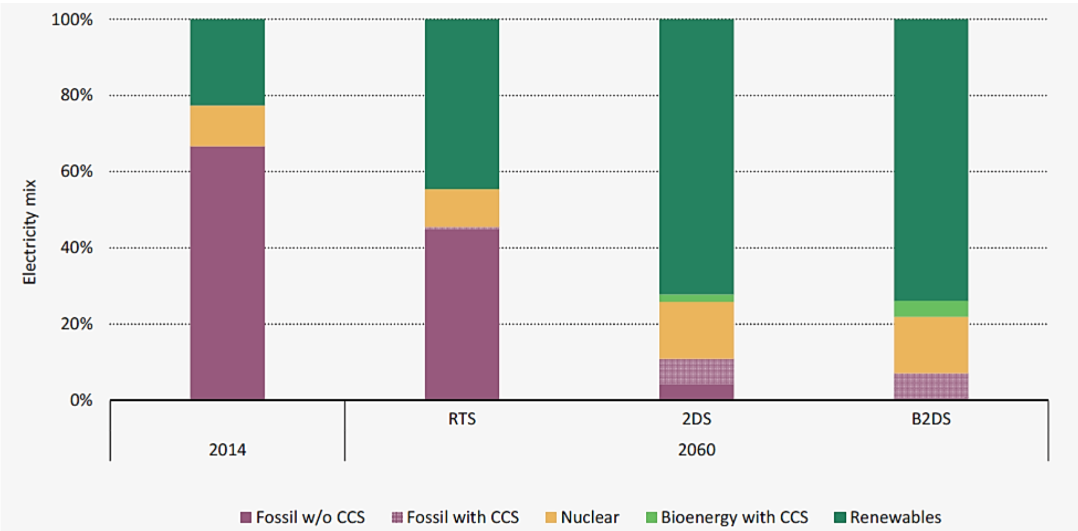


Figure 129 The global electricity mix in 2040 and under the IEA scenarios in 2060 (RTS, 2DS, B2DS)

In the 2DS, which is the more plausible scenario, renewables deliver around two-thirds of the emissions reductions achieved in the power sector, with CCS providing 18% and nuclear 16% of reductions. By 2060, 98% of electricity generation is from low-carbon sources, with the carbon intensity of power generation approaching zero, which should be a great achievement given the today's level of around 520 grams of CO_2 per kilowatt hour (gCO2/kWh). In addition such reduction will also be far greater than the 254 gCO2/kWh achieved in the Reference Technology Scenario

(RTS), which incorporates existing energy- and climate-related commitments by countries, including Nationally Determined Contributions pledged under the Paris Agreement [10]. In the B2DS, the carbon intensity of electricity generation falls below zero, to-10 gCO_2/kWh in 2060, effectively making the power sector a source of negative emissions to offset residual emissions in industry and in transport.

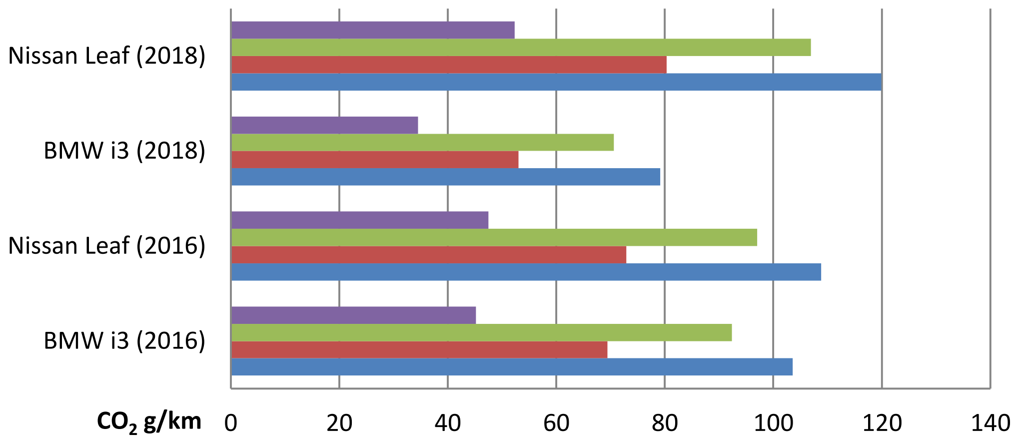
The Carbon intensity of electricity and the energy efficiency of the vehicle are the parameters which determine the indirect emissions of Electric Vehicles. The indirect emissions could be partially avoided even in systems with carbon intensive centralized power generation with the introduction of charging infrastructure which employs self-power generating units with RES (mostly solar panels).

Carbon intensive power systems in combination with high penetration of EVs in the market may just transfer the emissions from the city centers towards the power plants. Of course decentralizing the pollution sources is a wanted effect and in combination with the introduction of Carbon Capture and Storage Systems (CCS) might tackle the problem of the indirect emissions resulting from the carbon intensity electricity use of EVs. However, large CCS especially in large plants are not yet a mature technology and hence very expensive to retain the low electrical energy cost advantage of carbon intensive plants. CCS technology is expected to be widely implemented by the end of next decade, when it is expected that international environmental sanctions as well as research and development of this technology would push their adoption to the major centralized power plants.

B.(i) Decarbonization of Greece's on-road transport and indirect on-road carbon emissions

Greece's power sector is one of the most carbon intensive ones among IEA countries with emissions that reached 582 grams of CO_2 per kWh produced in 2015, which is significantly higher than the average emissions of IEA member countries which were 390 gCO_2 per kWh in 2015. Even though, the carbon intensity of power generation of the country fell by 26% between 2005 and 2015, due to greater deployment of renewable energy and natural gas, the introduction of EVs in such an electricity mix would not suggest a "green" transport solution.

Specifically, the deployment of two reference passenger EVs, the BMW i3 (94 Ah battery) (2016) which is the only EV that have enjoyed some success in Greece's motor vehicle market with energy consumption and the standardized mixed driving cycle of 0.178 kWh/km and the Nissan Leaf (2016), which has achieved the most sales worldwide in 2016 and is one among the more widely successful vehicles in the worldwide EV market with consumption of 0.187 kWh/km are examined. Moreover, with the carbon intensity of Greece's power system, the deployment of a BMW i3 would result in indirect emissions of 103.6 grams of CO_2 per km traveled, while in an average IEA country the same vehicle would emit only 69.4 g CO_2/km. In addition, a less efficient vehicle like Nissan Leaf (2015) would emit indirectly 108.8 grams of CO_2 per km traveled in Greece, which is similar to the emissions of a highly efficient small petrol vehicle or higher than a hybrid like Yaris hybrid by Toyota (2016), which emits 103.9 CO_2g/km [8], while it would emit 72.9 g/km in an average IEA country.



	BMW i3 (2016)	Nissan Leaf (2016)	BMW i3 (2018)	Nissan Leaf (2018)
IEA's RTS Scenario for 2060	45.212	47.498	34.544	52.324
Global Average (2014)	92.382	97.053	70.584	106.914
IEA Member Countries' Average (2015)	69.42	72.93	53.04	80.34
Greece (2015)	103.596	108.834	79.152	119.892

Figure 130 Indirect CO_2 Emissions of reference EVs in systems with different carbon intensity of electricity NOTE: [1] For BMW i3 (2018) the fuel consumption and CO2 emissions utilized in the formulation of this graph were determined in accordance with the measurement process as defined by European Regulation (EC) 715/2007 in the versionapplicable at the time of type approval.

On the other hand the 2018 versions of the same vehicles show significantly different emission performances due to their significantly diversified orientation of technology towards either better energy efficiency (BMW i3) or electric range (Nissan Leaf). Specifically as shown, BMW i3 (2018) has focused on energy efficiency, which under the EU regulations of mixed driving cycle results in electricity consumption of 0.136 kWh/km amount which would be responsible for indirect emissions of 79.1 CO_2g/km in Greece, while in an energy system with carbon intensity values similar to the IEA average this value would be 53 CO_2 g/km. Alternatively, other vehicles like Nissan Leaf focus their technological development towards electrical range expansion as opposed to energy efficiency resulting in a more heavy vehicle than its predecessor (Nissan Leaf 2016), with an increased by 10% electricity consumption, which amounts to 0.206 kWh/km, resulting to high indirect CO_2 emissions of 119.9 CO_2 g/km for consumption of electricity with carbon intensity resembling Greece's power generation. In addition the use of Nissan Leaf (2018) would result to an 80.3 CO_2 g/km for consumption of electricity with carbon intensity resembling the average of the IEA Countries.

References

[1] *Autotriti.gr*, (2018), "Top-sale automotive companies in Greece for 2017"(in Greek), Available online at:
https://www.autotriti.gr/data/news/preview_news/Pwlhseis-aytokinhtwn-2017_163033_32632.asp

[2] *envthink.blogspot.com*, (2011), "Carbon dioxide (CO_2) now regulates the purchase and circulation of cars" (in Greek), Available online at:
http://envthink.blogspot.gr/2011/11/co2.html

[3] *EEA (European Environment Agency)*, (2018), "Monitoring of CO_2 emissions from passenger cars – Regulation (EC) No 443/2009 — European Environment Agency. European Environment Agency [DK]" Available online at:
https://www.eea.europa.eu/data-and-maps/data/co2-cars-emission-14

[4] *Hellenic Association of Motor Vehicle Importers-Representatives (AMVIR)*, (2018) "Databases of AMVIR Greece – Vehicle Registration Statistics – Segment: Passenger Cars", *ΣΕΑΑ*, Available online at:
http://www.seaa.gr/en/statistics/category/9

[5] *EEA (European Environment Agency)*, (2016), "Reported CO_2 emissions from new cars continue to fall", Available online at:
https://www.eea.europa.eu/highlights/reported-co2-emissions-from-new

[6] *European Automobile Manufacturers' Association (ACEA)*, (2017), "ACEA Report: Vehicles in use Europe 2017", Available online at:
http://www.acea.be/uploads/statistic_documents/ACEA_Report_Vehicles_in_use-Europe_2017_FINAL2.pdf

[7] *International Energy Agency (IEA)*, (2017), "Energy Policies of IEA Countries – Greece 2017 Review", Available online at: https://www.iea.org/publications/freepublications/publication/EnergyPoliciesofIEACountriesGreeceReview2017.pdf

[8] F. Munoz, (2018), "Brands with average CO_2 emissions between 110-130 g/km counted for 73% of European car regs in 2017", *JATO*, Available online at: http://www.jato.com/brands-average-co2-emissions-110-130-g-km-counted-73-european-car-regs-2017/

[9] BMW, (2018), "BMW i3 Series Sedan– Model Catalogue", Available online at: https://www.bmw.se/content/dam/bmw/marketSE/bmw_se/download/catalogues/modellkataloger/katalog-BMW-I01.pdf.asset.1520841449918.pdf

[10] *International Energy Agency (IEA)*, (2017), "Energy Technology Perspectives 2017 - Catalysing Energy Technology Transformations"

[11] *European Automobile Manufacturers Association (ACEA),* (2017), "The Automotive Industry Pocket Guide 2017/2018", Available online at: http://www.acea.be/uploads/publications/ACEA_Pocket_Guide_2017-2018.pdf

[12] *European Automobile Manufacturers' Association (ACEA),* (2018), "Truck industry reacts to EU proposal for first-ever CO_2 standards", Press release, Available online at: http://www.acea.be/press-releases/article/truck-industry-reacts-to-eu-proposal-for-first-ever-co2-standards

[13] *European Commission: Energy, Climate change, Environment*, (2016), "Climate Action: A European Strategy for low-emission mobility", Available online at: https://ec.europa.eu/clima/policies/transport_en

[14] *The World Bank*, (2014), "CO2 emissions from transport (% of total fuel combustion)", Data source: *IEA Statistics, OECD/IEA 2014*, *The World Bank Group*, Available online at: https://data.worldbank.org/indicator/EN.CO2.TRAN.ZS?end=2014&start=1990&view=chart

[15] C. Façanha, K. Blumberg, J. Miller, (2012), "Global Transportation Energy and Climate Roadmap: The impact of transportation policies and their potential to reduce oil consumption and greenhouse gas emissions", *The ICCT Report*, Available online at:

https://www.theicct.org/sites/default/files/publications/ICCT%20Roadmap%20Energy%20Report.pdf

[16] *International Energy Agency (IEA)*, (2017), "World Energy Outlook 2016 - Global Energy Trends", p318

[17] C. Shulock, E. Pike A. Lloyd R. Rose, (2011), "Vehicle Electrification Policy study – Task 1 Report: Technology Status", *ICCT*, Brussels, Available online at: https://www.theicct.org/sites/default/files/publications/ICCT_VEPstudy_Mar2011_no1.pdf

[18] Defined Term, (2011), "Well-To-Wheel (WTW) definitions", *Intergovernmental Panel on Climate Change*, Available online at: https://definedterm.com/well_to_wheel_wtw

[19] *European Automobile Manufacturers' Association (ACEA),* (2018), "First-ever CO_2 standards for trucks must reflect market diversity, EU truck industry says", Available online at: http://www.acea.be/press-releases/article/first-ever-co2-standards-for-trucks-must-reflect-market-diversity-eu-truck

[20] M. Moultak, N. Lutsey, D. Hall, (2017), "Transitioning to Zero-Emission Heavy-Duty Freight Vehicles", *ICCT*, Available online at: https://www.theicct.org/sites/default/files/publications/Zero-emission-freight-trucks_ICCT-white-paper_26092017_vF.pdf

[21] *European Automobile Manufacturers' Association (ACEA),* (2018), "ACEA Position Paper: Future CO_2 standards for heavy-duty vehicles", Available online at: http://www.acea.be/uploads/publications/ACEA_Position_Paper-Future_CO2_standards_heavy-duty_vehicles.pdf

[22] S. Edelsteinjune, (2017), "Daimler Isn't Worried About Tesla's Electric Semi Truck, Exec Says", *The Drive*, Available online at: http://www.thedrive.com/tech/11500/daimler-isnt-worried-about-teslas-electric-semi-truck-exec-says

[23] *Deloitte*, (2017), "Global Truck Study 2016 - The truck industry in transition", Available online at: https://www2.deloitte.com/content/dam/Deloitte/us/Documents/manufacturing/us-manufacturing-global-truck-study-the-truck-industry-in-transition.pdf

[24] *The International Tanker Owners Pollution Federation Limited (ITOPF)*, (2018), "Oil Tanker Spill Statistics 2017", Available online at: http://www.itopf.com/knowledge-resources/data-statistics/statistics/

[25] *International Energy Agency (IEA)*, (2018), "Monthly Oil Market report - May 2018"

[26] *U.S. Energy Information Administration (EIA)*, (2018), "FAQ - How many gallons of gasoline and diesel fuel are made from one barrel of oil?", Available online at: https://www.eia.gov/tools/faqs/faq.php?id=327&t=9

[27] *U.S. Energy Information Administration (EIA)*, (2018), "Refining Crude Oil - Energy Explained", *Your Guide To Understanding Energy,* Available online at: https://www.eia.gov/energyexplained/index.php?page=oil_refining

[28] D. Miller, (2015), "Diesel vs. Gas: Which Is the Better Fuel -- and Vehicle -- for Your Money?", *The Motley Fool,* Available online at: https://www.fool.com/investing/general/2015/06/04/diesel-vs-gas-which-is-the-better-fuel-and-vehicle.aspx

[29] *Ministry of Natural Resources Canada*, (2014), "Learn the facts: Fuel consumption and CO_2", Available online at: http://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/oee/pdf/transportation/fuel-efficient-technologies/autosmart_factsheet_6_e.pdf

[30] *U.S. Environmental Protection Agency (EPA)*, (2011), "Greenhouse Gas Emissions from a Typical Passenger Vehicle", (Archived on 5/2018), Available online at: https://planning.lacity.org/eir/ConventionCntr/DEIR/files/references/United%20States%20EPA%20Greenhouse%20Gas%20Emissions%20from%20a%20Typical%20Passenger%20Vehicle.pdf

[31] D. Carrington, (2017), "Diesel cars emit 10 times more toxic pollution than trucks and buses, data shows", *The Guardian*, Available online at: https://www.theguardian.com/environment/2017/jan/06/diesel-cars-are-10-times-more-toxic-than-trucks-and-buses-data-shows

[32] *European Commission*, (2018), "European Clean Bus deployment Initiative", Available online at: https://ec.europa.eu/transport/themes/urban/cleanbus_en

[33] P. Boulter et al., (2011), project "TEDDIE: A new roadworthiness emission test for diesel vehicles involving NO, NO_2 and PM measurements - Final Report" *European Commission, DG-MOVE, CITA*, Brussels, Available online at:
https://www.vdtuev.de/dok_view?oid=670477

[34] *European Environment Agency (EEA)*, (2018), "Tax breaks and incentives make Europeans buy cleaner cars — European Environment Agency", Available online at:
https://www.eea.europa.eu/highlights/tax-breaks-and-incentives-make

[35] E. K. Nam, T. E. Jensen, and T. J. Wallington, (2004) "Methane Emissions from Vehicles", *Research Laboratory MD-3083, Ford Motor Company*, Michigan, *Environ. Sci. Technol.* V. 38, p. 2005-2010

[36] P.F.Nelson, S.M.Quigley, (1984), "The hydrocarbon composition of exhaust emitted from gasoline fueled vehicles", *Atmospheric Environment*, v. 18, issue 1, p. 79-87

[37] L. M. Iversen, (2016), "Measurement of noise from electrical vehicles and internal combustion engine vehicles under urban driving conditions", *Danish Road Directorate,* Oslo.

[38] M. Barnard, (2016), "Will Electric Cars Make Traffic Quieter? Yes & No.", *CleanTechnica,* Available online at: https://cleantechnica.com/2016/06/05/will-electric-cars-make-traffic-quieter-yes-no/

[39] *U.S. Environmental Protection Agency (EPA),* (2014), "Report on the Environment: Particulate Matter Emissions", Available online at:
https://cfpub.epa.gov/roe/indicator_pdf.cfm?i=19

[40] *European Environment Agency (EEA)*, (2010), "Nitrogen oxides (NOx) emissions", (Archived on Feb 2018), Available online at:
https://www.eea.europa.eu/data-and-maps/indicators/eea-32-nitrogen-oxides-nox-emissions-1

[41] *World Health Organization - Regional office for Europe*, (2013), "Health effects of particulate matter - Policy implications for countries in eastern Europe, Caucasus and central Asia", Available online at:
http://www.euro.who.int/__data/assets/pdf_file/0006/189051/Health-effects-of-particulate-matter-final-Eng.pdf
[42] *TerranerPMC Safety Share*, (2015), "Vehicle Emissions (NOx and SOx)", Available online at:

https://eteba.org/wp-content/uploads/2015/10/SafetyShare-10-12-2015-Vehicle-Emissions-NOx-and-SOx.pdf

[43] *mathesongas.com*, (2015), "Threshold Limit Values (TLV) and Immediately Dangerous to Life and Health (IDLH) values", Source: *National Institute for Occupational Safety and Health (NIOSH)*
https://www.mathesongas.com/pdfs/products/threshold-limit-values-(tlv).pdf

[44] S. Guo, F. Yang, J. Tan and J. Duan, (2012), "Nonmethane Hydrocarbons in Ambient Air of Hazy and Normal Days in Foshan, South China", *Environ Eng Sci.* v. 29(4) p. 262–269.)", Available online at:
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3313607/

7. Electric Vehicles and Economic Repercussions

A. The effect of Electric Mobility Transition on the Employment market

In European Union (28), during 2017, 12.6 million people, accounting for 5.7% of the EU's employed population worked in the automotive industry sector, while the 3.3 million jobs in automotive manufacturing represented almost 11% of EU manufacturing employment.

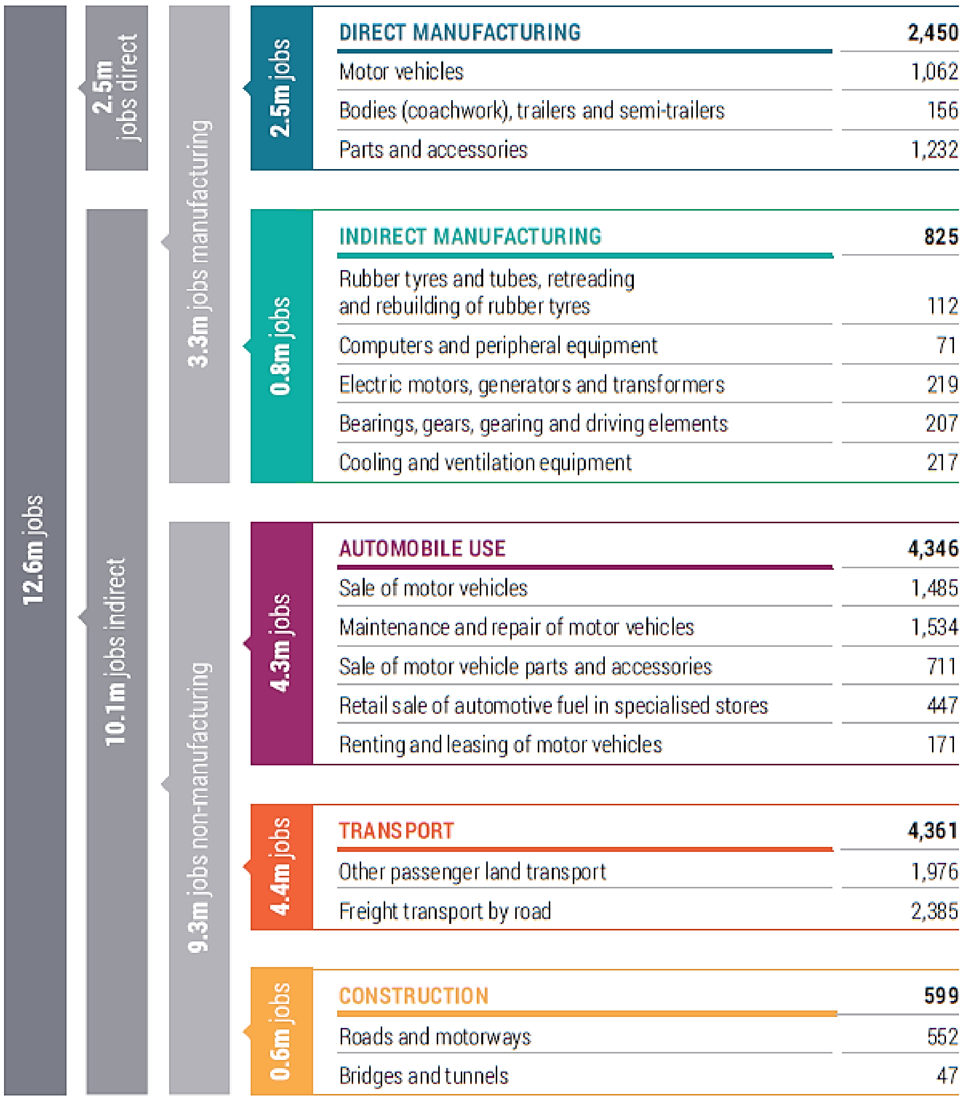


Figure 131 Figure Automotive sector:direct and indirect employment in the EU in thousands (2015) (Source ACEA [2])

The sector undergoes transition towards electrification and alternative fuel adoption, and doing so it has been in the spotlight as a key driver of knowledge and innovation by fostering advance technology adoption. As a result the European automotive industry is Europe’s largest private contributor to R&D, with more than €50 billion invested annually. The motor vehicles account for almost €396 billion in tax contributions in the EU15 while the industry generates a trade surplus of about €90 billion for the EU [1].

In figure 131 the employment in the automotive industry by segment is analytically presented. The human resource allocation observed in EU is indicative of the structure of the automotive industry based on the current developments and needs of the industry. However, transition to electric mobility and EVs is expected to have substantial impacts in the job market. These transformations are expected to happen both inside the industry and in relevant industries that are particularly connected to the new technology.

Specifically inside the sector, it is expected a job reduction in the direct manufacturing segment and the maintenance and repair of motor vehicles due to minimization of the number of functional components in the new EV vehicles in comparison to the predominant conventional ICE ones. Employment related to manufacturing and sales of motor vehicle parts will be reduced as well, while significant jobs related in retail sales of automotive fuel will be lost to the EV charging market namely towards the economic activity of PEV aggregators. In addition employment related to the chassis, the vehicle bodies, trailers and semi-trailers is expected to slightly increase in the research and development side while on the on the manufacturing side a slight decrease due to automation adoption and ramping up of production must be expected over time.

The number of Jobs created in EV related industries is expected to rise significantly the following years, with the battery industry being the most prominent one to accommodate these new employment positions in all its segments spanning from mineral mining, manufacturing to monitoring, researching and recycling.

It is safe to expect jobs transferring towards indirect manufacturing and specifically towards segments highlighted by the new technology, such as electric motors generators and transformers, while employment related to computers and relevant equipment will flourish under the adoption of the new trend of smart vehicle integration. Specifically, for the latter, high-tech vehicle companies already employ information technology systems of vehicle to vehicle (V2V) [3] and vehicle to infrastructure (V2I) [4] communication aiming to monitor performance for safety and maintenance reasons as well as to accommodate new transportation high tech products such as autonomous driving. Therefore, the constant development and support of such technologies are expected to be subjects highlighted in the future labor market.

Even though potential indication for the direction of the labor market in regards to the adoption EVs can be identified, it is difficult to reliably estimate the total job creation potential of EVs. It is safe to assume however, that the adoption of EVs will likely lead to some job losses in the oil industry. According to the International Economic Development Council (IEDC), drivers who switch to electric vehicles, due to their low operation and maintenance costs, will have more disposable income to spend in other sectors of the economy, such as housing and services. Spending in these sectors is expected to keep more wealth moving within local economies and to drive job creation in sectors not immediately connected to producing electric vehicles [5]. In addition to that Blue-Green Alliance and the American Council for Energy-Efficient Economy predicts that the federal vehicle standards passed in 2012 will result in the creation of 570,000 jobs in the US, including 50,000 in vehicle manufacturing until 2030.

B. Electric Vehicles and Economic repercussions in Greece and SE Europe

Table 25 Table Direct automotive manufacturing employment by country (2015 -EU 27) (Source: ACEA [2])

Austria	30,804	France	224,000	Netherlands	20,295
Belgium	30,838	Germany	850,857	Poland	178,274
Bulgaria	20,512	Greece	1,765	Portugal	33,436
Croatia	2,825	Hungary	88,532	Romania	168,689
Cyprus	104	Ireland	2,311	Slovakia	66,356
Czech Republic	159,732	Italy	159,148	Slovenia	12,746
Denmark	1,606	Latvia	1,821	Spain	142,480
Estonia	3,233	Lithuania	4,496	Sweden	68,336
Finland	7,282	Luxembourg	314	United Kingdom	169,000

Greece: The automotive industry in Greece employs a very small number of people in the direct automotive manufacturing, mainly because no manufacturing facilities are established in the country. Therefore, the 1,765 employees, currently active in the market segment (2015), are service providers in the manufacturing process mainly engineers and other professionals working on design, operations and research and development. Due to the country's highly trained engineers various companies have moved relevant positions to the country establishing collaboration with the local service industry. Moreover, low scale vehicle production is a reality but manufacturing is sent overseas mainly to China to achieve lower cost of production. Specifically a Greek motor vehicle company Eco Sun produced the first new age Greek passenger EV, “Eco Car”, which is manufactured in China but it was designed entirely in Greece [9]. In addition new investments are expected to move to the country mainly due to the numerous highly trained individuals in Engineering [6]. Specifically according to Technical Chamber of Greece (TEE), the country numbers approximately 35,000 academically trained Mechanical and Electrical Engineers [7], which are expected to attract the automotive industry mainly on the fields of electrical motors, power systems electronics, traction control and information technology and networks. Already, the electric mobility pioneer company Tesla has set a research and development hub in Greece which is expected to bring immediately 50 employment position in the local labor market [8].

On the other hand, EV introduction to the Greek System will bring numerous jobs in the energy industry, namely projects focused in renewable energy systems’ design and installation, as well as the installation of numerous charging stations and medium voltage substations, which will be aiming to facilitate the EV charging operations in a country scale. The need for expansion of the power generation sector due to the increased electricity demand, induced by electric mobility, is evident. In addition, the RES capacity must substantially increase its penetration in the local power system, in order for Greece, to make steps towards decarbonization of the on-road transport, by reducing the indirect GHG emissions of EVs (g CO2/kWh). Therefore the RES industry is expected to increase its activity significantly in the next years creating significant employment and investment opportunities.

The transition towards electric mobility is expected to affect more the vehicle manufacturing economies of the region. Namely Turkey, Romania and Slovenia which accommodate automotive and automotive parts manufacturing operations in their premises might be more affected by a potential transition towards electric mobility.

Bulgaria: Bulgaria, until recently had in its premises an ambitious project, a vehicle assembling factory, in the northern village of Bahovitsa, which had a local capacity of 50,000 units while employing approximately 200 people. The plant was co-owned by the Chinese Great Wall Motors (GWM) and the Bulgarian Litex Motors, authorized to produce GWM’s vehicles [12]. Litex Motors, filed for bankruptcy in April of 2017 ending the ambition of Great Wall Motors (GWM) in the region [14]. Unfortunately, for GWM, Bulgaria and the region of SE Europe, the GWM’s ambitions, which involved EVs, as the company currently produces 3 electric models, could not be realized. Given the fact that GWM has been involved with Mini (BMW) in the project of conjointly producing the mini EV in China in the future, SE Europe could potentially have missed an opportunity for a fruitful Chinese-European collaboration, which could have been translated in further expansion of GWM and electric mobility in the SE European region [10],[13].

Despite the failures of the automotive industry to establish production Bulgaria, the automotive parts industry has become one of the engines of its national output. The industry counts more than 100 enterprises in the auto parts sector employing over 33,000 people (2016), while producing products for more than 20 major global automakers such as Peugeot, BMW and Daimler. The number of companies active in the sector more than doubled since 2012, while the overseas investment is majorly attracted to Bulgaria's low tax environment, cheap labor and currency stability. In 2015 the sector generated revenue of €1.55bn, which amounts to more than 3% of the country's GDP [29].

The auto parts industry is located in two regions of the country, the North West and the South region. The North West region which though far from the capital Sofia offers proximity towards the central European car manufacturing facilities, while offering cheaper labor since it is the poorest region of the country. The south region, near the city of Plovdiv, the second largest city of Bulgaria, where the industry can have access to highly skilled graduates of its universities. Plovdiv's Trakia Economic Zone (TEZ) has attracted €1.2bn in investment, of which about €500m has been devoted to auto parts manufacturing, according to Plamen Panchev, TEZ chairman. Enterprises that are active in the area are the UK-based springs and wire-forms manufacturer William Hughes, the Swedish-Swiss ABB, the US-based Sensata Technologies and Canada's Magna Powertrain, whose customers include BMW and General Motors. Due to the foreign investment Plovdiv has started to transform into a high-tech manufacturing hub. [29]

Reflecting the recent aggressive adoption of EVs by global market, Bulgaria's component industry can potentially be in an advantageous position, since the companies active in the region have been pro-active in the EV market as well as in relevant markets, which are expected to be enhanced by the trending electrification. Namely Bulgaria's industry is also active on the power generation and transmission sector, while the vast majority of their products are not expected to reduce in demand due to the transition to on-road electrification. Specifically ABB, global leader in medium and low voltage power and automation solutions, produces a variety of components in Bulgaria, including wirings and switches, electrical motor control solutions, metallic enclosures, low voltage breakers, miniature circuit breaker components, fuse gears and many more. Also the company assembles solutions by combining primary components and secondary control and protection within a compact modular enclosure, which are intended for electrical distribution utilities and large industrial power users and producers, including wind farms and heavy industry [30]. Such products are in high demand for future of electrification, in which it is expected a major expansion of the global power system to accommodate renewable electricity demand. Even though ABB does not produce EV charging infrastructure solutions in Bulgaria, it has developed already a related product portfolio in this market segment [31] and given its expansion in the country with 5 production facilities and more than 2100 employees, one can expect such a development in the future.

Moreover, Sensata Technologies maintains in Bulgaria its largest globally testing laboratory and mechanization office employing more than 100 engineers. Its purpose it's to stress-test Sensata's sensors and controls designed for leading automotive manufacturers in harsh driving conditions [32]. Sensata's products are trending with the aggressive adoption of information systems on vehicles and is expected the relevant technology to be in higher demand towards the electric mobility era. However, in the specific industry a transfer of interest from monitoring and controlling of the transmission and exhaust systems is expected to be concentrated to electronic system stability and electric motor performance [33].

Turkey: Turkey in 2017 produced approximately 1.7 million motor vehicles, the 14th largest production globally and the 5th in Europe and is already established as an important part of the global value chain of international OEMs over the last 25 years. The 67.4% of the total local production are passenger cars while the rest 32.6% are commercial vehicles. The Global car manufacturers active in the automotive industry of Turkey include Daimler-Mercedes-Benz, Fiat/Tofaş, Oyak-Renault, Hyundai, Toyota, Honda, Anadolu/Isuzu, MAN, Ford/Otosan, Temsa, BMC etc., all of which maintain production facilities in the country.

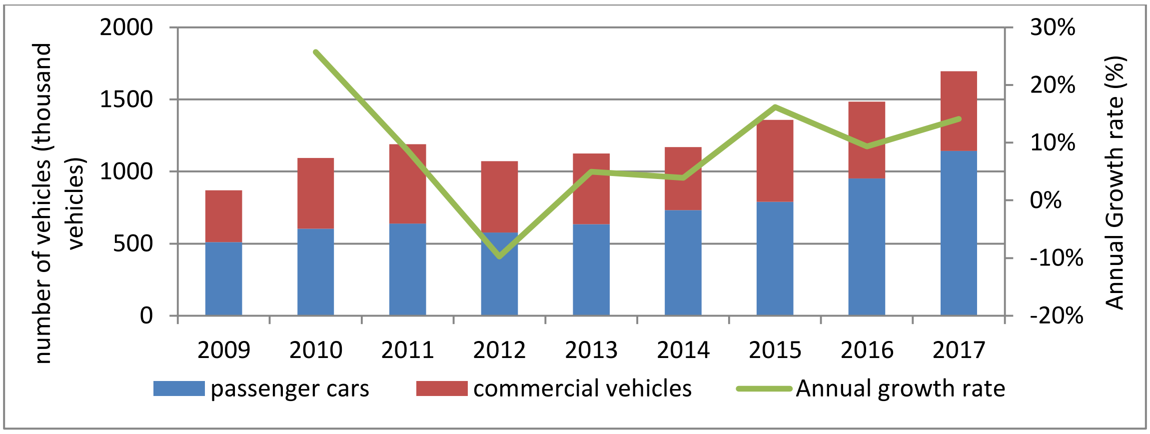


Figure 132 Turkeys Automotive industry output and annual growth rate in period 2009-2017 (Source: Prime Ministry of Investment – Republic of Turkey)

In addition to that, Turkey has 9 R&D facilities, which not only do they support the local operation, but also the operation in other plants of parent companies. Ford Otosan's R&D department is one of Ford's 3 largest global R&D centers, while R&D center in Bursa is the only center of Fiat outside of Italy serving the European market. Yeniköy plant is the sole production center in the world for Courier, Ford's new light commercial vehicle. In addition, Toyota's C-HR Hybrid is produced in Turkey and it is exported globally, while Daimler's R&D center is the center of competence for some vehicle parts carrying a global responsibility for their success. Turkey numbers more than 40 thousand employees in the local automotive industry, making Turkey's automotive OEMs, the major employers in the local manufacturing industry [15].

Turkey's industry therefore will be majorly impacted as global on-road transportation transitions towards EVs. Turkey already has activity in the new vehicle technologies with the most major company active in the field to be the Turkish subsidiary of the Austrian Engineering company AVL, employing over 140 engineers in the Istanbul area, while its activities expand in the fields of Hybrid electric and autonomous car technologies, being supported by Scientific and Technological Research Council of Turkey (Tubitak) in the specific projects. AVL is expected to expand its operations further on R&D, which is evident by its already announced expansion to a 3rd R&D center aiming in employing more than 200 engineers by 2018 [15]. Other important engineering companies mainly active on automotive consulting and automotive power train R&D are the German FEV GmbH, the Spanish Idlada and the British Ricardo.

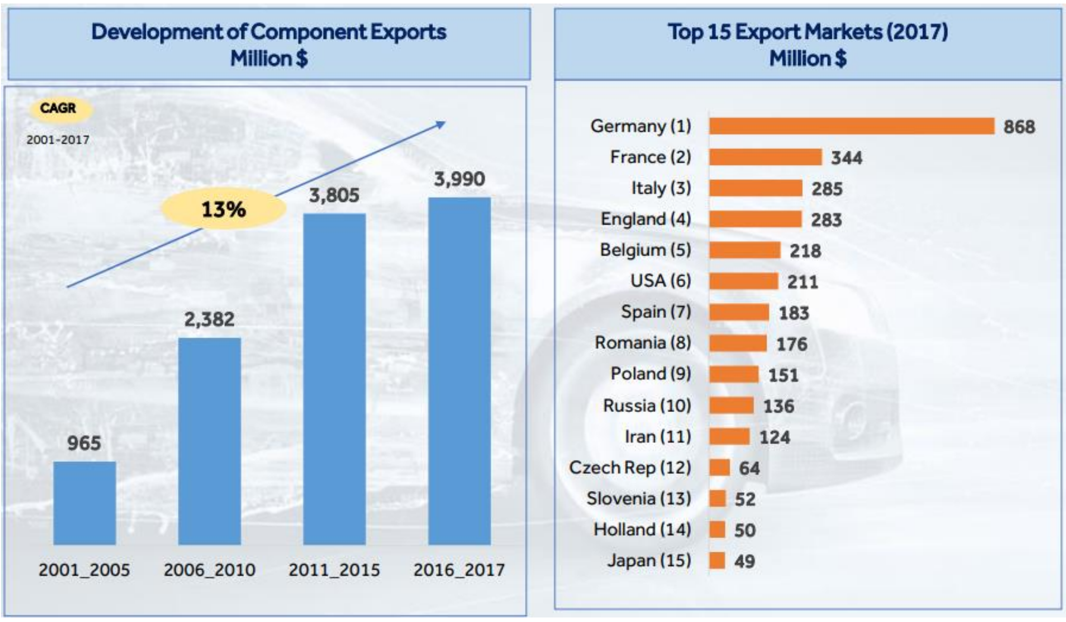


Figure 133 Turkey's automotive component exports and its export markets (Source: Turkish Statistical Institute (TurkStat))

Turkey is also a major supplier of automotive components with exports that reach $3,990 million in the period 2016-2017 showing a steady increase by 13% of cumulative annual growth rate over the past 16 years. This economic activity is expected to be mostly affected by the takeover of EVs by the end of next decade due to reduction of the active components of vehicles and also the reduction of maintenance needs. Component market segments associated with ICE Engines, transmission systems, fuel systems, exhaust, forging components and small general parts manufacturing are expected to be negatively affected by the transition to gearless, fuel-less, robust new vehicles. However, important segments of Turkey's manufacturing activity such as electric component development and manufacturing, electronic architecture systems and components and telematics are expected to attract new investors and expand their activity.

Table 26 Turkish top 10 automotive suppliers with USD 200 Million+ revenue in 2016 (Source: Istanbul Chamber of Industry: Top 500 Industrial Enterprises Study)

Rank	Major Suppliers	Products	2016 Revenue (Million $)
1	BOSCH	Brake systems, boosters, power limiters & regulators, repair kids, brake shoes, wheel brake cylinders, drum & disk brakes	901
2	BRISA	Tires, batteries, coverings	458
3	CMS	Wheels	336
4	YAZAKI	Electrical and electronics components	330
5	MAXION İNCİ	Wheels	309
6	GOODYEAR	Tires	309
7	DELPHI	Cables, electrical/electronic architecture systems and components, fuel pumps, fuel injectors, nozzles, valves	298
8	Autoliv	Steering wheels, seat belts, air bags	286
9	BEYÇELİK GESTAMP	Molds, chassis systems, lock technologies	238
10	HEMA OTOMOTİV SİSTEMLERİ A.Ş.	Drivetrain components, engine components	224

Concluding, Turkey playing the role of OEMs' production station in the region is expected to adjust smoothly to the transition towards electric mobility as the local market is influenced majorly by leading global OEMs from all major markets (Japan, USA and EU), which have already embraced the transition to electric mobility. This can be confirmed by the orientation of Turkish automotive economic activity towards R&D which amounts to 14% of the industry's budget resulting to rapid increase in employment of 96% in the period 2010-2015 and in patent applications of 165% in the period of 2010-2016 as shown in figure 133.

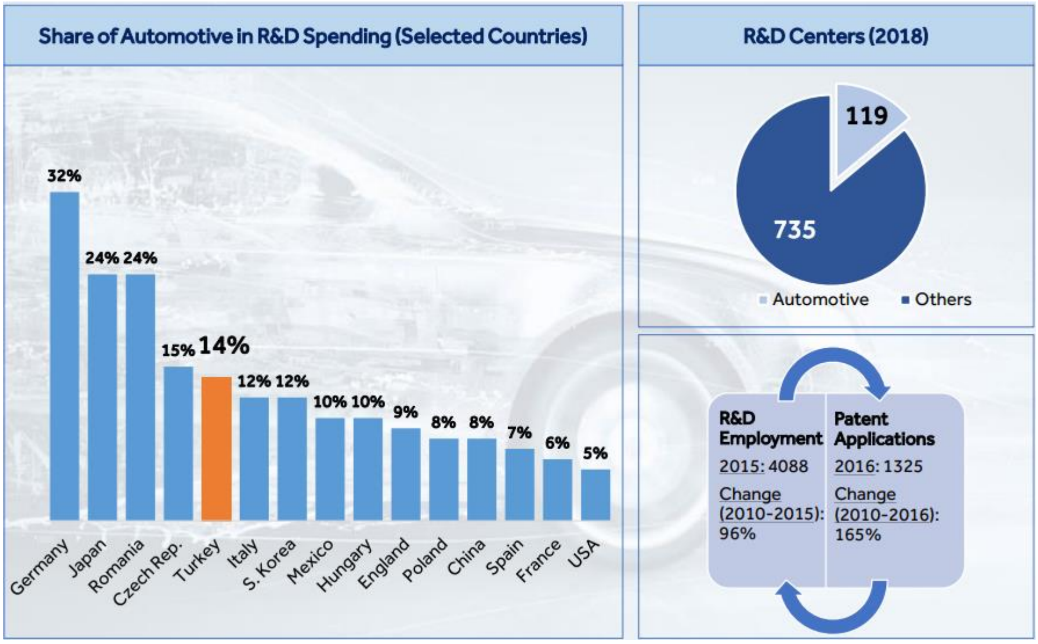


Figure 134 Turkish Automotive industry R&D performance (Source: Automotive Manufacturers Association of Turkey (OSD), Ministry of Industry, Science & Technology, Turkish Patent Institute (Turkpatent) R&D employment data consists of OSD members)

Romania: Dacia owned by Renault and Ford maintain production facilities in the country and are the backbone of the local industry, employing more than 17,000 people. The automotive industry in Romania is a major success achieving 5 billion Euros per year in revenue, while the automotive production more than doubled in the last 10 years reaching the 387 thousand units in 2015 [16]. Most of the vehicle production of Romania is exported to European Countries, with Germany and France being the recipients of the largest volume of vehicles, while Romania's vehicle exports are also directed towards African and Middle Eastern countries and Turkey [17]. The local vehicle industry didn't recess due to the crisis showing important growth in the period 2008-2010. Important to mention is that after a EUR 2.2 billion investment program as well as an intensive transfer of know-how, Dacia became one of Renault's most outstanding achievements and is one of the top technologically developed companies in Southeastern Europe.

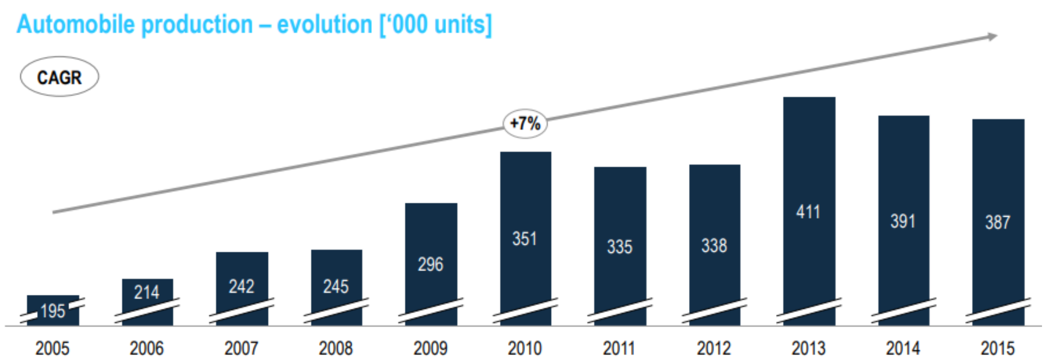


Figure 135 Evolution of Romania's automotive industry's vehicle output

The local automotive market though is more oriented towards automotive component production sector which was initially driven by vehicle industry. The specific industry which consists of more than 600 OEMs is actively producing Tires, Cables and conductors, Plastics, Rubber technical components, Bearings and transmission components, Electronics and Mechatronic equipment, Optical devices, Batteries - Capacitors, while it also offers advance services in Aluminum and metal manipulation and Recycling.

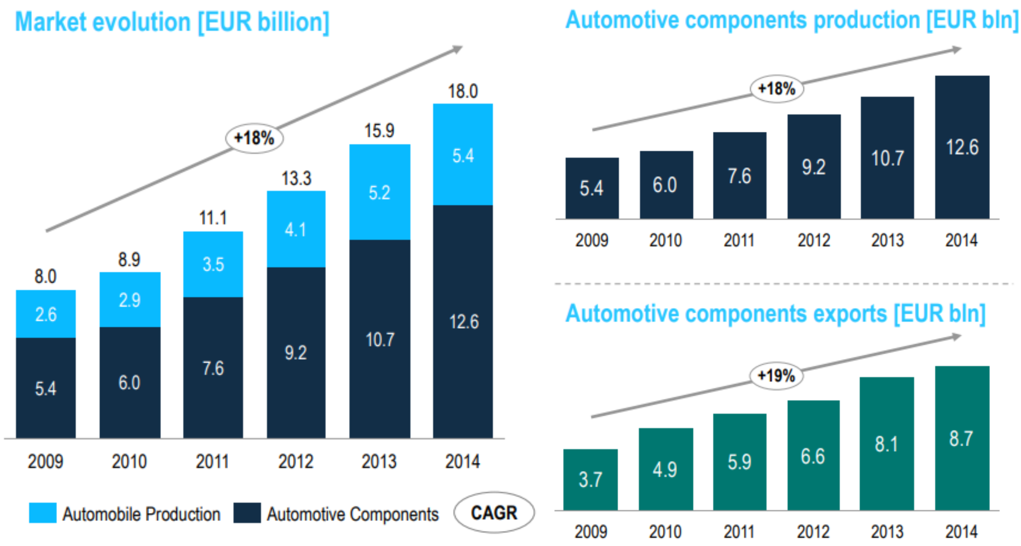


Figure 136 Evolution of Revenues of vehicle and automotive components industry in Romania

The components industry is mostly exporting its output, as the local vehicle industry cannot absorb its large production. Moreover, Romania exports the 69% of its component production which reached revenue of 12.6 billion Euros (2014).

Even though the Romanian automotive industry does not produce EVs, Dacia is intensively preparing for the on-road transport electrification revolution. The low cost profile of the company will be maintained in its effort to launch an EV [18], in which Dacia will be utilizing the underpinnings and the electric motor of Renault ZOE, exploiting the advantage of its participation in Renault-Nissan Alliance [19].

Romania also is promising, from a cost-effectiveness perspective, in being a quality and competitive market for establishing R&D facilities. Specifically a number of parameters such as the low tax rates, the low cost of industrial electricity, the low cost of gas, the increasing number of technically educated population, as well as the reducing cost to start a business are affecting the attractiveness of the local market for R&D investment. Moreover, the Romanian government has established economic incentives to support the R&D investment in the country, which includes: exemptions from profit tax, Income tax exemptions for IT&C employees, Deduction of R&D eligible expenses, and accelerated depreciation of machinery, equipment and real estate used for R&D purposes. In addition to that Romanian authorities also implemented a foreign tax credit aiming to attract foreign work force and offshore investors [16].

Electric mobility transition is expected to magnify the economic activity of the segment of manufacturing solutions for Electronics and Mechatronic equipment, Cables and conductors and batteries and capacitors, while we expect shrinking of other manufacturing segments like transmission components and metal manipulation products and services.

Slovenia: Slovenia has also an important automotive market for the region, counting approximately 278 companies and more than 14,000 employees. Like Romania it's mostly an exporting market with 2.9 billion export revenue from the 3.3 billion total achieved in 2016, while the main recipients of its products are European Markets, Mexico and the US. Slovenia has only one car manufacturer, Revoz owned by the French Renault, which is the number one exporter in the country employing more than 2,000 people. Revoz's cars are renowned for their quality and the company for its productivity. Revoz produced approximately 190,000 vehicles in 2017. In addition to Revoz, there is local activity in supercar development by Tushek, an Austrian/Slovenian company specializing in high performance vehicles which made important steps towards early development of solutions focusing into in-wheel electric motor integration as well as light material incorporation to the chassis [27].

The country also has a major automotive components industry counting an extensive number of products related to vehicle manufacturing as well as operation and maintenance. Some of the market's key products are: Seats and seat components, Components and materials for interior furnishing, Car body parts, Components for braking systems, Mechanical and electric/electronic components for engines, Exterior equipment and body lighting equipment, Exhaust systems, Engine and gearbox components, Steering system components, Drive components, Manufacturing spot welding equipment, Tooling for automotive industry etc. [21].

A segment of the automotive economic activity of Slovenia is expected to be impacted by the transition to electric mobility. These consequences are expected to reflect heavily on the segment of the industry affiliated with the manufacturing of exhaust systems and engine and gearbox components. Especially the exhaust system industry employing more than 1,000 people could be forced to reduce its activity [20]. On the other hand Electric mobility is an opportunity for Academic Institutes, Innovation centers, institutes for materials and technologies, knowledge academies to increase their activity, to mobilize the local economy in order to exploit productively such a transition. Such institutes could enhance their contribution in evaluation of the technical feasibility of new ideas and technologies and follow through to mass development and production. Such an example is the commitment of Hidria, a global leader in the supply and development of a variety of subsystems and components, to the development of innovative technological and product solutions for the automotive and HVAC industries, which is best illustrated by the construction of its third R&D facility co-financed by the European Regional Development Fund. Among others, the solutions developed by Hidria are also focused in electric hybrid engines for vehicles [24].

Croatia: The development of the Croatian automotive industry is based on a long tradition in related sectors, such as metal production, welding, plastics manufacturing and engineering. Croatian automotive component industry, which employs more than 2,500 people, has widely diversified production spanning from metal welded products and high quality screws until high quality powertrain technology testing services [22]. Moreover Croatian companies dealing with the production of automotive parts have a tradition in high-precision manufacturing with zero tolerance for breakdowns. On the Croatian market, there are companies that have successfully integrated into the system of supplying spare parts for the world's top automobile manufacturers (PSA, GM, Fiat, BMW, Audi, Ford, Renault, Toyota, Volvo, etc). Croatian automotive industry is also involved in EV development with the main actors being DOK-ING and Rimac Automobili. DOK-ING has recently launched its first electric passenger car, "Loox", while it has long experience with electric scooters and two wheelers [26]. Rimac Automobili is active in the development of all electric super cars. "Concept Two" and its predecessor "Concept One" are high quality vehicles with superb performances highlighting the integration of new technologies, of which Rimac is also the developer, focusing in the technology of battery packs, drivetrains, electronics, connectivity and advanced driver assistance systems [25].

Croatian market is very promising for the development of electric mobility and that is because it is already a pioneer in the field and even though the local automakers have minor productions of EVs with specific market orientation, the technology and capability is present and proven. Therefore, the expansion of the activity of the industry towards electric mobility with the diversification and the ramp up of the production should be considered certain in the following years. Moreover the component market is expected to face the consequences of the market transition; with the economic activity to move from gearbox components and related software development towards batteries and electric motor technology, while advanced services in relation to electric motor and battery testing are market segments that are expected to grow significantly given the presence of knowhow and a well-established market in the specific economic activity, with close proximity to the largest automotive production facilities of central Europe.

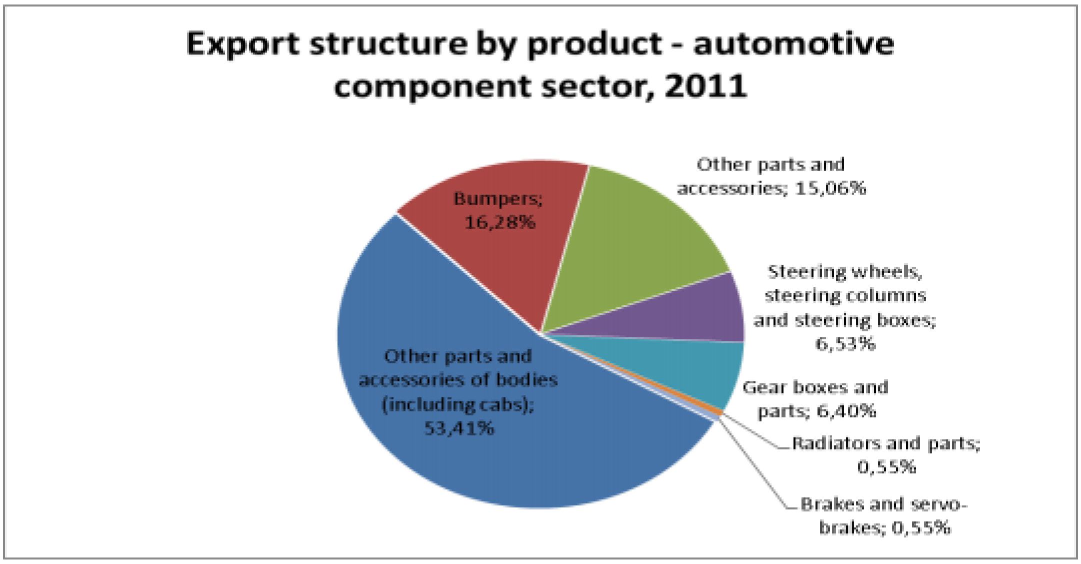


Figure 137 Croatian Export Structure by Product – automotive components in 2011 (Source: CROATIAN BUREAU OF STATISTICS)[28]

The rest of the SE Europe Markets are developing as peripheral small scale activity in relation to the automotive industry. The transition to electric mobility and EVs might be a significant opportunity for some of these markets to make a dynamic entrance in the EV industry and consequently the automotive industry.

References

[1] *ACEA*, "Comments on the proposal for Monitoring and Reporting of CO_2 emissions and fuel consumption of new heavy duty vehicles" Available online at: https://ec.europa.eu/info/law/.../090166e5b42511be_en

[2] *ACEA*, "The Automobile Industry Pocket Guide 2017-2018", *European Automobile Manufacturers Association*, Available online at: http://www.acea.be/uploads/publications/ACEA_Pocket_Guide_2017-2018.pdf

[3] W. Knight, (2015), "Car-to-Car Communication - MIT Technology Review.", *MIT Technology Review*, Available online at: https://www.technologyreview.com/s/534981/car-to-car-communication/

[4] P. Gáspár, Z. Szalay, S. Aradi, (2014) “Highly Automated Vehicle Systems - (Chapter 9) - Vehicle to Infrastructure interaction (V2I)”, *BME MOGI*, Available online at:
http://www.mogi.bme.hu/TAMOP/jarmurendszerek_iranyitasa_angol/math-ch09.html

[5] J. Todd, J. Chen, F. Clogston, (2013), “Creating the Clean Energy Economy - Analysis of the Electric Vehicle Industry.”, *International Economic Development Council*, Available online at:
https://www.iedconline.org/clientuploads/Downloads/edrp/IEDC_Electric_Vehicle_Industry.pdf

[6] V. Georgopoulos, C.Vassiliadis, B. Manhire, “Engineering Education in Greece”, *ASEE Peer 1999 Annual Conference,* Session 3660, Available online at:
https://peer.asee.org/engineering-education-in-greece.pdf

[7] Technical Chamber of Greece, (2018),“Registered Members” (in Greek), Available online at:http://portal.tee.gr/portal/page/portal/TEE/TEE_MEMBERS

[8]H. Smith, (2018), “Elon Musk to open Tesla R&D plant in Greece”, *The Guardian - Technology*, Available online at:
https://www.theguardian.com/technology/2018/mar/02/elon-musk-to-open-tesla-rd-plant-in-greece

[9] ECOSUN, “The electric car ECO-CAR by ECO//SUN”, (in Greek), Available online at: http://www.ecosun.gr/ecocar-2/

[10] D. Tan, (2018), “BMW-Great Wall Motor JV to produce electric MINIs”, *Auto Breaking News*, Available online at:
https://www.autobreakingnews.com/2018/02/bmw-great-wall-motor-jv-to-produce-electric-minis/

[11] C. Busch, J. Laitner, R. McCulloch, I. Stosic, (2012), “Gearing Up: Smart Standards Create Good Jobs Building Cleaner Cars”, *BlueGreen Alliance, American Council for an Energy Efficient Economy (ACEEE)*, Available online at:
http://www.drivinggrowth.org/wp-content/uploads/2012/06/BGA-Auto-Report.pdf

[12] *BBC News,* (2012), “China’s Great Wall Motor opens first European plant”, Available online at: http://www.bbc.co.uk/news/mobile/business-17119797

[13] M. Sheahan, (2018), "BMW, Great Wall sign letter of intent for electric Mini joint venture in China", *Reuters - South China Morning Post*, Available online at: https://www.reuters.com/article/us-great-wall-motor-bmw-jointventure/bmw-great-wall-sign-letter-of-intent-for-electric-mini-jv-in-china-idUSKCN1G7105

[14] V. Subev, M. Daynova, (2017), "The fall of the Great Wall of China in Bulgaria – a lesson to foreign investors", *BNR – Radio Bulgaria - Economy*, Available online at: http://bnr.bg/en/post/100816551/the-fall-of-the-great-wall-of-china-in-bulgaria-a-lesson-to-foreign-investors

[15] *Republic of Turkey – Ministry of Investment - Support and promotion Agency*, (2017), "Why Invest in Turkish Automotive Industry ?", Available online at: http://www.invest.gov.tr/en-US/infocenter/publications/Documents/AUTOMOTIVE.INDUSTRY.pdf

[16*] The Government of Romania – InvestRomania,* (2016), "Romania – an emerging auto hub", Available online at: http://investromania.gov.ro/web/wp-content/uploads/2016/04/Automotive_EN_.pdf

[17] *OEC*, (2016), "Export destinations of Cars from Romania", Available online at: https://atlas.media.mit.edu/en/visualize/tree_map/hs92/export/rou/show/8703/2016/

[18] M. Panait, (2017),"World's Cheapest EV Could Come From Dacia, Renault's Low-Cost Arm", *autoevolution online magazine*, Available online at: https://www.autoevolution.com/news/world-s-cheapest-ev-could-come-from-dacia-renault-s-low-cost-arm-119169.html

[19] R. Ingram, (2017), "Cheap Dacia electric cars could be close hints boss", *Auto Express*, Available online at: http://www.autoexpress.co.uk/dacia/101148/cheap-dacia-electric-cars-could-be-close-hints-boss

[20] *Sloexport - Database of Slovenian Exporters*, (2018), "Review on Akrapovič", *Invest Slovenia*, Available online at: http://www.sloexport.si/en/company-card?ms=1387570

[21] *Invest Slovenia*, (2018), "Automotive Industry Review", Available online at: https://www.investslovenia.org/industries/automotive/

[22] *Trade and investment promotion agency - Republic of Croatia*, (2008),"Croatian Automotive Industry", Available online at:

http://www.ukrexport.gov.ua/i/imgsupload/Croatian%20Automotive%20Industry.pdf

[23] *South-East European Industrial Market*, (2016), "Automotive industry in Croatia", Available online at:
http://see-industry.com/industrial-statii.aspx?br=66&rub=397&id=1321

[24] *Hidria*, (2009), "Projects and references - Hidria's Solutions in the New Hybrid Versions of Mercedes C- and E-Class", Available online at:
http://www.hidria.com/en/about-us/projects-references/7690/detail.html

[25] *Rimac Automobili*, (2018), "Technology Review", Available online at:
http://www.rimac-automobili.com/en/technology/

[26] *DOK-ING, robotic mine clearance and firefighting systems*, (2017), "Loox model Specification", Available online at:
http://dok-ing.hr/products/automotive/loox?productPage=general

[27] *autoND.net*, (2016), "Supercars in detail: Tushek, from Slovakia to Slovenia", *Automotive News on autoND.net*, Available online at:
http://autond.net/supercar/supercars-in-detail-tushek-from-slovakia-to-slovenia.html

[28] *Maxwel Stamp PLC*, (2012), "Croatian Automotive Sector Overview", *Ministry of Economy, Labour and Entrepreneurship (MELE) and the Central Finance and Contracting Agency (CFCA), Government of the Republic of Croatia* , Available online at:
https://poduzetnistvo.gov.hr/UserDocsImages/arhiva/Podr%C5%A1ka%20razvoju%20klastera/11.Sa%C5%BEetak%20hrvatskog%20automobilskog%20sektora.pdf

[29] T. Troev, A. Petrov, (2016), "Bulgaria's auto parts industry powers up", *Financial Times*, Available online at:
https://www.ft.com/content/4da3ca06-9a07-11e6-8f9b-70e3cabccfae

[30] *ABB*, (2018), "Locations in Bulgaria", Available online at:
https://new.abb.com/bg/en/abb-in-bulgaria/locations

[31] *ABB*, (2018), "EV Charging Infrastructure", Available online at:
https://new.abb.com/ev-charging

[32] *Sensata Technologies*, (2017), "Sensata Technologies Opens New Testing Facility in Bulgaria", Available online at:

https://www.sensata.com/about/newsroom/sensata-technologies-opens-new-testing-facility-bulgaria

[33] *Sensata Technologies*, (2018), “Automotive Products”, Available online at: https://www.sensata.com/industries/automotive

8. Key Messages

A. Key messages

A.(i). Vehicle Technology

- The Advantages of EVs in comparison to ICE vehicles include: (a) the decarbonization of transport sector with the utilization of power generated by RES. (b) The less primary energy utilization for road transport (63.3% when Energy is coming from renewable, 8.4% when is generated by gas turbines), (c) the overall high energy efficiency, reaching up to 81% of the total electrical energy stored in the EV battery transformed to mechanical in comparison to the 14% of a conventional ICE vehicle, (d) the subtraction of the noise pollution resulting from the engine operation, (e) the low operation cost due to the low cost of electricity in comparison to petrol, (f) the low maintenance cost resulting from the lower amount of moving parts.

- The Disadvantages of EVs include (a) The limited driving range, which is enhanced by (b) the lack of publicly available charging infrastructure, (c) The charging time which is spanning from 1 to 40 hours, depending on the power output of the available charging infrastructure and the battery size of the EV, and (d) the high acquisition cost of EVs due to low technology maturity which can be identified in ongoing production ramp ups and adjustments, which are present today in the EV industry.

- Most common EVs are Battery electric Vehicles (BEVs), Plug in Hybrid Electric Vehicles (PHEVs) and Fuel Cell Electric Vehicles (FCEVs), which come in various drivetrain architectures, enabling different mobility features and inside-the-vehicle energy management.

- Reduction of the weight of a passenger car of 10% can lead to decrease in energy requirement of 6-7%. Towards this direction, reduction of the chassis' weight can be achieved by size reduction and utilization of lighter materials, such as high-strength steels, aluminum and aluminum alloys, magnesium and magnesium alloys, titanium and titanium alloys, carbon fiber composites, nanocomposites.

- Autonomous driving technology is the natural development of assisted-driving technologies and includes emergency braking, backup cameras, adaptive cruise control, parking systems and lane violation control. The automotive industry hasn't yet determined the optimum technology archetype for semi-autonomous vehicles with the predominant candidates being : (a) Camera over radar, (b) Radar over camera and. (c) hybrid approach (light detection, radar, camera systems, sensor-fusion algorithms).

A.(ii). Battery Technology

- The battery technology utilized by EVs are mainly Lithium-ion batteries composed of high capacity metal oxides for cathode materials, high capacity anodes and new electrolytes with high oxidation potential.

- The cathode materials developed for EV batteries are metal oxides that can release more Lithium-ions during each charge operation. The Cathode materials that show competitive oxidation capabilities, high cell voltage induced capacities and are highly utilized in the EV market are lithium cobalt oxide (LCO), lithium nickel cobalt manganese oxide (NMC), lithium nickel cobalt aluminum oxide (NCA), lithium manganese oxide (LMO), or lithium iron phosphate (LFP).

- The electrolytes developed for EV batteries are solvents with high oxidation potential such that can withstand higher than 4.2 V of Li-ion battery cell voltage that the current Li-ion electrodes can reach. This will enable the use of high-voltage cathodes such as LiCoPO4 and LiNi0.5Mn1.5O4, which can increase significantly the battery's specific energy. In addition, the development of new solid and liquid electrolytes, aiming in replacing the flammable polyethylene separator has led to development of ceramic coated membranes providing superior adhesion, excellent stoichiometry transfer and precise porosity control, at a low temperature in a cost effective manner.

- Solid state batteries developed for EV applications are batteries with low power-density and high-energy density which could provide two to three times the energy storage capability of Li-ion batteries. Candidates for solid state battery materials include Ag4RbI5 for Ag+ conduction, LiI/Al2O3 mixtures for Li+ conduction, and the clay and β-alumina group of compounds (NaAl11O17) for Na+ conduction, which can provide high energy to weight ratio significantly extend the driving range and the energy efficiency.

- Battery cell technology transition from the proven lithium manganese oxide (LiMn2O4) with a blend of lithium Nickel Manganese Cobalt Oxide (LiNiMnCoO2) prismatic battery pack towards Lithium Nickel Cobalt Aluminum Oxide (LiNiCoAlO2) provides significant development in energy efficiency as it provides specific energy of 3.4Ah per cell or 248Wh/kg.

A.(iii). EV Market Development

• The EV market in 2016 showed significant growth of 40% with the global sales of plug in electric vehicles reaching 753,000, 60% of which were battery-electric vehicles (BEVs). China was for the 2nd consecutive year the largest EV market in the world with more than 40% of the global sales, while Europe is the 2nd largest market with 215,000 EVs sold, which corresponds to 28,5% of the global market. Such market performance is still on track with IEA's 2DS scenario which predicts 35% of constant annual growth rate till 2025.

• The main barriers that dictate the EV market penetration the technical limitation of EVs in terms of efficiency and driving range and the technical limitations of the charging infrastructure in terms of charging time and availability of public charging stations as well as the non-technical boundaries of EV adoption that comprise of the EV acquisition and ownership cost, the lack of communication of the advantages of EVs as well as the lack of support policies like fiscal incentives and EV driving privileges that would initiate the EV market.

• The main driver for the success of the market is focused in the existence of support policies, aiming at the consumers, which either lower the cost of acquisition and ownership of EVs or provide driving privileges to EV owners. In addition, polices that aim at the automakers by incentivizing the research and development (R&D) of EV technologies to promote economies of scale or in the form of mandates aiming at achieving a specific market share of EVs or gradually banning petroleum vehicles, are also deemed successful for the cause of EV market penetration.

• Global Markets have significant positive reaction towards EV adoption as a result of the implementation of various fiscal incentives and support policies. On the other hand markets that reduced the policy imposed value proposition of EVs in comparison to ICE vehicles by halting or limiting the applied fiscal incentives showed an important decline in EV sales. Important example is Denmark, which has seen its EV market collapsing in 2016 after phasing out the 20% registration tax exemption for EVs.

• The Global trends in EV market are mainly identified to be the increased diversity of the Electric Vehicle stock both in vehicle segment or in technology, with some vehicles focusing in energy efficiency by reducing their weight and therefore integrating less battery capacity, while others focus in the extension of the electric driving range expansion. Moreover there is a major shift from buying a car to buying mobility, which is enhanced with introduction of Energy Efficient EVs in urban transportation. The future of EVs is prominent as analysts predict 60 million new EV sales globally by 2040 corresponding to 54% of new light duty vehicle sales. The global fleet of EVs could reach 7% and 33% in 2030 and 2040 respectively.

A.(iv). EV Battery Market and Cost Formulation

• EV batteries, the most cost intensive and also important part in determining energy efficiency and electrical range, are experiencing a radical price drop which reached to 73% in the period 2010-2016, driven by the rapidly decreasing manufacturing cost caused by the achievement of economies of scale and the aggressive pricing strategies by large market players. The average battery cost in 2016 was reached 250-270 USD/kWh while the most efficient manufacturers, namely GM and Tesla achieved prices of 180-200 USD/kWh. Cost efficiency in battery manufacturing is heavily influenced by volume of production and the size of battery pack. Specifically, 200,000 units/year are estimated to cost 200USD/kWh or less, which is 33% less than the 300 USD/kWh estimated for production volumes ranging between 10,000 and 30,000 units in 2015. Similarly, other studies reveal that scaling up production of 3GWh/year will lead to annual battery price reduction of 2.5%. Moreover, increasing of the battery pack size from 60 kWh to 100kWh can potentially lead to manufacturing cost reduction of 17% per kWh. The projected battery costs published by major battery producers point towards prices well below 100USD/kWh achieved between 2020-2022, while prominent analysts project, that the average battery cost will reach similar levels by the mid-late 2020s, reaching $73/kWh in 2030 as a result of a major ramp up in battery production.

• Research and development had lead into the formation of a competitive EV battery market, in which various battery technologies are present or under development, with the most utilized and expected technologies being: Conventional lithium-ion, Advanced Lithium-Ion, Intermetallic anode (eg. Silicon alloy-composite), Beyond lithium-ion (lithium metal, including lithium Sulphur and lithium air).The five largest battery manufacturers control 64% of Lithium-ion battery capacity production for EVs. Specifically, Panasonic supplies batteries to at least 18 models, LGChem to 12 and Samsung to 6.

• Lithium and Cobalt are the minerals that are crucial for current battery price formulation. While lithium is showing signs of abundance with possibility of ramping up its extraction operations, the same cannot be said for Cobalt which can only be produced as a byproduct of other mining operations, mainly as a byproduct of nickel mining. Therefore based on its scarcity and also to its significant leverage in the battery price of 4.3% increase per doubling of its price, Cobalt can create bottlenecks in battery production resulting by manipulation of its availability and therefore its price. As a result, major carmakers aiming in developing cathode materials with less of the sensitive Cobalt.

A.(v). Greek EV Market

• 2017 has been a significant year for electric mobility in Greece as the EV market share jumped up from 0.06% to 0.19 % with the market almost tripling in volume. The Greek Charging network has been developing very slowly by private initiative and numbers only 45 public stations providing 64 charging ports of which all but one are type 2 or type 1 charging ports. Currently Greece is experiencing a vicious cycle fed by the inability of the market to provide sufficient publicly accessible charging infrastructure to halt the electric driving range anxiety of the consumers. To break this cycle, in order to initiate the market expansion, the Hellenic Electricity Distribution Network Operator (HEDNO), the local DSO, made a proposal to The Greek Regulatory Authority for Energy (RAE) for the development of Greece's first country scale charging network, composed of 1,200 to 1,500 EV charging stations connected to the national grid and 100 to 150 charging stations installed at the Greek islands.

• The legal framework of Greece in regards to EVs needs to adapt to regulate charging operations as well as to determine the role of Charging system operators (PEV aggregators), which according to EU Directive 2014/94/EU should have distinctive role from the one of an Electricity provider.

A.(vi). EV Charging

• The development of standardization of charging infrastructure has made possible the interoperability of charging points limiting them in 3 types of connectors serving 4 modes of charging. Modes 1, 2 and 3 refer to AC charging in different maximum power outputs (11kW, 22kW and 43.5kW respectively) while mode 4 refers to DC fast charging in low voltage (max 38kW) and high voltage (170kW) The dominant connections are the Japanese CHAdeMO, the European-American Combined Charging System (CCS) and the Chinese GB/T. All charging connectors enable the charging station-vehicle data exchange and can provide the capable safety features for EV charging.

• Vehicle to Grid (V2G) is a system that enables the utilization of vehicles as energy storage systems and utilizing them as such by enabling their discharge to the grid for providing ancillary services. V2G has financial benefits for the vehicle owners which occur either by discharging for own consumption avoiding utilizing it as home energy storage as well as discharging to the grid gaining the financial benefit when the marginal price of electricity is high. However it V2G has also drawback which are the battery degradation and capacity reduction caused by over-use and thus battery depreciation. Also important is the energy loss during charging which is increased due to the more charging operations that V2G requires as well as difficulties for the user to maintain the required EV battery state of charge (SOC).

• EVSE “charging stations” implement several layers of redundant safety features to protect the user from potential electrical and fire hazards while connecting, disconnecting, and charging the vehicle. The vehicle through data exchange with the EVSE controls the charging process, while the EVSE maintains also an electrical isolation system. UL and IEC have released standards addressing specifications of integrated safety systems of charging equipment and ESVE. Battery management systems (BMS) are also highly utilized to monitor and control the EV battery performance and to avoid potential battery damage entailing hazards and health risk.

• The impact of EV charging to the Grid is identified in: (a) the Harmonic Distortion and Power quality effects, which are magnified in the end of charging potentially reaching to 28% requiring harmonic control which follow the IEC and IEEE standards for limiting the THD to 5% (3% amplitude), while research in the field showed the primary limitation of the number of fast EV chargers in a cluster is not the power capacity of the upstream power transformers, but the harmonic limits for electricity pollution. (b) Congestion and voltage drops resulting from simultaneous charging of multiple vehicles in the same distribution branch, which can be tackled with network upgrades by installing bigger transformers and thicker conductors, (c) Power generating capacity limitation due to high EV charging demand.

• Smart charging and discharging of EV fleets could help power plants produce in a more steady pace by shifting the electricity demand for charging to time periods of either overall low electricity demand or high power supply mainly due to the uncontrollable power generation from renewables. This means that power plants could avoid unnecessary output load adjustments (ramp-ups, ramp-downs) and minimize the number of start-ups resulting in a low marginal cost of electricity that benefits the consumers.

• EV Charging behavior has spatial and temporal characteristics therefore the impact of EV charging to the power generation and distribution networks it’s an issue that highlights the need of spatial and temporal planning of the EV charging operations. The management of charging operations is covered by PEV aggregators, which by maintaining information on the technical characteristics of the (a) EV fleet, (b) the driving and charging behavior of the users, (c) the technical characteristics of the EVSE infrastructure and (d) the local distribution network boundaries, control the charging operations in a cost-effective manner, both for the consumers and the power system.

- The introduction of 10,000 EVs in the system is expected to introduce annual energy demand of 17.6GWh. Moreover, the peak load of the corresponding charging operations is estimated to be 7.2 MW, while it's expected to increase the annual peak demand of the interconnected system by 0.92 MW. By 2040, Greece could potentially maintain a fleet of 1,000,000 EVs adding approximately 347.2 MW to its annual peak load demand. Such a power demand would require the introduction of power generation capacity resources equivalent to approximately 2.5% of the current dispatchable power generation capacity of the country. Assuming that the RES penetration will be significant, for the power system to maintain its resilience under such load introduction, the installed power generation in Greece would have to significantly increase its capacity by 2040 to accommodate the EV charging load.

A.(vii). EV Cost of Ownership

- Cost of Acquisition is heavily influenced by the battery cost which approximates 50% of the vehicles price. Battery prices could drop as much as 60% by 2030. Moreover additional cost reduction could be achieved by the scaling up of production and cost reduction of powertrains and electronics, which expected to experience a drop of 20-25%. Market estimates show that BEVs and ICEs in all segments will cost the same around 2025-2026.

- EV sales are correlated and should be influenced by gasoline prices. As gasoline prices declining moving towards a peak oil demand it is evident that the projected ownership cost competition between EVs and conventional ICE vehicles will shift towards ICE vehicles. This is due to the fact that EVs are not projected to achieve acquisition value parity with ICE until the mid-late 2020s' and at this point a rapid decline of oil prices driven by the trending electrification of the transport sector would be most probable. However, operational cost parity of ICE vehicles with EVs will not be achieved, due to the inability of retail vendors to offer petrol below $1.22 per gallon to compete with electricity prices because such a transaction would be a loss-making one, as indicated by Petrol's price decomposition for 2017 (US). However, this petrol floor price could vary due to spatial and micro-economic characteristics of the market, the exploitation of which could potentially formulate a marginal price of oil for which running costs of an ICE vehicle would be competitive to the ones of an EV. In addition this competition between oil/gas prices with electricity could potentially push marginally the electricity prices in retail market upwards as the demand increases and more cost intensive power generation units enter the energy mix.

A.(viii). Environmental impact of EV introduction

- Road transport is by far the biggest emitter accounting for more than 70% of all GHG emissions from transport. Therefore, a high potential of emissions' reduction could be realized by the adoption of electric mobility, given the fact that the energy industry is reducing gradually its carbon intensity and therefore is projected to cover with low-carbon electricity the energy demand of EVs.

- In Greece, the number of light duty passenger vehicles registered, which meet the EU emissions target of 95g CO_2/km for 2021, has been 71,260 in the period 2010-2016 accounting for the total 12.3% of the total cars registered in the same period. The total emission resulting from the use of passenger cars are estimated to be 8.16 million tons of CO_2eq, accounting for approximately 48.9% of the total emissions resulting from the activity of the transport sector in the country. The introduction of EVs, could lead to 2.3% tailpipe emission reduction (0.17 MtCO2eq) for substitution of the 100 thousand most carbon intensive cars with EVs, while substituting the 1 million most carbon intensive passenger cars with EVs will result to 21.9% tailpipe CO_2 emission reduction, equivalent to 12.5% total CO_2 emission reduction of passenger car fleet, taking into account the current carbon intensity of the Greek power system.

A.(ix). EV Market Development and Economic Repercussions for South East Europe

- In South East Europe, according to market analysis the EV deployment has be in a primary state even though it shows significant annual growth. The main barrier for adoption of electric mobility in the region is the inadequate publicly accessible charging network, which however shows signs of development with most significant initiatives being the activity of ABB in Bulgaria and the prospect of charging network development by HEDNO, the local DSO in Greece, smaller private initiatives, and initiatives of local municipalities, local businesses and institutions.

- The local automotive industry of the region mainly located in Turkey, Romania, Slovenia and Serbia has not made a significant turn in EV manufacturing.

However, Turkey being one of the major auto-manufacturing economies of the region, producing more than 1.7 million vehicles per year while having 9 R&D facilities which extend their operation beyond supporting the local industrial operation, has a lot of untapped potential of being an important market for the EV transition. In Romania the prospect of Dacia, in producing a very cost-effective EV, while utilizing the underpinnings and the electric motor of Renault ZOE, thus exploiting the advantage of its participation in Renault-Nissan Alliance, is deemed very important for the acceleration of EV adoption in the region. South East Europe also has highly trained engineering professionals, who can help meet the requirements of EV R&D operations in the region, mainly in the fields of electrical motors, power systems electronics, traction control and information technology and networks.

- The automotive component industry being a very significant economic activity in the region of South East Europe must also adapt to the EV transition. Significantly the regional markets segments associated with ICE Engines, transmission systems, fuel systems, exhaust, forging components and small general parts manufacturing are expected to be negatively affected by the transition to gearless, fuel-less, robust new vehicles. However, important segments of the regional manufacturing activity such as wiring, electric component development, electronic architecture systems and components and telematics are expected to attract new investors and expand their activity. Moreover the RES and electricity distribution industry is expected to be driven by electric mobility acceleration in the future with numerous new projects for new capacity installation and grid enhancement to facilitate "green" power to the electrified on-road transport.

---

[i] Preamble 10, Directive 2014/94/EU of the European Parliament and of the Council of 22 October 2014 on the deployment of alternative fuels infrastructure.

[ii] Directive 2007/46/EC of the European Parliament and of the Council of 5 September 2007 establishing a framework for the approval of motor vehicles and their trailers, and of systems, components and separate technical units intended for such vehicles (Framework Directive) and **Regulation (EU) No 168/2013** of the European Parliament and of the Council of 15 January 2013 on the approval and market surveillance of two- or three-wheel vehicles and quadricycles.

[iii] Article 2, Directive 2014/94/EU.

[iv] Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/E

[v] Directive 2007/46/EC.

[vi] JMD 77226/2017 GG B' 3824/2017

[vii] Art. 2 L. 2052/1992.

[viii] Art.46 L. 4410/2016; art. 17 L. 4346/2015; art. 2 L. 2682/1999.

[ix] [ΔΜΕΟ 1889/Φ.911 (GG B' 1140/11-8-2003)]

[x] Art. 2 & art. 134-135 L. 4001/2011.

[xi] [P.D. 455/1976 (GG A' 169)]

[xii] Art. 15 L. 4233/2014.

[xiii] Art. 11 L. 4513/2018.

[xiv] JMD 777226/1 GG B' 3824/31-10-2017 on the National Plan for the development of alternative fuels market.

List of Abbreviations

AC	**Alternating Current**
ACEA	**Association des Constructeurs Européens d' Automobiles (European Automotive Manufacturers Association)**
ACS	**Automation and Charger Solutions**
BEV	**Battery Electric Vehicle**
BNEF	**Bloomberg New Energy Finance**
CCS[1]	**Carbon Capture Storage**
CCS[2]	**Combined Charging System**
CEE	**Commission on rules for the approval of Electrical Equipment**
CEN	**Comité Eurpéen de Normalisation (European Committee for Standardization)**
CENELEC	**Comité Européen de Normalisation Electrotechnique (European Committee for Electrotechnical Standardization)**
CHAdeMO	**CHArge de MOve (Japanese EV charging standard)**
CP	**Contact Pilot**
DC	**Direct Current**
DCFC	**Direct Current Fast Charging**
DOD	**Depth Of Discharge**
ECU	**Electronic Control Unit**
EPA	**Environmental Protection Agency (United States)**
EPCI	**Établissements Publics de Coopération Intercommunale**
EREV	**Extended Range Electric Vehicle**
ESS	**Energy Storage Systems**
ETSI	**European Telecommunications Standards Institute**
EV	**Electric Vehicle**
EVSE	**Electric Vehicle Service Equipment**
FCEV	**Fuel Cell Electric Vehicle**
GIS	**Geographical Information Systems**
GPS	**Global Positioning Systems**
HCM	**Heavy Commercial Vehicles**
HDV	**Heavy Duty Vehicle**
HEDNO	**Hellenic Distribution Network Operator (Greece)**
HELPE	**HELlenic PEtroleum**
HEV	**Hybrid Electric Vehicle**
HHD	**Hydraulic Hybrid Vehicles**
HV	**High Voltage**
ICE	**Internal Combustion Engine**
IDLH	**Immediatelly Dangerous to Life and Helath**

IEC	**International Electrotechnical Commission**
IEEE	**Institute of Electrical and Electronics Engineers**
ITOPF	**Tanker Owners Pollution Federation**
kW	**kilowatt, a unit of power**
kWh	**kilowatthour, a unit of energy**
LDV	**Light Duty Vehicles**
LMC	**Lithium Manganese Cobalt oxide**
LMO	**Lithium Manganese Oxide**
LTNO	**Lithium Titanate Nickel Oxide**
LTO	**Lithium Titanate Oxide**
LV	**Low Voltage**
MaaS	**Mobility as a Service**
MCV	**Medium Commercial Vehicles**
NIOSH	**National Institute for Occupational Safety and Health (United States)**
NMC	**Nickel Manganese Cobalt oxide**
PCC	**Points of Common Coupling**
PHEV	**Plug-in Hybrid Electric Vehicle**
PP	**Proximity Pilot**
PPC	**Public Power Corporation (Greece)**
RAC	**The Royal Automotive Club Foundation for Motoring**
SAE	**Society of Automotive Engineers**
SOC	**State Of Charge**
TDD	**Total Demand Destortion**
THD	**Total Harmonic Distortion**
TOU	**Time Of Use pricing**
US DOE	**United States Department Of Energy**
V2G	**Vehicle-to-Grid**