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TECHNICAL, ECOLOGICAL AND MARKET ANALYSIS OF THE TRANSITION TOWARDS THE ELECTRIC VEHICLE

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TÍTULO:	TECHNICAL, ECOLOGICAL AND MARKET ANALYSIS OF THE TRANSITION TOWARDS THE ELECTRIC VEHICLE
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New European policies for the elimination of greenhouse gas emissions from the transport sector suggest that the replacement of the current car fleet with pure electric vehicles is imminent in the coming years. This paper analyses the different alternatives for electric vehicles, the advantages, and disadvantages of each of the different alternatives at a technical level in order to be able to glimpse the projection of these vehicles, which are a growing trend nowadays. On an ecological level, the aim is to understand whether they are really an effective alternative today and the improvements and investment necessary to achieve the objectives set by the institutions. The impact on the economy and the lives of EU citizens is undeniable given the importance of the sector in Europe, and therefore the rapid and effective adaptation of industry and citizens will be key to a successful transformation at all levels.

Keywords: Electric, Vehicle, electromobility, hybridization, transition.

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TECHNICAL, ECOLOGICAL AND MARKET ANALYSIS OF THE TRANSITION TOWARDS THE ELECTRIC VEHICLE

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Abstract

New European policies for the elimination of greenhouse gas emissions from the transport sector suggest that the complete replacement of the current car fleet with pure electric vehicles is imminent in the coming years. This paper analyses the different alternatives for electric vehicles, the road that has already been travelled for this transformation, the advantages and disadvantages of each of the different alternatives that exist today at a technical level in order to be able to glimpse the projection of these vehicles, which are a growing trend nowadays. On an ecological level, the aim is to understand whether they are really an effective alternative today and the improvements and investment necessary to achieve the objectives set by the institutions for the reduction of greenhouse gases. The impact on the economy and the lives of EU citizens is undeniable given the importance of the sector in Europe, and therefore the rapid and effective adaptation of industry and citizens will be key to a successful transformation at all levels.

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List of abbreviations

A	Ampere
AC	Alternating Current
BEVs	Battery Electric Vehicles
BSS	Battery Swapping Station
CO2	Carbon Dioxide
DC	Direct Current
ER-EVs	Extended Range Electric Vehicles
EU	European Union
EVs	Electric Vehicles
FCEVs	Fuel Cell Electric Vehicles
GDP	Gross Domestic Product
GHG	Greenhouse Gases
HEVs	Hybrid Electric Vehicles
i.e.	“id est”; That is
ICE	Internal Combustion Engine
Km	Kilometre
kW	Kilowatt
PHEVs	Plug-in Hybrid Electric Vehicles
TTW	Tank to Wheel
UK	United Kingdom
USA	United States of America
V	Volt

V2G	Vehicle to Grid
Wh	Watt hour
Wh/kg	Watt hour / kilogram
Wh/l	Watt hour / litre
WTT	Well to Tank
WTW	Well to Wheel

1 Introduction

1.1 Problem

In the last years, the reduction of Greenhouse gas emissions and the forecasted scarcity of fossil resources have been one of the most recurring subjects in the media and for the society in general. The commitment obtained by the countries in the Kyoto Protocol also reflects the compromise that the states politicians and the intergovernmental organizations have taken with the climate and environmental problem and has pushed them to start actions in order to improve the situation.

Automotive industry is closely related to this subject, as the main source of the Greenhouse gas emissions is from burning fossil fuels for electricity, heat, or transportation.

Specifically, transport sector is claimed to be directly responsible of the 25% of the GHGs emissions in the European Union. And as of 2019 the emissions attributed to the transport sector is on the rise (Transport & Environment, 2018).

This together takes more importance if it is taken into consideration that the automotive sector is crucial in the European economy, providing directly and indirectly 13.8 million of jobs, representing 6.1% of total employment in the EU and that the turnover generated by the automotive industry represents over the 7% of EU Gross Domestic Product, with around 4126 vehicle assembly and production plants located in the countries of the Union. Also, the implication that the automotive industry has with the steel, textile or chemical sectors make it a key industry in the economy of the region (European Comission, n.d.) (ACEA, 2020).

Given these critical conditions, the search for alternatives that reduce the emissions is gaining momentum in the sector, specifically the substitution of the combustion engines that use fossil fuels as its power source for Electric Vehicles, powered by electric batteries, powered by the grid, where the energy from fossil fuels could be replaced by renewable energies. In the last years is palpable to observe more EVs in the streets, and the first charging stations for EVs are flourishing in the public spaces of the cities. Thanks to the high competitiveness and cutting-edge technology of the automotive sector, this transition is being possible and starting to become a reality.

This transformation is promising to change most of the characteristics of the vehicles as we know them right now, not only the fuel will be different, and probably the new generations will never feel the particular smell of gasoline, but also their driving habits will be completely different, as well as the mechanical repairs, the sound associated with the traffic or the way of acquiring the vehicle are expected to evolve to a new era of automotive electrification.

1.2 Objective

The aim of this study is to observe the evolution of the automotive sector, with particular emphasis on the evolution of the EVs as a real alternative for both manufacturers and consumers and which of the available alternatives is witnessing a better future for replacing the actual fleet of vehicles.

Understanding the functioning of electric engines from a technical point of view, the targets that have already been achieved by the sector and those goals that are still to be reached to fulfil the environmental requirements of our era, is crucial to understand the scenarios that may arise in the short and medium term and to present the optimal solutions and the direction in which the sector has to grow in order to meet the objectives and satisfy the transition while maintaining or improving vehicle performance and continuing to improve safety, ecology and other key aspects for the improvement of citizens' quality of life in the near future.

From an ecological point of view, this work seeks to understand whether the electric vehicle is really a cleaner alternative to conventional vehicles, or whether, on the contrary, the different theories that defend that they pollute as much or more than the vehicles that are on our roads today are correct and changes must be made to guarantee the necessary improvement to preserve the environment and decarbonise the automobile sector as soon as possible.

With the study on how the European citizens are answering to the transition and their doubts and concerns regarding the new vehicle market that they are starting to face and is expected to be dominant in a foreseeable future, the objective is to comprehend how the society answers back to a substantial change on the past habits and adapts to the technology changes, and the improvements that are going to be necessary to make on the part of all the society to connect with the technological advances for the benefit of the planet and its inhabitants.

Being an actual technological and social trend, it is coherent to analyse this topic, given its crucial importance socially, economically, and culturally, interconnected disciplines that are studied in the Bachelor of Business Engineering that this Thesis is completing.

1.3 Approach

In order to reach a clear conclusion of the scenarios that are going to be faced in the next years, The methodology of this work will seek to understand the technical, ecological, social and economic implications of the adoption of this new means of transport. It also aims to understand the current state of development, the barriers that must be overcome to successfully achieve the benefits that the decarbonisation of transport will bring to society.

First of all, a brief historical review will be carried out, with the aim of discovering the milestones already passed by the electric vehicle, the problems it has faced so far, and which have not allowed its development on a larger scale, and the social perception of the electric vehicle throughout its history. An attempt will be made to present in detail the discoveries and findings that today serve to further develop this technology and to understand why it has reached a point where it seems to be the alternative for a sustainable future in the field of road mobility.

Subsequently, a study of the technical advantages that electric vehicles represent over conventional internal combustion vehicles, as well as the disadvantages and drawbacks that have prevented their prior establishment on the market will take place. The types of electric vehicles will be studied with the aim of understanding the role of each of them and what evolution they are expected to follow in the near future. The main components and characteristics of electric vehicles such as batteries and charging processes will be investigated in order to obtain a clear conclusion of the current stage of development of electric vehicles and what prospects they have to prosper depending on what can be expected in the next few years.

It will then proceed the demonstration of the ecological advantages of the electric vehicle, how certain efficiency terms such as well-to-wheel can be interpreted, and what measures or developments will be needed in the future to realise the full ecological potential of replacing the vehicle fleet with electric vehicles.

Following, an in-depth market study of EVs in Europe will be carried to unveil the tendences of the last years and the patterns that might stay in the market in the coming years. Bearing in mind that the COVID19 pandemic has paralysed part of the economy in most of the European countries in 2020, particularly affecting the transport industry, the data for this period will be treated as a particular situation, which, although it may affect the future development of the industry, does not represent clarifying data for the purpose of this study given that it is due to social and economic circumstances external to the industry and the technical development of the EV itself. This market study will witness how the society is accepting the transition towards electromobility and which are the areas that should be worked on to improve the penetration of the EVs in the population.

Given the breadth of the topic, and in order to stick to the scope determined for a bachelor thesis, many of the issues of interest, such as battery recycling, charging infrastructure, or the role of governments and public institutions and their regulations in the transition to electromobility are not covered in detail in this paper, and the main methodology of this paper is to analyse the different vehicle technologies themselves and their environmental and economic impact to gain insight into their current implementation and future scenarios that can be envisaged.

2. History of the Electric Vehicle

The conception and design of artifacts that could improve the speed that the human being could naturally reach using only his locomotive system seems to have been an inherited dream and desire for the species. Exploiting the wind´s force, or animal power, were the first tries of constructing vehicles that could carry humans more efficiently improving its quality of life.

An electric vehicle, or EV, will use an electric motor for propulsion rather than a gasoline-powered motor. Besides the electric car, there are bikes, motorcycles, boats, airplanes, and trains that have all been powered by electricity (Bellis, 2020).

This historical review is of great relevance for this thesis in the attempt to make an approach to analyse the technical background and the socioeconomic influence that the EVs had in the past and could be replicating in our era, and the inheritance that the EV is now gathering from the past discoveries.

2.1 Early years of the EV

In 1800, the Italian physicist Alessandro Volta put the first stone for the electrical mobility, discovering that electrical energy could be stored chemically, and designing a chemical non-rechargeable battery (Hoyer, 2008).

Two decades later, in 1821, the British Michael Faraday, demonstrated the principles of the electric motor using Volta´s chemical pile, making way for the paradigm of applying these devices to fulfil the mobility dream, two of the most important parts for the functioning of the electric vehicles had been proved, a portable battery able to store and transmit electrical energy to a motor able to produce movement on wheels, another of the key features in a terrestrial vehicle, and a discovery that changed the future of humanity back in the prehistoric age.

Therefore, having these critical tools, the first attempts of applying them to produce a vehicle did not take a long time to appear.

In 1828, the Hungarian engineer Ányos Jedlik designed the very first experimental vehicle based on an electric motor, provided with stator, rotor, and commuter that he developed the previous year (Guarnieri, 2012).

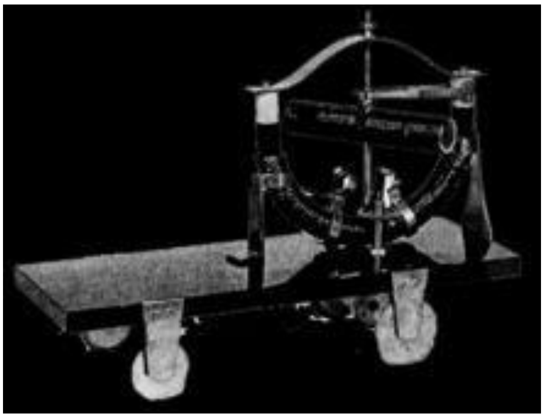


Figure 1: Ányos Jedlik vehicle. (Awasthi et al. 2011)

Sometime between 1832 and 1839 (the exact year is unknown), the Scottish inventor Robert Anderson developed a “horseless carriage” that was claimed to be working on rough roads carrying two persons.

Contemporarily in the Netherlands, professor Sibrandus Stratingh designed another small-scale, three-wheeled electric vehicle that was built by his assistant Cristopher Becker.

Also, in the United States in 1835, Thomas Davenport operated a model trolley car by using a direct current motor that he developed himself the previous year (Guarnieri, 2012).

According to the communication technological advances of these times, these contemporary inventors were not aware of each other discoveries. Among other early experimental early cars moving on rails these were the first attempts of developing EVs. Despite the current beliefs that might imagine that the electric vehicles are a new discovery of our era, the reality is that humanity has been believing and making attempts on developing EVs for around 200 years ago (McFadden, 2020).

The next key improvement in the field of batteries was achieved by the French physicist Gaston Planté, who discovered the lead-acid battery in 1859, this invention, in fact, is still nowadays in use as the base of the starter battery in all the Internal Combustion Engines (ICE). This huge improvement in batteries technology, cleared the field for its usage on vehicles, as it was the first rechargeable battery, and with the improvements made by his compatriot Camille Alphonse Faure, in 1880, by coating the lead plates with a paste of lead oxides, sulphuric acid and water, the capacity of the batteries was significantly increased and possible to manufacture in industrial scale (Guarnieri, 2012).

The next year, in 1881, another French engineer, Gustave Pierre Trouvé, introduced in Paris a tricycle that operated Faure´s battery, considered as the first Rechargeable Electric Vehicle in the world. During this decade, further vehicles using lead batteries were constructed in the United Kingdom and the USA, contemporarily, in 1885, German Benz demonstrated the first ICE vehicle, that eventually would win the technological battle in the upcoming XX century.

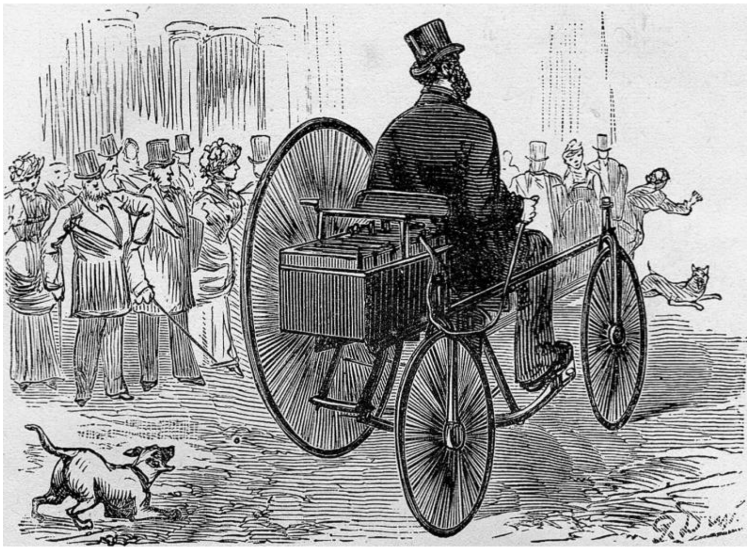


Figure 2: Gustave Trouvé tricycle (Cattelin, 2012)

The two last decades of the XIX century represented the biggest time of improvements and success of the EVs in the history until our days. The absence of gearbox made the usage of the EVs easier than their concurrence, the early ICE vehicles, and the steam-powered ones. The EVs also were silent and had no vibrations or bad smelling smoke emissions, capturing the attention of the engineers who worked trying to find a solution for the electric vehicle problems. In New York there was developed the first charging station operated by an electricity supply company and systems to prolong the batteries duration like the regenerative breaking were discovered. Car usage was mainly restricted to urban areas given the conditions of the countryside roads, and the autonomy of the EVs was enough for meeting the needs of the customers (Hoyer, 2008).

Given the beneficial conditions, some Taxi fleets were satisfactorily spread over some cities like London, Paris, or New York, growing thanks to the improvements constantly achieved in the technologies of the electric vehicles, using garages to maintain the batteries of the cars. (Hoyer, 2008)

In this context, Charles Jeantaud founded the first electric automotive company in 1893, and was involved in the fight for breaking the maximum speed record, increasing the mark every other year. Eventually Camille Jenatzy broke the barrier of 100 km/h with his bullet-shaped car “La Jamais contente” (Michelin , 2010)

Figure 3: La Jamais Contente (Wikimedia commons)

Another prominent name in automotive history, Ferdinand Porsche, designed the first hybrid car in 1900 in order to extend the reach of the batteries of the electric vehicles (Guarnieri, 2012). The model designed by Porsche was also equipped with the regenerative braking system and could make long travel distances outside of the cities. However, Porsche´s vehicle was quite expensive by that time.

Henry Ford launched the Ford Model T, an incredibly cheap ICE vehicle to the market in 1908 and its assembly-line production in 1914 that lowered even more the price to around 440$, making it impossible to compete for the electric producers. In addition, the discovery of oil reserves popularized the usage of ICE vehicles and allowed these to improve technologically, solving some of the problems that they faced the previous century, like the replacement of the starting crank for an engine start (Guarnieri, 2012).

The role that the Model T played in the First World War was crucial. Given its liability, easy repairments and low cost, it was widely used, even as ambulances by the Allies.

Ironically, also in 1914, Henry Ford was working with Thomas Alva Edison on an Electric Vehicle, as he recognised in an interview with The New York Times on January 11, 1914: (Strohl, 2010)

"The fact is that Mr. Edison and I have been working for some years on an electric automobile which would be cheap and practicable. Cars have been built for experimental purposes, and we are satisfied now that the way is clear to success. The problem so far has been to build a storage battery of light weight which would operate for long distances without recharging. Mr. Edison has been experimenting with such a battery for some time." (Ford, 1914)

In this paragraph from the interview, Ford recognises the two problems that he had to produce the electric automobile, the price, and the practicability due to the autonomy and the weight of the battery. These two weaknesses of the electric automobiles, eventually, put Ford aside from the development of his electric car with his friend Edison, after buying him 100.000 batteries for the project (Martínez, 2021), in favour of his successful ICE powered Model T.

The crash of 1929 brought bankruptcy for most EV companies, and electric vehicles lost most of their prominence due to the use of diesel and gasoline vehicles in World War II. Only periods of post-war petrol shortages allowed the development of electric vehicles in countries such as Germany or the UK where the government promoted their use due to the abundance of electric power from coal-fired power stations.

2.2 The start of the environmental concerns

The second half of the XIX century started with the undisputed dominance of the ICE vehicles in the worldwide markets, but in 1962, Rachel Carson published the book *Silent Spring*, in which she remarked the environmental problems and air pollution in larger cities. By this time, the gasoline had led as an additive, and the ICE vehicles were not occupying filters for the polluting emissions. In the beginning of the seventies, the book *The Limits to Growth* was published by the Club of Rome, pointing out the problem of the exploitation of non-renewable resource, one year before than the 1973 Arab Israeli War, that ended up with an oil embargo by the Arabic oil producers to most of the western countries. Those events pushed not only the public energy debate, but the governments to find a solution, and support the research of the new renewable energy sources. In this period, the EV started to get momentum as a possible alternative to the ICE vehicles, the highest exponent of the usage of fossil fuels, but they did not see any fruitful attempt apart from several prototypes that eventually got cancelled and were not successfully commercialized (Hoyer, 2008).

In the nineties, the problem of pollution and smog in big cities increased, and for the first time, the State of California introduced a regulation to reduce the emissions. The concepts of sustainability and sustainable development were the main part of the Ambiental discourse, and the transport sector started to be directly pointed out as a subject to change in this sustainable direction (Hoyer, 2008).

The Kyoto Protocol ratified the commitment of the United Nations Framework Convention on Climate Change (UNFCCC), signed by 197 countries where the environmental problem was officially recognised, and entered into force the 16th of February 2005, limiting the emissions of GHG for all the signing parties. (United Nations, 2021). Between those gases, transportation occupies CO_2 specifically, and the vision about the Carbon Dioxide emissions changed the focus from a local pollution problem in urban areas to a global transportation issue that culminated into the development of new vehicles that can reduce the emissions and eventually only occupy renewable energy sources and be completely emission-free vehicles. That transition is represented by all the improvement in the hybrid and electric vehicle technology that has been reached the last years.

In 2002, C. C. Chan, predicted the growth that electric vehicles would experience given the world's growing population, the environmental and air pollution issues and the limited resources associated with it. Chan conducted a survey in which he observed the growth of scientific interest in EVs from 1984 to 2001, years in which the number of papers published on commercialisation increased and predicted a growth in the market by 2020 (see figure), which is largely accurate to the present scenario.

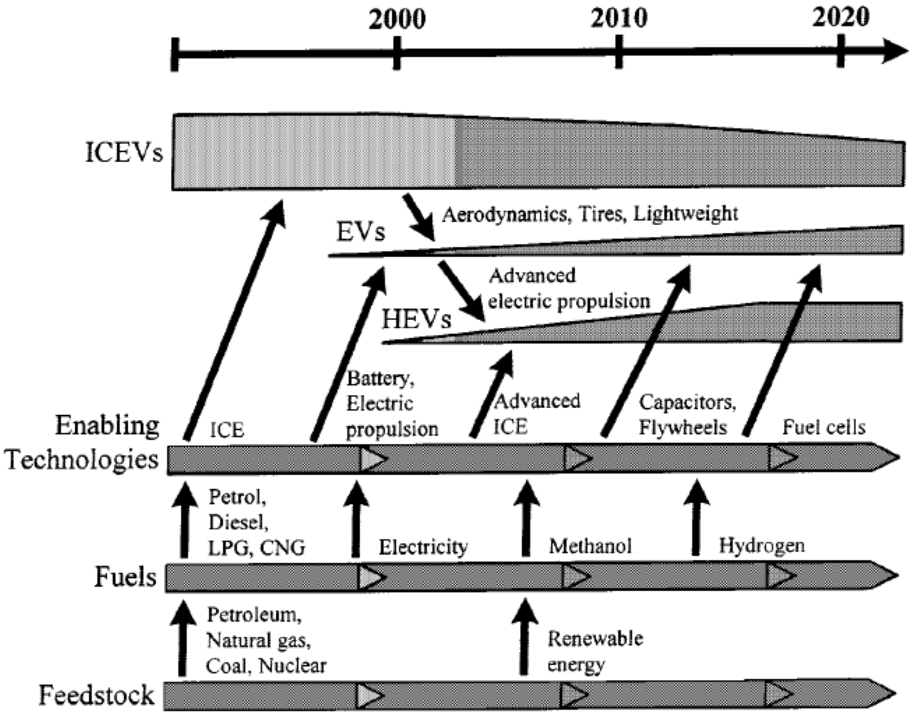


Figure 4: Prediction of EVs growth (Chan, 2002)

3. Technical Overview of Electric Vehicles

From a performance point of view, the electric vehicle offers four times the performance of conventional ICEs. While an electric motor is able to convert approximately 80% of the energy that it receives from batteries into motion, an ICE converts 18-25% of the energy produced in combustion, while the rest is dissipated in the form of heat and friction, which also means greater deterioration of motor components over time, and therefore higher maintenance costs. In addition, the incorporation of regenerative braking technology allows EVs to recover some of the energy dissipated as heat during braking. This technology includes an electric generator in the vehicle's braking systems, and in addition to improving the vehicle's efficiency, it also reduces wear on the braking system, thus extending its service life (European Environment Agency, 2016).

The (Idaho National Laboratory, n.d.) refers to a CALSTART report, according to which up to 70% of the components of an electric vehicle may be different from those of an ICE. A notable advantage in this regard is the considerable reduction of moving parts in EVs, increasing reliability and reducing wear and associated maintenance. In fact, the only moving part of the electric motor is the shaft, which is quite reliable and needs little care. On the other hand, EVs do not require oil and particulate filter changes, with the battery being the most prominent component that would eventually need to be replaced.

Electric motors have therefore, a simpler construction and functioning than ICE and, apart from being silent they provide instant and high torques, even at low speeds, what allows them to perform better in the phase where the ICE vehicles have a bigger fuel consumption. (Un-Noor et al. 2017).

The Idaho National Laboratory also claims that the EV engine is more economically efficient than an ICE, comparing the distance they can both cover with 1 dollar of electricity and petrol, with the distance covered by the EV more than doubling the distance that the ICE vehicle could cover.

3.1 Types of Electric Vehicle

There are many ways to configurate an EV. There are EVs that work uniquely with an electric motor using the energy stored in batteries, some of them can incorporate an ICE to produce this energy or can be driven by a combination of both.

In this section, these different configurations of EVs will be classified into five groups according to Sanguesa et al. (2021), based on the font of energy that supplies the electrical engine (see Figure). The main technologies that the EVs carry will be described, remarking the differences between them and the ecological impact and technological improve that they represent will be compared. The five-type classification that it is going to be followed is:

- Battery Electric Vehicle (BEV)
- Hybrid Electric Vehicle (HEV)
- Plug-in Hybrid Electric Vehicle (PHEV)
- Fuel Cell Electric Vehicle (FCEV)
- Extended-range Electric Vehicles (ER-EVs)

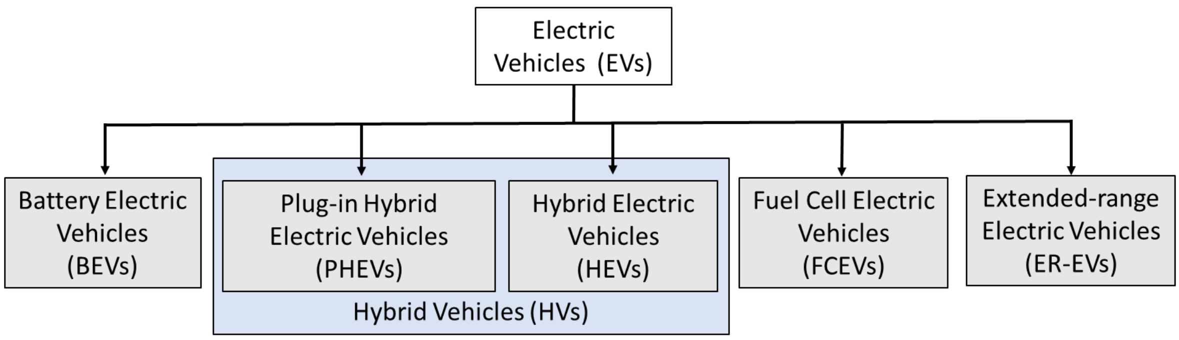


Figure 5: Classification of EVs (Sanguesa et al. 2021)

3.1.1 Battery Electric Vehicles (BEVs)

The architecture of the BEV is quite simple and mainly consists of an electric battery, an electric motor, and a controller solely. The battery is recharged from mains electricity by using a plug and a battery charging unit that can be either carried on board or fitted at the charging point. The controller regulates the power supplied to the motor and the direction of the rotation, when the vehicle is decelerating the motor can act as a generator and charge the battery and helping to brake without friction (Larminie & Lowry, Electric Vehicle Technology Explained, 2012).

BEVs are vehicles with 100% electric propulsion, i.e., all the energy used to drive the vehicle comes from the batteries, and therefore the vehicle's range is the distance that can be covered by the battery pack. Speed and driving style, as well as external factors such as outside temperature and road conditions, influence the range of the battery pack, that, at the present time, is generally between 300-400 km, depending on the conditions mentioned above, what makes them perfectly operative for urban area usage. Charging is in any case slower than refuelling in the tank of a conventional ICE vehicle, and depends on many factors, such as the charging mode, the power available in the grid, or the charging infrastructure (Un-Noor et al. 2017).

3.1.2 Hybrid Vehicles (HVs)

This type of vehicle combines an electric propulsion system with an ICE. The combination of two different types of propulsion generates a high degree of technical complexity and a wide range of configurations depending on the size and function of the components. There are hybrid vehicles with a greater role for the electric system, which have larger batteries that can be recharged by plugging them into the mains and can operate in full electric mode, and hybrids where the electric system is of a reduced size, and simply serves as an assistant to the main engine (ICE) and to reduce fuel consumption. In hybrid vehicles, control systems and energy-saving strategies play a major role in order to exploit the full potential of the electric system and achieve optimal fuel economy (Onori et al. 2016).

Some sources such as Onori et al. (2016), refer to micro hybrid vehicles, which incorporate a start/stop system that switches off the combustion engine when the vehicle stops, saving fuel and reducing emissions, and mild hybrid vehicles, which also incorporate a small electric motor that assists the combustion engine at certain times, in addition to aids such as the start/stop system or regenerative braking. These types of vehicles are not considered electric as they incorporate these systems as an aid to reduce consumption and emissions, but their only mode of propulsion is a combustion engine.

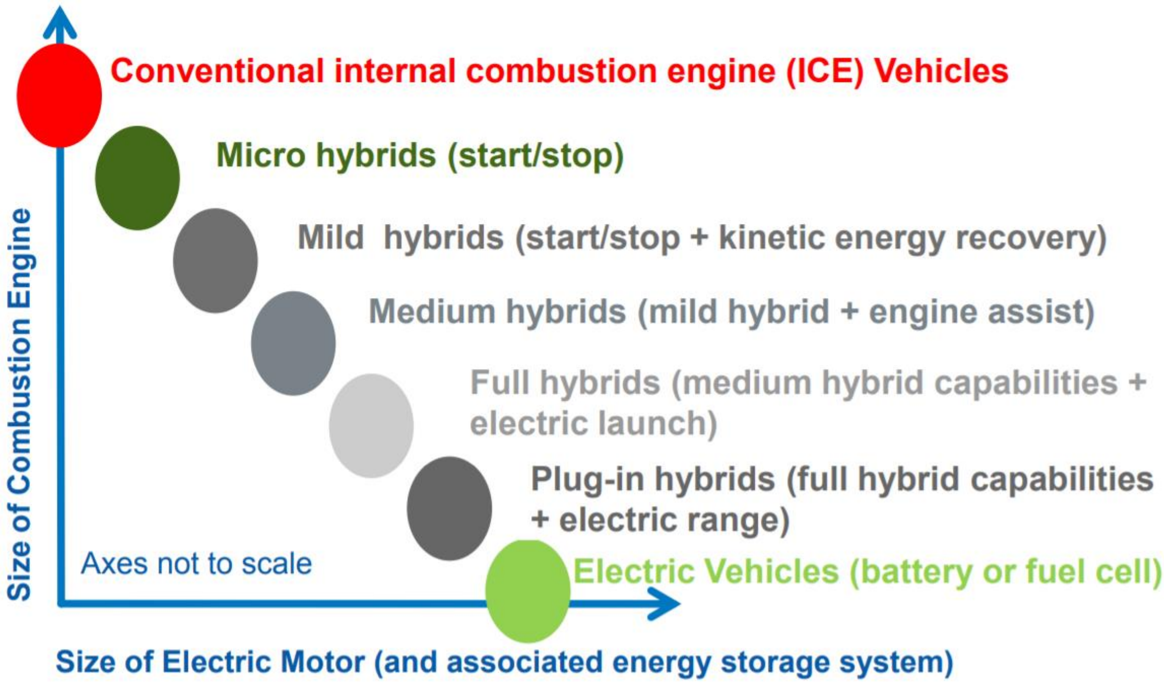


Figure 6: Grades of hybridization (Pesaran, 2011)

There are different architectures for the hybrid vehicles, according to (Un-Noor et al, 2017), those can be classified in four major groups according to the setup:

- **Series hybrid:** This configuration is the simplest one to make an HEV. The force of motion comes uniquely from the motor, while the engine is used as a generator to produce electric power. Power from the battery goes to the motor through a DC-DC converter. This type of architecture has several advantages, the most significant being that it allows the vehicle to be zero-emission if the batteries and electric motor are sufficiently autonomous (EREVs), it is also a mature, efficient, and well-optimised technology. The main disadvantages relate to the length of the process, which requires several energy conversions, and the traction drive system is large.

- **Parallel hybrid**: In this architecture, the engine and the motor are both connected to the wheels in parallel. Either one of them or both can be delivering the power. The battery supplies DC power and a bidirectional inverter converts it to AC power (Jose & Meikandasivam, 2017). This bidirectional inverter allows that when the ICE is producing more power than the needed one for the motion, it charges the batteries of the electric system. This configuration offers more flexibility than the series one and it is also capable of reaching zero emissions in certain circumstances. On the other hand, is more complex and expensive than the previous one and provides less relative gain in fuel economy.
- **Series-parallel hybrid:** This kind of configuration allows to combine the series and the parallel types; it requires an additional generator compared to the parallel type and an extra mechanical link than the series one. It has a bigger complexity and cost than the previous two systems, but it provides the same advantages than both of them. The alternatives used to couple both systems are either a planetary gear or a trans motor (Un-Noor et al. 2017).
- **Complex hybrid:** In general terms, it is a Series-parallel system that allows bidirectional flow of power. It has the same disadvantages than the Series-parallel, the cost and the complexity. They equip a Constant Variable Transmission (CVT) system to split the power or to select the power system that is driving the wheels (Un-Noor et al. 2017).

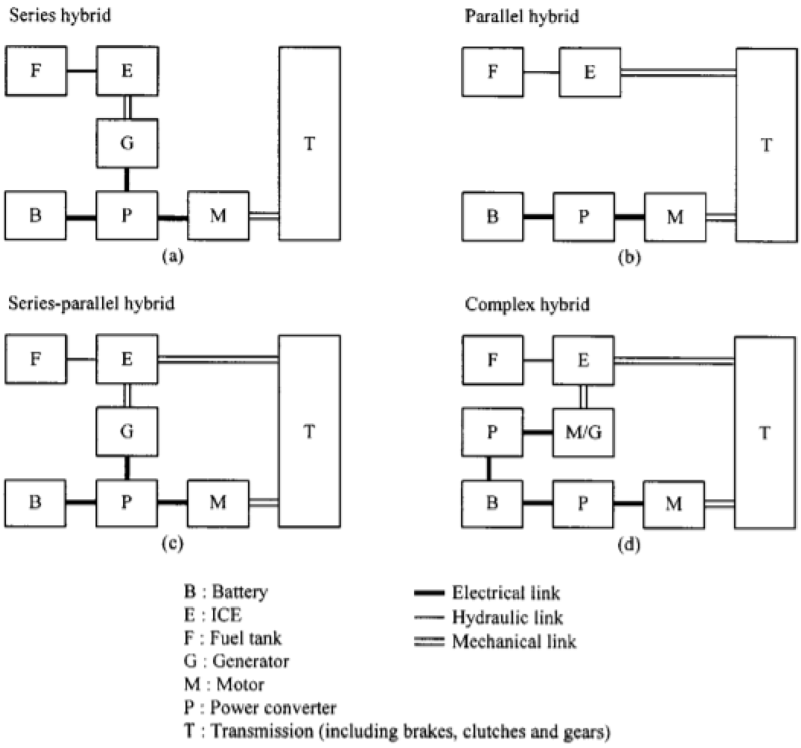


Figure 7: Hybrid Vehicles Architectures (Chau & Wong, 2002)

3.1.2.1 Hybrid Electric Vehicles (HEVs):

HEVs cannot be connected to the grid to charge their batteries, so the method of recharging is by harnessing the energy generated by the combustion engine and the regenerative braking system. In hybrid electric powertrains, the primary system is the ICE, and the electric motor powers the vehicle in situations of high combustible consumption such as starting the engine or for covering short distances. Given this feature, this technology is not considered as a zero-emission technology as it still covers the usage of fossil fuel but improves the efficiency of the regular ICE vehicles (Ajanovic, 2015).

3.1.2.2 Plug-in Hybrid Electric Vehicles (PHEVs):

The PHEV represents a further step in hybrid technology. In this type of vehicle, the electric motor plays a major role, which is why the batteries have a higher capacity and can be recharged by plugging them into a mains socket. They are able to travel around 50 km in all-electric mode and the ICE engine kicks in when the battery charge is low to recharge the batteries or to drive the wheels. This type of vehicle can therefore be used for zero emission daily movements and have the flexibility of a conventional ICE vehicle for longer journeys (Un-Noor et al. 2017)

3.1.3 Extended-range Electric Vehicles (ER-EVs):

The extended range electric vehicles work in the same way as a battery electric vehicle since all the traction energy is provided by the electric motor, with the difference that they have an auxiliary ICE that can function as a generator to recharge the batteries when they are below a certain charge level or to provide energy to the electric motor, so it can also be deduced that they work as a series hybrid but have a larger battery since this is intended as the main source of energy. The capacity of the fuel tank is reduced because the ICE is uniquely used to generate energy for the batteries, and this implies that it works on constant regime, presenting much less wear and emissions than an ICE, PHEV or EV vehicle (Ford, 2021). Many car sellers consider these vehicles as BEVs and the Range Extender as an extra intended for its usage under specific conditions like large road trips, such as BMW (n.d.) with the i3. There is a lot of research on range-extenders, as for the concept of extending the range of EVs beyond their range, not only an ICE can be used. The use of a free piston linear generator, a micro gas turbine or Zn-air batteries is being investigated, as the range-extender is a direct solution for the biggest obstacle of EVs, the capacity of their batteries (Tran, et al., 2021).

3.1.4Fuel Cell Electric Vehicle (FCEV):

The FCEVs are also entirely propelled by electricity, this electricity is produced in an on-board system, the fuel cell. These are devices where a chemical reaction takes place to produce electric energy. For the reaction in the most common type of fuel cell used in vehicles the reagents are compressed hydrogen and oxygen obtained from the air, giving rise to the following chemical reaction (equation 1):

$$2H_2 + O_2 \rightarrow 2H_2O \quad (1)$$

The product of the reaction is energy and water, and this type of vehicle is zero-emissions. There are several types of fuel cell depending on the electrolyte used, and they have seen different applications such as, for example, space vehicles (Larminie & Lowry, 2012, pág. 86).

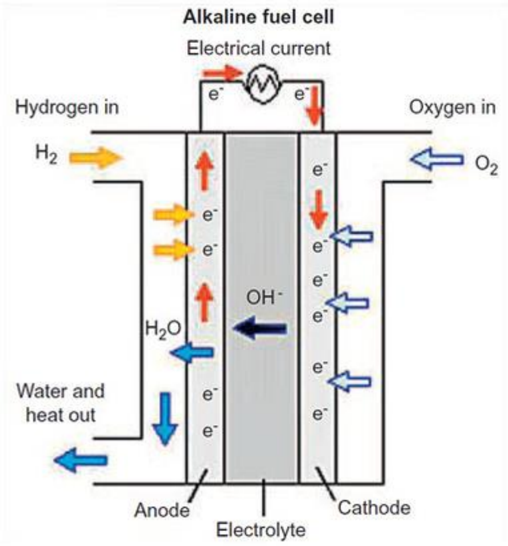


Figure 8: Functioning of a fuel cell (Breeze, 2017)

The electricity generated in the fuel cell of the FCEV goes to an electric motor and drives the wheels, and excess energy is stored in batteries or supercapacitors. A big advantage of the FCEVs is that they produce their own electricity, reducing the carbon footprint more than any other type of vehicle (keeping in consideration that the BEVs depend on the energy source used to obtain the electricity), but the most considerable advantage over other EVs is the filling time of the hydrogen tank, which is comparable to refuelling a traditional fossil fuel vehicle. On the other hand, the major disadvantages associated with hydrogen are the scarcity of refuelling stations, the potential danger of a hydrogen leak that could cause an explosion, and the price of hydrogen. Most of the hydrogen nowadays is extracted from natural gas, although there are ways to obtain green hydrogen (Sanguesa et al. 2021). If a sustainable, safe and reasonably inexpensive way of obtaining hydrogen for refuelling fuel cells can be found in the future, this type of vehicle has a good chance of being a great alternative. (Un-Noor et al. 2017). It is also remarkable that due to the size and weight of the fuel-cell stacks, FCEVs are better suited for medium-sized or large vehicles that cover long distances, like logistics vans or trucks. (European Environment Agency, 2016)

3.1.5 Comparison of the EVs

In the first section of this chapter, the advantages of EVs over conventional combustion vehicles were described, as well as the technical drawbacks that need to be developed in order to successfully achieve the transition to zero emissions. Having described the main characteristics of each of the types of EVs, it is possible to make a technical comparison in order to identify the potential benefits of each of them, as well as their needs for improvement in order to represent a real alternative to replace combustion vehicles and achieve the goal of decarbonisation of transport. Figure 9 shows a schematization of the actual alternatives in which we can observe the characteristics explained above.

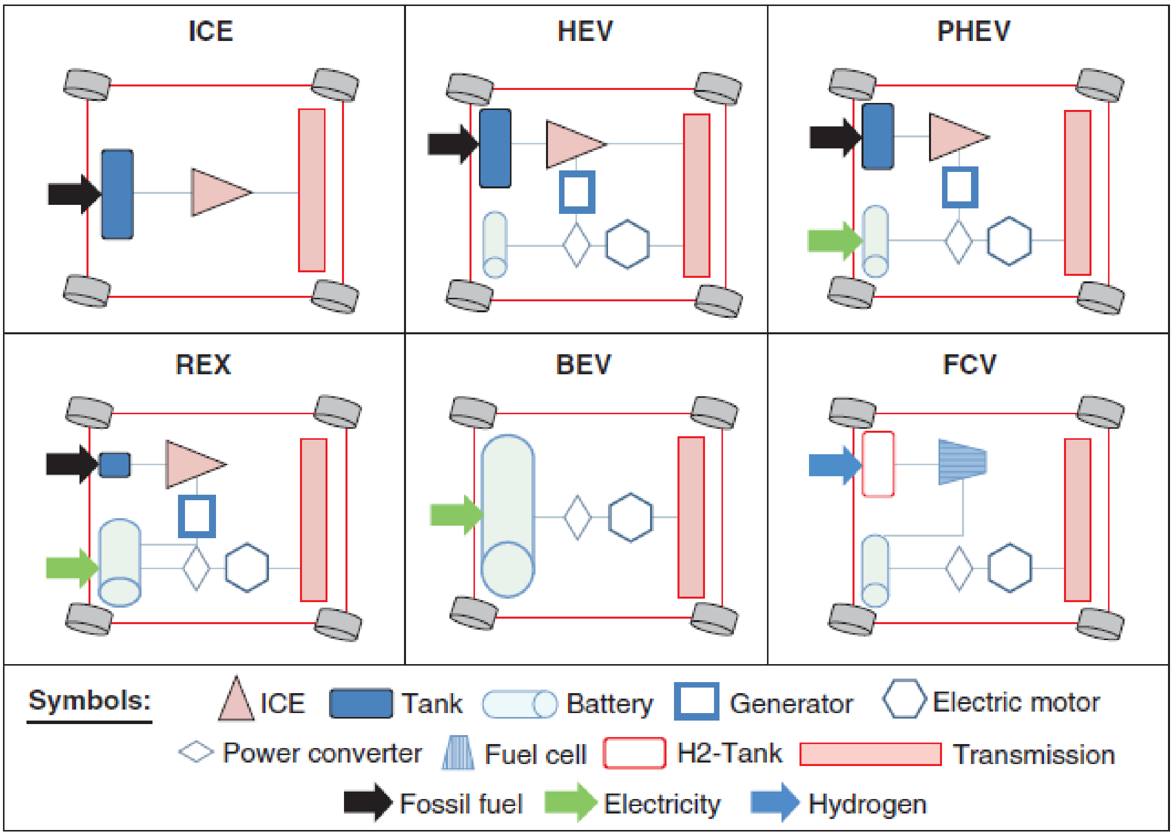


Figure 9: Schema of all the EV types (Ajanovic, 2015)

At first glance, it is evident the similarity in simplicity of the BEV and the ICE, while the hybrids contain a more intricate system. The difficulty of fuel cell vehicle adoption will be determined by the future development of the fuel cell. The biggest technical challenges for the massive adoption of the BEVs are the ones related with the batteries and their charging process, with these issues improved, the ICE incorporated on the HVs will be no longer necessary, so these vehicles could be considered as a transitionary step towards the zero-emission objective. Un-Noor et al. (2017), summarizes these advantages and problems of each type in the following table:

Table 1: Comparative of the major types of electric vehicles. Based on Un Noor et al. 2017

EV Type	Energy source	Features	Problems
BEV	Battery Ultracapacitor	No emissions Not dependent on oil Available commercially	Battery capacity, vehicle range Charging time Availability of charging stations High price
HEV	Battery Ultracapacitor ICE	Long range High flexibility Big choice of models	Technical complexity Battery/engine optimization Not zero-emissions
FCEV	Fuel cell	Very little or no emissions High efficiency / Long range Not dependant on electricity supply	High cost of the Fuel cell Low availability of fuelling facilities Feasible way to produce fuel

3.2 Batteries

3.2.1 Characteristics of the EVs Batteries

The principal features that characterise the batteries for EVs are the following, as described by Sanguesa et al. (2021)

- Capacity. It can be defined as the maximum amount of energy that can be extracted from the battery under certain defined conditions. The most common unit is the watt hour (Wh). It is a crucial characteristic for the EVs to keep evolving, given its direct influence in the autonomy of the vehicles, so there are huge money investments in batteries that could storage more energy in the shortest possible time.

- Energy density. The energy density is the energy that a battery is able to supply per unit volume (Wh/L). An improve in energy density means that a battery can accumulate a higher energy quantity with equal size or reduce its size and accumulate the same amount of energy.
- Specific energy. The energy that a battery can supply per unit mass (Wh/kg)
- Specific power. The power that a battery is able to provide per unit weight (Wh/kg)
- Lifespan. The number of charging/discharging cycles that a battery can hold.
- Internal resistance. The conductivity of the materials of the batteries is not perfect, and there are some losses of energy dissipated by that internal resistance in the form of heat. In relation with the charge process, this also implies that in the high-power charges (quick charging) there are more power losses than in the slow ones.
- Efficacy. The percentage of the power given in relation to the energy charged.

Of these characteristics, in addition to high capacity, specific energy and specific power are crucial for the development of electric vehicles. The ability to be charged quickly, and to be discharged efficiently, safety, maintenance cost, service life and degradation also have to be taken into consideration (Chan, 2002).

But the technical properties of batteries are not the only aspect that needs to be improved for the future. Predictions suggest that 90% of the demand for batteries in the next two decades will be for electric vehicles (Flowers, 2021), so the processes of manufacturing, recycling, and reusing batteries or obtaining the raw materials for them will have to be optimised and improved to meet the sustainability of the whole process. Batteries are the most expensive element of an electric vehicle - for example, the Nissan LEAF's batteries account for a third of the total cost of the vehicle - (Sanguesa, et al. 2021), the Figure 10 shows how the cost of batteries has been reduced by almost 3 times in the last 5 years and by around 7 times since 2011.

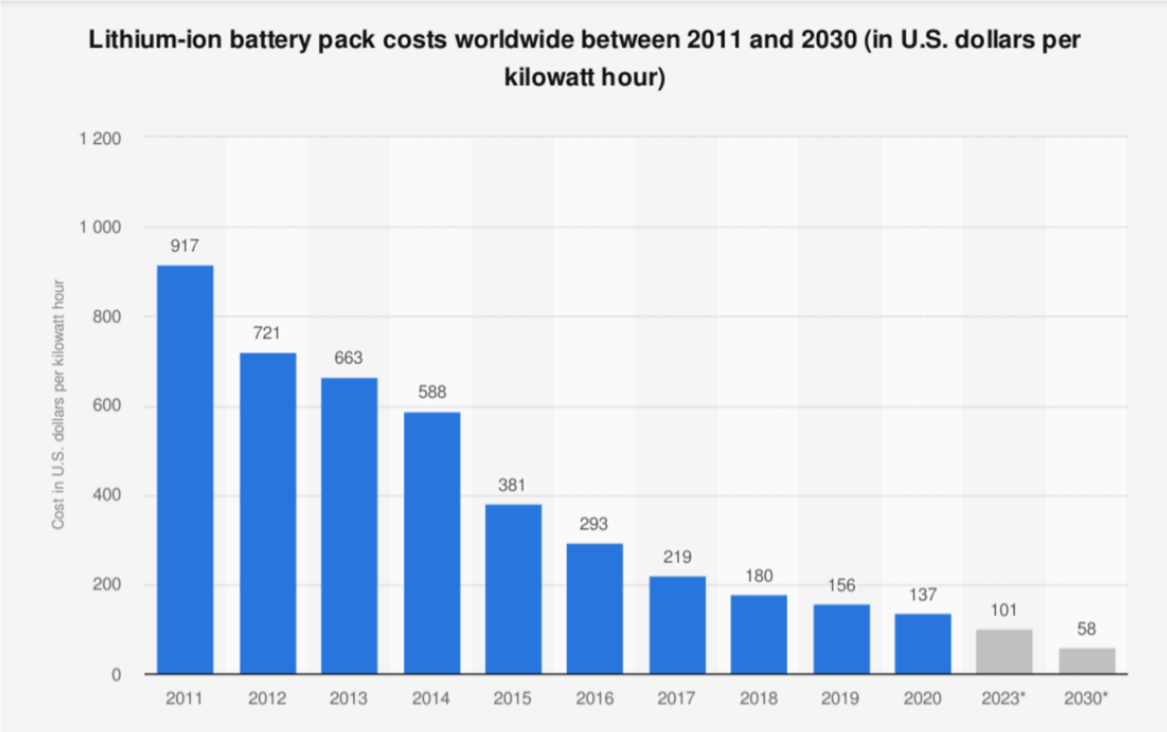


Figure 10: Historical and forecast of the Battery pack price (US dollar / kWh) (Statista Research Department, 2020)

3.2.1 Composition of the Batteries

There are many types of batteries used in EVs, based on their chemical composition they present different properties and characteristics. The most used batteries nowadays in EVs are the Li-Ion batteries, but there are other kinds and also a lot of research and promising types of batteries being tested that could develop the actual batteries. The most common batteries in EVs in the present according to Un-Noor et al. (2017) are:

- Lead-Acid batteries ($Pb\text{-}PbO_2$): They are the first batteries to be discovered and the cheapest. Although their general use is widespread, they are generally not used in EVs due to their low specific energy and energy density. However, some low-speed EVs are equipped with this type of battery due to its low cost, high reliability, and availability. Another important aspect of this type of battery is that the recycling rate is around 95-99% (Sun et al. 2020)
- Nickel-based batteries: The composition of these batteries is nickel hydroxide in the positive electrode and potassium hydroxide solution as the electrolyte, while the negative electrode can be iron (Ni-Fe), cadmium (Ni-Cd), zinc (Ni-

Zn), metal hydride (Ni-MH) and hydrogen (Ni-H_2). The use of Cadmium was common in the past, because of its great number of life cycles (over 2000) and great energy density (Ghosh, 2020), however, the high cost and environmental hazards of Cadmium, caused the substitution for the Ni-MH batteries, that have a higher rate of self-discharge and present memory effect as disadvantages, but are used in hybrid vehicles such as the well- known Toyota Prius (Sanguesa et al. 2021).

- Lithium-ion (Li-ion): In this type of battery, there are reactions inserted from both electrodes with the common feature that in both, lithium-ion act as the charge carrier (Miao et al. 2019). Lithium-ion batteries have high specific power and energy, twice as the energy density of the NiMH batteries and, in addition, they are light, have a great charging capacity, low internal resistance, great lifespan, and a reduced memory effect, making them the most popular choice for BEVs. The temperature and the input voltage must be within a security window to guarantee their security and performance (Sanguesa, et al. 2021), thus polymer materials in the electrolyte are being tested to solve this issue.

Table 2: Comparative of the Battery compositions (Un-Noor et al. 2017).

Advantages Over	Lead-Acid	Ni-Cd (Nickel-Cadmium)	NiMH (Nickel–Metal Hydride)	Li-Ion (Lithium-Ion)	
				Conventional	Polymer
Lead-acid		• Volumetric energy density • Gravimetric energy density • Range of operating temperature • Rate of self-discharge reliability	• Volumetric energy density • Gravimetric energy density • Rate of self-discharge	• Volumetric energy density • Gravimetric energy density • Rate of self-discharge	• Volumetric energy density • Gravimetric energy density • Rate of self-discharge • Design features
Ni-Cd (Nickel-Cadmium)	• Output voltage • Cost • Higher cyclability		• Volumetric energy density • Gravimetric energy density	• Volumetric energy density • Gravimetric energy density • Rate of self-discharge • Output voltage	• Volumetric energy density • Gravimetric energy density • Rate of self-discharge • Design features
NiMH (Nickel-Metal Hydride)	• Output voltage • Cost • Higher cyclability	• Range of operating temperature • Cost • Higher cyclability • Rate of self-discharge		• Volumetric energy density • Gravimetric energy density • Range of operating temperature	• Volumetric energy density • Gravimetric energy density • Range of operating temperature • Rate of self-discharge • Design features
Li-Ion (conventional)	• Cost • Safety • Higher cyclability • Re-cyclability	• Range of operating temperature • Cost • Safety • Higher cyclability • Recyclability	• Cost • Safety • Rate of discharge • Re-cyclability		• Volumetric energy density • Gravimetric energy density (potential) • Cost • Design features • Safety
Li-Ion (polymer)	• Cost • Higher cyclability	• Range of operating temperature • Higher cyclability • Cost	• Volumetric energy density • Cost • Higher cyclability	• Range of operating temperature • Higher cyclability	
Absolute advantages	• Cost • Higher cyclability	• Cost • Range of operating temperature	• Volumetric energy density	• Volumetric energy density • Gravimetric energy density • Range of operating temperature • Rate of self-discharge • Output voltage	• Volumetric energy density • Gravimetric energy density • Range of operating temperature • Rate of self-discharge • Output voltage • Design features

Other known batteries that were tested in EVs but that nowadays are in disuse are the zinc-bromine batteries (Zn-Br2), the sodium chloride and nickel batteries (NA-NiCl), also known as ZEBRA batteries and the Sodium sulphur batteries (Na-S) (Sanguesa, et al. 2021), that for diverse reasons have not been largely applied to EVs. In the table collected from Un-Noor et al. (2017) paper, the characteristics of the main types of batteries are compared. It can be seen that, apart from the cost, lithium-ion batteries excel in all facets, and there is current research focused on developing this type, if the polymer is viable as an electrolyte, the advantages in battery design and safety will be greatly enhanced. Another line of research for the improvement of Li-ion batteries is focused on electrode materials, substituting the graphite anode for metals and on improving the thermal characteristics of electrode materials and cooling methods (Miao et al. 2019).

But there are many efforts put on the development of new technologies that can improve the durability, charging processes and densities of the Li-Ion batteries. Lithium Iron Phosphate ($LiFePO_4$) batteries have started being tested in EVs, and promise to offer high durability and energy density, fast charging, and a very good response to high temperatures. Magnesium is also being tested by some accredited institutions and enterprises like NASA or Toyota to substitute Lithium in the batteries (Mg-Ion), these batteries could have much more capacity and energy density. Air batteries, with a supply of Oxygen from the exterior to the battery are being tested with different minerals like Lithium, Aluminium and Sodium. These two last batteries would allow to discontinue the usage of Lithium in the batteries, and are cheaper, Aluminium is easily recyclable, and Sodium is the sixth more abundant element in the Earth. The use of graphene in batteries has a lot of potential given its conductivity and lightness, that might convert into great energy density properties and better charging times (Sanguesa et al. 2021).

3.2.2 Structure of the Batteries

The architecture of battery packs can vary as there is a wide variety of electric vehicle models and, as can be seen in the previous section, many different types of batteries. The most common today are li-ion battery packs, which are composed of battery modules and battery cells. Battery cells are energy storage units that need protection from temperature conditions, vibrations, shocks that they may receive, for this they are grouped in modules. Finally, the pack incorporates all the modules together with a cooling device that controls the voltage and temperature of the modules, guaranteeing the safety of the batteries and optimising their performance (Samsung, n.d.). It is important to maintain the battery cells at the same state of charge (SOC) to have the same degradation rate and capacity over the lifetime of the battery cells, the voltage equalizer is the electronic device that ensures this feature by transferring energy from the higher energy cells to the lower energy cells (Un-Noor et al. 2017).

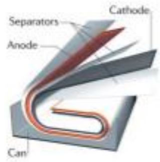
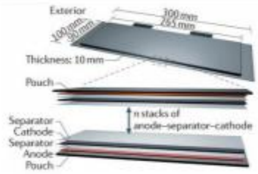
Shape	Cylindrical	Prismatic	Pouch
Diagram			
Electrode Arrangement	Wound	Wound	Stacked
Mechanical Strength	++	+	−
Heat Management	−	+	+
Specific Energy	+	+	++
Energy Density	+	++	+

Figure 11: Battery cell geometry and characteristic comparison (Miao et al. 2019).

The cells can be presented in three shapes, as it is displayed in the figure above, cylindrical (a), prismatic hard-case (b) and prismatic pouch (c). The pouch cell has significant advantages in terms of manufacturing costs, energy, and packaging density; however, current manufacturing processes are inefficient (Schröder et al. 2017). Improving these manufacturing processes can be a crucial improvement in terms of production capacity, quality standards and battery costs, directly impacting on EVs cost reduction. Tesla is developing a dry-electrode process that simplifies the manufacturing of the battery cells reducing energy consumption by at least a 70% (Tesla, 2020).

3.3 Charging Technology

For charging the EV, there are three ways, conductive charging, via a wire connected from the charging station to the vehicle, inductive charging based on electromagnetism technologies, and battery swapping. Conductive charging is the most common technology nowadays given its simplicity and the low number of EVs that are still on the roads, providing availability of a charging station for most of the users, while wireless charging exists but it has not been standardized yet, and battery swap has possibilities for being widely used in the future, however, it should overcome some big disadvantages (Hans, 2020).

3.3.1 Conductive Charging

The chargers can be designed as one-way power flow, which simplifies the design and allows to reduce the cost and the weight of the EV, and two-ways power flow, that enables both directions of the current and permits the addition of new features, as the battery of the vehicle working for the grid when connected (Sun et al. 2020).

The charging points can be categorised in private, semi-public and public. Private or domestic charging points can be placed in homes, public ones are located in public parking spaces or near the roads, and semi-public are in private locations but can be accessed by external users (Raff. 2019).

3.3.1.1 Charging Modes

The simplicity and speed of charging are the two most important features regarding the charging process, and the flexibility and the variety of charging processes and infrastructure plays a huge role in order to satisfy the needs of charging the EVs, from individual chargers in the houses, to fast charging infrastructure in the highways and public spaces (Falvo et al. 2014). Different charging standards apply depending on the region of the world. In USA and the Pacific zone, the standard SAE-J1772 classifies the modes in different levels, according to the power type (AC or DC), the same way that the GB/T 20234 does in China. In Europe, the standard IEC-62196 provides a four-mode classification according to the nominal power of the charge (Sanguesa et al. 2021).

- Mode 1 (Slow charging) allows vehicle charging using common sockets and cables. It can be found in residential or working buildings and provides a range between 2 and 3,7 kW (Raff. 2019). It works with AC at a maximum intensity of 16 A, the average period of charging with this method ranges from 4 to 8 hours. Given the absence of security devices (other than the building fuses) this charging mode is discouraged and unsafe, in fact in some countries like the USA its use is forbidden (Paulraj, 2019).
- Mode 2 (Semi-fast charging) also uses a normal socket but with dedicated cables provided by the car manufacturer, that includes protection to the electrical installations and increases the performance of the charge, as well as the price of this mode. It also works with AC current from 16 to 32 A, and the maximum power is 7 kW or 22 kW (AC single or AC three). (European Environment Agency, 2016)

- Mode 3 (Fast charging) It is a three-phase AC charging mode that uses a special socket and a dedicated circuit to charge at higher power levels. The infrastructure can be a wall-box, installed in residential buildings or stand-alone poles located in public spaces (European Environment Agency, 2016). The power supplied by the charging station is from 22 to 43 kW and the maximum load is from 32 to 63 A, while the charging time is of 1 to 2 hours. The key feature of this mode is that the power supply circuit is dedicated to the EV charge, so it does not affect other appliances and meets the standards of electrical installations (Raff. 2019).
- Mode 4 (Ultra-fast charging) In this mode, the charging station is provided with an AC/DC converter that allows it to supply the EV directly with DC, and not to be equipped with an on-board charger. These charging points are mostly located in public areas, gas stations or highways. The power supplied ranges from 50kW to 240kW while the maximum current is 400A and the voltage 500V, the charging stations are usually equipped with batteries that allow them to offer these high tensions (Raff. 2019). This mode also includes the external cable that provides communication between the vehicle and the charging point as well as electrical protection and control (Sanguesa et al. 2021).

Besides these modes and the Chinese and American standards, the EVs company Tesla, has developed its own fast charging points, the Supercharger Stations. Although Tesla's superchargers are considered ultra-fast charging by the company itself, the reality is that they work in AC mode (being in the 3rd mode), supplying 120kwh, and are capable of recharging half the battery of a Model S in 20 minutes (Sanguesa et al. 2021).

3.3.1.2 Types of connectors

The connectors provided by the charging stations, allow the safe and user-friendly charge of the EVs. The sealing is one of the features of this connectors that protects them from water or humidity, also the security is reinforced by the presence of a blockage that can be electronic or mechanic, and the charging does not start until this blockage is active. The communication established between the charging points and the vehicle secures also in this direction that the vehicle does not move during the charge (Sanguesa et al. 2021).

As for the charging modes in the previous section, in this section the classification of the types of connectors that are currently in use in Europe will be described according to the IEC 62196.

- Type 1, SAE J1772/2009. This type is commonly found in the USA and Japan EVs and it was concieved to work in Mode 1 connected to an AC output socket. There are two levels of charge for this connector. Level 1 allows up to charge with a 16 A current and provides 2 kW, meanwhile in level 2, the current is up to 80V and the power up to 19,2 kW (Raff et al. 2019). It is represented in the Figure as a).
- Type 2, Mennekes, takes its name from the german enterprise that invented it for industrial use, and it was readapted for its use in EV. It is designed to be connected in modes 2 and 3 of charging, and it is the standard in the EU. It is versatile, given that it can work in AC and DC, as well as single-phase and three-phase, providing a maximum of 300 A. The connector presents 7 pins, four for the power, two for communications with the vehicle and features like blockage, and the last one for ground connection (Raff et al. 2019). This type can be see as b) in the Figure.
- Type 3, Combined Charging System, or CCS. These are also named COMBO1 and COMBO2. They derive from the types 1 and 2 of connectors and are an adaptation to these models to support higher currents and therefore, DC charging in Mode 4, even though they also support slow charging (Sanguesa et al. 2021). COMBO 1 has a maximum charging power up to 80kW, and 200 A of maximum current supported. COMBO 2 meanwhile, supports up to 350 kW and 500 A. They are represented in the figure as c) and d) respectively.
- Type 4 of connector is also called CHAdeMO, it was designed in Japan and it is used also in the USA, and only supports DC. The charging current is 125 A and the power supply 62.5 kW (Raff et al. 2019). Nissan, one of the manufacturers including CHAdeMO chargers in their vehicles, has

announced to transition to CCS, and infrastructure companies like Electrify America, are planning to phase out CHAdeMO, forecasting that by 2025 over the 90% of the charging stations in the USA will operate CCS (Moloughney, 2021).

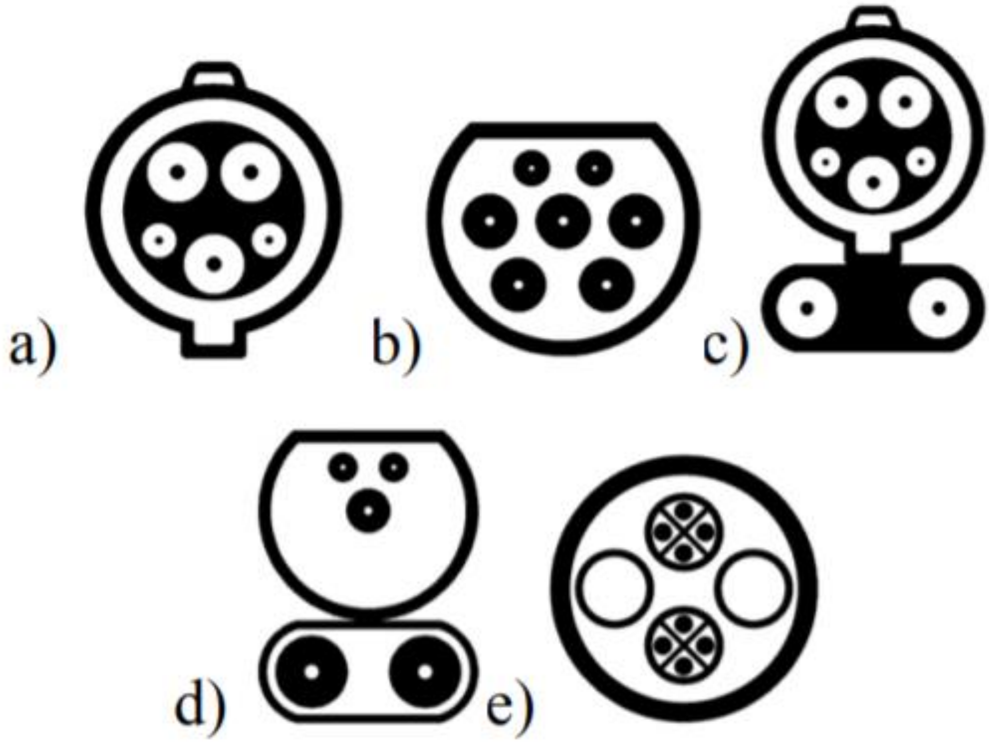


Figure 12: Standardized connectors for EVs (Raff et al. 2019)

3.3.2 Wireless charging

Wireless charging is the application of Wireless Power Transmission or WPT to the EVs, this means, without requiring any physical contact during the process of transferring electric energy (Yang, 2018). using inductive power in most of the cases. The wireless charging method can be static or dynamic. Static charging consists of two coils, one placed in the lower part of the vehicle and the other one just under the road surface. The coils interact electromagnetically supplying charge to the battery of the vehicle. Dynamic charging is similar, coils are buried under the roads in order to provide charge to the vehicles that are moving on top (Hans, 2020).

The technology is still in early development stages, most methods have not been tested yet, and there are quite a lot of unknown facts about the adoption of this technology such as the costs, the infrastructure allocation, or the paying method. Also, there are already some researches that claim that wireless charging is not competitive with battery swapping and with super-fast conductive charging, however there are some projects and investments on this method and a proper development could head into a practical use with a good adoption, and has potential to solve the actual problems of the other methods to charge the EVs. (Yang, 2018).

There are projects for specific situations that have been successfully tested, public transport, specifically buses, are a great opportunity to exploit wireless charging, given its high use frequency, equipping the routes with the infrastructure needed by this technology can be worth the investment. There are 17 cities in Europe that are using or planning to use electric buses, particularly in Madrid, public buses operating the line number 76 that cover 7 kilometres, are equipped with wireless charging equipment since 2016, to power their 124 kW Li-ion batteries (Sawilla & Schütt , s.f.)

Figure 13: Wireless charging system and E-bus in Madrid (ETRA, s.f.)

3.3.3 Battery swapping

Battery swapping is one of the fastest and easiest charging methods. It is carried out in a battery swapping station (BSS) where simply the discharged batteries are changed for a full one. BSS are adequately equipped for battery swapping and charging with equipment such as converters, chargers, and the robotic infrastructure to perform the battery swaps automatically (Hans, 2020). This technique, faces big obstacles to be performed, given that the volume of batteries that have to be stocked in the BSSs are big and there is not a standard of battery pack type or size among the EVs available right now in Europe, in fact, most of them do not support battery swapping (European Environment Agency, 2016). Nevertheless, the Chinese EV manufacturer NIO, has an infrastructure consisting of 301 BSSs in China, where they have successfully performed around 3 million battery swaps. Given these results they have announced that by the end of 2025, NIO will have more than 4000 BSSs and 1000 of them will be placed out of the Chinese borders, offering this technology also to other EVs manufacturers (Lambert, 2021). NIO is operating the BSSs with a business model of Battery-as-a-Service (BaaS) where the owner of the batteries is NEO, and the customers pay a subscription price for using the batteries alongside the BSSs, withdrawing the price of the battery from the price of the car. This gives hope to this technology that could also be beneficial in other terms, like in the case of the grid supplying, where the BSSs could be storing energy in the batteries and supplying it in required periods of time, or for the customers who would no longer own the battery, reducing the initial investment in the vehicle´s purchase, and opting to battery upgrades and flexibility when choosing the capacity of the batteries (NIO, 2020).

3.3.4 Comparison of charging methods

According to (Sun et al. 2020), and to the descriptions made above, in the comparison of these three types of battery charging, conductive charging is the one with most chances to spread in the short term, given its low costs and faster supply of energy to the vehicle, being this last feature the main objective of battery charging technology nowadays. The chinese EVs manufacturer GAC, has recently tested a new ultra-fast charging method that can refill the batteries of their model Aion from

0% to 80% in 16 minutes, and from 10% to 80% in 10 minutes without affecting the battery lifespan. Hyundai has also tested an 800 V charging system that allows the IONIQ to charge the battery from 10% to 80% in 18 minutes (Noya, 2021). Inductive charging is safe and user-friendly, but its conditions at this moment, make it situational given the early stage of the technology development. Battery swapping is an incognita given all the factors that surround it, however it is the fastest way of charging a vehicle, but the high investment in BSSs and the management of these are still to be tested and improved. NIO´s business model could make a big impact, especially if this technology could be combined with the other two.

4. Ecological Implications of the Electric Vehicle

On 14th July 2021, the European Comission adopted a new package of measures on climate, energy use, and transport among others, in which it approved the measure to reduce GHG emissions by at least 55% by 2030 compared to 1990 levels, and all the new cars registered from 2035 to be zero-emission, with the objective of being the first climate-neutral continent by 2050. In the 2050 climate-neutral strategy, seven main blocks of action are identified as listed:

1. Maximise the benefits of energy efficiency, including zero emission buildings
2. Maximise the deployment of renewables and the use of electricity to fully decarbonise Europe’s energy supply
3. Embrace clean, safe, and connected mobility
4. A competitive EU industry and the circular economy as a key enabler to reduce GHG emissions
5. Develop an adequate smart network infrastructure and interconnections
6. Reap the full benefits of bioeconomy and create essential carbon sinks
7. Tackle remaining CO_2 emissions with Carbon Capture and Storage (CCS) (Directorate-General for Climate Action (European Commission), 2016).

Point 3 is the one that aims directly to the adoption of electric vehicles as clean mobility, but most of the points are closely related to the future and present of the automotive industry in the European continent. The first two points are related with energy efficiency, which, consequence the decarbonisation of transport, will have the electric vehicle as one of its greatest exponents. The recycling and reuse of batteries will be a key element in the development of the circular economy, just as the end-of-life combustion vehicles will need to be properly managed as they will be phasing out.

4.1 Well to Wheel Analysis

As it is described in the technical analysis section, the different types of EVs have reduced GHG emission levels or zero-emissions in the case of the BEVs and the FCEVs. But EVs, although they do not emit gases during their operation, do have an environmental impact, either due to the metals used in their components, especially the batteries, their manufacturing process, the residual waste after the cycle of life of the vehicle, the recycling processes or due to the energy source from which the electricity they use to operate comes from (European Environment Agency, 2016).

The analysis Well to Wheel (WTW) takes into account all the energy chain of the vehicle, as (Simonsen & Walnum, 2011) describe, including:

1. Extraction/production of the energy source.
2. Transportation of the energy source.
3. Production of the energy carrier (fuel, electricity).
4. Distribution of the energy carrier.
5. The net direct energy consumption, this is the energy applied for passenger car propulsion.

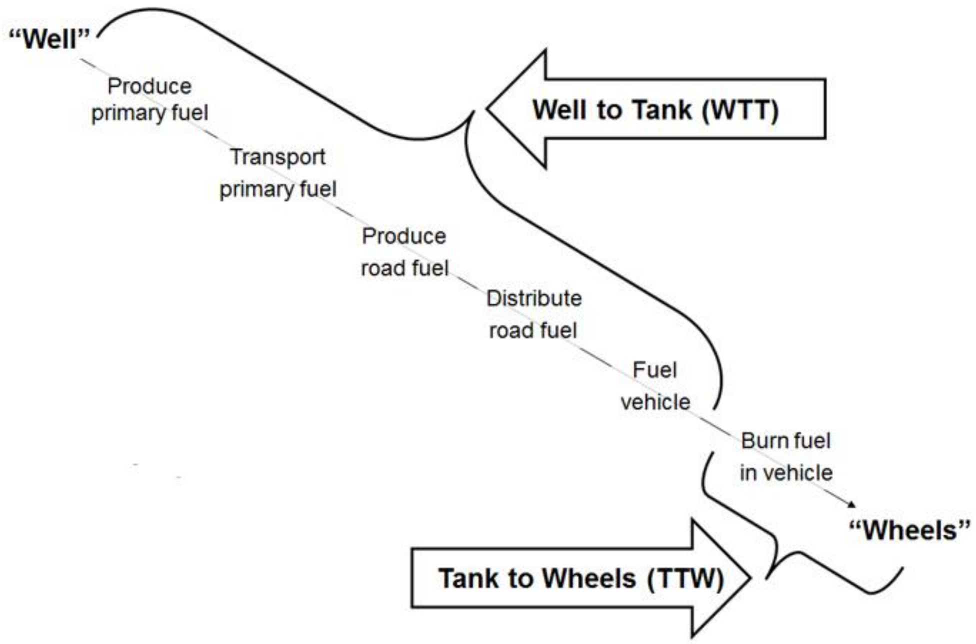


Figure 14: Well to Wheel Analysis (European Comission, 2016)

The WTW analysis is applied to the GHG emissions during all these stages and to the energy consumed during the process and consists in two big and well differenced stages, the Tank to Wheel stage and the Well to Tank stage. (Ramachandran & Stimming, 2015).

4.1.1 Tank to Wheel

Tank to wheel (TTW) is the sub-range of the vehicle energy chain that comprises the period from the introduction of fuel or electricity until it is translated into motion. Well to tank, on the other hand, covers the processes from the production of that energy to its supply (Volkswagen AG, 2021).

Tank to Wheel emissions in EVs are zero. However, energetic efficiency in EVs in the TTW analysis, is associated with the effective electricity that, once charged the vehicle, causes the motion. There are power leaks in the process of transforming energy to charge the vehicle from the supply, especially if it is coming from an AC charger, given that there are loses in the AC/DC transformation to supply the batteries. Then, in order to supply the motor, a further transformation into AC current is necessary, where there are also leakages (Markowitz, 2013).

As it is seen in the graphic (Figure x) summarized by (Hass et al. 2014), not only the GHG emissions are zero in the BEVs and FCEVs, but also the energy consumption is quite lower in comparison with other alternatives, and the efficiency within BEVs components has seen an improvement in performance over the last decade, reducing their energy consumption. Thus, the most important feature of the EVs regarding this subrange is the electricity consumption per km traveled (Wh/km).

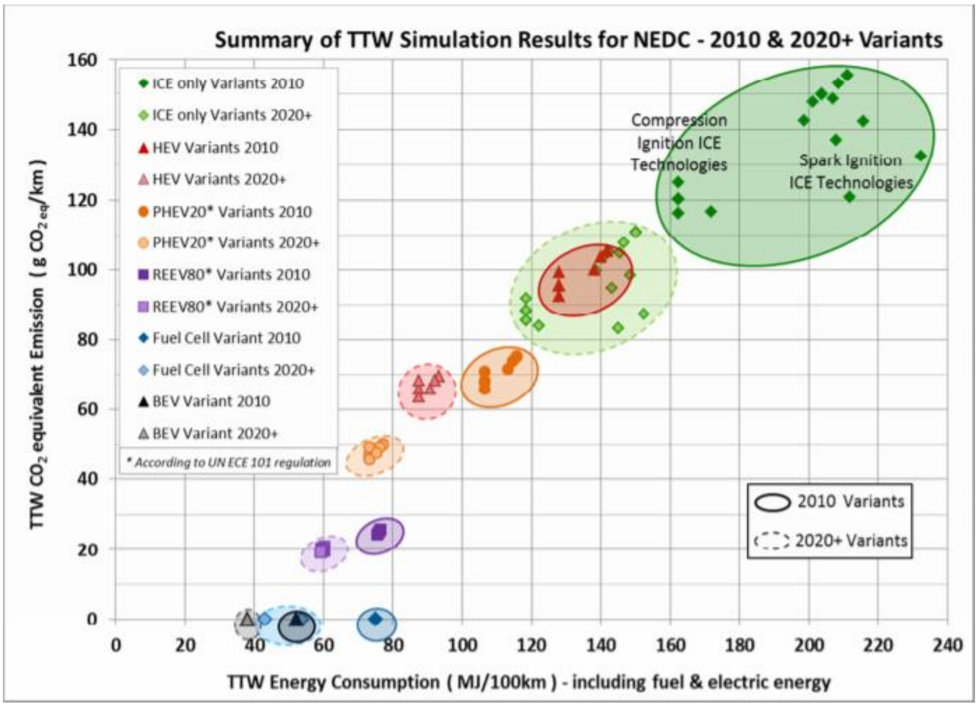


Figure 15: TTW Emissions and Energy Consumption in 2010 and 2020 by vehicle type

4.1.1 Well to Tank

The Well to Tank subrange covers the energy supply, from the production of the energy source to the fuel supply, including the transformations of energy occasioned in the processes (Volkswagen AG, 2021).

It can be deduced from the above that for this range, the energy efficiency and the level of emissions involved in the electric vehicle will be determined by the energy sources used to obtain the electricity to charge the batteries (Liu et al. 2021) as well as by the manufacturing process of the vehicles, slightly more pollutant in the case of the EVs at this moment.

In the inform realised by The European Federation for Transport and Environment in April 2020, the emissions of the EVs (BEVs and PHEVs) compared to the diesel and petrol vehicles are compared, including the battery manufacturing and the whole lifetime energy consumption of the vehicles. The report claims to use updated 2020 data for comparison where it shows that CO_2 emissions of EVs are on average almost 3 times lower than those of conventionally powered vehicles for the average EU (including UK) power generation mix and the CO_2 savings during the complete cycle of use of the vehicle is more than 30 tons. The "debt" that EVs start with due to the emissions produced in the manufacture of the batteries is covered in little more than a year of vehicle use, Tesla estimates in their 2020 Impact Report that the difference in the GHG emissions occasioned during their Model 3 manufacturing is compensated after 8600 km driven. It is also worth noting that with the increased role of renewable energies expected by 2030, the reduction of the carbon footprint will be much greater, and EVs will be 4 times cleaner than traditional vehicles in that year, as it is a more modern technology and has more capacity for improvement. The improvement is even more noticeable in the case of vehicles that travel long distances during their life cycle, as the amortisation of the battery is higher, so that vehicles such as taxis or shared fleets will save up to 85 tonnes of CO_2 compared to a diesel vehicle. As can be seen in the graph, even in the case of Poland, the country where the least amount of renewable energy is obtained of those present in this study, and which is therefore most dependent on coal, there is today a 29% improvement in emissions using EVs (Transport & Environment, 2020).

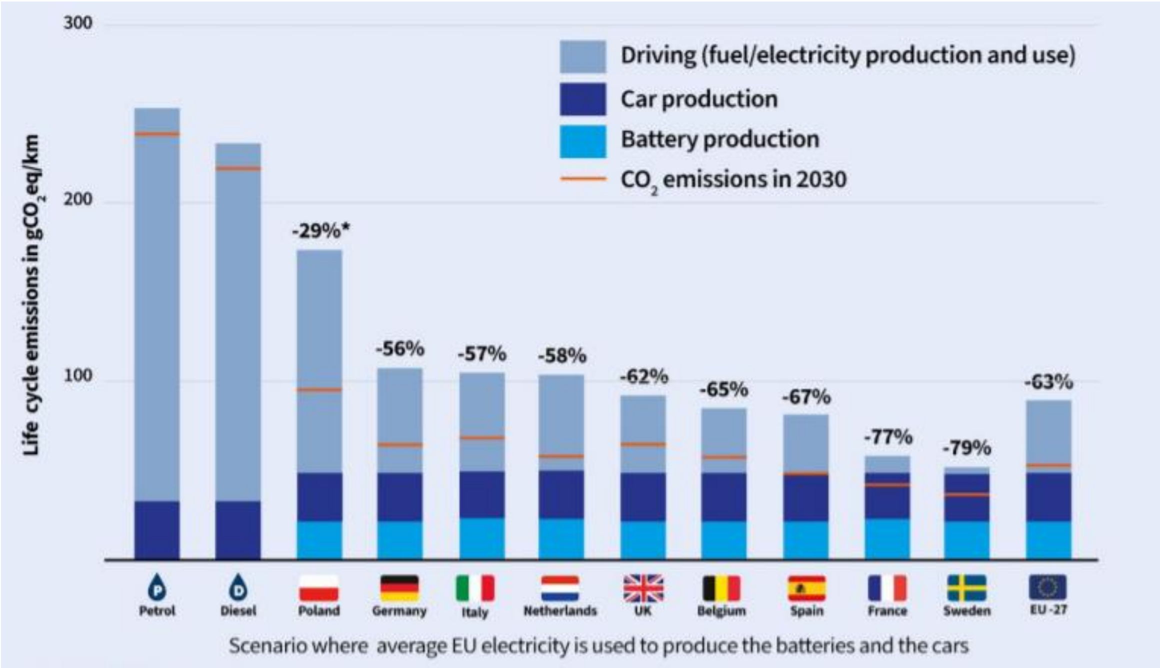


Figure 16: Average emissions of vehicles in different European countries (Transport & Environment, 2020)

It is important to highlight that the graph considers that the batteries are manufactured in Europe, in the case of being manufactured in China, the manufacturing process generates 110 kgCO2/kWh instead of the European average of 75 kgCO2/kWh, given the high dependence on coal in the Asian country's electricity mix. A relocation of battery production to Europe would be another important factor in reducing emissions in the process. Manufacturing batteries on a larger scale as EV use becomes more popular should lead to significant emissions reductions, as should the use of natural gas boilers where there is high dependence on coal for heating and drying processes. (Transport & Environment, 2020). Europe (UK and EFTA included) is the region with higher renewable sources and nuclear energy production, topping USA and China, so the emission gap between the ICE vehicles and the EVs is more noticeable (Tesla, 2020) and the reduction objective more realistic.

4.2 Possibilities for improving the environmental impact of EVs

According to the Well to Wheel analysis presented in the previous section, the improvement made on the efficiency and ecological impact of the EVs can be classified. There are many techniques that are being investigated and promoted to accomplish the challenge of reducing as much as possible the ecological footprint of the vehicles, and the way that them and their associated technologies can also help in harnessing the energy usage, some of them are the following:

- Battery recycling: Currently there are almost no batteries in the recycling phase but estimates for 2030 are that there will be around 1,2 million of batteries ready to be recycled. The recycling process also involves several emissions, so finding a method to reduce them should be a line of research to develop a greener electric vehicle, in this direction, direct cathode recycling could potentially reduce the emissions compared to other battery recycling methods such as pyrometallurgical or hydrometallurgical processes (Transport & Environment, 2020). Tesla presents a plan to recover 92% of the end-of-life batteries as raw materials ready to produce new batteries (Tesla, 2020).
- EV to Grid: Electric vehicles can contribute to the grid by being connected, supplying the energy stored in their batteries to the grid, contributing to the improvement of the energy mix towards renewables and covering the demand that these cannot supply at certain times and being charged back on the peak hours of the grid using smart charging technologies, taking the maximum advantage of the clean energy and preventing the use of fossil fuels due to lacks of supply. The owners of the EVs can be rewarded and get paid for the energy that they provide in the V2G service, so the development of these system can be a claim for the users to transition to the EVs faster (Purtill, 2021).
- Second life of Batteries: EV batteries that have reached a certain degree of degradation can still be used to store energy in a fixed location, such as a charging station, contributing to grid storage capacity and management in favour of clean energy sources. The large volume of batteries from electric vehicles that are expected to be available in a few years' time (it could exceed 200 gigawatts per hour in 2030) for less demanding uses means that this option could be considered in order to continue to obtain batteries before they are recycled by car companies, as well as requiring less material from the mining sector and allowing more time to improve extraction techniques to

make them more efficient and environmentally friendly (Engel, Hertzke, & Siccardo, 2019).

5. The Electric Vehicle market in Europe

EVs have gained popularity in recent years thanks mainly to the development of batteries, their most pronounced weakness, range and recharge time, and their decreasing price. The urgency to decarbonise the sector is increasing and the charging infrastructure is growing, gradually bringing EVs to the forefront worldwide. Europe is the second largest EV market, ahead of the US and only behind China, and the EU's economic efforts and CO2 reduction policies are driving the sector. The policies employed differ substantially between EU countries, as well as their development and context, making the EV market very different from one country to another (Hall et al, 2020). As seen in the previous section, the weight of renewable energy in the mix of each country influences the energy efficiency and emission reduction of EVs, so the higher the share of renewable energy in a country, the more efficient and faster the adoption of EVs in that country.

The growth of electric vehicle sales in Europe is remarkable in the last decade, as can be seen in Figure 17, except in the first quarter of 2020 due to the exceptional situation caused by the COVID-19 pandemic, the sale of electric vehicles has not stopped growing on the European continent, and it is becoming more and more remarkable.

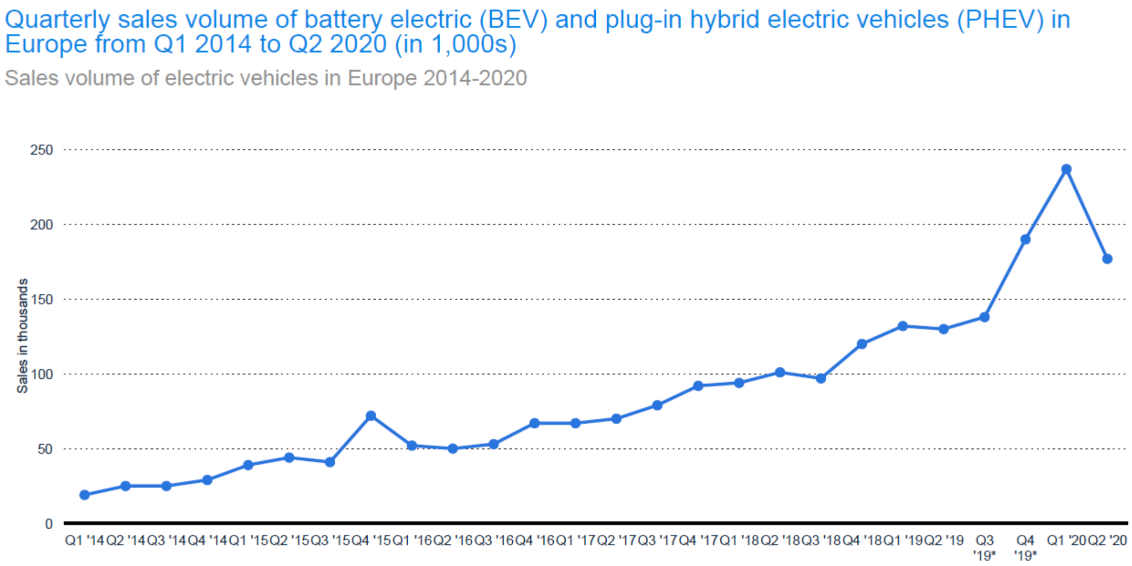


Figure 17: Sales of BEV and PHEV in Europe (2014- Q1 2020) (Statista, 2020)

The EU's EV push to manufacturers is also playing a key role in this regard. The 2020 CO2 standards for vehicle manufacturers obliged them to make 5% of their sales EVs if they did not want to face financial penalties, and by 2021, the total volume of EV sales for each manufacturer must double to 10% of their total. This transition by manufacturers creates greater possibilities for customers and more than 200 different EV models are expected to be available on the market by 2021 (Transport & Environment, 2020). Figure 18 shows the increase in the percentage of BEV and PHEV sales in Europe, among other factors thanks to the above-mentioned measures, in 2020 thanks to the European CO2 policy applied to manufacturers, this figure multiplied.

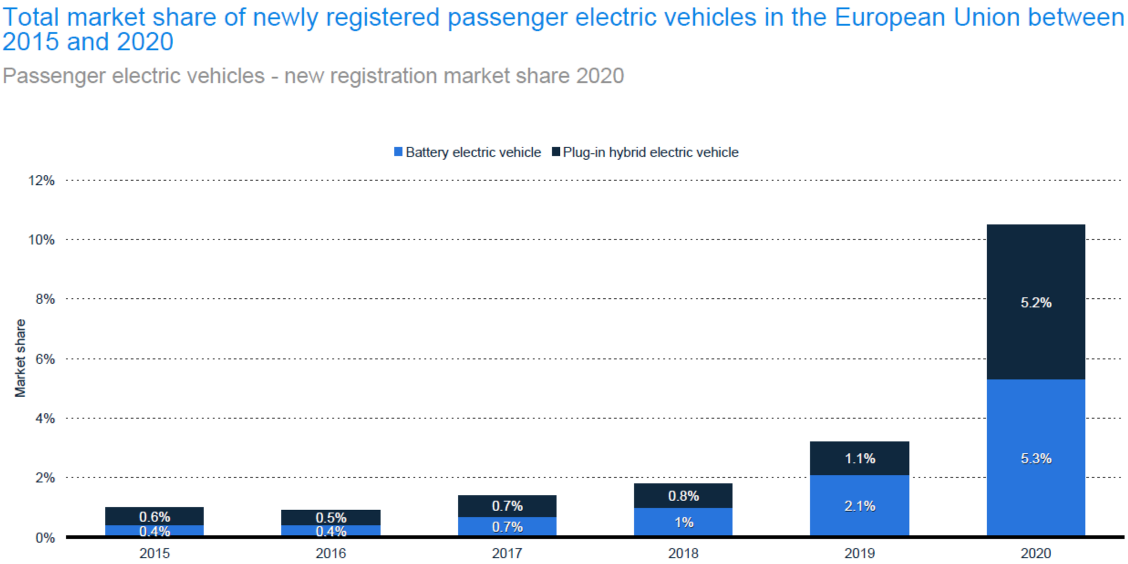


Figure 18: Market share of new passenger vehicles in Europe (Statista, 2020).

Closely related to the overall growth in the number of EVs is the growth in the infrastructure of charging points, both public and private. By the end of 2019 there were around 185,000 charging points in the EU, one for every 7 vehicles. For the successful growth of the number of EVs, the charging infrastructure must continue to grow in the EU, so that there are charging points along the entire road network of the EU countries, even in the most remote places, as well as a wide variety of charging modes at the different charging points, so it is necessary to increase the number of fast charging points. As can be seen in Figure 19, the number of public charging points by 2030 will grow exponentially and will involve an investment of 20 billion euros in public infrastructure by 2030 and three times as much in private infrastructure, totalling 80 billion euros by 2030, which, although it may seem a large figure, only represents 5% of the total budget for road transport infrastructure (Transport & Environment, 2020).

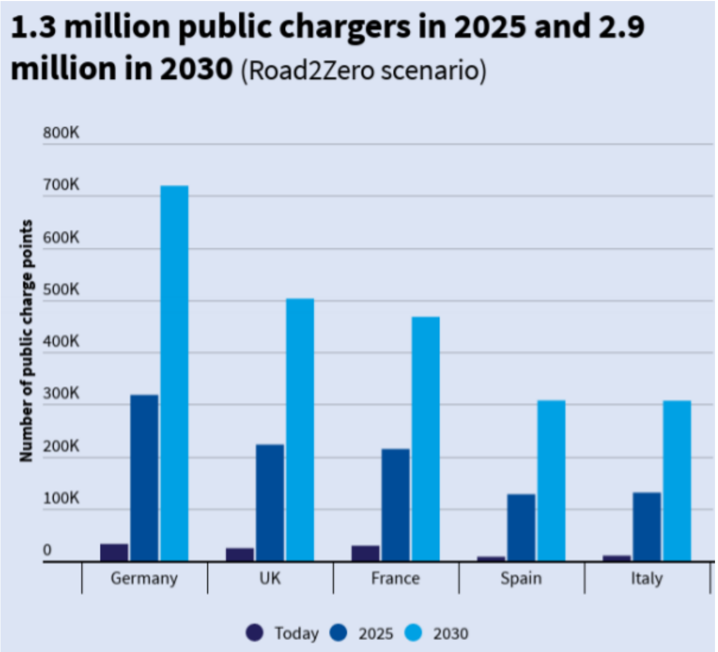


Figure 19: Public charging points in the Top5 EU economies (Transport & Environment, 2020)

Also, the change in the market is causing a profound restructuring of car manufacturers, who are looking to reinvent themselves in the face of the new situation, and new competitors such as Tesla. Some manufacturers are offering services to convince customers to buy an electric vehicle, such as Peugeot with its mobility pass, which offers a traditional car rental with the purchase of the EV to reduce range anxiety and allow the EV buyer to make the few long trips per year in an ICE vehicle (PSA Group, 2017).

The entry into the European market of Chinese EV manufacturers such as BYD, NIO, XPENG, AIWAYS, in 2020 and 2021, is a threat to European manufacturers, who see that, although the best-selling vehicles are still from the large European groups and Tesla (Renault ZOE, Tesla Model 3, Volkswagen ID3), Chinese manufacturers can offer an attractive and competitive product on the European market, both in terms of price and quality (Sugiura & Sun, 2021).

6. Conclusions and Outlook

The main motivation of this thesis was to clarify the scenarios for the near future of electromobility, and their environmental, social, and economic implications, as well as to understand the current state of the art of the technology and the current limitations to be overcome for the mass adoption of the EVs. Based on the need to move away from combustion vehicles given the environmental problems they bring and the forecasted shortage of the fuel they use, EVs have been considered as a solution in recent years but have not been without controversy and doubts about their real viability.

In the first part of the thesis, the history of EVs has been briefly presented, going through the most important milestones in their technological development. In this way, it has been explained that contrary to what one may think at first about EVs being a modern creation of the 21st century to respond specifically to the current scenario, the development of the first electric vehicles was not long in coming since the first batteries and electric motors appeared. In fact, every advance made throughout the 19th and 20th centuries was quickly applied to EVs with the intention of improving the functionality of the cars by the inventors in order to market them, and around 130 years ago it was the most promising vehicle for the future, and many of the major manufacturers, founders of some of the largest vehicle companies known today such as Ford, Mercedes or Porsche, developed electric models or electric functionality. It is no coincidence that a little more than a century ago the same technical advantages were identified in electric vehicles as those offered today, and that the limitations, which have diminished due to advances mainly in batteries, both in price and capacity, were what made EVs disappear from the roads for practically the whole 20th century. The beginning of real environmental awareness at the end of the last century led to the identification of road mobility as one of the problems with a feasible solution, the EV. Since then, there has been a strong interest in its implementation at all levels, from the level of international organisations and governments all over the world, to companies that started to invest again in the technology, with the objective and the forecast of the total decarbonisation of road traffic by the second half of the 21st century.

The current state of the art provides insight into the current implementation possibilities and the lines of research and improvement that need to be explored to facilitate the adoption of EVs in a way that is beneficial at all levels and does not represent a step backwards in how the use of the vehicle is conceived. At the outset of the research, it is easy to recognise all the performance advantages of an EV over an ICE - basically, an electric motor is much more efficient and simpler to operate. But the disadvantages that exist today are also evident, the low battery capacity produces the range anxiety effect on potential EV users, making them feel unprotected and causing aversion to buying vehicles that cannot deliver when it comes to long journeys. This is compounded by the current state of charging technology, which is not yet able to reach the fast-refuelling speeds of conventional vehicles and is still too small for the number of EVs on the road. In this context, the solution of mixing the good of both technologies in hybrid vehicles can be a solution for the present, while allowing time for the technological development of electric systems, eliminating the range anxiety of users, and gaining the environmental and technical advantages of EVs. These vehicles, despite their high technical complexity, can be established in the short term because their range allows them to cover urban journeys, which represent a high percentage of vehicle use by citizens, without any problem.

In hybrids, the variety of motorisation architectures, can be a great advantage because of the flexibility it gives manufacturers to design a vehicle according to the intended use of the model on the market, but it can also lead to cost problems, as the technology is not standardised, and prices are still high compared to traditional competitors. If the goal is zero emissions, these vehicles are also not viable in the long term, as their ICE functionality will be obsolete by the time full decarbonisation takes place. The use of fuel cells is a real option, especially for commercial vehicles or trucks, as they provide great range and refuelling speed, but they still need to be researched and developed to reduce their weight and minimise their danger. This progress must go hand in hand with the development of clean ways of obtaining hydrogen on a large scale, as most hydrogen currently comes from natural gas.

In terms of battery development, the reduction of the price and the improvement in the performance of the cells have been excellent in recent years and encouraging for the future, and the manufacturers' forecasts and promises are that they will continue to improve. It seems that lithium-ion batteries are the most promising and functional, and the implementation of solid-state batteries instead of liquid electrolytes would allow a giant step forward in terms of storage capacity and design versatility.

Charging modes are also being improved and standardised, and as batteries improve, different charging modes and technologies allow for a faster and more efficient charging process. Standardisation of connectors is underway and is a key point in increasing the charging infrastructure and globalising the vehicle market for suppliers. Alternative charging methods such as wireless charging by induction, or battery replacement at specially designed charging stations, are being designed and tested in real-life situations, and there is a real possibility that all these methods will coexist and interpenetrate with each other to provide EV users with the greatest possible flexibility and availability, as well as the possibility of using EVs for public transport or company fleets where wired charging is a less efficient option. The development of business and payment models for charging is also evolving, with companies such as NIO offering a battery replacement service to reduce the initial price of the vehicle, while Tesla has its own superchargers and offers customers a free annual kW of charging at its stations.

In terms of the ecological improvement that the adoption of EVs brings over ICEs, there has been much controversy in recent years as to whether this environmental improvement was real, or whether by producing the energy and batteries, the pollution generated by EVs was greater than during the lifetime of combustion vehicles. With the measures adopted by the European Commission for the coming years, it is clear that public institutions believe that the EV is the solution and various studies confirm that with the electricity mix in European countries today, the reduction in pollution is significant. The well-to-wheel analysis allows the identification of the causes of emissions and at what point they occur, during energy production and vehicle production or during vehicle use. In the well-to-tank section, the most significant improvement in terms of emissions can be made by producing as much renewable energy as possible. There is also room for improvement in the manufacturing process of batteries and vehicles, and if these are produced in Europe, their ecological efficiency increases, as it is the continent with the highest percentage of renewable energies in its energy mix. On the other hand, the conclusions obtained from the tank to wheel section relate to the different degrees of electrification of vehicles, given that there is room for improvement in terms of their energy efficiency. Hybrid vehicles are not fully zero-emission and are therefore a solution in the short and medium term, but in the long term pure electric vehicles (BEVs and FCEVs) are expected to become established. It is also worth highlighting the role that the development of EVs can play in terms of global energy efficiency, as the development of batteries and their second uses, as well as the fact that there are a large number of vehicles with large energy storage capacities connected to the grid, can be a great help when it comes to wasting as little energy as possible and storing the renewable energy produced in peaks so that it can be used at times of greater need.

The growth of electric vehicles in the European market is already a fact. EU-driven policies to convince consumers and persuade manufacturers to switch to electric vehicles have led to a surge in EV sales over the last ten years, which is expected to grow sharply in the 2020s. Lower prices and government support, as well as the resolution of technical barriers to adoption, have made EVs an increasingly common reality on European roads. The adaptation of roads and cities to electric vehicles should be parallel, and it should not be a huge economic effort to provide a wide variety of charging stations of different types and in different locations for EV users. Traditional manufacturers are adapting by offering their electric models and a range of new facilities and applications to persuade buyers, in the face of the threat of the entry of new brands from China, where EVs have come a long way, and which represent great competition due to the quality they offer at lower prices.

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Declaration of Authorship

I hereby declare that I have written this Bachelor's Thesis independently and only using the literature and aids indicated. The passages taken directly or indirectly from external sources are marked as such.

The thesis has not been submitted to any other examination authority in the same or a similar form and has not been published.

Magdeburg, 23.09.2021

Place, Date

Signature