UNIVERSIDAD PONTIFICIA COMILLAS

ESCUELA TÉCNICA SUPERIOR DE INGENIERÍA (ICAI)

OFFICIAL MASTER'S DEGREE IN THE ELECTRIC POWER INDUSTRY

Master's Thesis

"Analysis of different methodologies for the design of the electric vehicle's fast and ultrafast public charging network in Spain"

Autor: Íñigo Díez Olleros
Supervisor: Jesús López Martínez
Company: IBERDROLA S.A.

Madrid, 8th June 2019

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ABSTRACT

The world that we know is experiencing a great change locally as well as internationally. In recent years the problems arising from the intensive use of resources and the pollutant emissions have reached unexpected levels. Climate change is presented as the main problem of the XXI century, this problem is aggravated by air pollution, with very severe damage to human health in urban areas.

These problems owe their origin mainly to mobility and transport, specifically about a quarter of total emissions and 36% of energy consumption in Spain. In this context, multiple policies have emerged at European and international level with the aim of achieving sustainability and the energy transition through energy efficiency and clean energy. Highlighting the Climate and Energy Package 2020, the 2030 Framework and the 2050 Roadmap.

Electric mobility is presented as a unique solution to this change, although, the electric vehicle sector has to face multiple factors that will be discussed during the development of the work, but we can highlight range anxiety, investment cost and the lack of policies. Furthermore, the state of the art in terms of technology charging infrastructure, modes and types.

Concretely, the present research analyses the Spanish case, introducing the characteristics of the electric mobility sector in Spain, the political measures, the market perspective and being more specific in the main problem, the lack of charging infrastructure. Spain is one of the European countries with the lowest public charging infrastructures and with very high estimated penetration of the electric vehicle.

This project is presented as a useful tool in the planning of this network and as a starting point to implement in the development of the infrastructure ensuring the selection of locations efficiently and optimizing the resources. To reach this objective we will introduce a methodology that will allow us to make the right decisions in the deployment of the network

This methodology focuses on the study of the main mathematical models in the location of facilities and their corresponding solution algorithms with the aim of introducing the most optimal and adapted to the established problem. In addition, in the development of the document, the main tools that should be used for the correct development of the network are included. Furthermore, many of these tools are presented as inputs of the future model. Bearing in mind that this project was started from zero, the source of data collection can be considered a critical phase

Finally, a survey of great value and representativity is introduced, with the objective of considering the final users 'opinion, knowing the needs of the market and drivers' concerns regarding electric mobility. These opinions are considered essential to implement the model as very relevant for the design of the problem.

FOREWORD

I would like to express my gratitude to all those who helped me completing this project.

I would like to thank Iberdrola's Smart Mobility team, especially Jesús López, my supervisors, and Santiago Blanco, one of my co-worker, for guiding me through the research, for their vision and knowledge in the electric mobility field.

I would like to thank the survey participants, who dedicated their time to contribute and enrich this research.

I thank all those who encouraged and gave me support during my Master, specially to the "MEPI gang".

My friends for their unconditional support and friendship around my life, specially you, Lucia.

To my parents and family for instilling in me the moral values that now represent me and the goals to aspire.

"The scientific man does not aim at an immediate result. He does not expect that his advanced ideas will be readily taken up. His work is like that of the planter - for the future. His duty is to lay the foundation for those who are to come and point the way." Nikola Tesla

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1. INTRODUCTION & MOTIVATION

Global warming is one of the 21st century's major risks, mostly produced by greenhouse gases emissions, like CO2, CH4 or N2O. Transport and mobility are one of the main responsible for this problem, contributing for about the 25% of total emissions considering just Spain. Furthermore, in located areas like large urban centres, the atmospheric pollution produced by this activity is very harmful to human health. This causes around 35.000 deaths worldwide yearly.

These problems are the action core of European and international policies. Starting with the Kyoto protocol (December 1997) the European Union decide to set the 2020 climate and energy package, which three key targets respect to 1990 were stablished: reduction 20% GHG emissions,20% of renewable energy in the total energy consumption and increasing energy efficiency to 20%.

The next step came with the Conference of the Parties to the United Nations Framework Convention on Climate Change (COP 21) where 196 countries establish as a goal to limit global temperature increases to well below 2 degrees Celsius, compared to pre-industrial levels. Then, the Clean energy for all Europeans (2030) which improve the three objectives mentioned above: 40% cut in greenhouse gas emissions (from 1990 levels). At least 27% of RES weight in global consumption. An improve in energy efficiency for at least 27%

The most recent agreement, 2050 Energy Roadmap set: Greenhouse gas emissions reduced by 80%, ensure viability and economic feasibility for the transition and the total decarbonization of transport sector. More recently the Clean Mobility Package, whose aim is promoting sustainable and clean mobility.

In order to reach these targets several changes in our consumption patterns and the way to produce energy have to be made. Starting with the decarbonization in all sectors of the economy, with special emphasis in transport. Thus, the substitution of conventional fossil powered vehicles for eco-friendly vehicles is completely needed and the EV are the main protagonist of this transformation. In the figure below it can be seen the critical share of GHG emissions that the transport sector represents.

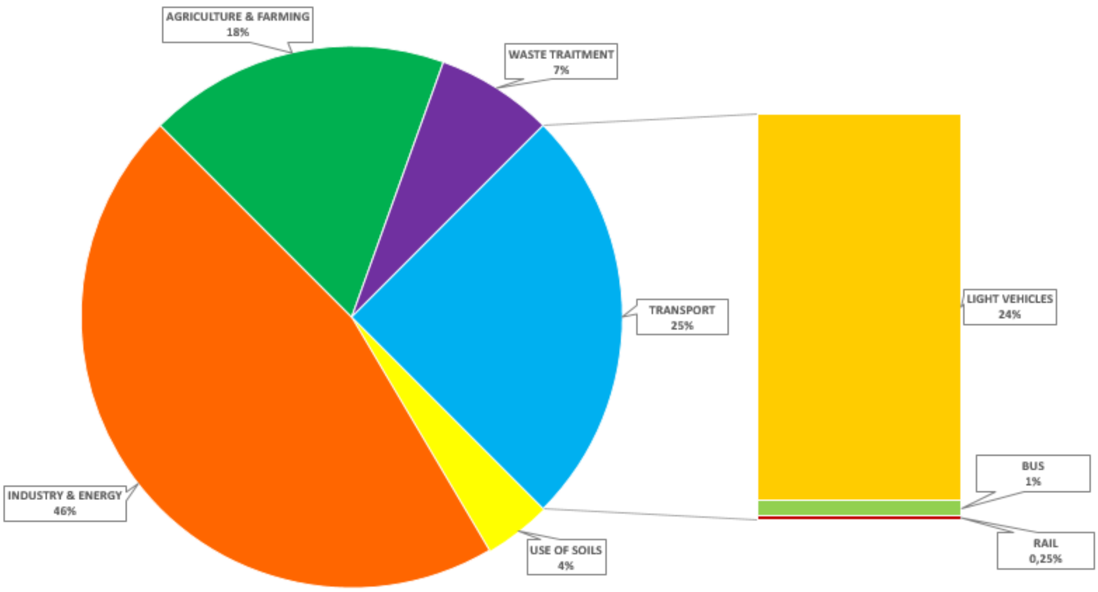

Figure 1. Greenhouse gases emissions per sector [own elaboration]

It is being forecasted that the EV market penetration will experience a significant increase in the coming year. Other important driver to analyse is the economy, electric transport it is going to change the whole mobility sector. Nevertheless, at this moment the two main barriers that hampers large-scale Electricity powered vehicle adoption are:

- Acquisition cost. But this problem has been reduced in the last years and the EV are becoming more competitive.
- "Range-anxiety".

The range anxiety can be defined as the driver's concerns being stranded on the road and the delays associated to long recharging times. So that, consumers are not willing to purchase EVs if there is not a guarantee to satisfy its driving needs, as it can be described by Eberle and von Helmolt [1]. This fact is mostly affected by two parameters, the low storage capacity of batteries and the lack of well-developed charging network at it can be seen in Figure 2.

The first problem is being solved by the improvements in technology and the last advances in economies of scales in battery production. Charging infrastructure requirements is being largely debated in the context of transport electrification. The issue of locating and securing the availability of charging infrastructure becomes a complex question which needs to be answered in order to ensure the correct integration of the EV. To this problem we have to add the charging time delay.

Furthermore, the correct design of the whole infrastructure will allow to charge the vehicles in a more dynamical way therefore, a reduction on the battery capacity needs optimizing the net social benefit.

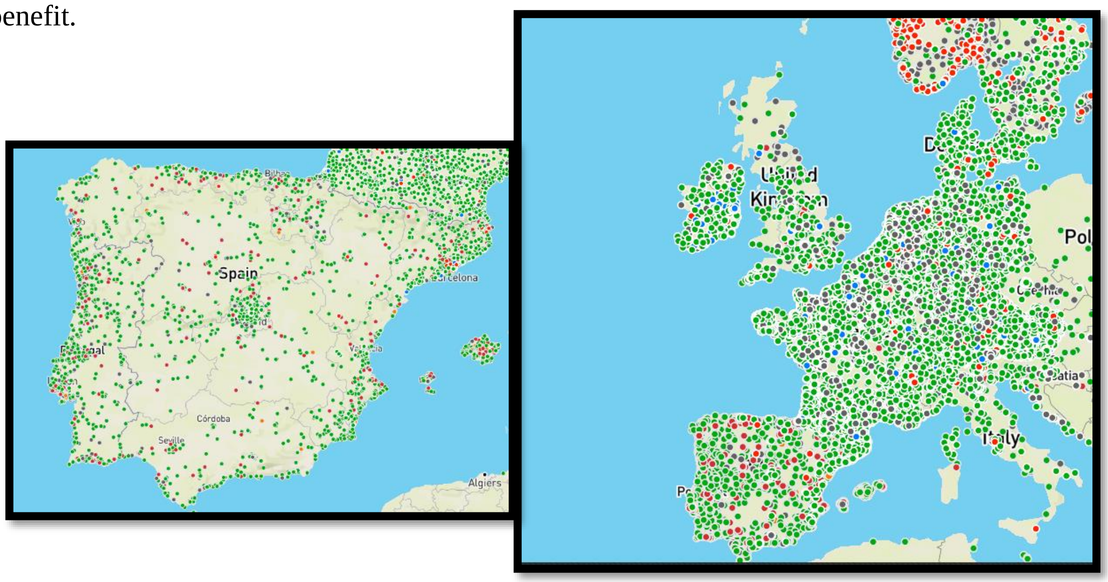

Figure 2. Occidental European and Spanish Charging points map. [72]

The motivation for the development of this project is the need to develop an efficient interurban public charging infrastructure. Based on statistical analysis of real word datasets of diverse driving patterns and charging behaviors, datasets of geographically located points of interest, main road traffic flow records, demographic and economic statistics. Finding an optimal location and level of service for each charging facility has become a critical issue since correct adoption of EVs heavily depends on the availability of public charging stations. There is a need of

coordination between technology, human behavior, economy and policy in order to ensure the correct electrification of the transport and a sustainable and eco-friendly mobility.
Currently, the development of simulations and modelling tools are indispensable in making decisions for the correct deployment of the network, allowing to cover driving needs for customers.
Furthermore, this type of analysis and the proposal of tools of great value and utility for decision making in the design of the network is practically null at the level of Spain, so this project is presented as an innovative research with large projections for the future.

1.1. OBJECTIVE & SCOPE

As first objective, it is important to give the reader a clear picture of the current situation of electric transport sector. For that purpose, the current state of the art in the EV sector (types, batteries technology, charging modes) and the current regulation will be explained. Furthermore, it is important to emphasize the panorama and the continuous progress on this field, extremely affected by technology changes. We will focus on the Spanish case analysing the main regulation, policies and standards. The market vision, EV adoption and current infrastructure will be also commented.

The main objective of this project is to introduce the Spanish case in the absence of public charge infrastructure and present a useful methodology in the planning of the interurban network, starting from the current state of infrastructure deployment and proposing efficient tools in the development of the fast and ultra-fast charging network nationwide. These tools will provide the selection of locations efficiently and optimizing resources.

For such purpose is essential to identify the main drivers that impacts the location and features of the charging points (vehicle's battery capacity, number of charges, total power output etc.). The installation of chargers and the locations proposed would require a careful planning and a specific study for each one. So that, different modelling tools and planning methods will be considered in order to facilitate the final design.

During the work, the study of different models and possible algorithms is developed in order to select the most optimal or adapted to the proposed problem with the aim of its future development. In addition, we will introduce and explain different tools of great utility for the correct decision making, regarding the selection of the locations and the development of the network. Some of these tools will also be the main sources of data for the development of the model.

The main object of this work is the fast and super-fast interurban charging network; therefore we do not develop an explicit study on the electrical network or the need for the distribution network reinforcements. The considerations of the distribution network in this work arise when selecting the possible candidate locations, only considering those that allow the incorporation of the necessary infrastructure for a charge point. So that, there is no aim to evaluate the effect of the placement and sizing of charging stations on the electricity network, such as losses or power quality problems (fluctuations, harmonics). Currently, there are several studies which are focus on this evaluation.

The study of the distribution network is postponed to future work, in which the LV and MV network are analysed.

A secondary objective is to analyze users concerns and needs through a survey in order to take into account these results as possible inputs on the model or as constraints for the design of the fast charging network.

Other secondary objective is to consider future Spanish requirements during the development of the network, such as EV penetration curve, national environmental objectives, etc.

Finally, this study will allow us to understand and evaluate the different tools used, optimizing the sources and infrastructure, turning this project into a useful tool for the design of the electric vehicles fast and ultra-fast public charging network for the whole Spanish system.

1.2. PROJECT LINE

Once and introduction of the Thesis has been done and the main objectives are explained, we will comment the state of the art on this technology. Therefore, the part 2 will be focus on the EV, its main components and the different configuration of EV. We will continue with the charger's types and the whole infrastructure, then the different charging technologies will be explained, and we will comment the strategies used for charging the EV with the advanced systems new alternative's methods. Finally, we will end with a comparison between conventional vehicles and the EV.

Next, we will focus on the Spanish panorama, the main policies and regulations will be commented, and we conclude with the market context, the adoption curve and future requirements and concerns.

From Chapter 3 we will start with the core of the Thesis, where we will explain the problem to face and the methodology that will be implemented to affront it. Chapter 4 is focus on analysing several models to design the problem, in order to find the most adequate one. Then the chosen model and the algorithm will be explained in detail for its future implementation.

Chapter 5 will describe in detail other additional tools to study during the deployment of the network which will help us when making decisions. Some of these useful tools are the main database for the model. The project will include in Chapter 6 a user survey base on EV drivers from several parts of Spain in order to consider the user opinion and concerns.

The ending conclusion of the project will be summarized in chapter 7. Finally, we will introduce the next context for future developments and proposed works on the deployment of the electric vehicles fast and ultra-fast public charging network.

2. STATE OF THE ART

2.1. ELECTRIC VEHICLE

Most people think that the concept of "electric car" is relatively recent, but the truth is that this idea is more than one hundred years old. The fist EV was created is 1834 by Robert Anderson, who invented a pure electric car when designing a carriage with electric traction and a non-rechargeable battery.

Subsequently, at the Paris International Electricity Exhibition of 1881, the French Gustave Trouvé presented what for many is considered the first electric car in history, since it was a functional three-wheeled car. Note the contribution of physicist and engineer Nikola Tesla, who introduced the AC motor for the first time in 1888. Since that moment, serial production of electric vehicles on a global scale begins and, in 1894, the first functional electric vehicle, known as the Electrobat and its creators, Henry Morris and Pedro Salom, founded the first electric vehicle company in U.S.

At the beginning of the 20th century, there were 19 electric vehicle manufacturers in the world, and the sales data in the United States reflected the dominant trend; Of the 4,200 vehicles sold, 38% were powered by electricity, while 40% were steam and the remaining 22% used gasoline. In this context, Thomas Edison adds rechargeable nickel-iron models to the batteries in 1911, which implies an improvement in the quality of the same.

However, with the arrival of the assembly line of Henry Ford, which caused a price decrease in its combustion cars and made it more accessible for the middle class, even reducing its price from $ 600 in 1909 to $ 250 in 1925. In addition to producing fuel cheaper due to the proliferation of oilfields in the southern United States, resulting in a change in the functioning of the market. Another important fact was the introduction of the electric starter in 1912, patented by Charles Kettering, disappearing one of the few weak points of the combustion car, the complicated and unpleasant starting by crank.

In the 1920s, the electric car was restricted to cities. The few manufacturers that maintained their production could not fight with the rest of cars whose price was three times lower. As history shows us, the gasoline car ended up being imposed on the electric battery.

In the decade of the 90s, favoured by the law "Zero Emission Mandate" in California, returns the electric vehicle to the international scene, with great acceptance among the public, by the hand of General Motors, the EV-1 with a maximum speed of 130 km/h and an autonomy of 250km. General Motors was followed by other manufacturers such as Toyota, Honda and Ford. Later, in 1997, the Toyota Prius, the hybrid car that combines the electric motor with the combustion engine, had a big impact on the market. This new configuration has gained power in the market.

In this area, it is necessary to mention the Californian company Tesla which begins to lead in terms of technology and presentations and demonstrate the viability of the electric vehicle. At the same time models as the BMW i3, the Nissan Leaf or the Renault Twizy and Fluence begin to take over part of the market. Finally, the electrical or hybrid configurations appear in practically all the manufacturers of the market.

At present, "green" vehicles are in fashion, and there are many examples of aids and changes in a legislation that is increasingly favourable to them and more restrictive for combustion vehicles. [2]

2.1.1. Types

Electric Vehicles can be typically divided in 4 types, which are Hybrid Electric Vehicles (HEVs), Plug-in Hybrid Electric Vehicles (PHEVs), Battery Electric Vehicles (BEVs) and Extended Range Electric Vehicle (EREV).

I. **HEVS.** This configuration only uses as an energy source the fuel and does not allow the battery to be charged by an external source of electricity, such as charger. Its battery does not have as a mission to store a large amount of energy, but is, every time, reversing the cycles of loading and unloading. The reduction in gasoline consumption is between 25% and 40% depending de vehicle efficiency. The battery can be recharged trough the gasoline engine and the regenerative braking.

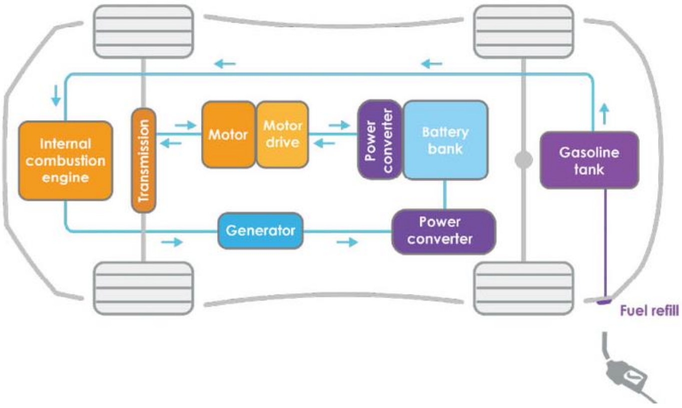

Figure 3. HEV desing [3]

II. **PHEVS.** They are hybrid models like the previous HEV, but they can be connected to the electrical network to recharge their battery. We can find two different configurations: hybrid series and parallel one. In series mode, the design is commonly called a range-extended electric vehicle. The ICE motor runs as a generator and delivers energy to the battery by the power electronics extending the range of the vehicle. This configuration gives a much higher efficiency than the next one.

On the other hand, the configuration, parallel plug-in hybrid. The vehicle is propelled by both the ICE and the electric motor and normally the driver can decide. Under this design two energy sources are coupled mechanically through a differential gear. Thus, they have three main elements shown in next figure: an internal combustion engine, a battery and an electric motor.

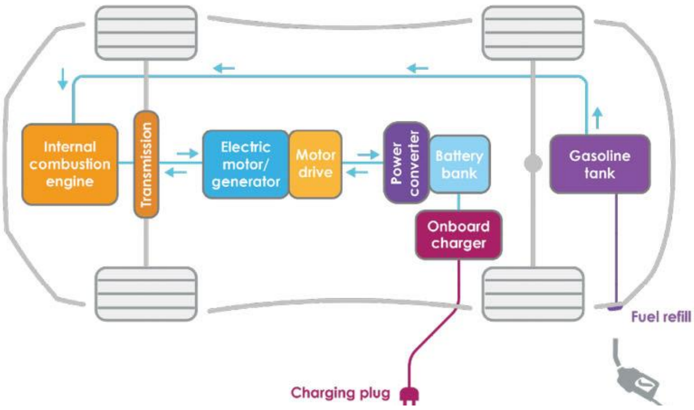

Figure 4. PHEV series design [3]

III. **BEVS.** It is the basic configuration of electric vehicles. Propelled only by one or several electric motors, they obtain the energy through their rechargeable batteries by connecting them to the network. Against BEV we have the problem of autonomy, recharge time and the higher acquisition cost, given that the price of batteries is still high, and we have complete dependence on battery life. Regarding the previous ones, it is the only one that considering its cycle of use is 0 emissions. However, considering the whole lifecycle several pollutants are produced mostly during construction time, in the process of assembling the battery and obtaining materials.

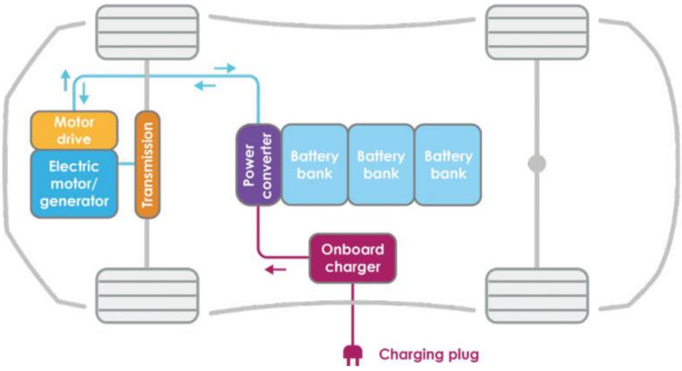

Figure 5. BEV design [3]

IV. **EREV.** With the same characteristics as BEVS, the EREV, also known as PHEV-RE, also have a combustion engine that acts as a generator, charging the battery linearly by means of an electric generator entering in operation without being determined by the driver. This combustion engine is extremely small, charging the battery at a lower rate than it is discharged, hence being a hybrid vehicle, it is classified as electric, due to its 100% electric traction, with extended autonomy. They are able to make more than 450 km.

2.1.2. Components

Battery

The batteries store energy in the form of chemical energy and transform it into electrical energy that is used in the electric traction of vehicles. The battery or BESS is composed of three basic elements, the anode or negative electrode, yields electrons and oxidizes during the redox reaction, the cathode or positive electrode, accepts electrons and is reduced during the redox reaction and the electrolyte, which is the element that allows the passage of electrons from one terminal to another. The following scheme allows to understand the process.

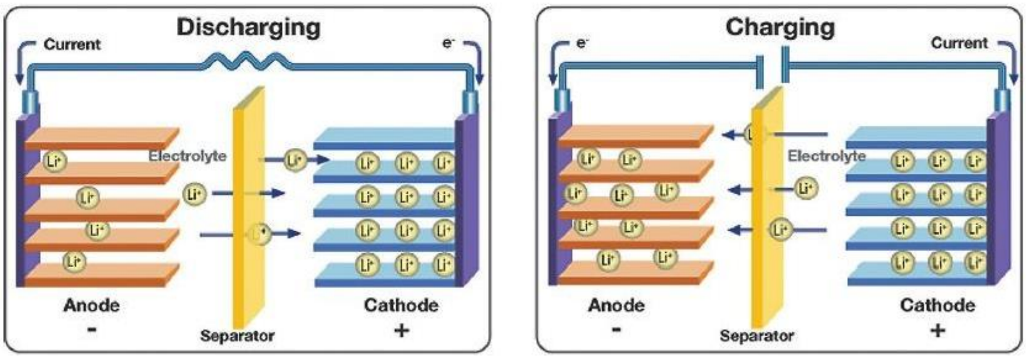

Figure 6. Battery components and functioning [4]

Highway electric vehicles require batteries that contain a large amount of energy and can provide high power for acceleration. The weight and volume should to be low, as it represents a very high percentage of the cost and weight of the electric vehicle. The number of kilometres that can be made depends on them.

This section gives an overview of the different technologies presented on the figure next figure; The classification is also explained on

Table 1.

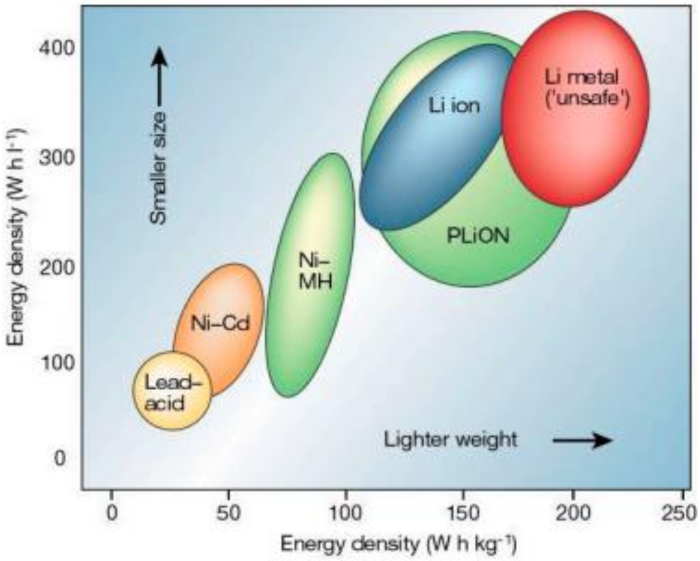

Figure 7. Comparison between technologies [5]

Lead-acid. Lead-acid batteries are the first that have been used. It dominated the market from the start and its cost is low but have a low energy ratio for each unit of weight and volume, not accepting discharges of more than 20%. Furthermore, the lead is toxic, and the batteries can explode during overcharging. Other problem is Hydrogen gas emission during charging step. So that, ventilation is required when the battery is charged indoors.

Nickel-Metal-Hydride (NiMH). The specific energy is higher than for previous ones, around 50Wh/kg and the specific power is good enough. It also stands out for its life cycle, a high operating temperature range and is resistance. It is commonly used in EV, specially HEVS and PHEV. Its main drawback is a high self-discharge effect and its memory effect, not allowing to reach 100% of charge state.

Nickel-Cadmium (NiCd). This battery has similar characteristics than NiMh, but its performance is quite worse. Although the cost is high of these batteries, they are still used in EV. Their main problem is the memory effect, so maximum capacity is reduced with use, which limits the useful life. cadmium is a toxic heavy metal, and needs to be handled [6]

Zebra batteries. They have a high energy density (around 5 times higher than Lead-acid), have no memory effect and low material cost but have the problem that they work at very high temperatures (270-350ºC) and are easily discharged. The battery has to be placed in an insulated container and needs energy supply during standstill to for heating. [7]

Lithium-Ion batteries. This one is the most used in EV because the specific energy and power are very high, they have no memory effect, they tolerate a high number of charge cycles and have a low self-discharge. With deep discharge, battery can suffer damage and its working lifetime is quite poor. It also requires sophisticated battery management circuit.

Battery type	Energy (Wh / kg)	Power / Weight (W / kg)	Nº cycles	E. efficiency
Lead-acid	40	150	500	82,5 %
NiMH	70	250-1.000	1.350	70 %
NiCd	60	150	1.350	72,5 %
Zebra	125	100-115	1.000	92,5 %
Li-ion	125	1.800	1.000	90 %
Li-polimer	200	>3.000	1.000	90 %

Table 1.Batteries comparative [own elaboration]

The Li-ion batteries are the true protagonists of the Market, having staged an 85% drop in costs since 2010, in addition experts say that this technology has a long way to go and multiple advances waiting. In particular, one of the most prominent advances is to replace the liquid electrolyte, which causes instantaneous inflammation, Figure 8, by the so-called "solid electrolyte battery".

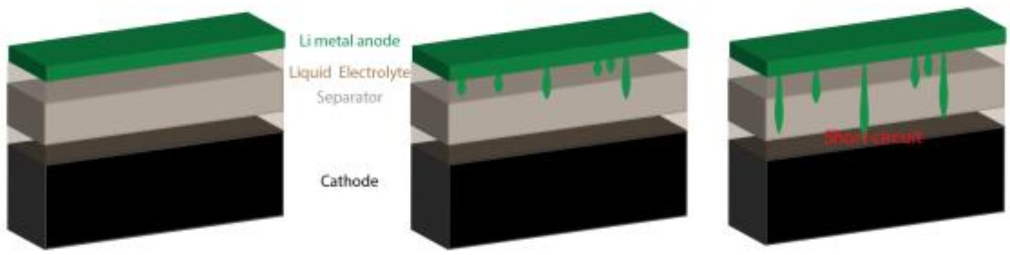

Figure 8.Deterioration Li-ion battery. [8]

The increases in temperature decreased the capacity of the battery, shown in the following figure, even more if these increases are high enough it produces the inflammation effect commented above.

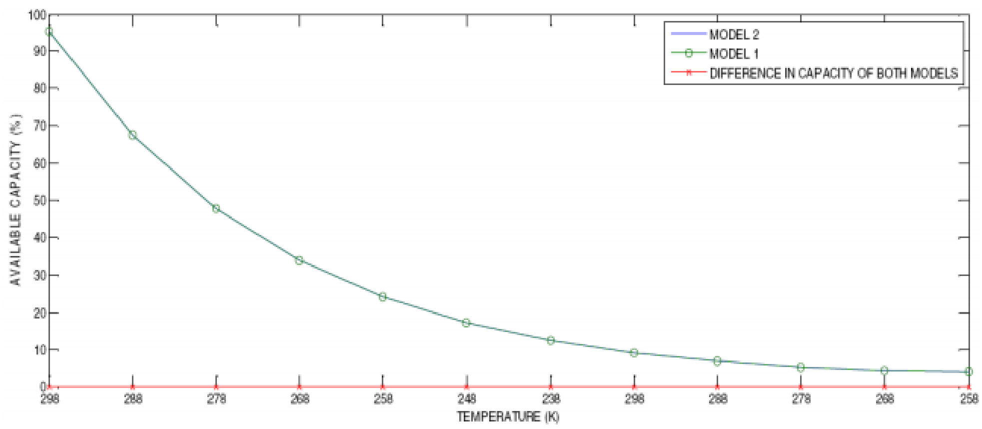

Figure 9. Temperate influence on capacity [9]

The solid state batteries, which are still modified lithium batteries, come to solve this problem by replacing the flammable electrolyte with another in the solid state, much safer. The heat that is produced in a solid state battery is much easier to control, which allows to implement much simpler, cheaper and less bulky refrigeration systems. In addition, this design presents greater efficiencies, its energy density, or the amount of energy that a battery can store in relation to its weight and volume is very high. Some studies announce that the current battery density figures could be doubled, which means that a battery in solid state would offer twice as much autonomy occupying and weighing the same. Other advantage is the reduced costs.

Another big problem that occurs in the process of charging lithium batteries in addition to high temperatures, it is the relation in voltage and intensity. When the charging current is too high, the lithium ions do not settle fast enough between the intercalation layers of the anode and they are accumulated on the surface of the anode forming a metallic lithium plate. This effect is known as "Lithium planting”. This process is very specific and can strongly deteriorate the life cycle of the battery. The charging process is defined on next figure.

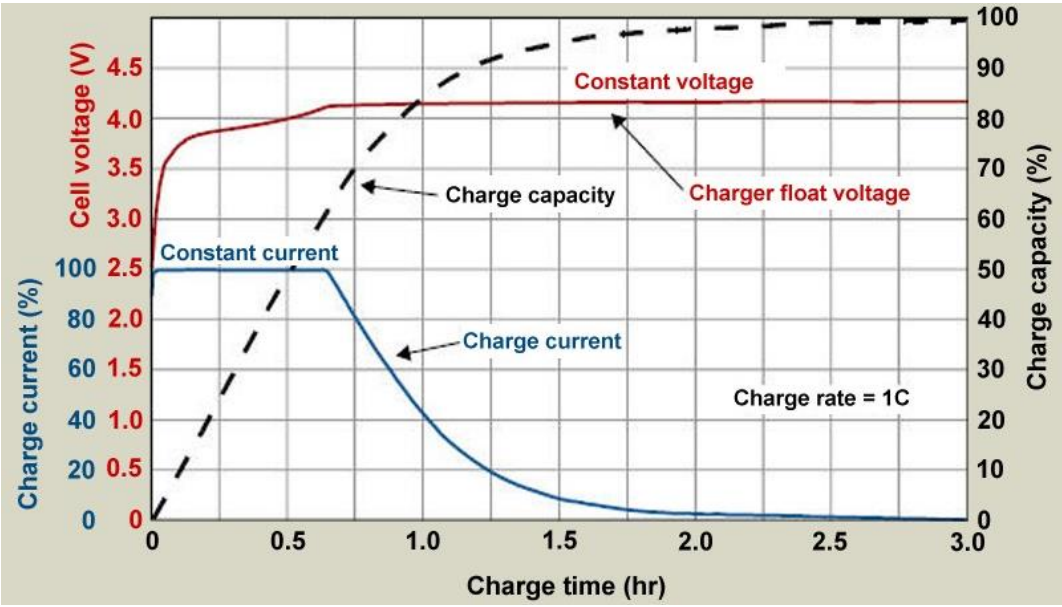

Figure 10. Li-ion charging process [5]

These batteries characteristics are the ones that limit the charging capacity, since for powers higher than 200 kW the batteries have to be able to overcome voltages higher than 500 V while the most advanced vehicles do not exceed 400 V. This limitation of Load, materials and cost of batteries are the main fields of research today.

Future batteries. There are other battery technologies in experimental stage, which are focus on the EV sector and cost reduction. The main ones are lithium-air (Li-air), lithium-sulphur (Li-S), zinc-air (Zn-air). [10]

The main vehicle manufacturers have realised that the limited driving range is one of the most relevant limitations or maybe the biggest one when customers are deciding to buy an EV. Therefore, the main researches on this field is to design new battery technologies with higher driving range. For example, new vehicles of Volkswagen will have an autonomy of almost 500 km by 2020. According to the International Renewable Energy Agency (IRENA), in 2030 the cost of batteries will have been reduced by around 50% over 2017 levels due to economies of scale. [11]. This estimation is show non next figure.

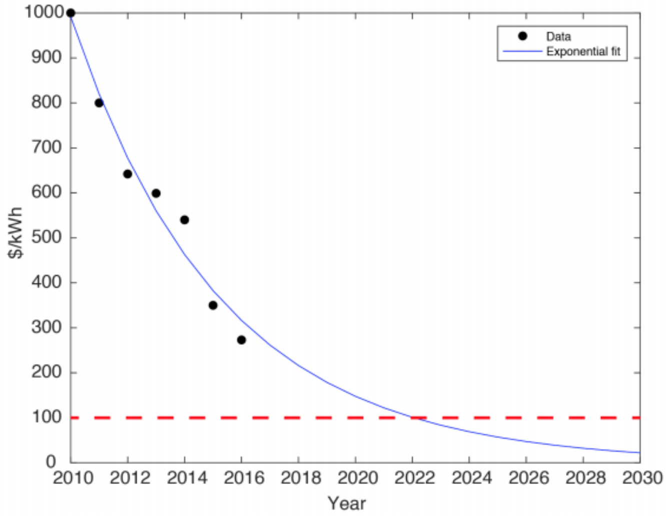

Figure 11.Li-ion price [12]

BMS

The Battery Management Systems is an electronic system that manages and monitors a series of parameters (voltage, temperature, SOC, etc) of the battery and with these parameters is responsible for performing functions so that the use of the battery is within standards that we consider acceptable and safe. Also is responsible for managing the power demand of the electric vehicle on the load point

Electric Motor

The electric motors used in automotive must be high-efficiency and robust, have a good weight / power ratio and the smallest size possible. In addition, a good control of the speed of rotation and torque is needed. The main electric motors used in vehicles are the induction motor, the permanent magnet motor and the Synchronous reluctance electric motor. On Figure 12 we can examine the Electric machine classification. [3]

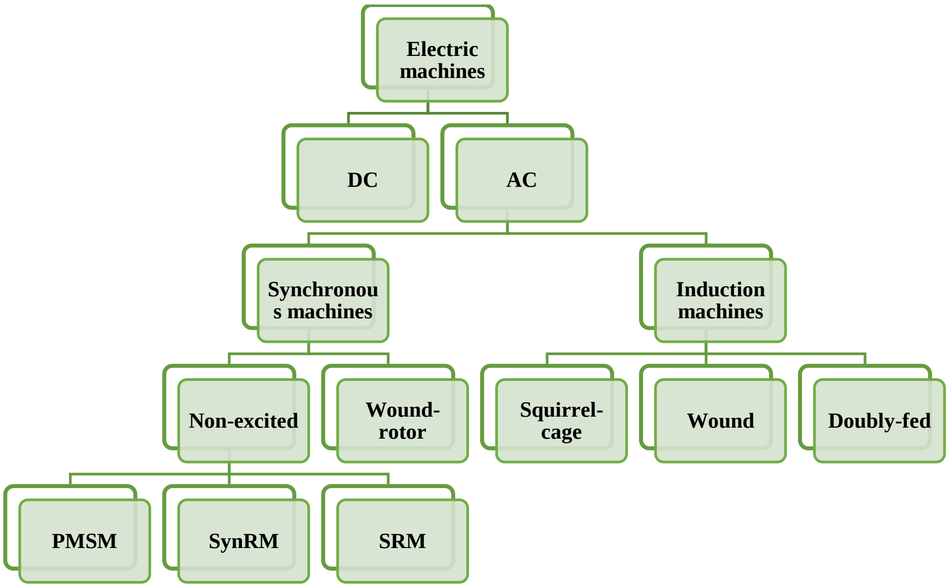

Figure 12. Electric machines classification [own elaboration]

Asynchronous motor or Induction: They are the most widespread in the industry (80% of the motors) due to their robustness, low cost, high efficiency, constant torque and low maintenance. However, they have low power density, and low starting torque. Furthermore, it requires complex inverter circuit and control of the motor is difficult. It is employed by Tesla Motors

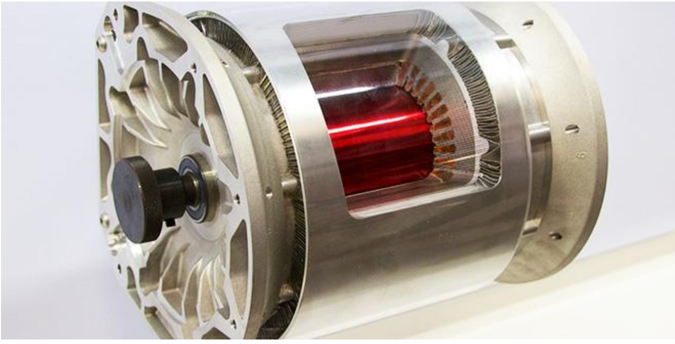

Figure 13 Induction motor Tesla Model S 2019 [13]

Permanent magnet synchronous motor (PMSM): Its main advantages are high performance, simple speed control, low weight and volume, low noise and low vibration. Although they present a quite high cost, together with the asynchronous motors they are predominant in the market. These types of engines are used by manufacturers such as BMW, Nissan, VW or Toyota.

Figure 14. Permanent magnet motor Toyota Prius 2014 [14]

Synchronous reluctance motor (SRM): This type of motors does not require permanent magnets or brushes and they present high torque, great robustness and low cost. However, they develop low power and have high complexity. It also has some noise issues. Renault is the main company that uses this engine and Ricardo the main developer. [15]

Figure 15. SRM developed by Ricardo [16]

Currently, for high-power applications such as high-performance two-wheelers, automobiles or buses, the ideal choice of engine would be PMSM or induction motors. But when the SRM engine has become cost effective and competitive, some experts argue that they can remove the other two as the most optimal option for electric mobility.

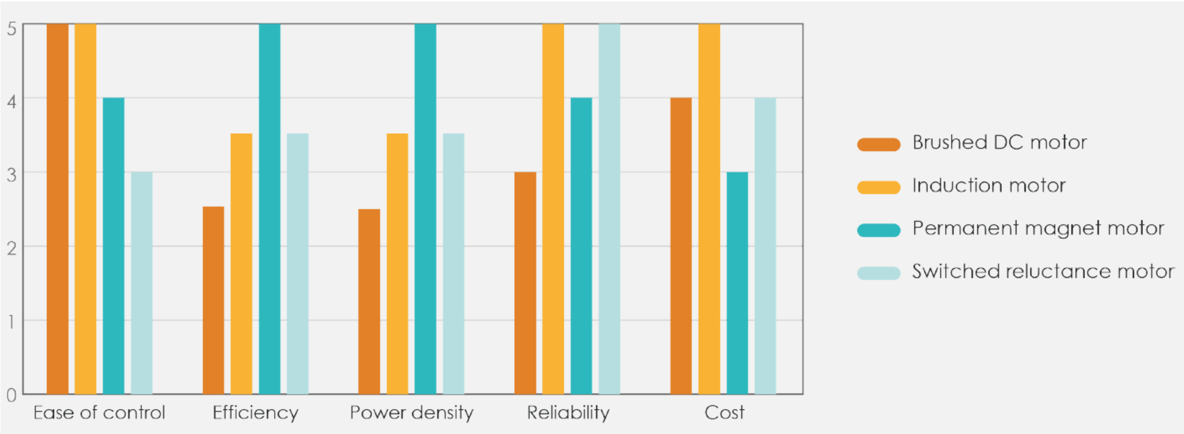

Figure 16.EV motors comparison [17]

2.2. CHARGING INFRASTRUCTURE

2.2.1. Charging Technologies, types and strategies.

Modes

There are different ways of recharging the electric vehicle, which differ mainly by the power supplied and the type of current and connector used. The power supplied depends on the voltage and current that the charging point can provide.

Depending on the communication between vehicle and RP, the control and the infrastructure characteristics different charging modes can be differentiated:

Mode 1: This mode is based on slow AC charging via a regular electrical socket and requires no additional circuitry. There is no communication between the vehicle and the charger. It is required to provide an earth wire to the electric vehicle and also to have an external means of protection against faults. This mode of charging is considered to be unsafe and is illegal in many countries.

Mode 2: This mode entails slow AC charging from a regular electricity socket. It uses a special charging cable provided by the vehicle manufacturer, which has a protection device that verifies the correct connection of the vehicle to the network. In addition, the cable is equipped with an In-Cable Control and Protection Device (IC-CPD), which is responsible for control, protection and communication and protection. Mode 2 charges at a power rating of 6.6 kW, increasing to 19.2 kW depending on the current's level that can be sustained by the supporting circuitry. Most home and almost all commercial mode 2 charging, are limited to 6.6 kW.

Mode 3: This mode provides both slow and semi-fast charging through a specific electrical socket for electric vehicle charging. The charger generally corresponds to Type 1 or Type 2. The charging station is normally responsible for the control, protection and communication of the charging process. This mode with a direct current charging bypasses onboard can charge the battery directly delivering much higher levels of electrical power. This type of charger is commonly known as a Direct Current Fast Charger (DCFC) with power delivery up to 50 kW and is normally used only in commercial locations or public charging stations.

Mode 4: Like in mode 3, it uses a dedicated electrical socket for electric vehicle charging. the charger normally has a charging cable with an EV charging plug. Mode 4 provides DC power through an AC / DC rectifier located in the charging infrastructure, instead of inside the vehicle as in Modes 1, 2 or 3. Mode 4 is specifically used for fast charging or ultra-fast charging and can reach 150 or even also 350 for ultra-fast DCFC but has not yet been deployed on a commercial basis, and no EVs commercial brand can currently handle this amount of power. Furthermore, this requires high insulation equipment,. [18]. The control, protection and communication functions are built within the charging station.

In the following figure we can see an explanatory diagram of the different charging modes

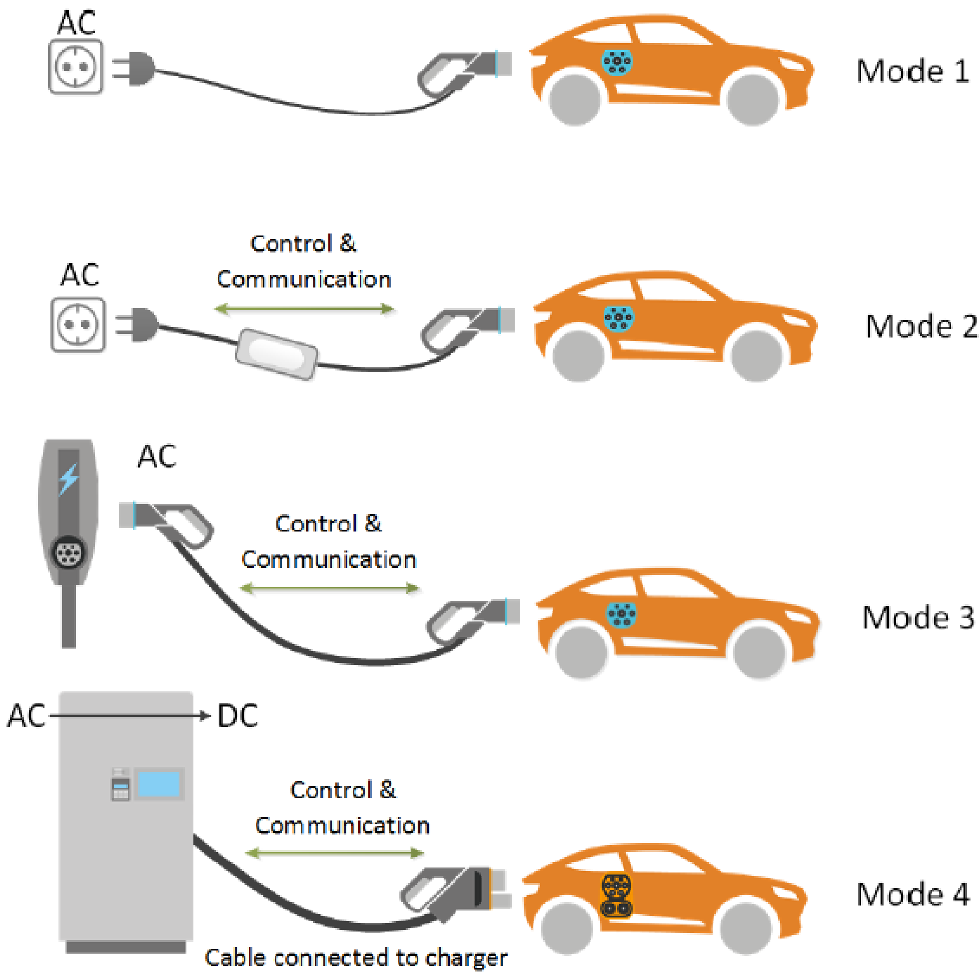

Figure 17.Charging modes [3]

Following the charging mode, we can find several types of charging depending on voltage level, current, so that, power and charging time. [19]

Types

Standard or Slow charging: it is the most common due to its simplicity and is compatible with all vehicles on the market. Normally mode 1 or 2. The charge is made using single-phase alternating current at 230V and 3.6kW maximum power. It only involves connecting the vehicle to a standard plug, and the charging time varies between 6-8 hours. This type of charging is implemented in private garages, whether communal or single-family.

Normal charge: Normally mode 3. This charge is made by single-phase alternating current at 230 and 16A or 32A, so maximum power levels of 3,3kW or 7,4 Kw. Reaching a fully-charge in around 3-6 hours. Suitable for recharging the electric vehicle during the night period in community garages or single-family homes.

Semi-fast charging: With mode 3 Charging is made through a single-phase alternating current of 230V, 32A and 8-14 kW, allowing a charging time of between 1.5-3 hours, or with three-phase alternating current of 400V, up to 63A and 22-43 kW, getting to charge a battery in 30 minutes. This type of charging is aimed at fleet car parks, cinemas, shopping centres or street charging points, where the parking period of the vehicle is a few hours.

Fast charging: Fast charging is done through an off-board charger that rectifies the AC current to DC current. This technology charges at high voltage (230V-400V) and can provides 80A or 200A, depending on the chargers. These conditions allow them to supply a power between 20 kW and 90 kW, which means that it takes between 25 to 80 minutes to fully charge an EV.

Ultra-fast charging: Mode 4 is needed. It also requires a complex electrical installation. The charging is made through a direct current of up to 600V and 400A, reaching powers between 150kW and 350 kW. At maximum power, it allows to charge a battery up to 80% in 5-30 minutes. This type of charging is still considered experimental and its use is intended for on-road and service station but nowadays there is no vehicle`s battery that support this power, neither the most advanced ones shown in next figure. [2] At it has been mentioned the main reason for these limit of charging power are : The supportable voltage for batteries (<500 V) and the efficiency losses (≈25%).

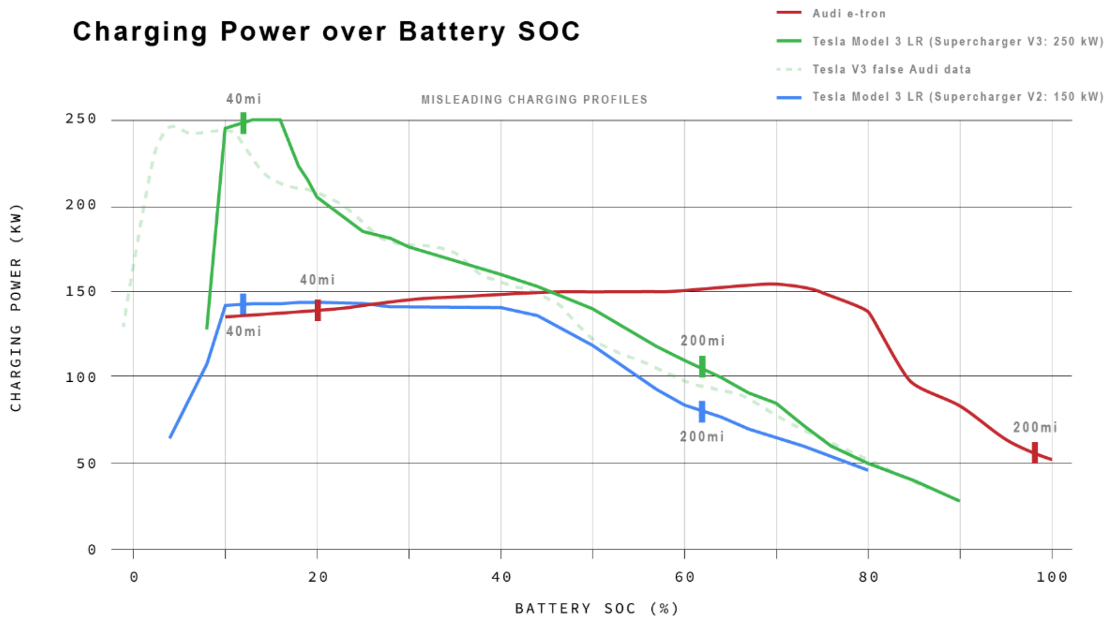

Figure 18. Ultra-fast charging process [20]

In the following table,

Table 2, we can see the main parameters of comparison between charging types.

Charging type	Slow	Normal	Semi-fast	Fast	Ultra-fast
Voltage(V)	230	230	230	230/400	400/800
Current(A)	16	32	32	125/200	400
Current Type	AC (Single phase)	AC (Single phase)	AC (Single/ 3 p)	DC	DC
Power(kW)	3,3	7,4	22	20-90	150-350
Charge time	6-8	3-6	1,5-3	20-60 mins	10-30 mins
Mode	1-2	1-2-3	3	4	4
Application	Home and business	Home and business	Public spaces	Service station/ On road	Service station/ On road
Connector	Shucko	Type 1/ Type 2	Type 1/ Type 2/CCS	CHAdeMO/CCS/ Type 2	CHAdeMO/CCS

Table 2. Charging types resume [own elaboration]

2.2.2. Type of chargers

Next, we are going to present which are the different types of connectors that we can find in the market. [19]

- **Schuko.** It is the common connector, used by the usual electrical appliances in Europe. It is technically called Type F and standardized by the CEE 7/4 standard. This outlet is standard on most electric vehicles and is compatible with Modes 1 and 2(single-phase), on the side of the wall. Due to this characteristic, this connector is widespread in motorcycles and electric bicycles. Its maximum current intensity is 16A, with voltages levels less than 250V.
- **Type 1.** Technically called SAE J1772 or Type 1 following the IEC 62196-2 standard. It is the most used connector in electric vehicles because it came from the American market where has been used since 2010. It has the same characteristics as normal single-phase plug, adding two extra pins whose function is to communicate with the vehicle and detect proximity. This type of connector presents a special design to ensure security and prevents third party access. The J1772-2009 has been designed for voltages up to 250V and up to 80A single-phase currents, being capable of supplying a maximum power of 19.2 kW, but the usual recharges are at 32A and 7.4 kW.
- **Type 2.** Technically known as VDE-AR-E 2623-2-2, called Mennekes and due to the norm IEC 62196-2 it is also called Type 2. The European Association of Constructors (ACEA) has implemented this connector as the European standard, for that reason it is carrying out an important expansion at global level, although one of its main drawbacks

is the elevated price. It presents seven pins, four for current, being able to charge in three phases, two for communications and one for earth. It is compatible with every modes of charge in AC, Mode 2 and especially Mode 3. Charge at 16A in single-phase and three-phase currents up to 63A, voltages from 100V up to 500V and providing power from 2.5 kW to 43.5 kW. It has been designed with a pin lock and other added protections.

- **Tesla supercharger.** Tesla has designed his own type 2 connector, to be adapted within the European market, it is capable of providing 120 kilowatts, both in alternating current and in continuous.
- **CHAdeMO.** It is the connector developed by Japanese manufacturers and used in every EV built in this country. It is designed exclusively for a fast charge in DC, so in Mode 4, and it is regulated by the standard IEC 62196-3 and UL 2551, known as Type 4. The name CHAdeMO comes from the abbreviation of CHArge de MOve. It has ten pins: two for power, seven for communication through CAN bus and one free. It is the connector with the most spread network of charging stations. This connector is capable of supplying direct current of up to 200A and 500V. Normally its charging process starts at 110A until it reaches 50% of the battery capacity, after it continues at 44A up to 80%, and ends the charge at 14A. CHAdeMO offers up to 62.5 kW of power.
- **SCAME.** Born in 2010 due to the so called "EV Plug Alliance". It is also called Type 3 following the IEC 62196-2 standard. It is commonly used in Formula E, in small electric vehicles, allowing a semi-fast charge with alternating current, but it is not very widespread. It offers specific technical and protection solutions that none of the other connectors do, so maybe it is the best option to place on the wall side or recharging infrastructure. It is limited to 32A being much cheaper than other rivals. Allows to charge using single-phase and three-phase currents in the same connector with a maximum power of 22 kW and up to 500V. It has several protections such as: shutters that prevent access to the terminal, a plug and cover lock. Furthermore, it counts with different models of 4.5 or 7 pins.
- **CCS.** Denominated as Combined Charging System and also known as Combo 2. The main advantage of this connector is that allows from the side of the car to have room for a Type 1 or Type 2 along with the space for the 2 pins of DC. It allows to charge up to 200A, so it extends the range of refills. The main technical characteristics are: 5 pins, two for power, two for signaling and one for earth protection. It allows to charge up to 850V and 200A, although not exceeding 125A is recommended. CCS charge in mode 4 and can reach maximum powers of 350 kW.
- **SAEJ1772 Combo.** It is based on the SAE J1772 (Type 1), being the American version for the load with CC, for that reason it is also known as Combo1, or Hybrid J1772 Connector in the USA. Is able to charge with voltages of 200V-450V and 80A for powers of 36 kW, or with 200A powers of up to 90 kW. Furthermore, has PLC technology for it use in Smart Grids.

For this type of charge, the connectors used are; CHAdeMO, CCS Combo and SAE J1772 Combo. These three connectors can be found in fast charging stations, with CCS being chosen as standard by both European and American manufacturers. [2] On Figure 19 the different type of connectors are presented.

1-CHAdeMO

2-SAE J1772

3-SCAME

4-CCS Combo

5-Type 2

Figure 19.Types of EV connectors [2]

2.2.3. Alternative methods

I. Induction charging

Induction or wireless charging technology is based on an electromagnetic field to charge a battery by transmitting power from the source of energy to the battery. An alternative to the installation of charging stations is installing the induction infrastructure on the road pavement. The main advantage is that there is no need of physical connection with the battery.

This technology works by alternating current which is sent by a transmitter circuit to a coil. In this coil, the alternating current creates an induced magnetic field which at the same time generates current within a secondary coil when it is placed in this field. The current that the vehicle receives is converted into direct current to charge the battery.

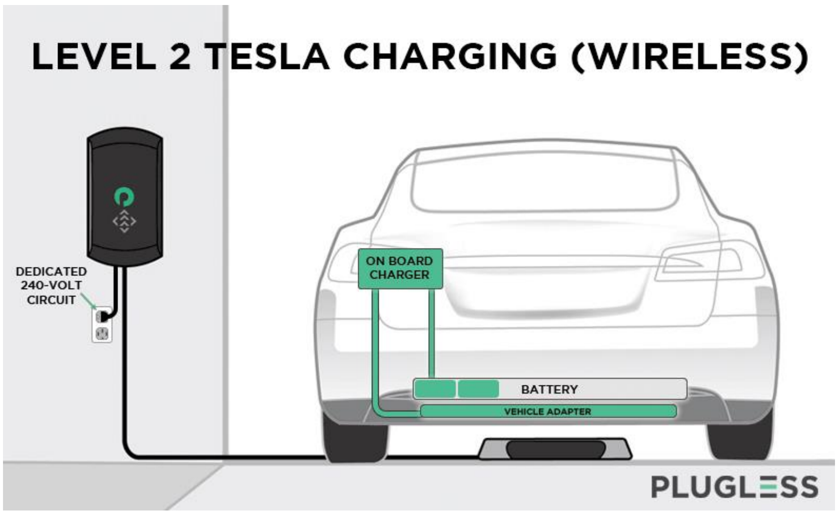

Figure 20.Induction charge [21]

This type of power source can be placed under the road pavement and vehicles passing over this pavement can charge while driving over it. Different investigations have been developed through different configurations for these power source, depending on the types of vehicles.

Vehicles without any battery or with very small capacity, receiving the whole power through the magnetic fields. So that, a full circuit would be necessary over the whole trajectory of the vehicle. This configuration tends to be specially interesting for bus-lines within a city centre. Installing the infrastructure becomes much more interesting when the number of electric vehicles increases.

However, this technology is not presented as a competitive option with respect to the fast charge or on-road charge, since, with current technology, it can only operate at very low powers (3.3kW, 6.6kW or 20 kW with the most advanced systems) so the charging times are very high. The charge at higher powers supposes very high losses reason why the efficiency of the system diminishes a lot. Nevertheless, this technology is undergoing multiple changes and it is possible that in the next decade we will talk about a rapid charge by induction.

Dynamic inductive charging,

II. Battery swapping

This technology cannot be considered as real recharging process. Battery swapping means that the EV battery is removed from the vehicle to be charged. At the same time, a fully charged battery is substituted in the vehicle.

This method has advantages for both vehicle owners and all the whole electric system in general. The main advantage for vehicle owners is the waiting time reduction, to have a fully charged battery is reduced to only five minutes. This could significantly decrease the range anxiety problem and lower battery capacity is needed.

For the social welfare point of view this method is especially interesting, the possibility to charge the battery in "valley" moments where the prices for electricity are the lowest and the electricity demand is at its minimum so no congestion and voltage problems can be produced. This creates enormous benefits for the whole society, as the batteries could reduce the peak demand by offer energy to the system and even also stabilize the system. This fact could also allow a higher penetration of RES in the system.

However, this approach also has some disadvantages. The biggest difficulty that can be defined is the necessity for battery standardization. Companies might not want to install a standard battery, which will have affected the car development and influence its previous design. The other big problem is the weight of a battery. These types of batteries can weigh between 100 kg and 500 kg. So that, the process cannot be done manually and must be automatized. Furthermore, battery swapping stations built in the past cost several million euros, making them unattractive from the investor point of view

III. Electric Road Systems (ERS)

The ERS or dynamic conductive charging system offers the possibility to reduce the need for batteries and EV requirements. This technology can supply energy from three possible directions, from the top, the road and the size. ERS have a huge potential reducing on-board requirements. Nevertheless, the main concern that present this technology is the needed infrastructure which would have to be developed in the transport network.

A. Pantograph

It is an innovative system within the ultra-fast charge that allows to reach currents of up to 1,000 A and maximum powers around 400 kW, charging the battery in 5-10 minutes. Moreover, it can be a fully automated charging process. This technology was initially designed for buses due to the large power needs and time limits, allowing the use of lighter and smaller batteries. However, this technology is being experimented in the passenger car sector also due to its great advantages.

B. Slot car track

This technology has capability to charge the EV on-going, it is based on a strip embedded in the road that provides the power. The EV will need a movable arm to deploy and contact the strip, which will provide the circuit necessary to charge the car's batteries.

The main benefits of this electrified road are batteries size reduction and elimination of the waiting time. Of course, there are some drawbacks. The first one is the tear up parts of the road. There's also the matter of the arm, which would require to add another component to the vehicles in order to make possible this charging process.

The first pilot project is the 1,2 miles long slot-car track in a road near to Arlanda airport, in Stockholm, Sweden.

IV. Underbody charging

The underbody charging system will allow ultra-fast charge in few minutes through a dispositive embedded in the ground and the interface installed in the EV underbody allowing extremely high powers up to 1 MW. Even more this system will be completely autonomous. This new technology shows great potential for interurban static ultra-fast

2.3. MAIN INFRASTRCUTURES

The recharging infrastructure must respect the international standard IEC 61851 which has the objective of standardizing the internal and external recharging systems to the vehicle for voltage levels up to 1000 V-AC and 1500 V-DC, as well as any other service or additional system that requires the vehicle to connect to the electrical network. These standards are guaranteed by all the manufacturers of the market both of vehicles and of infrastructure of charge. In this section we are going to talk about the main companies.

-Circontrol/Circutor.

It is a Spanish company with headquarters in Barcelona and founded in 1997. Its business model focuses on providing solutions in the world of mobility and charging solutions for electric vehicles. It is probably the company with the largest variety of electric mobility services nationwide with domestic products, for public use and fast charging, up to 50 kW with its model: Raption 50.

-Ingeteam.

Ingeteam is an international Spanish Group specialized in power electronics and control, (inverters, frequency converters, controllers and protections) and electrical engineering and automation projects. INGETEAM has designed the range of INGEREV® chargers for electric vehicles, both in alternating current and direct current. Counting with 6 types of points from domestic charge to fast (50kW). [22]

-Tritium.

This Australian company was founded in 2001, by a group of entrepreneurs that develops in 1999 the Gold Controller motor inverter for solar vehicles, which is still used by most of the world's solar car racing teams. Tritium commercialise specific technology for e-mobility. Concretely fast and ultra-fast chargers. Its model, Veefil-RT 50kW DC is one of the best sellers in Europe with a 50% of market share in Norway. It also has the fastest model in the world, Veefil-PK. The new charger is a scalable and flexible charging solution with output powers between 175 and 350 kW in direct current. [23]

-Power Electronics

Power Electronics is a Valencian service company and manufacturer of power electronics. It has a wide range of products aimed at electric mobility. From domestic loaders to solutions for heavy vehicles, passing through specific models of the public charge. So its charging power goes from 7.7 kW to 350 kW. This firm also has hybrid solutions that implement solar installations in their charging points. [24]

-ABL.

It is a company founded in Germany in 1923 with great experience in the field of electronics and electrical equipment. In 1935 they invented the SCHUKO plug. Since 2011, they have become world leaders in e-mobility products. They have 4 different models, which are capable of charging with a power of: 11kW, 22kW, and 44kW. Focusing their business in domestic, companies and public charge.

In the following figure, we can see the increase and variation of charging points since its implementation in 2012 to the present.

Figure 21.Charging points evolution [25]

2.4. COMPARISON WITH ICE

In order to analyze the main difference between ICE and EV we can analyze several parameters.

I. **Cost.** Once the investment cost has been implemented. The energy consumption for the conventional vehicle is around 6.5 litres per 100 km that implies a cost of about 10 € per 100 km at current prices which is much higher than for a regular BEV with a consumption of 15 kWh per 100 km, at 0, 13€/kWh, which entails a cost of around 1.80€/100 km. Furthermore, this cost could be reduced in case of applying a tariff with hourly discrimination. In addition, the prices of gasoline and diesel are constantly increasing and show an ascending trend.

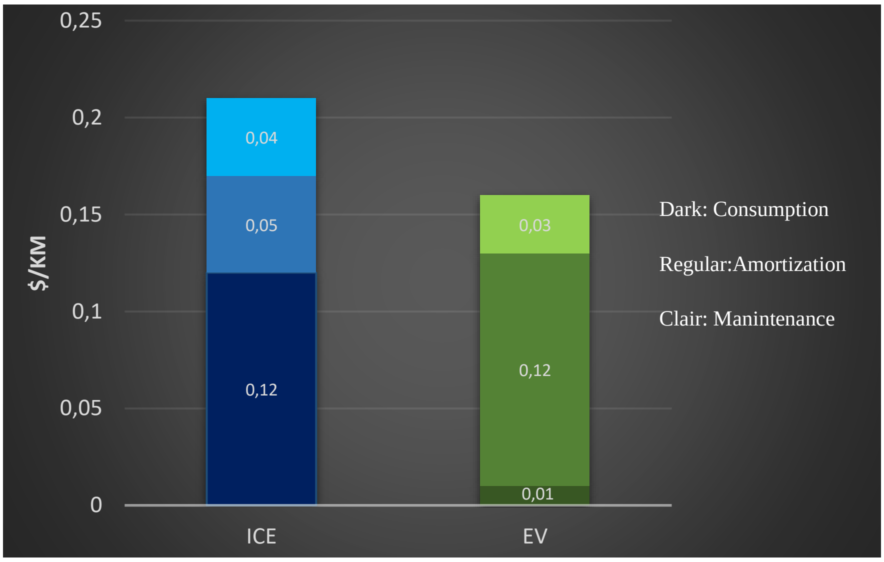

Figure 22. Total cost comparative for 2035 [26]

In addition, the main savings that we find are in fuel consumption and in maintenance costs. The Electric Vehicles have multiple aids depending on the country and autonomous community. Among the main highlights: technical inspection of vehicles (ITV) cheaper, discount on the road tax, exemption from payment or reduction of registration tax, free parking etc.

II. **High efficiency**. The conventional gasoline vehicle has an overall efficiency of 25%. That means, the energy of the fuel introduced into the vehicle is obtained only in the form of mechanical energy for the movement of the wheels consisting of 25%, losing the remaining 75%. In the case of BEV, an efficiency of 77% is reached if a fully renewable origin is considered and 42% if the energy comes from natural gas. Logically, the PHEV, being a combination of conventional and electric motor, will have a mixed efficiency between 31-49%, according to the distribution between both engines.

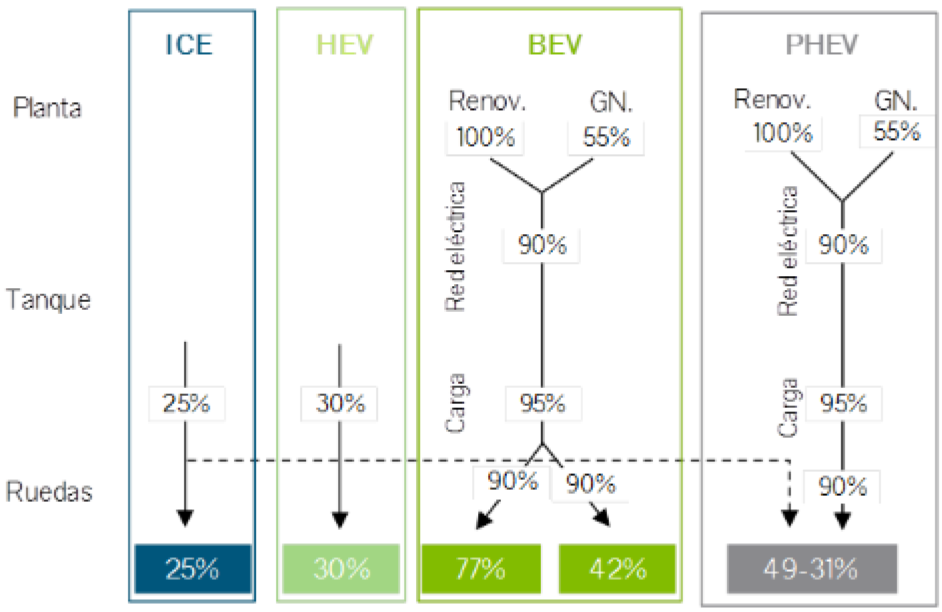

Figure 23.Efficiency analysis: "Tank-to-Wheel" and "Well-to-Wheel" [10]

To make a more accurate calculation we would have to consider the energy losses produced in all phases of energy: generation, transport and transformation. The three key factors to properly consider efficiency are: The "Well-to-tank" efficiency factor of transporting energy from its source to the tank or battery of the car, the "Tank-to-Wheel" from the tank / battery to the wheels and finally the combination of both the "Well-to-Wheel".

III. Ecofriendly. The electric vehicle can play a fundamental role in reducing emissions of greenhouse gases for two main reasons: Greater efficiency and the process of energy transformation, especially if it is of renewable origin.

Based on the data provided by Electromobility we can make a simple calculation to see the difference in CO2 emissions. To do this, we start from the following average values: The average consumption of electric vehicles is currently around 14 kWh / 100km and the average emissions of the Spanish electric generation mix is 0.235 kgCO2 / kWh. So, calculating this simple operation we can reach values of 3,4 Kg Co2 per 100 km.

On the other hand, the consumption of a diesel vehicle is approximately 5l / 100km. The emissions produced by one litre of diesel consumed are 2.68 kgCO2 / l. Taking into account this information, a consumption of 13.4 Kg CO2 for the conventional vehicle can be estimated.

This shows how electric vehicles provide a real solution for the reduction of CO2 emissions in the transport sector. Therefore, an optimal alternative to reduce climate change.

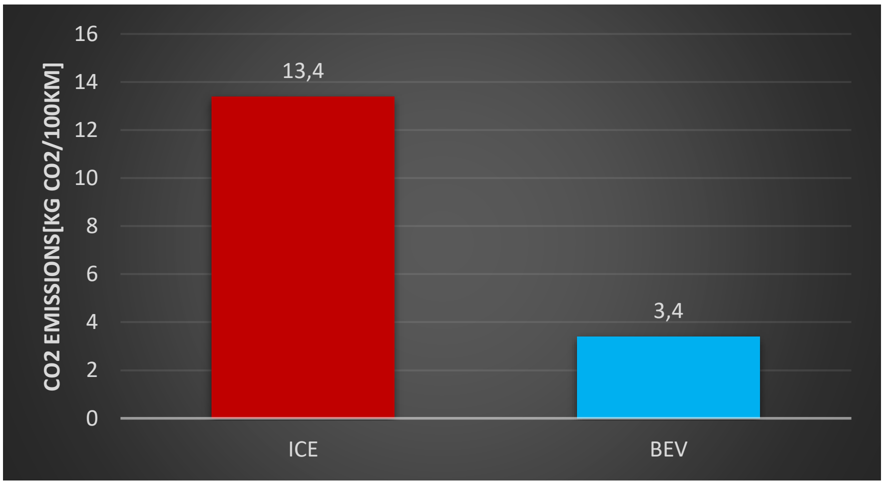

Figure 24.CO2 Emissions comparative [10].

To this reduction of emissions, we can add the complete elimination of harmful gases for health, especially NOX and SO2, particles in suspension (PM5, PM10) and Non-methane volatile compounds (NMVOC). In addition, waste such as oils, filters and other additional elements of the engine are removed.

Following an study done by the Citelec, Association of European Cities interested in Electric Vehicles¸ general primary emissions under the assumption that vehicles meet the general requirements in force and considering Spanish energy mix, we can see the comparative in the

Table 3 .´

[g/km]	OIL	DIESEL	ELETRICITY
CO	6,32	1.05	0,02
NOx	0,82	1,120	0,2
SOx	0,085	0,215	0,45
NMVOC	0,865	0,22	0,01
Dust	0,014	0,127	0,013

Table 3.Primary emission per technology [27]

Even more, energy used to charge vehicles is commonly generated through clean energy or conventional plants situated far from populations and cities.

It should be noted that the values of the current electric mobile fleet have nothing to do with the next generations, due mostly to energy efficiency and RES. Therefore, these values will tend to separate more and more.

IV. **Noise.** Another sign of environmental improvement is the savings in noise pollution. This aspect was especially interesting in urban areas. However, what seemed an advantage has ended up being a disadvantage, since the pedestrians could not perceive these vehicles and, every hybrid or electric car sold from July 1, 2021 will have to add an acoustic warning when they circulate at an urban speed, known as AVAS (Audible Vehicle Alert System), although this noise will not be as annoying as the one of conventional vehicles.

This measure approved by the European Union establishes that the sound must be similar to that of the conventional engine and a frequency that must be at a minimum of 55 decibels and a maximum of 75 decibels for speeds below 25 km / h.

V. **Maintenance.** Although it has been commented previously. The electric vehicle presents a reduction of moving parts with respect to the conventional vehicle, being the rotor the only mobile part. Even more an EV has not a clutch, filters or engine oil, so its maintenance is much simpler. It is estimated a saving of around 45% compared to a conventional vehicle.

Moreover, this lengthens the vehicle useful life, having less mechanical parts suffer less wear.

VI. **Comfort and easiness.** Another of the most relevant factors of EV is the increase in driving comfort. This more comfortable driving is due to the automatic change, the technology and the smoothness of the movement. To the comfort factor it is necessary to join the flexibility of being able to charge our vehicle in different places: home, work, public way or commercial centre. Specifically, this means saving time and displacement. Other comfort extras may be: Free parking, different permits to drive at special hours or restricted areas.

At the national level we can include other specific benefits that derive from the correct implementation of the EV:

-Non consumption of fossil fuels, which translates into lower dependence on imported oil. In addition to millions (around 25.000 million euros) of savings in exports

-Management of clean energy and more efficient. The electric vehicle allows a use of the energy of greater efficiency in addition to a 100% green energy. It is very important to highlight, that EV implantation has to go hand in hand with RES energy production in order to guarantee a real Sustainable model, because if energy is coming from fossil fuels like coal or fuel we cannot speak about sustainability. Especially relevant with the "smart charging"

- In the not too distant future, a cheaper and more optimal management of the electric network, e.g. V2G (A concept that enables BEV to act as a distributed energy storage system by providing demand-response services to the power network)

2.5. ELECTRIC VEHICLE IN SPAIN

2.5.1. Energy Policy. Legislation and regulation

Energy has always been an especial concern on human life and has been used as a main indicator for level of development and social welfare. Furthermore, in the recent years the use and management of the energy has become an important issue respect to economy, politics and social ambit. This fact can be easily appreciated in several policies that have being implemented at global level but specially at European level, with the so call "energy transition" policies. Which main objectives is the change towards a new energy model based on renewables, energy savings, efficiency and concern about global warming and atmospheric pollution.

The first step was taken with the Treaty of Lisbon (2007) where energy and climate change start to play a major role at European scheme. This treaty following the Kyoto protocol objectives was translated into the first measures taking by the European Union through the Energy and Climate Change Package 2020 and its three main objectives:

- To reduce emissions of greenhouse gases by 20% by 2020 taking 1990 emissions as the reference.
- To increase energy efficiency to save 20% of EU energy consumption by 2020.
- To reach 20% of renewable energy in the total energy consumption in the EU by 2020.

Following the previous energy package a new framework was stablished in 2014 improving the targets:

- Reduction of GHG emissions by 40% compared to 1990.
- 27% renewable energy share in final energy consumption.
- An improve in energy efficiency for at least 32.5%.

The Conference of the Parties to the United Nations Framework Convention on Climate Change (COP 21) held in December 2015 in Paris resulted in a historical agreement among 196 countries, the Paris Agreement. The main objective of this conference was to reach two goals: Maintain the global temperature increase below 2°C and 0 emissions.

Figure 25 explain the different European Union's targets and the specific objectives for Spain.

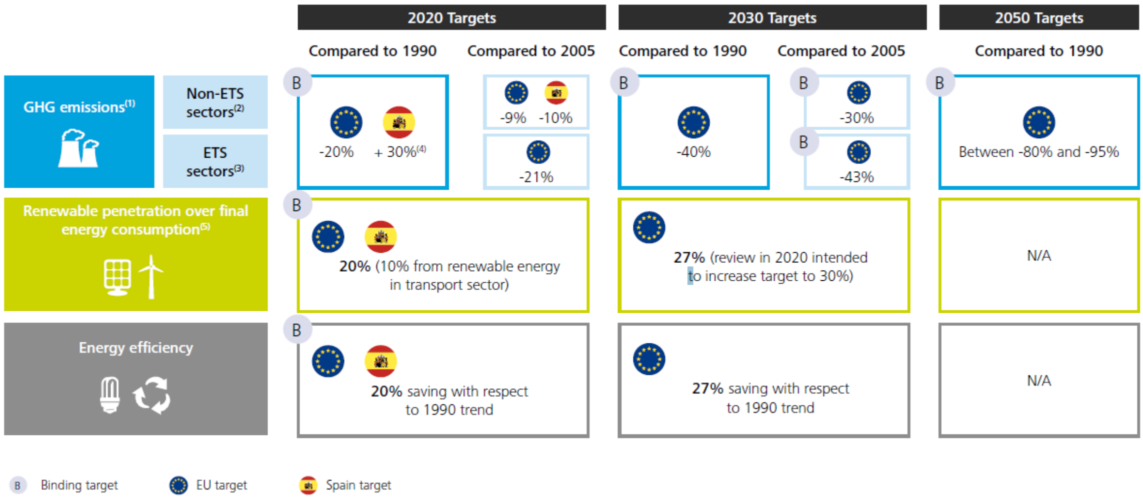

Figure 25 European energy targets [28]

Regarding the main strategy focused on mobility we highlight the Clean Mobility Package, which aims to move transport further towards sustainability and environment protection, raise funds for new infrastructure and alternative transport, invest in new technologies and to encourage behavioral change.

Furthermore, explain the specific normative of the EV, the main regulation that we find at European level comes from the hand of the International Electrotechnical Commission, the IEC is a global organization for standardization, which includes all the national electro technical committees, its objective is to promote international cooperation on all issues relating to the electric and electronic fields. Among the main regulations at European level we find:

IEC 61851. Load conductive system for EV. This standard applies to EV charging equipment for AC supply voltage up to 690 V and DC up to 1000 V and regulates these systems as well as the EV requirements for such connections. It also defines the requirements of charging stations.

IEC 62196. International standard for connectors and charging modes for electric vehicles.

The national normative that regulates charge installations is the Electrotechnical Regulation for Low Voltage or REBT. Which mostly, describes the assembly conditions, operation and maintenance of LV installations. The successive improvements are introduced through the Complementary Technical Instructions, specifically dedicated to different electrical applications. Concretely, The ITC dedicated to the electric vehicle charge is the ITC BT-52, which stablishes the requirements for the installations.

Spanish Energy Policy

In accordance with the European directives, Spanish government stablish the Energy Saving and Efficiency Action Plan (2011-2020) which then was replaced by the National Energy Efficiency Action Plan (2014-2020). Where we highlight the Urban Mobility Plans (PMU) and the Plans of Transportation for Companies and Activity Centres. We should also introduce the National Integrated Energy and Climate Plan, PNIEC, (2021-2030), which defines the objectives of reducing greenhouse gas emissions, the penetration of renewable energies and energy efficiency. In the mobility line we highlight the imposition by the government to place 50 kW charging points in every service station that are built from this date.

Following this plan and under the European union measures Spain is on the path of fulfilling the objectives of 2020 specially for the emissions target which was change for industrialized countries to 30% of reduction. However, the objective of penetration of renewable energies will require an additional effort to ensure compliance.

The last Spanish regulation in the sector was the Law on Climate Change and Energy Transition, which objective is to ensure the fulfilment of the objectives of the Paris Agreement, to accelerate the full decarbonisation of the Spanish economy so as to guarantee the rational and solidary use of our resources and the implementation of a model of sustainable development that generates quality employment. [29]

The main regulatory legislation that we can highlight are:

The standard UNE-EN 61851, or standard of the charging conductive system for electric vehicles. It is a translation of the European standard IEC 61851. It defines the types and requirements of charging models that electric vehicles will use in Spain. And also, the UNE-EN 62196 corresponding with the IEC 62196.

The national normative applicable to charging installations is the Electrotechnical Regulation for Low Voltage or REBT. Describes the conditions of assembly, operation and maintenance of low voltage installations. The successive improvements are implemented with Complementary Technical Instructions, specifically dedicated to different electrical applications. The ITC dedicated to the charge of the EV is the ITC BT-52. Establishes the requirements applicable to the installations for recharging the EV by driving technology, not applicable to induction charges.

Charging manager. The charging manager is a figure that was created in April 2010, according to article 23 of R.D.-law 6/2010. Providing a solution for the creation of an agent commissioned to promote the development of the electric vehicle at a national level, framed within a set of measures for the Electricity Sector, which seek to favour economic recovery and the creation of employment through energy savings, efficiency increase and environment protection.

The rights and obligations of the charging manager were subsequently regulated in the Royal Decree 647/2011, May 9, which defines their activity as the performance of energy recharging services for electric vehicles. This decree also regulates the procedure and the necessary requirements to the exercise of this activity. [2]

Finally, in October 2018, the Government eliminated this figure by The Royal Decree Law 15/2018. This figure has been shown to be very rigid and demanding, which was discouraging activity and a barrier for infrastructure deployment.

In this way, any company (hotels, shopping centers, public or company car parking, etc.) or self-employed can install recharging points in their facilities and offer this service, although in any case complying with the corresponding industrial safety regulation and tax. Thanks to this modification, administrative procedures are simplified by eliminating the obligations of annual information remission to the corresponding administration.

- Other secondary regulations regarding the mobility sector are:

-Royal Decree 216/2014. Regulation of regulated tariff, PVPC, for the Electric vehicle. With to new tariffs specially designed for electric cars: EV 2.0 DHS (<10 kW) and EV 2.1 DHS(10-15 kW). [30] In the Portal of Transparency of the Spanish Electricity Network (ESIOS) we can check how this tariffs works.

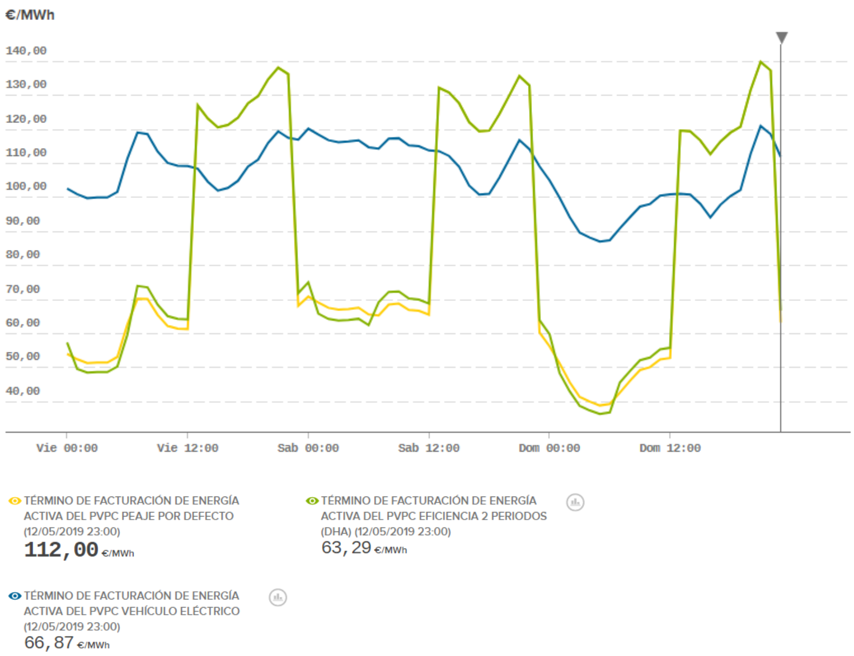

Figure 26. Different regulated tariffs. [88]

We can differenciate 3 tariffs: PVPC, 2 periods PVPC and the 2.0 DHS. Tree different prices bands can be easily appreciate: Peak(13h-23h), Valley(23h-1h,7h-13h) and Supervalley(1h-7h).

In this line, we can also find multiples tariffs on the free market that compete with the regulated such as: Plan vehiculo eletrico (Iberdrola), EV special tariff (Holaluz) or Tempo Zero tariff (EDP).

- Law 19/2009. Modification of the Horizontal Property Law, to avoid the need for voting among neighbors when one of them decide to install a recharging point in the community garage. Nowadays, only a communication by the interested party to the community is required. [31]

-Air quality and climate change plan for the city of Madrid. The main objective is to reduce atmospheric pollution and slow climate change by reducing GHG emissions. Among the main measures we find:

Reduced space dedicated to the automobile in favour of more sustainable means and pedestrian mobility. Increase in bicycle mobility through the amplification of BICIMAD. Regulation of parking and limitation of speed in the access roads to the city, Restriction of access, Amplification and renewal of the fleet of public transport (EMT). Development of the charging network.

The most relevant measure is Madrid Central. Regulation and limitation of vehicle access to the centre of Madrid city, shown on Figure 27. Identification and classification of vehicles according to the emission criteria: 0 emissions (electric, fuel cell or hybrid vehicles with autonomy greater than 40 km.). ECO (hybrid vehicles with autonomy less than 40 km and vehicles powered by gas). Type C (EURO 4, 5 and 6 [registered as of 2006], and Diesel EURO 6 [registered as of 2014]). Type B (petrol EURO 3 vehicles [registered from 2000] and Diesel EURO 4 and 5 [registered as of 2006]). The oldest vehicles like (petrol EURO 1 and 2, and Diesel EURO 1, 2 and 3) no need environmental distinction because they are considered too much polluting.

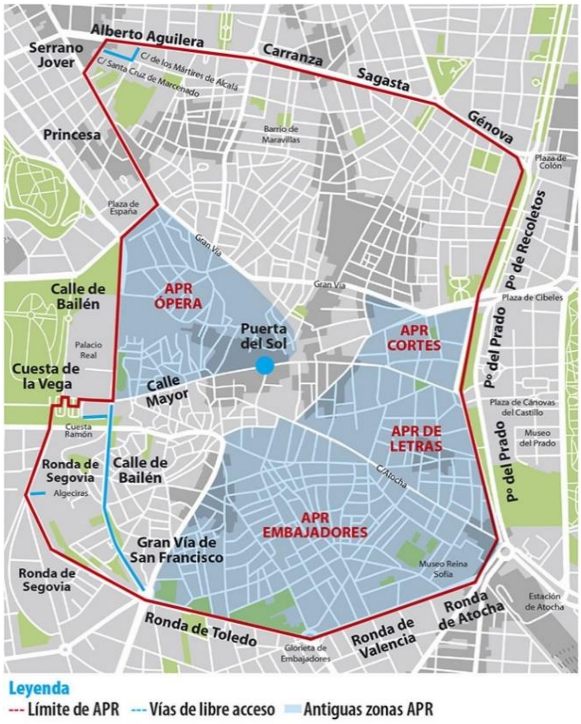

Figure 27. Madrid Central Map [32]

The access restriction supposes fines for those who skip the directives. The restrictions have an extension over the next few years, which is shown on next table

Ambient distinctive DGT	2018		2019		2020	
	<3.500 kg	>3.500 kg	<3.500 kg	>3.500 kg	<3.500 kg	>3.500 kg
0 emissions						
ECO						
C						
B						
None						

Table 4.Access restrictions [own elaboration]

Madrid Central has been suspended in July 2019 by the current mayor's office leaded by the Partido Popular, with its consequences and future problems for the citizens of Madrid.

- Other most outstanding measures to incentivize the Electric mobility are:

-MOVES Plan. Royal Decree 72/2019, of February 15, which regulates the incentive program for efficient and sustainable mobility. This plan has an economic donation of 45 million euros.

Autonomous Community	Budget [€]	Percentage of total
Andalucía	8.096.943,04	17.99%
Aragón	1.264.570,62	2,81%
Asturias	1.000.022,93	2,22%
Baleares	1.078.326,30	2,40%
Canarias	2.036.957,32	4,53%
Cantabria	560.706,02	1,25%
Castilla y León	2.343.913,42	5,21%
Castilla La Mancha	1.962.902,51	4,36%
Cataluña	7.300.768,41	16,22%
Comunidad Valenciana	4.774.698,85	10,61%
Extremadura	1.043.465,22	2,32%
Galicia	2.616.913,80	5,82%
Madrid	6.287.521,47	13,97%
Murcia	1.420.641,10	3,16%
Navarra	621.520,40	3,16%
País Vasco	2.120.089,97	4,71%
Ceuta	82.091,05	0,18%
Melilla	83,212,85	0,18%

Table 5. MOVES plan share per AACC [30]

The whole budget has to respect some conditions:

- Between 20-50% for EV
- Between 30-60% for charge infrastructure
- Around 10-15% for electric bicycle loans

This year is the first decentralised plan. The previous plans are: MOVALT (2017-2018), MOVELE (2010-2015) and MOVEA (2016-2017) were centralised.

-Registration tax exemption

- MUS Plan. Is the Sustainable Urban Mobility Plan (MUS) of Madrid, an incentive plan for the purchase of alternative mechanical cars, motorcycles and light quadricycles, as well as charging infrastructure, with an allocation of 3 million euros.

-Renove Plan. Introduced by the Basque administration the Renove plan is an incentive strategy to renew the vehicle fleet with an economic dotation of 5 million euros.

In order to understand the lack of policies in Spain and compare the situation with other European countries where the EV adoption is much higher, we have include Figure 28.

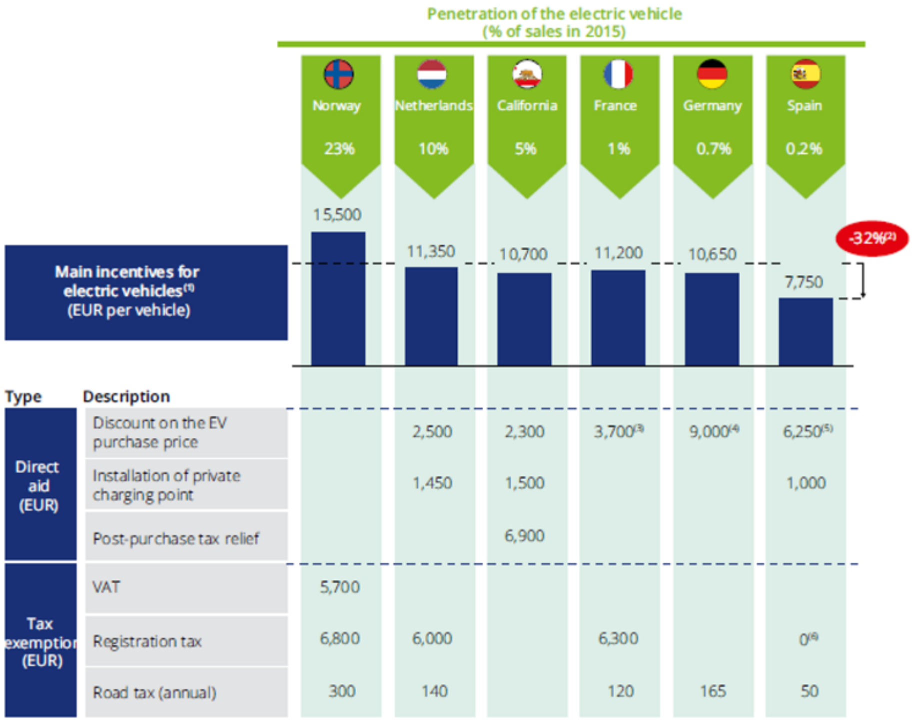

Figure 28.Main economic incentives around Europe [28]

2.5.2. Market context and penetration curve

The number of electric vehicles registrations (pure electric as well as hybrid) has grown exponentially in recent years in Spain, reaching 11.639 electric vehicles in 2018. In addition, sales reached 4,090 units in the first four months of the current year, which translates as a rise of 78% compared to 2,300 units sold in those months of 2018. Finally, the total number of electric vehicles in June 2019 is around fifty thousand. This trend can be seen in the Figure 29.

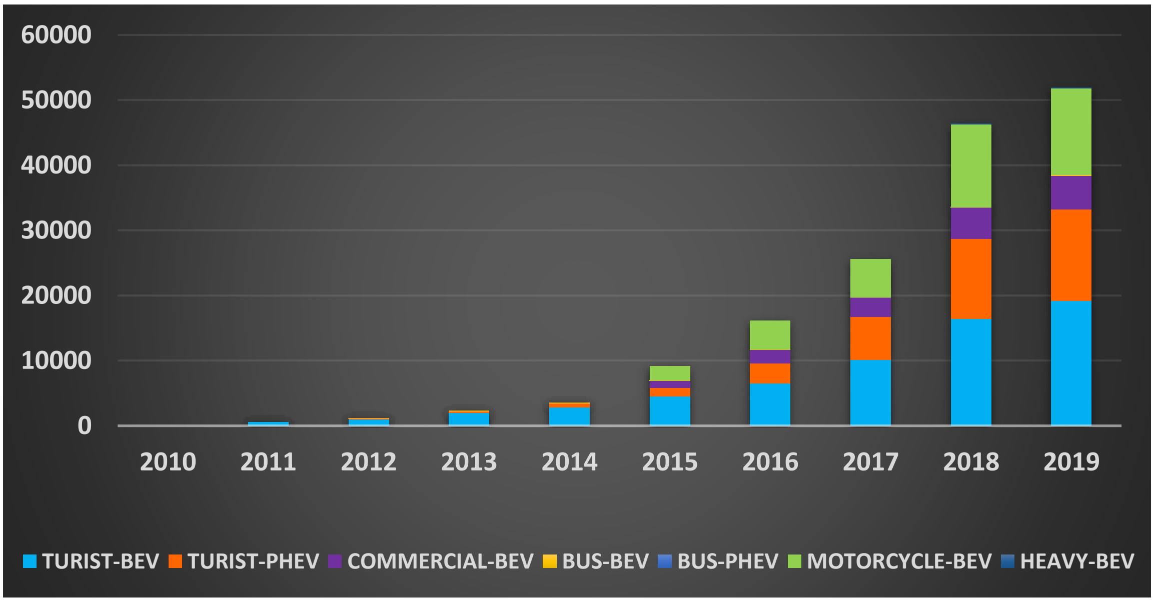

Figure 29. Number of EVs in the last years [33]

Although the numbers are very promising Spain is far behind compared to other countries in the European Union. Being one of the European countries with lower acceptance and registration of electric vehicles, as shown by the 0.3% market share compared to 1.8% of the European average. [34]

In addition, maybe, the great obstacle are the recharging points. Although this infrastructure is in development process, but in recent years has suffered a period of latency.

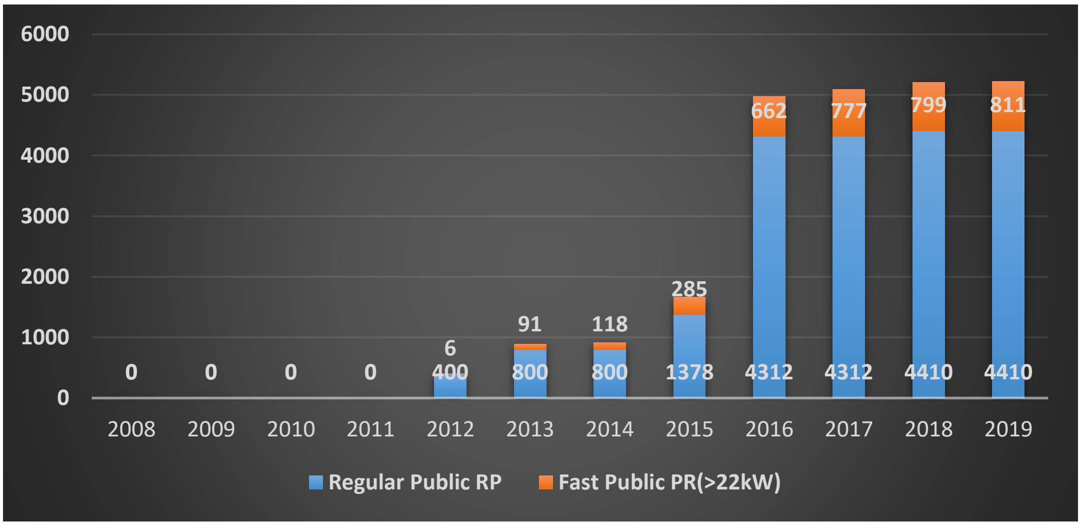

Figure 30. Charging points in the last years [33]

It is especially important to analyze both curves in Figure 29 and Figure 30. In the first one we can see an exponential trend while in the second one is almost flat. This lack of relationship could be caused by administrative barriers, unattractive business plans and past doubts about the EV. Therefore, strong coordination and strategy is needed in order to update the infrastructure which should be over-dimensioned in order to meet the future EV demand.

Spain is in the fifth position at European level with around 5.000 points, there being a huge difference between the 4.25% that they represent compared to the previous position, occupied by the United Kingdom with 12.5%. And far behind others such as France (13.96%), Germany (21.6%) and Netherlands (28.4%) as is visible in the following table. In addition, the composition of these points is very varied. The situation gets worse when it comes to fast charging points (>50 kW), reaching the number of only 811 points.

Country	Charging points	Semi and Fast charging(>22kW)	GDP per capita (2018)
Spain	4.974	811	42.120€
UK	20.594	4.743	47.042€
France	25.479	2.866	47.113€
Germany	28.377	4.457	54.894€
Netherlands	39.200	1.092	59.105€

Table 6. Charging points and connectors around Europe [33]

We have considered the previous table to include the GDP per capita in order to appreciate the relationship of this parameter with the introduction of the EV demonstrating the relevance of the wealth factor in this sector. In addition, in Figure 31 we can see the comparison according to the percentage of type of connectors in Spain with respect to other countries of the European Union.

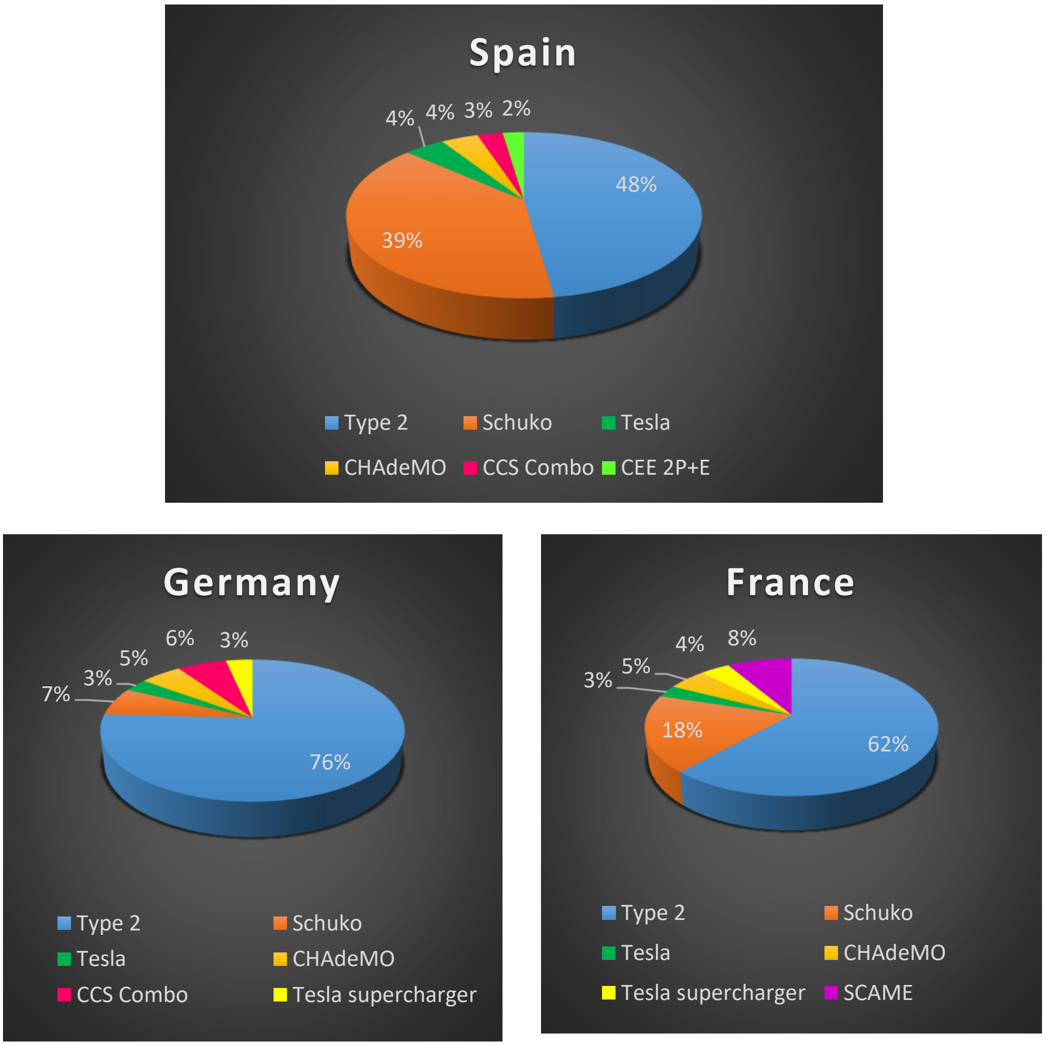

Figure 31. Connector share in different European countries [81]

As it was expected the three systems present very common characteristics but in Spain there is a large representation of Schuko type connectors, which in the case of its neighbouring countries has already been replaced by more modern technology, specifically type 2 or Mennekes. This result is also justified due to the high number of home chargers in Spain compared to the low number that are located on the public road or in market centres.

On the next figure we can analyze the European ranking considering PHEV, the share among total vehicles and the number of public charging points per country, so that these numbers will be lower than the previous ones that considers both public and private ownership. The source is quite outdated, but it is interesting to analyze the difference among European countries.

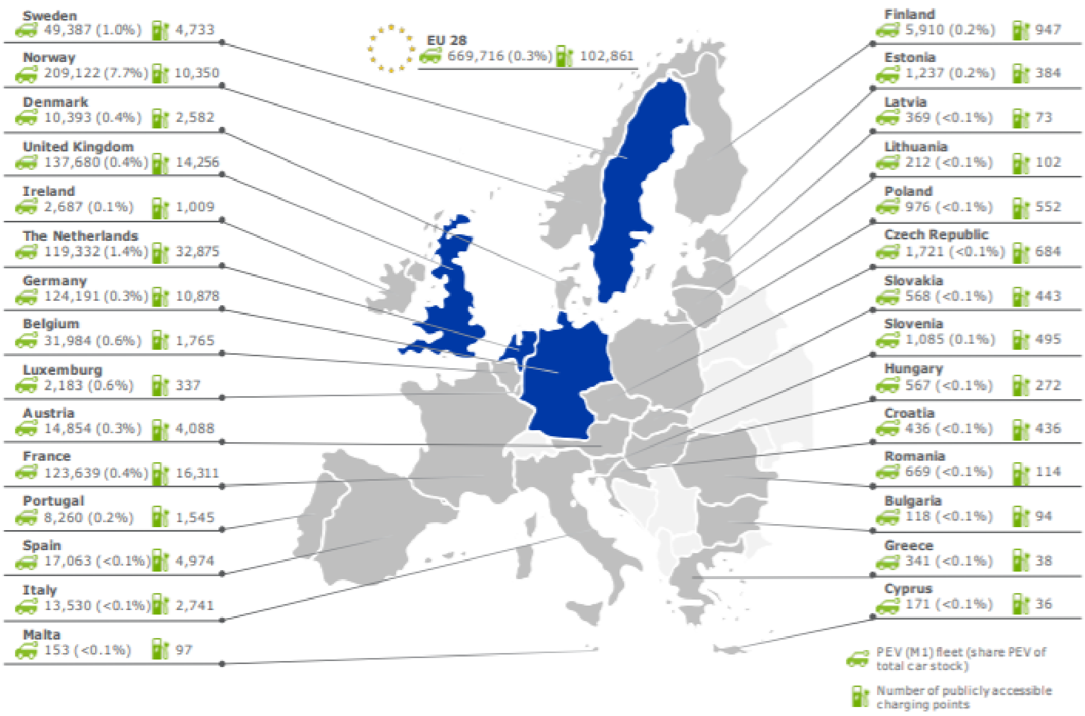

Figure 32. Number of PHEVs and public charging points [35]

-Spanish EV market

As it is shown on Figure 33, the bestselling pure electric vehicles models are the Nissan Leaf, Renault Zoe and the Smart Fortwo ED, reaching almost 60% of the market. Among the main reasons to find these vehicles as the top representatives of the market are: very good quality / price relationship and high degree of autonomy. Followed by the BMW i3 which has achieved a relevant place due to its family size and its considerable autonomy.

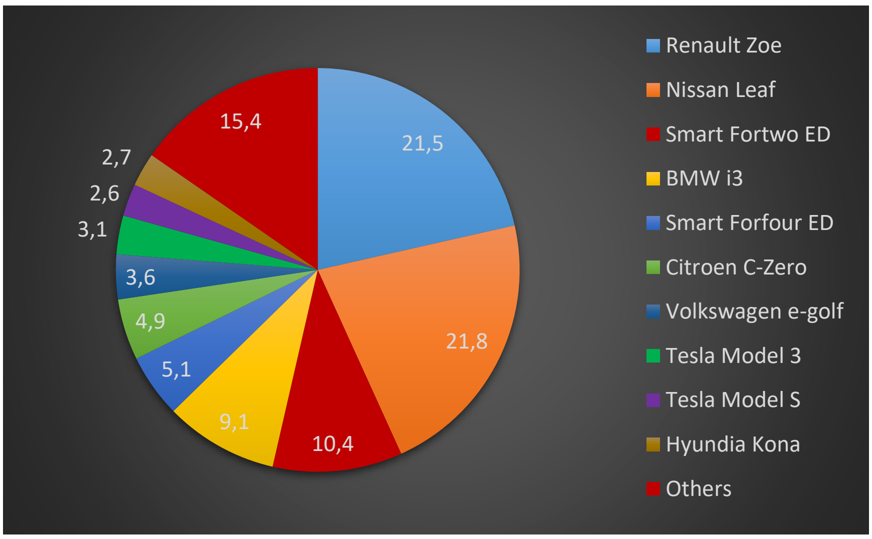

Figure 33. EV share in Spain 2019 [36]

On the other hand, among the plug-in hybrid vehicles there is a great variety of models in the market and their sales are not so concentrated, except for the SUB Mitsubishi Outlander, which has been the market leader since its launch, due to a very high performance at a very affordable price.

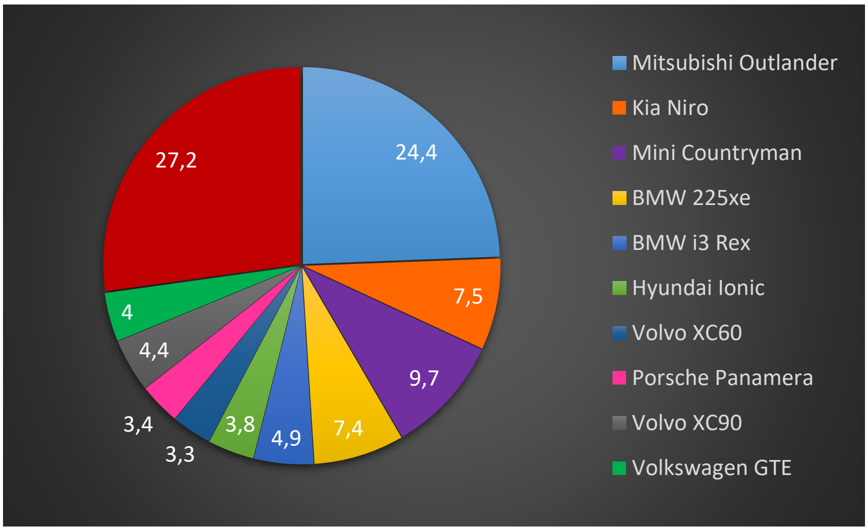

Figure 34.PHEV share in Spain 2019 [36]

-New business model

As we have presented above, electric vehicles are a clear tool to reduce fossil fuel consumption, reduce CO2 emissions and increase the penetration of renewables. Therefore, follow the route towards the European objectives.

Some of these problems are especially important in cities due to traffic restrictions and the difficulty in finding a parking space. In this new situation, several private companies have found a business opportunity with sustainable initiatives such as shared mobility vehicles or smart charging.

- Carsharing. It is a service that offers both cars and motorcycles for rent, with multiple locations and for specific periods of time. The vehicle is identified and reserved via App. The cost of the service depends on the time of use.

  In a city like Madrid, today there are already 2.760 electric carsharing and 3732 motosharing. From calculations of previous year where the number were: 1460 and 610 respectly. Furthermore, according to Car2Go estimations, each vehicle is rented 16 times a day on average. This result makes Madrid, the third city with higher number of users (240.000).

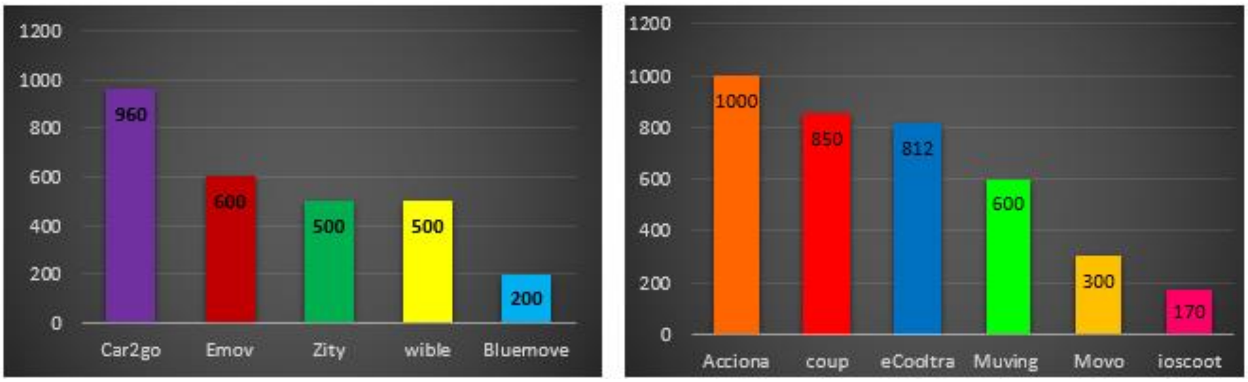

Figure 35. Shared mobility business model [36]

- Smart charging. The electric recharging process can have a significant impact on the battery's useful life, therefore on the vehicle's life. In addition, this process also affects the final cost of recharging. smart charging seeks to optimize the recharging process. One of the main providers of these services are: EnerNOC or EV-Box.

-CECOVEL. Control Centre of the Electric Vehicle is the control centre of Red Eléctrica that, from January 2017, allows to track and control the electricity demand for the recharging of electric vehicles. The CECOVEL is at the service of city councils to facilitate the deployment of public charging points throughout the country. Ensuring a secure and efficient integration on the Spanish grid.

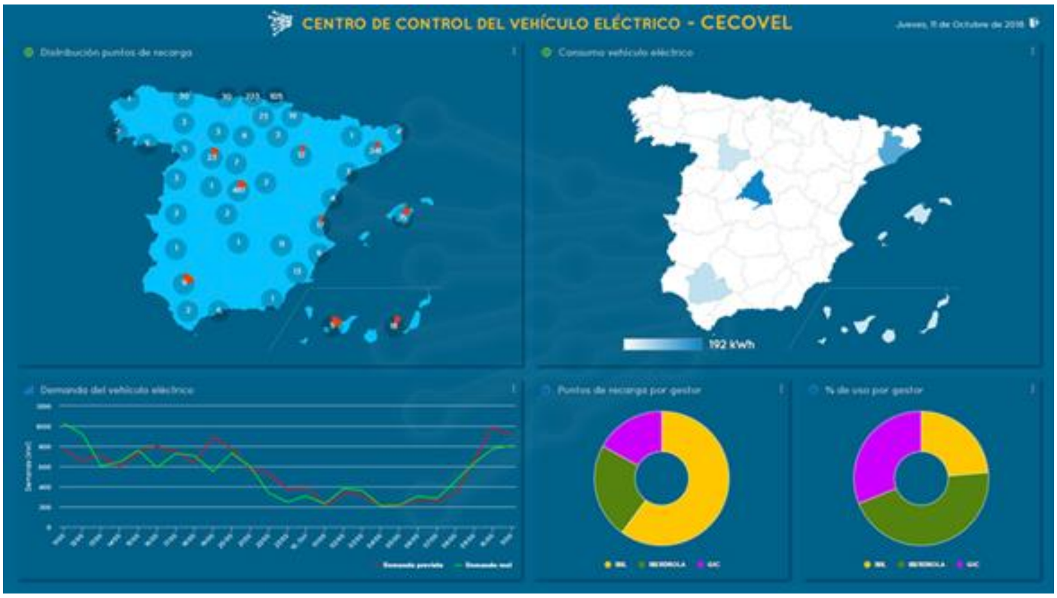

Figure 36.CECOVEL control panel. [37]

To ensure compliance with the decarbonisation objectives, a high penetration of electric vehicles is necessary. Approximately 10% in 2025, 25% in 2030, 70% in 2040 and practically 100% in 2050. To achieve these levels of penetration, a much higher level of sales of electric vehicles is necessary, around 50-60% in 2030 and the prohibition of registration of petrol, diesel, gas and hybrid vehicles in 2040. Therefore, considering that in Spain, we have a fleet of 25 million cars, annual sales of approximately 1 million cars and a car useful life of 12 years, this transition could last more than 40 years. Some analysis developed by specialized agencies affirm that by 2030 the number of electric vehicles in Spain will be around between 1 and 2.5 million, which would represent 10% of the total fleet. These results are appreciable in Figure 37. [38]

This EV adoption is low due to the following factors: 1) EV the purchase price; 2) Autonomy and the well-known range anxiety 3) Model variety (this situation is in change, from 15 types in 2015 to more than 60 in 2019); 4) EVs charging infrastructure; 5) Many consumers consider that technologies are still immature.

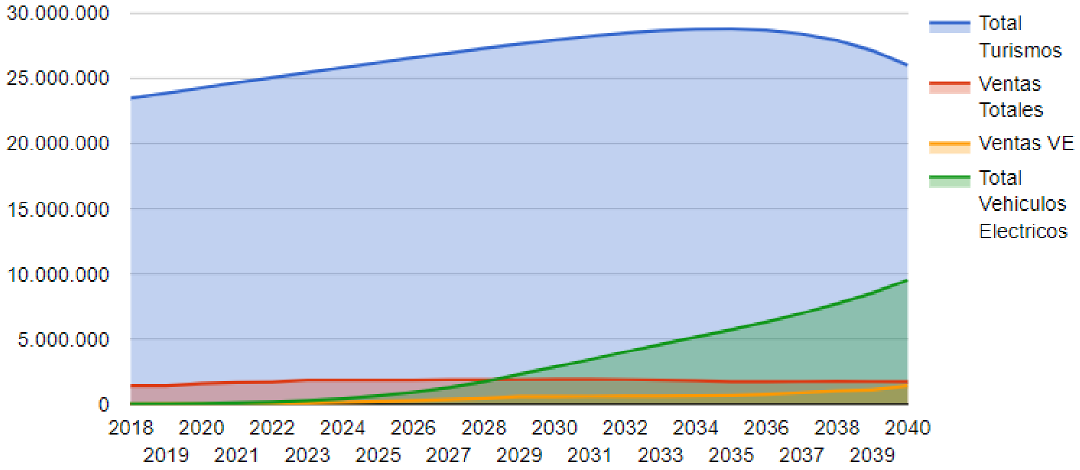

Figure 37. Spanish vehicle park evolution projection [36]

Furthermore, experts argue that in case of Spain an impulse by the government is key for the transition. This impulse should be in the way of subsidies increases or a commitment to more restrictive policies regarding emissions. Some of the measures that could be implemented could be tolls exemption, tax benefits or even also, VAT reduction or exemption.

In addition, a huge coordination between technology, politics and economy is essential to achieve the so-called "electrification of transport" and the Zero emissions target.

3. PROBLEM STATEMENT AND METHODOLOGY

Once we have analysed the current state-of-the-art about electric mobility and we have commented the Spanish situation and future needs.

We are going to explain the problem to face. Spain has a great need to develop the public charging network at national level to ensure interurban mobility throughout the territory and therefore ensure the correct adaptation of the electric vehicle.

This project is presented as a useful tool in the planning of this network and as a starting point to implement in the development of the infrastructure ensuring the selection of locations efficiently and optimizing the resources.

To do this we will introduce a methodology that will allow us to make the right decisions in the deployment of the network.

It is important to mention that this project is completely innovative at a national level, since it starts from scratch. Therefore, there were no previous references or methodologies already used. This consideration should be valued since it is presented as a starting point with respect to the problem posed. In addition, the phase of obtaining data and analyzing sources has been especially critical when starting from the beginning.

The first step is to see the point where we are and the objectives we are looking for. The starting point is the absence of an electric recharging network throughout the Spanish territory, as the main barrier to interurban sustainable mobility. The need is to locate a certain number of locations ensuring the electric vehicle users to move around the main high-speed roads at national level, the six radial and transversal corridors (A1, A2, A3, A4, A5, A6, A66, A67, A8) and guarantee the possibility of traveling to all provincial capitals.

These recharging points should be located along the commented tracks, or at adjacent points located at a maximum distance from the roads. In addition, to optimize the network and ensure the degree of coverage these locations have to be located at a maximum distance of 100 km from each other and a minimum distance predefined according to the specific considerations.

In order to carry out this development, a methodology has been considered that allows the planning and implementation of the network.

This methodology is based on the definition of a mathematical model that allows optimizing the problem posed and the study of different tools that will help in decision-making, in the correct development and also be presented as the main database of inputs raised in the model.

It is important to understand that this is the starting point, therefore continuous improvements will be proposed to the methodology introduced with the aim of improving the final results. In addition, the complexity of this is going to be reinforced with the progress of the network.

On the other hand, it should be noted that the electricity grid has not been explicitly considered in this model, to reduce its complexity and facilitate the solution. However, the specific considerations and parameters of the electric network, specifically the distribution network have been analyzed in the proposal of the possible locations. In addition to this work a study has been developed on the dimension of the network its capacity at global level. During this step we have front the main problem, that in Spain, currently there is no study about the whole distribution grid in detail and obtaining this information is quite tricky.

It should be noted that in this first phase the development of the interurban network is only being considered, the urban network is not the object of this study, which does require an exhaustive study of the distribution network. In later phases, the urban network and therefore constraints and specific parameters of the grid will be included. In the following figure we can see the methodology proposed.

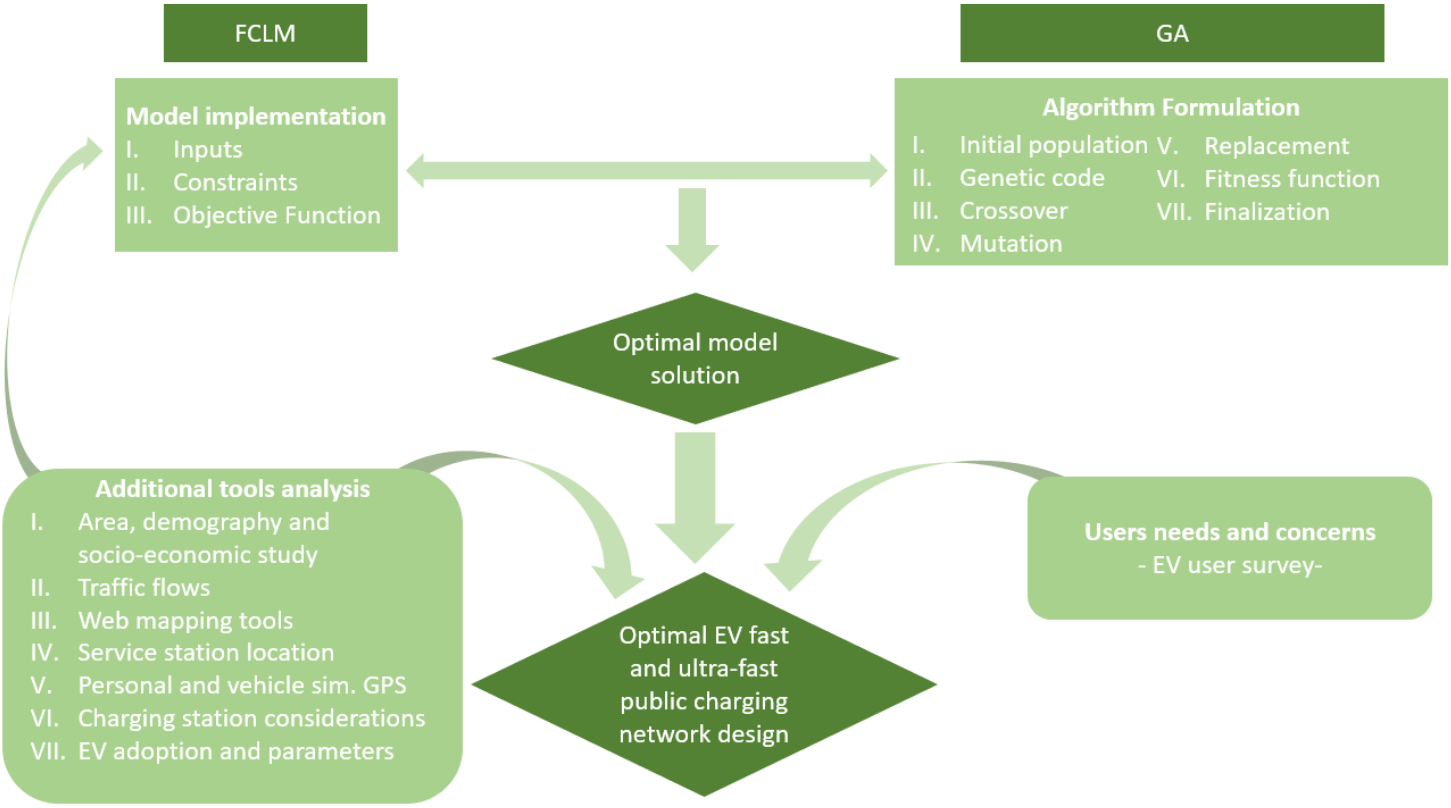

Figure 38. Project methodology. [own elaboration]

4. STUDY OF METHODOLOGIES FOR THE DESIGN OF THE EV PUBLIC CHARGING NETWORK

After having introduced the proposed methodology, we continue with the presentation of the proposed model, as the main tool in making decisions about how this electric vehicle ultra-fast public charging network should be built in an effective way. For this process we have considered different models as well as the tools or algorithms necessary to solve them. It is important to emphasize that in every process a Brownfield method have been followed, that is, starting from the existing facilities.

Firstly, we will introduce a literature review of the main researches about the siting and sizing charging station problem. For that purpose, we will consider several types of studies that has been done during the last years in order to ensure the correct implementation of electric mobility at global level.

Then we will continue with the study of possible models to consider in our project, analysing the scientific literature of the moment we have decided on the location models since this is a problem of location of charging stations this type of models works very well with the established problem. Within the location models we will study different possibilities.

On the other hand, we will analyse different heuristic algorithms since they are the most adequate to solve the type of problem that we have raised, NP-hard problems. It is important to mention that the analyses we carry out will be based on our own hypothesis and considering the main research work in the sector. However, we cannot affirm until the moment in which the algorithm is riled and tested with the problem, which is the most optimal solution and therefore the algorithm best adapted to the problem.

4.1. LITERATURE REVIEW

The EV network design problem has been highly discussed on last years. The charging infrastructure location problem is more complex than classical facility's one, as several parameters are specific of technology nature such as: long charging periods, grids necessities or battery characteristics. The existing literature of optimal location and sizing of charging points can be classified in two main techniques which are: Set-covering and Flow-capturing. The difference between both methods is how demand is considered, in first one through specific locations and the second one considers the refuelling demand on road. In the same way methods can be classified under the objective of the study:

The Flow Capturing method was firstly introduced by Hodgson [39], then Wu and Sioshansi [40]focus the research on the design of the location problem for public fast charging stations, when the number of stations is limited. They use a stochastic Flow Capturing Location Model (FCLM) to formulate the problem and finally to compute the expected flows captured by the charging points. Efthymiou et al. define the EV charging station locations problem and applied to solve the problem the origin– destination approach. Kuby et al. [41] presented a Flow-refuelling location model (FRLM) introducing vehicle range parameter and shortest deviation. Wang et al. [42] introduced a Flow capturing model minimizing total cost of the network design but ensuring coverture of demand. Li et al. [43] propose a heuristic-based genetic algorithm. Then Kuby et al.

[44] introduce the heuristics algorithms to solve the FRLC and analyse their behaviour. Cuiyu et al [45] introduced a three-layered system model for fast charging optimal locations. Obtaining in the first layer the location and then on second and third layer considering grid and battery characteristics constraints. MirHassani et al. [46] formulated the FRLM and present an adaptable MILP model to reach optimal solution for problems with small-medium size. Moreover, Andrews et al. [47] implement an optimization model using de vehicle tours data and minimizing the total distance travelled until candidates ubications. In the same line, Ji et al. [48] define optimal locations through travel data from ICE vehicles and considering range anxiety for BEV. Finally, this model is evaluated in Arizona and North Dakota. Bayram et al. [49] proposed a method of allocating a network of only fast charging stations, minimizing the cost function of charging capacity and speed of charging for the customer. Sathaye and Kelley [50] implemented a new way to locate charging stations on the highway. They introduced a continuous algorithm which minimizes the vehicle's deviations from the programmed trips.

Binjie et al. [51] defines a planning model for siting and sizing the electric vehicle charging infrastructure with temporal and spatial characteristics of the charging demand, considering real world data sets such as driving patterns and charging behaviours. Dong et al. [52] based its studies on real-world data from private vehicles, analysing origin-destination (OD) trips.

Other researches focused on increasing the efficiency. Zhang et al. [53] Analyse the efficiency increased while using multiple cables from one charging stations.

Some researchers investigate the charging network layout problem for the urban areas. Sadeghi Barzani et al [54] define a model that combines substation's locations, energy losses and total cost. Andrenacci et al. [55] proposed a cluster analysis of the demand to divide the entire network into several subareas. The centroids of each subarea would be an appropriate location for ubicate a charging station. Chen et al [56] introduce an optimization problem to design slow charging network in Seattle, WA. One of the most relevant is the one introduced by Frade et al. [57] Which recommend a maximal-covering model to ubicate level 1 and level 2 chargers around Lisbon, Portugal. Their works maximizes the EV charging demand base on maximum charging distance acceptance. Then Xi et al [58] also consider the number of chargers and the EV charging time. X. Tang introduce an optimization model which combines the searching ability of the Swarm Optimization and weighted Voronoi diagram. Firstly, an area is partitioned by Voronoi diagram and secondly the Swarm Optimization is applied to define the best distribution of charging points.

The are several studies in placing the charging stations that's consider power systems constraints such as network reliability, power losses etc. Xiang et al. [59] define a multi-objective optimization model for the electric vehicle layout through the distribution grid expansion. For the same purpose Dharmakeerthi et al. established a model that used a combine's power and voltage consideration to find the best locations in a power system analysing grid energy loss, and power flow. Neyastani et al. [60] present a two stage model minimizing the whole system costs allocating parking lots but considering energy losses and network reliability. Kristien et al. [61] introduce an optimal charging model to analyse power losses and voltage deviations an implement a system with high efficiency. Liu J. [62] Proposed a method to analyse the power grid impacts in the city of Beijing due to the EV charging network implementation.

There are also a lot of research work done dealing with the charging behaviour of EV drivers mostly focus on the users' requirements about the charging infrastructure. For example: Ralf Philipsen et al. [63] focus its study on customers evaluation of Fast- charging locations. This research is especially interesting because it considers urban and rural point of view and different criteria are proposed. Sun et al. [64] try to make a balance between power network constrains, charging behaviour of users and traffic flow, optimizing the location of charging facilities. Yang et al. [65] introduce a study to analyse the range anxiety influence on EV users and the chosen path.

Arias and Bae [66] applied a cluster analysis of driving and traffic patterns and also identified some specific factors of customers charging behaviour. Huang et al. [67] Introduce a location model that considers multiple deviation tours to introduce the drivers behaviours willing to deviate from the route to refuel Monica Alonso et al. [68] develop a model for EV smart charging management. Where drivers' behaviours have been used to determined mobility patterns and parking availability. Considering networks constraints and finally obtaining a charging schedule within the day. Furthermore, Investors point of view is also review by Liu et al, [69]who presented a mathematical model minimizing the total costs(investment cost, operation and maintenance cost) for the whole planning period.

Several methods of optimizing the performance and design of charging station infrastructure have been studied in the literature recently. However, the optimal layout of a whole country charging network has rarely been studied and even more, each country has its main characteristics and specially one like Spain.

4.2. ANALYSIS AND ELECTION

After having carried out a complete study on the different models and tools used globally in the problem of locating public recharging stations, we will present the most outstanding models and solution algorithms for further analysis with the objective of propose the most appropriate or adapted to our specific problem.

I. Model

We start with the choice of the most optimal model, all of them are the design set commonly called "facility locational models (FLM)", whose main function is to determine locations according to the predefined specific needs. This type of models has reached a high level of maturity in recent years regarding research on the location of recharging points in a certain area and have been presented as the main players in the formulation of this type of problems.

Within this set we have analysed different possible configurations in order to determine which of them best suits our problem (discussed in the previous chapter). The most relevant during the study were: p-median models, The Maximum Covering Location Model, The Approaches model and finally The Flow capturing location model.

-The p-median models try to find the best location for a predefined number of facilities, minimizing the separation distance between users and facility.

-The Maximum Covering Location Model (MCLM) maximizes the amount of demand covered by locating a given fixed number of new facilities.

-The Tour Approaches Model (TAM) are the most realistic one, about real tours with current demand.

-The Flow Capturing Location Model (FCLM), tries to maximize capture traffic flows if one facility is able to catch on-road any electric vehicle.

In the following table we have introduced the main considerations of our specific problem, and the different models' characteristics with the aim of analyzing how the different models introduced behave with respect to these parameters. This methodology is used to select the most appropriate method or that can best represent the problem posed, allowing to maximize the solutions obtained to those necessary for the interurban recharging network in Spain.

	P-MEDIAN MODELS	MCLM	TAM	FCLM	FCLM IMPROVED
Consider O-D flows	NO	NO	YES	YES	YES
Data requirement	Low	Low-Medium	Very High	Medium	Medium
Distance (facility-road) Radius coverage	NO	YES	YES	YES	YES
Max/Min distance between facilities	Problems with formulation	YES	YES	YES	YES
Type of demand evaluation	Node or located demand	Node or located demand	Flows or dynamic demand	Flows or dynamic demand	Flows or dynamic demand
Availability to implement shortest path	YES	NO	YES	YES	YES
Consider EV autonomy	NO	NO	YES	NO	YES
Coverage valuation	NO	NO	YES	YES	YES
Deterministic/Stochastic	NO	Bad adaptation	NO	YES	YES
Formulation problems with Min/Max distance between facilities	NO	YES	NO	NO	NO
Cannibalization*	YES	Controlled or avoided	YES	NO	Controlled or avoided
Complexity	LOW	LOW	HIGH	MEDIUM	MEDIUM

Table 7. Models comparison [own elaboration]

* The cannibalization problem occurs when facilities are so close together that they cover same demands, which result in other demand flows not being covered at all.

Finally analysing the previously established considerations for our concrete problem and studying the characteristics of each type of model, it has been decided that the model that best fits our needs is the FCLM improved, since it differs from the conventional FCLM, allowing to introduce the autonomy of the electric vehicle in the problem and therefore optimize the final solution taking into account this constraint.

II. Algorithm

After defining the most adequate model we have to study different possibilities to solve the problem and finally choose the most optimal option, considering the specifications on the problem previously commented.

As it has been demonstrated, the EV charging infrastructure location problem is clearly an optimization problem with high degree of complexity, mostly due the station combinations demands, the nature of the constraints and specifically the size of our model, implemented at national level which huge number of O-D paths and multiple possible combinations, considered as NP-hard problem. Therefore, heuristic algorithms have to be studied. To introduce a MILP model for solving the problem, it is necessary to generate previously all possible combinations of possible facilities for each tour, so that this solution is unfeasible considering the problem size and the different possible candidates. [70]

The heuristic algorithm has appeared on the last years as the main protagonist for solving location problems, among them the most experimented ones for this problematic are: The Greedy algorithm, the Greedy-adding with substitution Algorithm and the Genetic Algorithm.

-The Greedy Algorithms starts finding the first facility that optimizes the objective function, then add this facility to the determined set, and finally choose the next facility the one which, been combined with the already chosen facilities, will optimize the objective. Following this process until the predefined number of facilities is reached.

-The Greedy-adding with substitution Algorithm, substitute one facilities from the selected set with other facilities from the non-selected set after a new facility is added to the set. This process last until the maximum number of substitutions is reached or there are no improvements. This variation can improve the solution.

-The Genetic Algorithm is other type of heuristic one, that simulate the natural selection process in order to find the most accurate solution. Using GA to solve these types of complex problem requires some modifications on the algorithm design in order to be well adapted to the problem. This process entails greater complexity and time. However, this concrete characteristic allows the GA to be highly adapted and present specific characteristics for each problem.

In general cases, for this size of problems GAs tend to generate better solutions than the other algorithms, but spend more time running. Furthermore, in several researches it has been demonstrated that GA increase its efficiency respect to other heuristic algorithms when the number of possible candidates increase. The GA if it is well designed is able to obtain the optimal solution or a huge approximation. It is important to mention that the mutation process in GA sometimes suppose reaching worse solutions with longer run time. [71]

In same line, the Greedy Substitution Algorithm normally reaches better solutions over the conventional Greedy Algorithm solutions in most cases. However, do incur in higher running times. Moreover, the results generally improve with more substitution iterations.

	MILP	GREEDY ALG.	GREEDY SUBS. ALG.	GA
Possibility to be implemented	None, due complexity and size	YES	YES	YES
Addaptability to the problem	-	NO	NO	VERY HIGH
Stochastic procedure	.	NO	NO	YES
Type of solution	-	Single-Accumulated	Single-Accumulated	Population of solutions
Robustness	-	VERY HIGH	HIGH	VERY HIGH
Computational Timing	-	REGULAR	HIGH	HIGH-VERY HIGH
Improvement	-	None	Limited through substitution	Continuous through crossover, mutation and replacement
Solution	-	Low-good	Good	Optimal or good approximation

Table 8. Algorithms comparison [own elaboration]

Analyzing the different characteristics of the proposed algorithms and their behavior, we can conclude that the algorithm selected for our problem, mainly due to the nature of its results, the degree of stochasticity, the possibility of improving. all times due to its operators: crossover mutation and replacement. In addition to its ability to adapt or design with respect to the type of problem that arises, it is the Genetic Algorithm. However, an important factor to study during the formulation it is the high computing time.

It should be noted that the proposed choice is not final, and much work remains ahead, since the correct functioning of an algorithm depends on how it adapts to the model and the problem posed. Therefore, future studies should be done before affirming the superiority of GA against the other proposed options. In addition, improvements or specifications in the different areas can be introduced with the aim of improving the solution obtained.

4.3. FLOW-CAPTURING LOCATION MODEL

The Flow Capturing Location Model was firstly presented by Hodgson [39] in 1990, with the objective to introduce a new methodology that allow him to express the demand considering the flow and not static points. Hodgson defines the capacity of a determined facility to capture or catch some specific flow.

This model permits to determine the location for a fixed number of fast EV charging stations given a specific region to maximize the volume of EVs served by the whole network.

It is important to highlight the FCLM can be modelled as stochastic or deterministic. Through the deterministic way we can introduce difference number of EV and analyse how the model acts. On the other hand, the stochastic method tends to be much more interesting because the great uncertainty in EV future demand, through the stochastic procedure we can analyse different scenario tree. Some researchers as Tan et al [72] or [40] determined that stochastic models works better in this type of problem with high uncertainty on EVs flows and especially when the number of charging points is limited due a limitation of the investment cost. Especially interesting when the objective is to build an efficient charging infrastructure that ensure the correct EV adoption.

The main goal of the FCLM is to catch as much traffic as possible considering a limited number of charging points. So, from a centralized point of view it is preferable to locate the stations at the places where customers drive through, so as serving a large number of customers. [39]

The flow capturing location model can be simplified through the scheme provided in the Figure 39. Where B is a charging station and the circle represents its coverage range. A is the consumer location while Z1 and Z2 are two possible trip O-D.

Considering a conventional facility location problem, consumers from A are not covered because they are outside of facility coverage radius. However, with the FCLM, whether they are capture or not depends on the chosen trip. For customers through the Z1, they are covered by B. While if the chosen trip is Z2, they are not covered by B. [72]

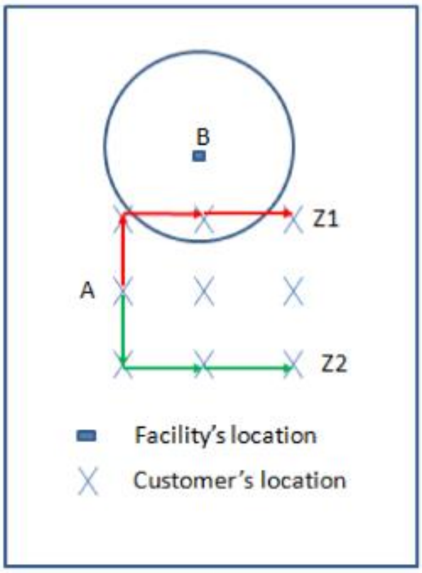

Figure 39.Flow capturing location model representation. [61]

We have proposed a modification from the initial FCLM, which includes the EV range anxiety parameter on the model, because FCLM does not consider this specific problem. So that this consideration has to be implemented on the model, the best way to do it is through a new constraint. It is important to comment that it is an own contribution.

In the FCLM several assumptions have to be done before being applied for a charging station location problem. [73]

- O-D and flows on each path are known.
- The facilities are considered with a predetermined capacity level and a coverage radius.
- Every path can only have a limited number of exit points (e.g. exits on the freeway).
- Paths are considered covered only if at least one of their exit points is within the coverage radius of a determined facility.
- Consider EV autonomy, so that several facilities have to be implemented in this same path considering this limitation.
- Information about the status of any facility is known by the customers.

4.3.1. Advantages and drawbacks

The FCLM is a model with a lot of experience and especially used in location problems so there will be no problems to adapt to our specific case. Furthermore, this model allows to work considering specific EV demands or, on the contrary, to model a scenario tree in order to analyse the uncertainty effects. In particular, the Flow capturing model works very well with large size of scenario tree.

On the other hand, this model allows us to compare different situations according to predefined considerations to obtain a very robust solution. Specifically, setting a specific number of locations or, on the contrary, establishing an investment limit is especially interesting for the overall design of a network.

Another great advantage of this model is the possibility of setting different levels of coverage, being able to determine multiple solutions based on the minimum degree.

Siting and sizing charging infrastructure problem is an oriented traffic flow one, so that FCLM permits to consider demand flows instead of static demands. Furthermore, it avoids the cannibalization problem, that occurs when locating facilities are so close together that they cover same demands, which results in other flows not being covered at all and multiplying the cost of not capturing other possible demands on the problem. [39]

Finally, an improvement on the basic model has to be implemented in order to introduce the EV autonomy constraint, considering the driving distance. The so-called “range anxiety constraint” which is a representative advantage for the model.

4.3.2. Inputs

The main inputs to consider in the FCLM are the next ones:

I. Traffic flows.

II. EV volumes on the whole charging network will be considered uncertains, so that this uncertainty will be implemented through a scenario tree. On the other hand, sometimes could be specially interesting to consider a determined number of EV in order to analyse robustness of the model. For that purpose, the number of EV by each region can be considered as approximation. Or knowing the total vehicles flow an approximation of EV shares can be done.

III. A limited number of possible locations for charging points.

IV. O-D. Consider specific origin and destination tours.

V. Rent per capita.

VI. Any assumption introduced considering EV users driving and charging patterns.

VII. Main road networks, that captures most vehicles and the major intersections. Information easily obtained from the corresponding minister.

VIII. Specific tour data recorded: O-D paths and time spent.

Other secondary inputs data with relevant information can be socioeconomic and demographic factors for the EV adoption. The geography of the area and the highly interesting points.[40]

Furthermore, if we want to consider the budget limitation. We can do it in two different ways. Introducing a new constraint, the budget constraint. Or in the case that we want to minimize the total cost, due to this budget limitation which is especially interesting in order to define a business plan, the objective is to minimize the total cost of installing our fast charging network given a minimum amount of flow to be captured. Therefore, the number of charging point is not predefined and is the model which determine it, we only have to set the charging point cost, considering different types of stations and the minimum level of flow captured. [74]

4.3.3. Main constraints

I. Binary variables constraint.

II. Maximum distance between two possible locations.

III. Minimum distance between two possible locations.

IV. Coverage radius.

V. Range anxiety constraint.

VI. Facility capacity constraint.

VII. Design constraint.

VIII. Budget constraint.

4.3.4. Model implementation

The FCLM is normally considered through two stages or phases and as it has been mentioned stochastic models normally works better for charging location problems. Therefore, a stochastic mixed-integer two-stage problem is considered.

In first phase, the objective is to locate a fixed number of charging stations. This is done based on the importance of the location and its capacity to capture electric vehicles through the route. This first stage is determined with an objective function that maximized the expected number of EV captured. As we might know, this problem considers as a main constraint the limited number of charging stations and the two binary decision variables of the model are the following: x (If the facility k is located) and y (that express the captured paths by the facility). [74]

As we have mentioned these models tends to work better with stochastic number of EV. So that, in this secondary phase, once we have the location of charging points, the number of electric vehicles captured by each charging station is determined considering several scenarios. In these scenarios, different volumes of vehicles are considered.

In this second stage, the result is determined through an objective function maximizing the EVs capture under complete uncertain scenarios of EV flows. For that, different constraints have to be implemented like the ones following. [72]

-Charging station and EV relation.

-Time of delay.

Furthermore, several assumptions have to be implemented in our model. One of the most important one has been previously introduced:

-EV drivers will follow the shortest path, knowing the speed if not, the minimum distance path.

-An EV can only be captured by a charging facility if it passed within a fixed distance, the coverage radius.

-EV drivers will be willing to charge if its vehicle battery SOC falls below certain range.

An extra step could be determining the correct number of chargers. This problem is widely known as “charging station size”. To reach this objective, an approximation of the facility capacity can be defined estimating the number of electric vehicles waiting to use a specific charging stations, through the queuing time.

For that purpose, we can assume the starting point of every battery and then we simulate the SOC during a whole day. Furthermore, we have to define a SOC threshold, so that every driver will use the first charging points below a considered distance (the coverage ratios) from his planned route. Then, the charging duration time will depend on the charging station capacity defined and the SOC of the EV battery.

Finally, determining the cumulative probability of use for a determined charging station we can calculate the necessary number of chargers. Even also, this determination can be done using several discrete charging points capacities (50 kW,100 kW,150 kW, 350 kW), in order to determine the most correct one for each specific location. [73]

This last part of the model is especially interesting for a whole network.

It is important to highlight that another middle step can be done through a cost minimization method, where we optimize the number of facilities considering a limited budget, so that following this methodology, instead of considering a limited number of charging points we consider the charging stations cost, a minimum level of captured vehicles and we minimize the total cost. Therefore, we finally obtain a list of specific locations that ensure to cover a predefined level of capture.

4.3.5. Results

The FCLM is a very interesting tool for the design of the network of public charge because it allows adapting the model to the specific characteristics that we look for, in addition as we have seen also allowed to design different phases depending on the final objective of the model. Either only determine the location of a predefined number of locations or set a global limit cost and that the model itself determines how many charging stations and where they have to be located. [74]

The main importance of FCLM improved is its better representation of demands than nodes locations one, especially for the RP publication problem. Furthermore, this model can provide huge benefits avoiding the cannibalization between facilities.

It is important to comment our contribution to the model, implementing the EV driving distance limitation trough the "range anxiety" constraint.

Moreover, this type of model is very interesting for the design of the network since it allows to obtain an optimal solution considering a high degree of uncertainty through the different scenario tree. This characteristic is especially important considering that there is no guarantee of the future number of EV in the national territory, even more, the correct development of the network will allow the future introduction of the electric vehicle. Moreover, when consider a limited source or a budget constraint, the stochastic problem provides a more robust solution. This is mostly because with budget constraint marginal stations are not build while the most relevant one are. [72]

On the other hand, another very important tool of this type of model is that it allows to obtain an approximation of the size or characteristics of the charge points, which is especially important for designing a national charging network.

So, by implementing different phases or steps for the same problem, we can see how the optimal solution varies depending on small changes in the network due to variations in the defined budget, in this way the most optimal solution can be reached depending on the predefined specific characteristics.

In conclusion, FCLM improved have been presented as a perfect option for the EV public charging network layout with high degree of robustness. Moreover, this model works very good with basic available information as an input data. [40]

4.4. GENETIC ALGORITHM

Once we have defined our problem, we have to decide the best algorithm to find the solution, for that purpose and due to multiple reasons, that have been explained before, we have chosen the Genetic Algorithm.

Genetic algorithms were born in the 1970s from the hand of John Henry Holland and first introduced by Hopgood and Goldberg to solve constrained and unconstrained optimisation problems. They are a mathematical tool used in optimal search problems based on a random heuristic.

GAs is based on natural evolution processes, simulating Darwin's natural selection (1859). The initial population will change through emergent variations of crosses between the fittest ones and mutations, which are clearly inspired by natural sequences. That means, through natural and genetic evolution.

The Genetic Algorithm is able to create solutions for real world problems. It encodes a specific problem on a chromosome, applies to the population genetic processes and then, generate new offspring. Finally, using a fitness function it preserves the best individuals. So in conclusion, it determines the best solution to the problem.

In Darwin's theory of evolution, a set of individuals form an initial population that inhabits a determined environment, in this specific environment, an individual is considered more or less suitable depending on their ability to adapt and progress in it. In this environment resources are limited and therefore individuals compete for survival. The better adapted beings, or with some evolutionary advantage, will have a better chance of subsisting and surviving. Therefore, they can get to reproduce, and in this way transmit those advantages to their offspring.

On the other hand, improvements may appear due to the natural mutations of individuals. Genetic mutations are changes produced spontaneously in the genes of a given individual. As a result, the population is not static, but changes over time. Improving always, thanks to the selection of the best individuals or the most adapted to the environment. Next, we will define the main factors in the evolution process.

-Initialization: Defines the first population that will live in a specific environment. The individuals are very diverse as well as their level of adaptation to the environment.

-Natural selection and adaptation: This process represents the competition of individuals to survive. The best is more likely to survive and reach the stage of matured to be able to reproduce. On the other hand, the less adapted will be defeated in the competition and therefore disappear without generating descendants.

-Crossover: The crossover is the reproduction between two individuals by which new individuals are generated that contain characteristics of both parents, that is, the genes of the parents combine to give rise to the genes of the offspring. This combination can lead to multiple crossing operators. The result of this mixture of genes does not have to suppose a better result than its predecessors.

-Mutation: Random appearance of new genes in the members of the population.

-Replacement: The inhabitants after a while age and end up being replaced by their descendants. This process is necessary for the progression of the population, reaching higher levels of adaptation as a result of the survival of the individuals that are best prepared to the environment.

-Finalization: This phase indicates in what conditions the process of evolution ends. The conclusion may correspond to reaching a certain level of adaptation or surviving a predefined number of generations.

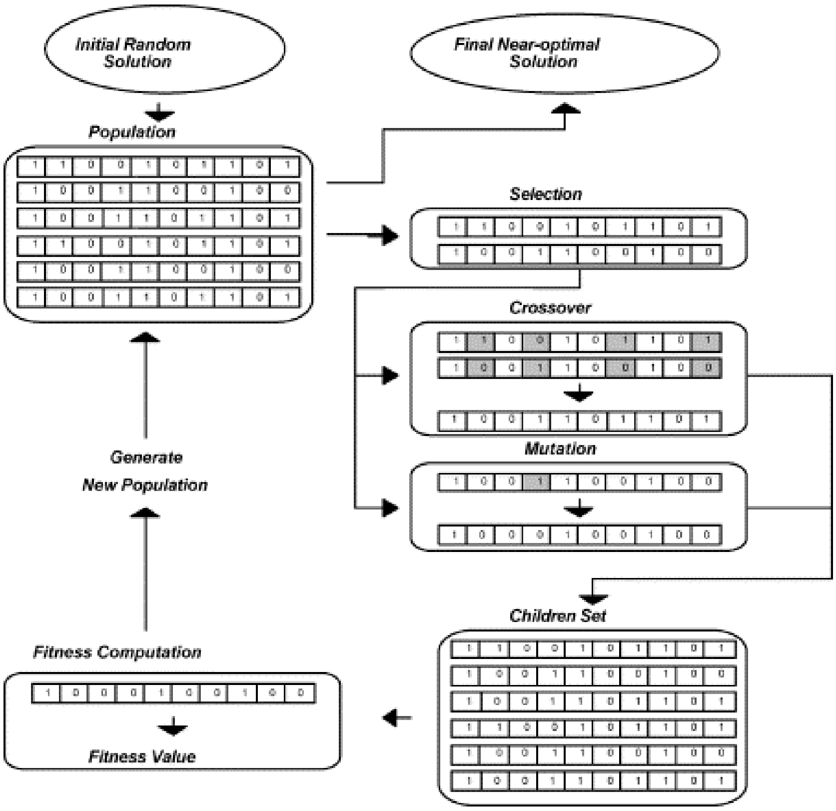

Figure 40.Genetic Algorithm structure. [75]

The application of GAs has received remarkable attention on the last years because of the difficulty of extending conventional optimization techniques to complex problems and assessing the problem in almost real time. For this reason, GAs appear to be an optimal algorithm for the EV charging infrastructure layout problem. The main reason is that, the siting and sizing problem is a NP-hard problem. [76] So that, a heuristic algorithm will be better adapted instead of an exact algorithm, which are inactive for several variables and constraints. [77]

Furthermore, the GAs has been introduced and experimented for specific charging facility location problem. Ge et al. implemented a methodology for EV charging locations, through grid partitioning and GA .In the same way, Dong et al. [52] studied the electric vehicle charger location problems, using a genetic algorithm to minimize range anxiety, employing GPS data from vehicles in the metropolitan area of Seattle.

4.4.1. Advantages and drawbacks

The main advantages that present this type of algorithms and make it very interesting in the optimal design of the public charging network problem are among others: High speed of the process, simplicity of the coding, If the representation is correct, we can find a solution without a very deep work. They also offer great flexibility to consider multi-objective functions and they are able to work efficiently with several constraints in a simultaneously way.

Furthermore, GA is a robust technique that works very good for problems of very different nature and has a high degree of flexibility, dealing with non-linear and non-convex problems. They can work with a set of possible solutions, called the population, that are modified at each stage or generation. The Genetic algorithm do not require starting information to begin the optimization process because they work with genetic codes or chromosomes, which will be optimised through the objective functions and the corresponding constraints. GA has the ability to explore several regions in the space simultaneously by using multiple points of the global population. This can be the most important advantage from traditional algorithms, which can only follow one direction in the search space. [78]

Other relevant characteristic is the selection process. The best individuals are selected among parents and offspring, making this process more likely to converge in a global optimum.

Another secondary advantages could be implicit parallelism, low data demand, no restriction for search space and existence of derivation.

On the other hand, Genetic algorithms also present multiple disadvantages: random heuristic, so there are times when finding the optimum is very difficult. It is not a complete algorithm. It may get stuck with local maxima in certain circumstances. In some cases, GAs require more time to determine a solution than other optimization algorithms. [71]

Moreover, the running time depends strongly with the mutation rate, so considering an optimal mutation rate is very important to obtain a good solution of the problem while the calculation time does not get too much. This process increase complexity for the GA.

4.4.2. Steps or Formulation

As we have mentioned before, GAs are stochastic techniques based on the mechanism of natural selection and the survival of the fittest. The number of possible combinations in the FCLM grows exponentially with the number of nodes and possible location. This is the main reason to decide using a Genetic Algorithm for our problem rather than other types of algorithm which tend to work worse. [79]

The Genetic Algorithm begin his formulation with an initial set of solutions commonly called the population. Each individual within the population is called a chromosome and each one represents a solution to the optimization problem. A chromosome is a chain of digits or symbols; in some cases, is a binary chain. The generations involve several successive iterations. In each generation the chromosomes are evaluated trough the objective function or fitness function.

The following generations will be created through new chromosomes or offspring. The offspring can be created by means of two different processes:

-Merging two different chromosomes from the current generation using a crossover process.

-Modifying a chromosome through a mutation.

So that, a new generation will be formed from this population by selecting some of the parents and offspring that comply with the fitness and rejecting the other. The population size has to be constant always. The natural selection process is produced in the next way. Fitter chromosomes have higher probabilities of being selected. Therefore, after several generations, the most optimal solution will converge, representing the optimum or suboptimal solution to the optimization problem.

Two termination criteria are implemented in the GAs to end the iterations:

-The GA converges. So after repeating the whole iteration several time, the best solution does not change.

- The GA had been executed x number of interventions, defined previously.

On the next figure we can appreciate the algorithm whole structure. Which will be explained also in the next section.

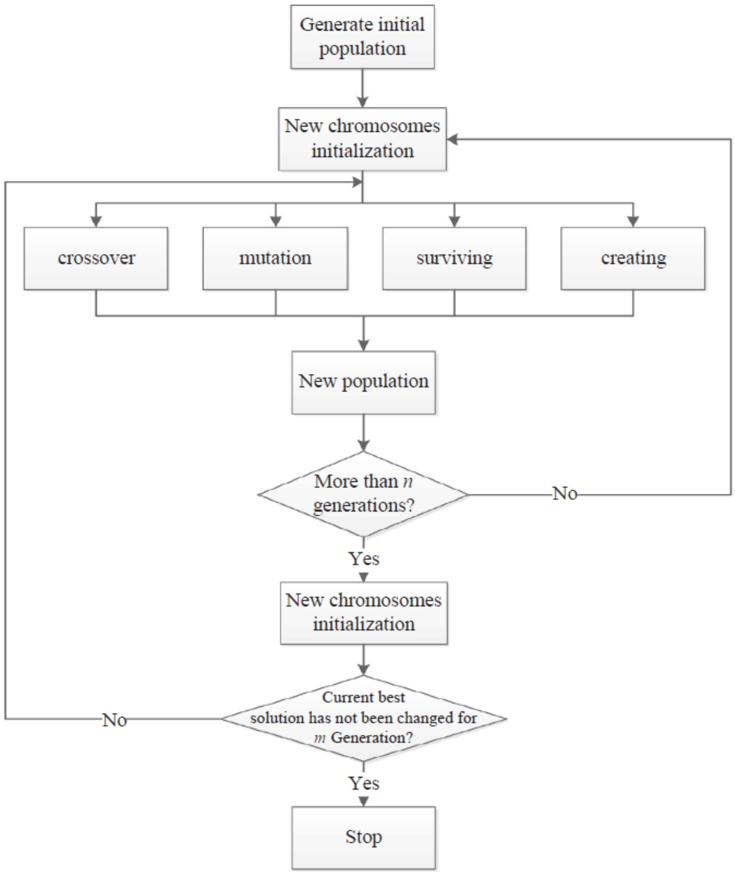

Figure 41. GA flow chart [80]

I. Initial population.

The initial population is defined by randomly picking elements from the combination set. Then a chromosomes population will be created. The population size depends on the number of possible combinations. It is important to specify that small populations will not guarantee the diversity of the population, while very large populations will produce unacceptable times of calculation. The ideal situation may be the one where the population is enough to contain every possible combination.

II. Genetic code.

Also called, Chromosome coding. In this process, we create the population of chromosomes. For the EV charging location problem the chromosome will be a binary string with a specific length, the number of possible charging stations. This binary string can be easily understood in Figure 42. So that, the charging points are consider as genes of the chromosome. For example, a specific chromosome will be encoded as {01010111} for eight locations, where station 2, station 4, station 6, station 7 and station 8 will be deployed.

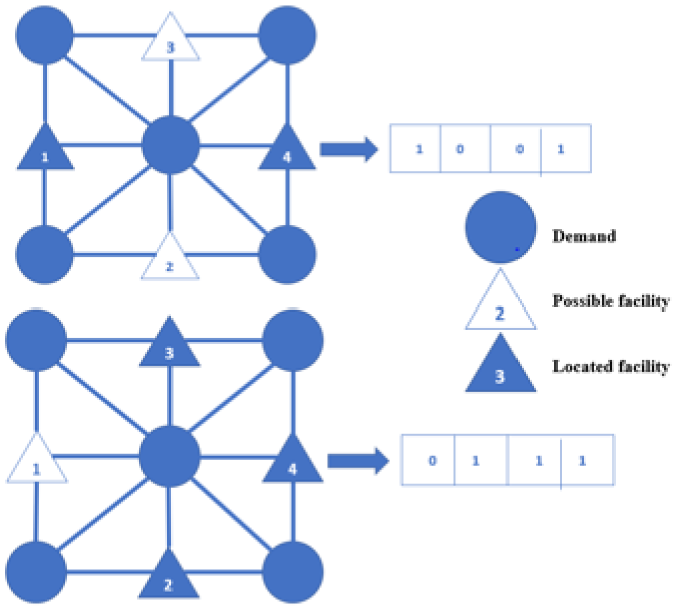

Figure 42.Binary representation [own elaboration]

Moreover, a second layer in the chromosome can be introduced, in this second layer the size of the station is encoded. We follow the same principle, a binary code where the scale of the station can be 0 or 1. In the next figure we can see the chromosome structure, known as two-layer chromosome.

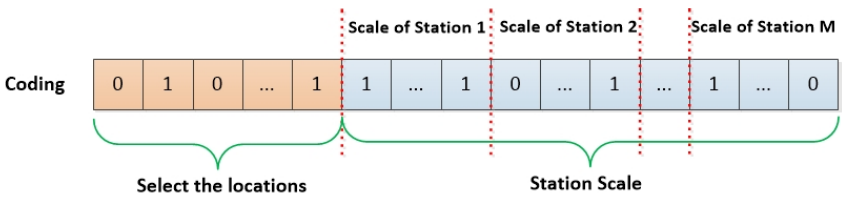

Figure 43.Two-layer chromosome [79]

III. Crossover

As it has been mentioned, the crossover process is to generate new chromosomes by exchanging part of chromosomes with other chromosomes. Through this operator, two chosen chromosomes will exchange a part of code. The exchanged partial proportion is known as crossover probability and is pre-defined.

Specifically, for the EV the main used crossover operator is the fitness-based function, because this operator is better adapted to generate new solutions when the two parent solutions have very similar structure. This operator allows to define very different structures for the charging problem and allows to obtain better results. Nevertheless, the possibility of obtaining quite similar offspring to one of its parents still remains in the problem.

IV. Mutation

Mutation changes some of the chromosome's genes, helps in exploring new area of solution space and provides an opportunity for the combinations that are not in the current population. Moreover, Mutation is a very effective way to avoid local optima, preventing solutions to be trapped in these local maximums or minimums. Following this methodology, we can define two types of mutation operators:

-Complete random mutation operator, which works by selecting randomly one of the charging points and moving it to another site. This new site is also chosen randomly from the possible places to locate new facilities.

-Restricted mutation, where the locations that participated in the mutation process are limited, with the idea of only considering nearby locations. This method allows improve the correct location, avoiding non feasible solutions.

V. Replacement

The replacement process consists on the substitution from one generation by other generation.

We can find two main options to do this:

-Generational replacement. The new population of offspring will replace the whole parent population.

-Incremental replacement. The offspring solutions will replace the less fit members of the population. So that, the average fitness of the whole population will improve with the iterations. Using this method, the best solutions are always in the population.

VI. Fitness function

The fitness function in the Genetics Algorithms measures the goodness of a solution to the considered objective function and evaluate the performance of each genome in the population.

The fitness function is determined through the objective function of the model, which normally considers an economic efficiency as reference. The best economical individuals have priority to the ones with less economic efficiency. So that, the algorithm keeps the chromosomes with the minimum fitness value.

VII. Finalization

The algorithm only terminates if the best solution does not change for a several iteration or number of generations, this guarantee reaching the best solution until it cannot be improved. Nevertheless, we can reach a problem when the algorithm reaches a local optimum. The other way to finalize occurs when the number of generations reaches a predefined number.

In order to confirm the best solution, not being a local optimum it is highly recommended in FCLM to combine both strategies. [79]

4.4.3. Results

As it was mentioned before, due to the nature of the problem: NP-Hard problem, which has been demonstrated by Berman et al. [76], the heuristic algorithms are better adapted and in particular the GA is presented as an especially interesting option due to its specific characteristics, previously commented. [81] Its high degree of flexibility and coding for each problem is very important and will allow us to attach multiple features to our locations. In addition, the Genetic Algorithm is a very robust algorithm with great adaptability. [80]

On the other hand, a difficulty in the behaviour of the Genetic Algorithm may be the existence of a large number of local optima, as well as the fact that the global optimum is very isolated. Moreover, it is important to highlight that in general terms, the GA can perform better with no mutation. This behaviour was demonstrated by Alp et al [54]. However, we have to remember the algorithm with no mutation could reach a local optima, obtaining an incorrect solution. [77]

The results obtained in several researches show that the EV charging stations design based on GA are simple, practical, highly adaptable, very scalable and optimal. However, we must keep in mind that a lot of work has to be done to affirm the suitability or superiority of this type of algorithms.

5. OTHER ADITIONAL TOOLS

Other very important tools that will help us designing correctly our public charging network, are the following ones, besides many of these tools will be likewise the source of inputs for our future mathematical model. Among the main tools we highlight.

5.1. AREA, DEMOGRAPHY AND SOCIO-ECONOMIC STUDY

I. Area

The development of an optimal public charging network requires the study of the specific area in which the network is going to be developed.

In our case it is the whole of Spain, for it we will differentiate three sub-areas:

-The Iberian Peninsula.

-Balearic Islands.

-The Canary Islands.

The study of the area entails an exhaustive study of the main cities, urban centres, connection routes and other points of common interest. The main tool to be analysed in this phase will be the database of the Ministerio de Fomento y el Instituto Geográfico Nacional (Centro Nacional de Información Geográfica).

For this development we are going to consider a Brownfield methodology, that is, the already active installations are going to be considered, as it is shown in Figure 44 the installed RP will be taking into account. In this way the set of roads of the state will serve as a reference to develop our network. Specifically, high-speed interurban roads such as highways and motorways will be our starting point.

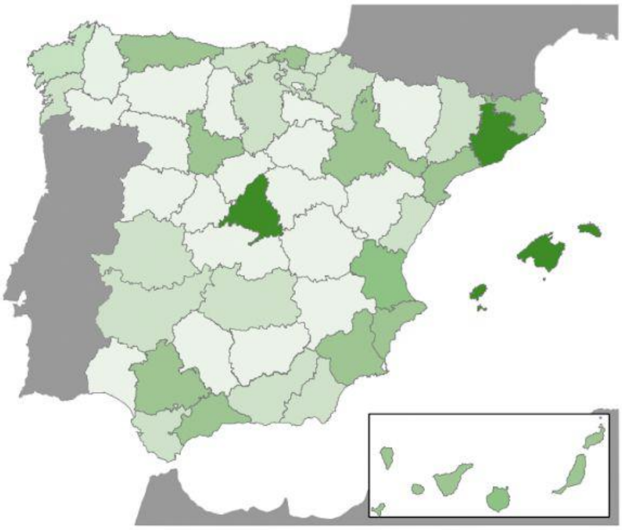

Figure 44. RP Distribution [82]

One of the methodologies that is being developed at the geographical area level and that greatly facilitates the concrete analysis of the needs of the network is the method known as the area / grid partitioning. That consists of dividing a specific area into multiple subareas of a specific size, allowing the detailed analysis of the specific characteristics of each zone. Furthermore, this methodology allows classifying the set of areas and their needs by priorities.

Moreover, if we consider a certain number of possible recharging points due to budget constraint, it is especially interesting to divide the study area into a number of areas equal to the charging stations. This methodology is very well explained in the document by Shaoyun et al. [83]

Regarding more technical indicators, it would also be very interesting for the public charge to locate the CUPS and the low voltage transformers. In this way, we can know very predisposed locations and with great accessibility. This type of data can be obtained through the corresponding DSO. Furthermore, the possibility of mapping this data will be a highly useful tool.

II. Demography and socio-economic study

Once the development area is studied, the next step is to consider the demographic profiles of the country, in order to analyse the whole population, for this we will use the data provided by the Instituto Nacional de Estadística (http://www.ine.es/).

The study of Spanish demography for our specific objective, will focus on the population by Autonomous Community, the concentration of the population globally and migration to cities.

On the other hand, the socio-economic study is especially relevant when analysing the introduction of the electric vehicle in society and therefore its needs. For this we have multiple sources such as The Organization for Economic Cooperation and Development and El Ministerio de Fomento. Another source with greater relevance for this study is the Institute for Energy Diversification and Saving.

These sources will be implemented as input data on the model.

5.2. TRAFFIC FLOWS

The vehicles intensity and the traffic flow are one of the main tools to be analysed in the development of an efficient recharging network. This study is especially important because it allows us to determine real flow values, a determining factor in the location of charge points as well as we can analyse locations with high concentrations and areas of high traffic intensity. Obtaining this information comes mainly from:

Ministerio de Fomento(https://www.fomento.gob.es/carreteras/) The data with more relevant information is the IMD (Average daily intensity measured in vehicles / day).

Dirección General de Tráfico(http://infocar.dgt.es/etraffic/)

The sources of information presented will be introduced on the model in order to consider the flows of traffic in the system.

Specifically, this study will be divided into two main phases:

I. The main roads of communication and state corridors: Autovía del Norte (A1); Autovía del Nordeste (A2); Autovía del Este (A3); Autovía del Sur (A4); Autovía del Suroeste (A5); and

Autovía del Noroeste (A6). And the three main corridors within the peninsula: Autovía de la Ruta de la Plata (A66), Autovía del Mediterráneo (A7), la Autovía del Cantábrico (A8).

The commented routes can be introduced in the model as the main O-D routes.

It is especially important to study different stretches or tracks in the same highway to analyse where displacements are concentrated e.g: A1 (Madrid-Aranda del Duero-Burgos-Miranda de Ebro-Vitoria).

II. Zones of high concentration of vehicles at the departures of major cities: Madrid, Barcelona, Valencia, Bilbao, Seville etc.

5.3. WEB MAPPING TOOLS

This tool consists of using a geospatial database and the ability to visualize this data in the form of maps. Therefore, it refers to the process of designing, generating and visualizing geospatial data for the subsequent analysis and study. Defining its main characteristics, we can affirm that it is a very interesting instrument and that it can be used and even linked to the mathematical model, afterwards the results of the model can be interpreted visually.

In addition, analysis can be carried out from the user's side, which is especially important to consider the future clients of the public charging network. This tool allows to design personalized maps considering specific characteristics of our network and even of certain areas.

For this process geographic information systems (GIS) are used. This allows the organization, to storage, manipulate, analyse and model large amounts of data from the real world that are linked at every time to a spatial reference and finally edit this data in the form of a map to analyse the spatial information and show the results. An example on that is the next figure.

Iberdrola sustainability's mobility plan [84]

5.4. SERVICE STATION LOCATION STUDY

The study of service stations or petrol stations within the same company in the national territory is a tool especially interesting to know the relevant locations as well as areas of interest.

However, it is important to keep in mind the differences between the business model and the characteristics of the petrol or diesel refueling with the electric charge. Among the main differences we can highlight: Homogeneity of gasoline service, with respect to the degree of heterogeneity of electric mobility (types of charge, different charging powers, etc.), service times or specific needs of the process.

This tool allows us to know specific areas with high supply needs due to traffic flows, proximity to large cities or concentration in a certain road. In addition, both services have the same characteristics of accessibility and additional services. For this study we can use the database of companies as:

-CEPSA : [85]

-Repsol: [86]

The selected ubications can be the first source of possible candidates ubications in our model, in order to analyse the model functioning.

5.5. PERSONAL AND VEHICLE SIM. GPS

This innovating tool is highly valued, using data from personal SIMs and SIMs incorporated in the vehicles to be able to know movement flows, interesting locations or high-fluency stop points. This information is recorded by the latitude and longitude coordinates through the geographic positioning system. Furthermore, these instruments allow to stablish socio-economic profiles, categorize the population, analyse several temporary stripes.

This study can be done through the accumulated data by the SIMs identification from different telecommunication companies, obtaining very enriched information that can be very useful for our work, allowing the possibility to introduce different interesting point which at the beginning had not been contemplate. Other option is deciding to build RP with higher capacity where the movement flow studies reflects that huge concentrations are stablished.

Moreover, much of this data can be considered as inputs data for the mathematical model increasing the value of the final solution obtained.

5.6. CHARGING STATION CONSIDERATIONS

During the design of the public charging network is very important to consider the specific characteristics of the charging points that want to be installed. The main factors that define the charge point are: its charge capacity or charging power, compatibility with standards (CHAdeMO, CCS, Type 2 etc.). It is also important to highlight the modularity of these systems, since in certain locations, it will be especially important to connect several recharging points or, failing that, to install higher capacity points.

Therefore, multiple equipment providers have to be contacted in order to decide the best solution for our grid and the most competitive manufactures: Circuitor, Ingeteam, EFIMOB.

5.7. ELECTRIC VEHICLE ADOPTION AND PARAMETERS

The presence and future penetration of electric vehicle is a decisive factor in the development of the public charging network. It is very important to consider the number of users of the future charging infrastructure, so this study has to analyse the sales and registration of electric vehicles in the country, as well as develop an estimate of the penetration curve for the coming years. This penetration depends strongly on the correct design of the network so, as we have already commented previously, we find the chicken and the egg problem.

The previous estimate plus the fixation of an estimated ratio of electric vehicles per recharging point will allow us to obtain an approximation of the required charging points.

A parameter that will also be relevant in the correct design of the public recharging network is the study of the current technology of electric vehicles. Generally, charging points and electric vehicles share compatibility standards. But even so, it is very important to analyse VE's current fleet and its projection to analyse the main needs of the final customer. Among the main characteristics to be determined are battery sizes, maximum charging powers, and charge acceptance curves.

Through the Spanish Association of Automobile Manufacturers and Trucks and their most up-to-date information we can know the registrations of electric and hybrid vehicles by autonomous community in 2017 and thus analyse the introduction of the EV by regions. This data is reflected on Table 9 and Table 10.

Autonomous Community	2016	2017	Variation
Andalucía	3.820	6.539	71,18%
Aragón	793	1.264	59,39%
Asturias	439	722	64,46%
Baleares	748	1.336	78,61%
Canarias	540	768	42,22%
Cantabria	336	518	54,17%
Castilla y León	1.019	1.964	92,72%
Castilla La Mancha	647	1.239	91,50%
Cataluña	6.818	4.855	72,31%
Comunidad Valenciana	2.688	2.152	80,62%
Extremadura	371	631	70,08%
Galicia	1.294	358	66,31%

Madrid	9.092	17.941	97,33%
Murcia	643	1.143	77,76%
La Rioja	229	358	56,33%
Navarra	301	492	63,46%
País Vasco	1.196	1.935	61,79%
TOTAL	31.046	55.769	79.54%

Table 9. Share of PHEV among AACC [87]

Autonomous Community	2016	2017	Variation
Andalucía	217	448	106,45%
Aragón	53	94	77,35%
Asturias	48	83	72,92%
Baleares	139	253	82,01%
Canarias	167	280	67,66%
Cantabria	20	45	125%
Castilla y León	78	163	108,97%
Castilla La Mancha	118	156	32,20%
Cataluña	1.213	1.951	60,84%
Comunidad Valenciana	194	384	97,94%
Extremadura	19	45	136,84%
Galicia	55	151	174,55%
Madrid	2.200	4.123	87,415
Murcia	48	81	68,75%
La Rioja	7	26	271,43%
Navarra	35	57	62,86%
País Vasco	136	294	116,18%
TOTAL	31.046	55.769	79.6%

Table 10.Share of BEV among AACC [87]

6. ELECTRIC VEHICLE USER SURVEY

6.1. INTRODUCTION.

This chapter presents a survey designed to learn and analyse the customer's behaviour and their points of view about the transport electrification in Spain.

The objective of the survey is to analyse, from the point of view of the end user, their habits and preferences in the use of electric vehicles and public infrastructure, drivers' profile and driving patterns and finally, some of the main problems in electric mobility today.

This survey can be very useful to know the user's needs and their future perception of the network, in addition to main clients concerns. The obtained results can be implemented in the model as inputs or even also can be considered as relevant information to taking into account during the development of the network.

The survey consists of two parts, one of a general nature and the other specific on public charge infrastructure. The results obtained will allow us to better understand the market needs and the main problems that must be faced and finally the future solutions that must be offered.

6.2. METHODOLOGY AND DESIGN OF THE SURVEY

The survey design starts with some common questions for a typical electric vehicle user, in order to know the patterns, the main considerations and concerns of a driver in Spain. Next, more specific issues of the public charging network and the possible needs are analysed.

This second phase is especially important because it can serve as another tool or even an input in future mathematical models to efficiently design the public charging network.

It is important to highlight that the users of the survey are people with a medium-high knowledge of the electric vehicle, the infrastructure developed to date and the most recent advances in technology. This target population was shaped by different types of professionals working in several business areas of an energy utility very conscious and committed with the environmental protection, the sustainability and the energy efficiency. Concretely this people live in Madrid, Bilbao and Valencia having purchased an EV ranging from 2016 to 2019.

The method selected to develop the survey was via online in order to facilitate their access and management. The survey was sent via a URL code in an email with a covering letter explaining the main points of the survey and its goals. Another of the main characteristics of online surveys is their cost, none as well as their high degree of privacy. The anonymity is ensured and very important to guarantee honesty answers, because there is no possibility of identity traceability.

The survey was carried out in Survey Monkey platform, a tool widely used and well known by people, which facilitated its acceptance by users. [88]

The whole the questionnaire was designed respecting the following criteria: clarity, ease to understand, objective and briefness. The survey is mainly based on three types of questions: answer questions, multiple choice and ranking. It was established that all answers must be answered to complete the survey, with the aim of guaranteeing useful and representative results.

The design of the survey was always supervised by my internship supervisor and the corresponding department. For more information, the survey has been attached in the annexes.

6.3. RESULTS AND INTERPRETATION.

The survey was launched on May 25th and closes on June 20th. The survey has 83 responses, that is, 72,3% of the potential population. Analysing the numbers, we can consider it a very representative survey with a high degree of response. To analyse the survey correctly and to be able to counteract results we will do it by questions.

During the results analysis we will compare and mention some differences with one of the main sources of user's considerations, "Encuesta Nacional de Usuarios de Vehículo Eléctrico" developed by All Media Consulting, Electromaps and with the sponsorship of Iberdrola. This survey collects the opinion from 1312 electric vehicle users throughout the Spanish territory. [89]

1. What brand and model of EV do you have?

As it could not be less, the first question had to study the main models of the market. To see how the state of the electricity sector is nationwide.

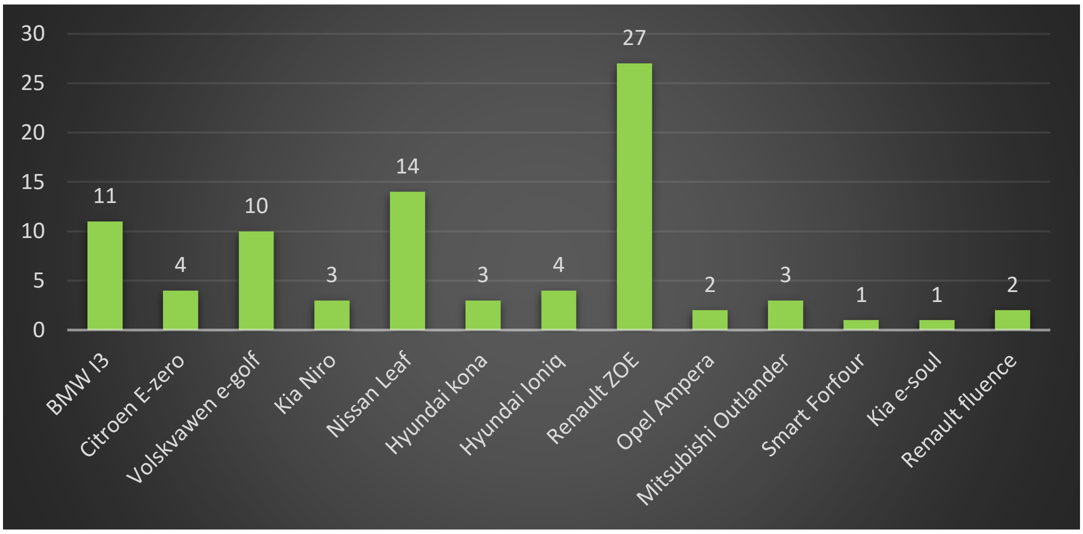

Figure 45. EV share among the users

The result obtained is quite expected, in which we find as main models, the most widely sold nationally and internationally Renault ZOE (25.500€) and Nissan LEAF (33.750€), due to its high performance and autonomy for a very affordable price. The main difference between both values is because the ZOE is quite cheaper. In addition, other models with great reference and a certain degree of experience Volkswagen e-golf (38.500€) and the BMW I3(39.500€) tends to be also representative. Other models are almost new in the market.

It is important to note the difference between 100% electric and hybrid models. Obtaining an 87.6% in BEV, considerably more than the remaining 12.3% of PHEV. It should be noted that the final number is 85 models with respect to the 83 responses, this is due to the fact that two users had two electric models.

The results obtained agree with those obtained by the "Encuesta Nacional de Usuarios de Vehículo Eléctrico", with the exception of the Volkswagen e-golf the vehicles with the highest score are Nissan Leaf, Renault Zoe and BMW i3. [89]

2. Month and year of purchase

In this question we only receive 79 answer, so that 4 users decide not to answer or did not remember the specific data. However, we have one user that has two EV so finally 80 dates.

The first result to be highlighted is the increase in the purchase of the electric vehicle in recent years, with respect to the first reference data, 2016, specifically 60% of the vehicles were purchased in the last two years (2018 and 2019). This is mainly due to the increase in acceptance by the public, thanks to different measures: Incentives, greater awareness, improved technology or greater market variety.

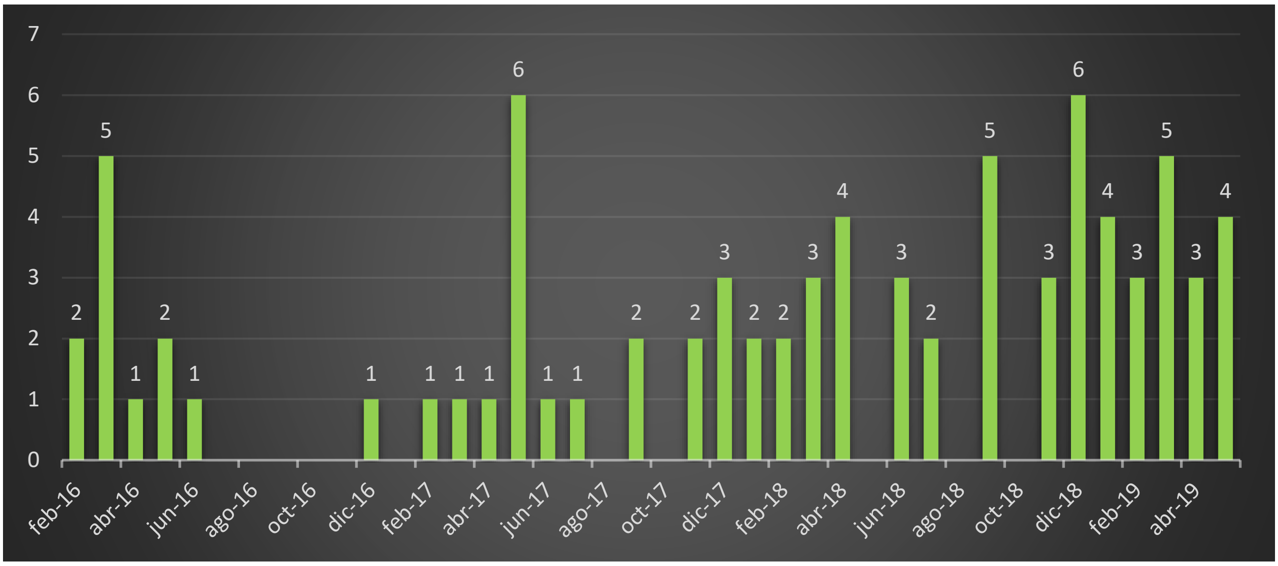

Figure 46. EV purchase date

Furthermore, the months of purchase are strongly related with the launching of incentives plans, such as: Plan Movea in February 2016 and in one month it was exhausted, this effect is easily appreciable on the graph. Then Plan Movea 2017 that was in force between September and December. Finally, Plan MUS in December 2018 where we can find a remarkable peak.

Another easily noticeable pattern is the fact that purchases have their maxima in the spring months (March, April and May) or in the winter months (November and December)

3. Order from greater to lesser importance. What made you decide for an EV?

It is very important to analyse the main factors that make a user decide for an electric vehicle. looking at the naked eye, the results, we appreciate that no reason stands out from the rest and that there are multiple opinions among the respondents. As can be seen in Figure 47, the user is primarily determined by three predominant factors.

The fuel price is also presented as one of the main factors of decision, this aspect, which corresponds to the main object of saving of the electric vehicle, is very relevant due to its high dependence and degree of volatility. On the other hand, environmental awareness, a very important factor considering the problem of climate change and more specifically the atmospheric pollution, great concern in large cities, where these users are located.

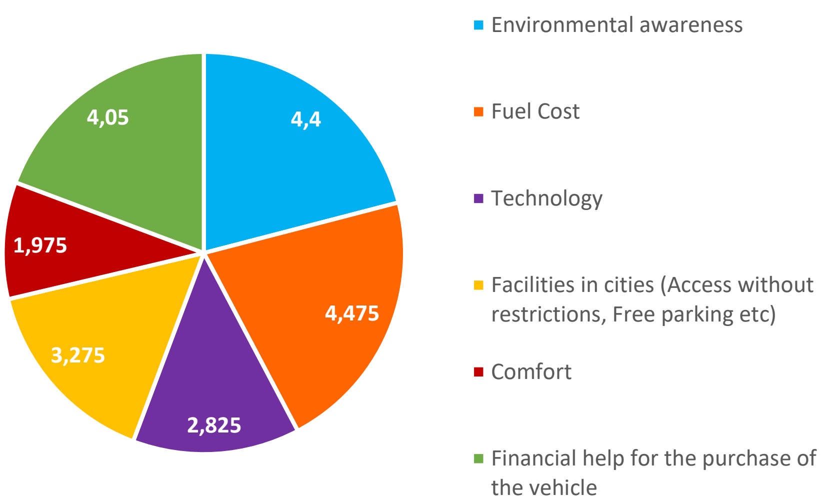

Figure 47. EV user considerations to buy an EV

In addition, we also highlight the financial support of the latest national and regional plans as a relevant factor, followed to a lesser extent by the facilities in cities which is a relevant factor considering where the surveyed live. Finally, the aspects of less relevance for the client are the technology and in last place comfort which actually make sense.

These results are partially confirmed by [89] where environmental concerns, economy and efficiency are the main drivers. However, technology is a very important parameter while in our survey is in fifth place.

4. What is the average monthly distance traveled in your different routes?

Analysing EV the patterns of use it is interesting to study the use made by the users, to see if it is secondary vehicles, if they are only vehicles to go to work or vice versa, they are the main vehicle of the respondent.

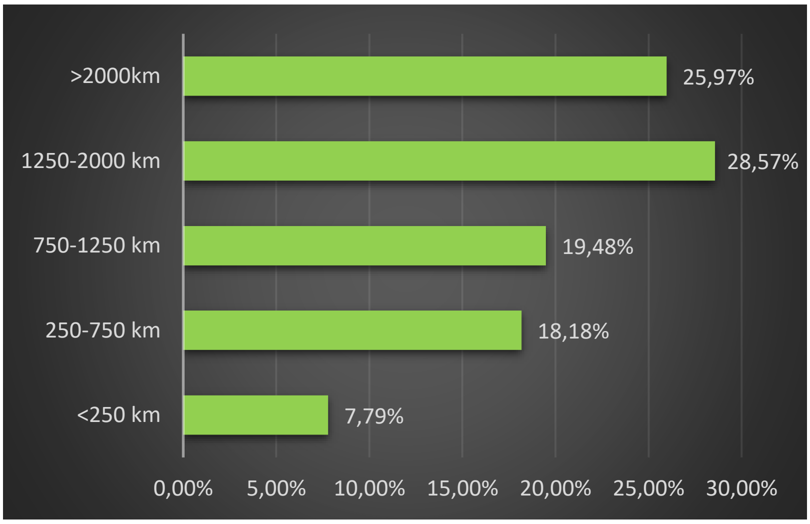

Figure 48. Average EV monthly use

As it is show non figure above, more than the 54% of the users has the EV as main the vehicle and even more, around 25% do an average of 66 km per day. Therefore, the conception of the electric vehicle as a secondary vehicle is very far from reality as it has been mentioned here it is starting to be the principal vehicle for users.

Moreover, the user that respond between 1250 or mora than 2000 km are the ones more concerned with the development of public charge infrastructure and even also the most optimistic in relation with the temporary horizon of electric mobility.

This result is also confirmed by [89] where surveyed's affirm to use their EV every day and travel with them.

5. From 1 to 10, what is your level of total satisfaction with your EV?

From the 83 responses, the final average grade stands at a score of 91 out of 100, which is a very high score. This response is in line with one of the main conclusions of the "Encuesta Nacional de Usuarios del Vehículo Eléctrico" [89]. In this survey, 99% of respondents said they would not buy a combustion car again. As we appreciate this result is reflected in our survey where more than 90% rate their experience with the EV with more than 85 points.

6. Order from 1 to 5. What do you consider to be EV's biggest impediment today?

This question allows to consider the main users concerns and the real needs for the correct implementation of the EV in our society. With the naked eye, we can see a more or less homogenous composition of the main factors. Nevertheless, the battery capacity also known as "range anxiety" suppose the highest score. The next most value, and the initial investment cost was quite expected with the specific conditions of the electric vehicle market in Spain. This fact can demonstrate why the most purchased value is one on the most economical. Nevertheless, as it was explained in section 2.4, the cost is getting lower with the time and it will equal ICE cost in the next future.

Both factors are closely followed by the absence of well-designed public infrastructure. This data is especially important for the current study as we see the users' concern for the need of a public charging network distributed throughout the territory. Finally, and to a lesser extent, we can find the lack of market models and the technological maturity. These values are quite low, as it was expected since in the last year the market variety of electric vehicles has reached unexpected levels and is already presented as a very mature technology.

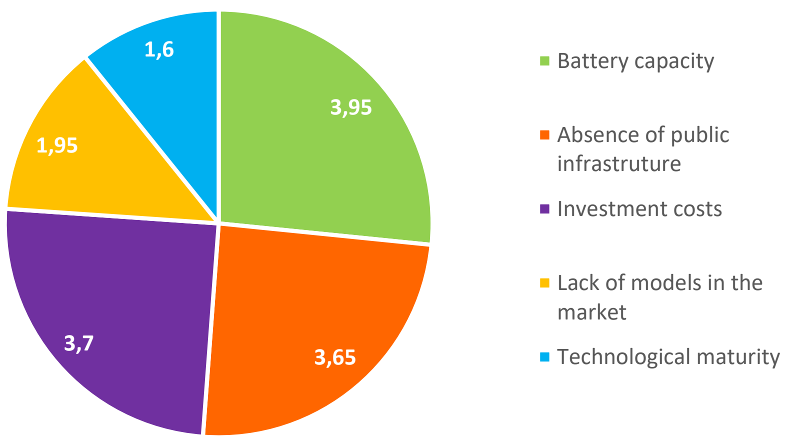

Figure 49. Main EV's impediments

Analysing concretely the relation between answers, we can highlight that some users whose vehicles has lower autonomy (e-golf, Zoe and Leaf) has responded battery capacity, while other with better battery but at same time higher cost, has mentioned the investment cost.

Another fact to highlight from these results is that the three first ones also occupies the first place in [89].

7. Order from higher to lower frequency the sites where you charge your EV

This question presents a great variety of opinions respect to the respondents and the charging places have a very similar valuation. However, most participants charge the majority of time their vehicles at home, this service can only be provided if they have access to a private charger in the community garage or private garage. Next, respondents also use shopping centres with high degree of frequency.

The following site of charge are the work, the main reason for that results is the availability of chargers in their workplace, then private parking follows with a slightly lower score.

Finally, the least frequented place for charge is the public. This result is especially interesting considering that most people has not access to public charge, due to the lack of infrastructure.

In addition, analysing the relationship between questions we can see that many of the users who have claimed to make more than 2000 km have rated the public road as a second charging place, only after their homes.

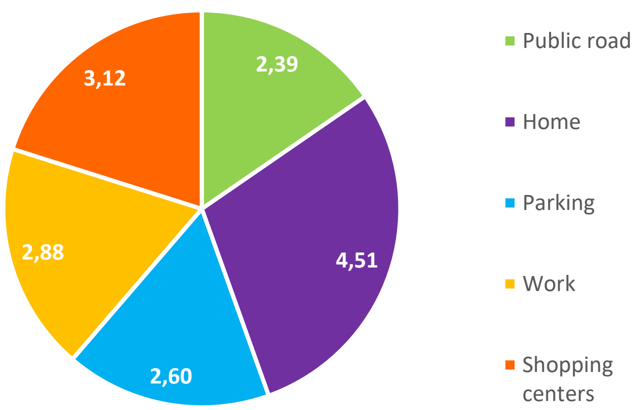

Figure 50. Charging sites

This charge pattern is also reflected in [89] where users around Spain use the same places that result from this question, with the exception of work place, which is not widely spread between the respondents. For the majority, this fact can be deduced to the absence of infrastructure in the workplace, the rest prefer not to do it.

8. How often do you use fast-charge points per month?

This question is especially relevant, since as we can see from the 79 accounts, more than 60% have not charged their vehicle trough fast-charging in the last month. This indicates mainly or that the user does not travel or on the other hand that the user does not have access to the fast charge network

Both aspects should be analysed but in particular the second is especially important.

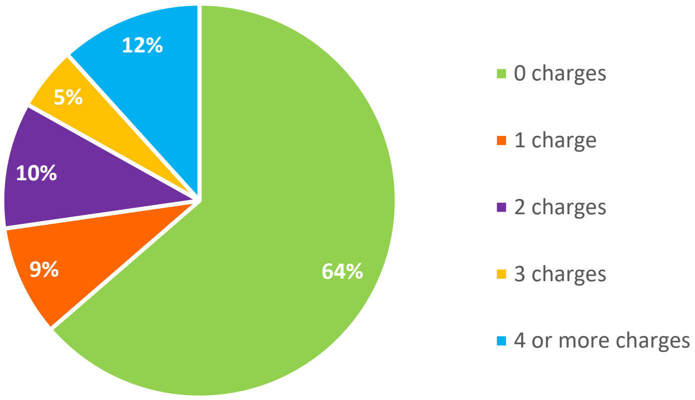

Figure 51. Fast charge points use per month

On the other hand, almost 12% of users have used up to 4 times the fast charge so we can say that it is drivers who have used their vehicle to travel. That's why they have required fast charging technology.

In addition, this 12% is almost the same that has claimed to travel more than 2000 km in question 4 and that use the public charge as second charging method. What allows us to affirm, that we have found a selected group of users that use fast charge to make trips with a certain distance.

The conclusion obtained is in line with [89] where around the half of respondents affirms not using fast charge in general, mostly because the lack of infrastructure.

9. Order from 1 to 5 Where would you like to have more fast charging points on high capacity roads (highways)?

This question allows to study the optimal places according to the user to charge his electric vehicle.

Analysing the results, we can see that the four main locations get a very similar score. So we cannot affirm that there is a determined site that is especially desired by the client. However, the station is the most chosen place, probably due to its proximity to the main road as well as the presence of other services, and because people are accustomed to traditional refuelling. In next place we find the public road and the restaurants, followed by the back by the shopping centres. We infer that restaurants as best second inter urban choice and public road in interurban. Far behind the commented locations we find the hotels with a very low valuation according to the user.

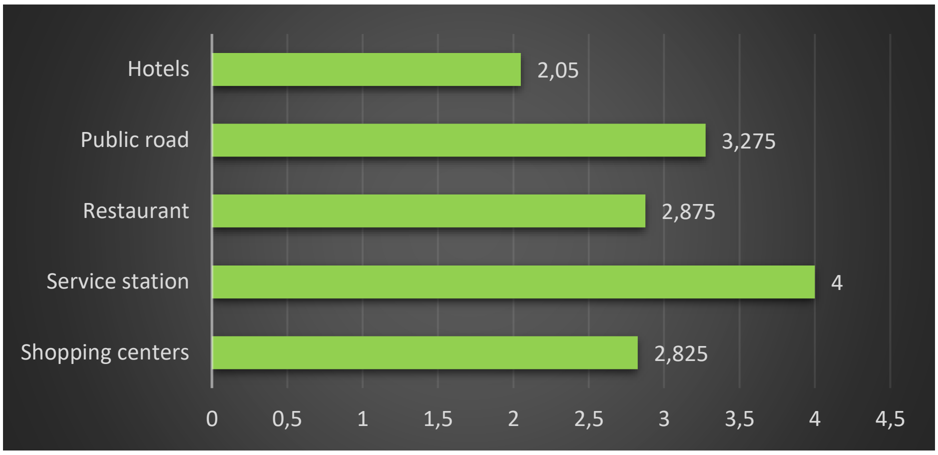

Figure 52. New fast chargers on-road

In this question it is important to point out that the majority of users who drive 2000 km or more and generally use public charge, prefer as location the service stations and the public road, in front of the users who have responded not to use or a very low use of the public charge preferred by restaurants and shopping centres.

Respect to this question, we can analyze certain differences in relation with the respondents in [89], since the most voted places were in the following order: Public road, Service station and Shopping centers.

10. How many kilometers would you be willing to deviate from your route to charge your EV?

This question allows us to check which is the maximum distance a customer is willing to deviate from their original route. The results are especially interesting to consider in the future development of the network, since as we all know it is very uncomfortable to have to leave the road to refuel.

With a naked eye, we see that most of the response are located around 2-5 km, specifically 68.42%, which is a fairly coherent distance. Almost 20% said they would not deviate 1 km what is a very striking result considering that 1 km of deviation does not suppose even the tenth part of time lost in a process of semi-rapid or rapid charging. Finally, the 13% would have no problem getting 10 km more to charge their car.

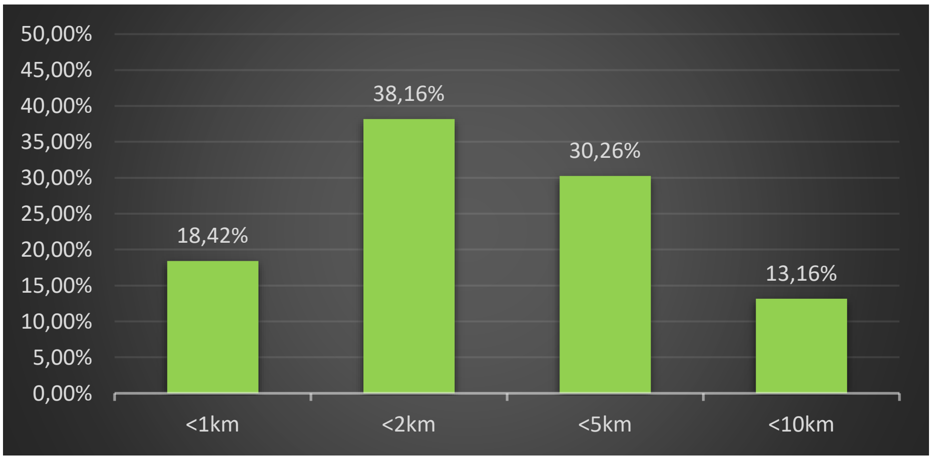

Figure 53. Number of km that a user is willing to deviate

11. What do you consider most desirable to cover a specific area with fast charge services: A charging station with several charging points or several charging stations in a reduced area (radius<10km)?

This question was raised to be able to study the opinion of the users regarding the concrete design of the public charging network, one of the most analyzed factors today is to choose between a single large charge station with multiple points, or the distribution of several recharging points in a certain area.

As it can be seen in Figure 54 almost 70% of respondents consider that it is more efficient to locate a high-capacity station.

Probably this answer is due to the fact that the respondents are employees of an energy utility and can know in advance the greater degree of efficiency and lower costs of using a point of high capacity with respect to several of lower capacity.

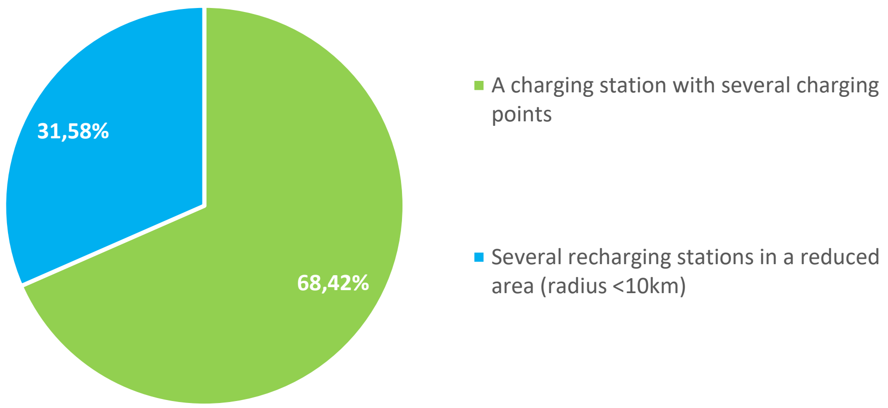

Figure 54. User consideration about charging station

12. On interurban roads, how many kilometers would you place charging stations?

This is another of the most relevant questions to consider the opinion of the user regarding the location of the recharging points and their distance from each other. Specifically, 50% of the answers confirm that a range between 50 and 100 km is the most optimal. However, more than 30% consider that the distance should be between 25 and 50 km, this distance reduction would imply a greater degree of coverage, but in the same way it supposes a greater number of locations and therefore assume very high investment costs.

Finally, only 17% has considered the optimal distance between 100 and 200 km. This distance may be too much, increasing in some way the concern of the drivers and range anxiety for models with lower battery autonomy.

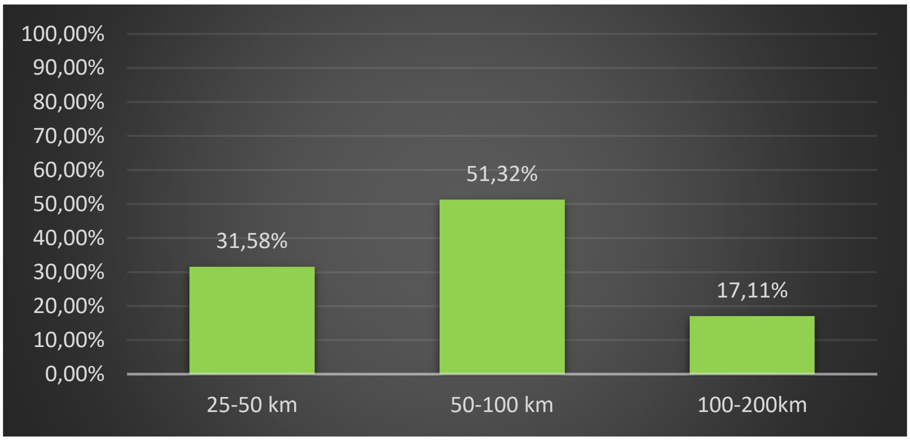

Figure 55. Number of km between charge stations on-road

Furthermore, it important to highlight that the 85,7% of the people that have answered to use more than 4 times per month the fast-chargers in question 8 have answered the range of distance between 50 and 100. This fact supposes a very representative parameter, because people that is currently using the fast-charge review the same.

13. What minimum power do you think every charging point should have on the road?

Most participants (65,79%) consider that minimum power should be 50 or 100 kW, this result make sense considering on-road charge. Actually, the main chargers on the road works at 50 or 100 kW so this result was quite expected. However, a great participation argue that the minimum capacity should be 150, which can be considered as a high power and not every charger can be able to charge at this level and even more a great part of their vehicles is not able to support this capacity. Nevertheless, the great charge capacity very convenient because of the time reduction.

On the other hand, as it was quite expected, almost 10% consider as minimum power 22 kW which in a realistic way cannot be considered at fast charge and the delay time for charge on-road can be very high. Even more, not every model can charge at 22 kW. Finally, around 5% of the participants consider as minimum capacity 350 kW, far from reality, considering that these are practically experimental powers and in no case supported by conventional vehicles yet.

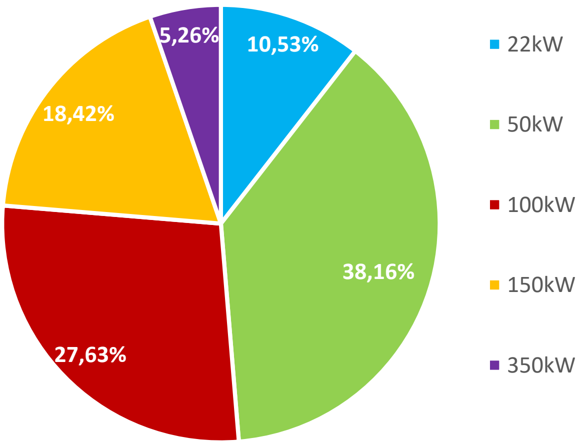

Figure 56. User consideration about charging station size

14. **For the charging services, what do you value more in order from highest to lowest?**

Service reliability is the most valued parameter in the charging service, this result is completely coherent considering the need to charge and the problem that this can suppose. The degree of dissatisfaction, due to having to stop at a point to charge the vehicle and see that this is defective, is very high.

Accessibility through the platform or the App is considered to be the second most relevant point, followed by the charging price. Finally, in last step we can find the charging stations added services.

Figure 57. User valuation about charging services

15. **From what year do you consider that the infrastructure will allow you to move freely throughout the national territory with your EV?**

The respondents evaluate when the infrastructure will allow free mobility around the whole country. As we can easily see, there is a great variety in the opinion of the users. The most voted answer is the last range of time, beyond 2023 with 35,53% of total vote. This response could be considered very pessimistic, but it is also true that the development plans of the main companies in this business have not yet made great progress and it is estimated that until the end of 2019 no remarkable results will be seen.

However, another big part of participants (28,95%) considers that in the next two years this objective could be reached. Maybe, the reason for such consideration is the intensive infrastructure planning that is being developed by some utilities. Next, practically the same number of users considers that the expected date is 2020 or 2022 respectively.

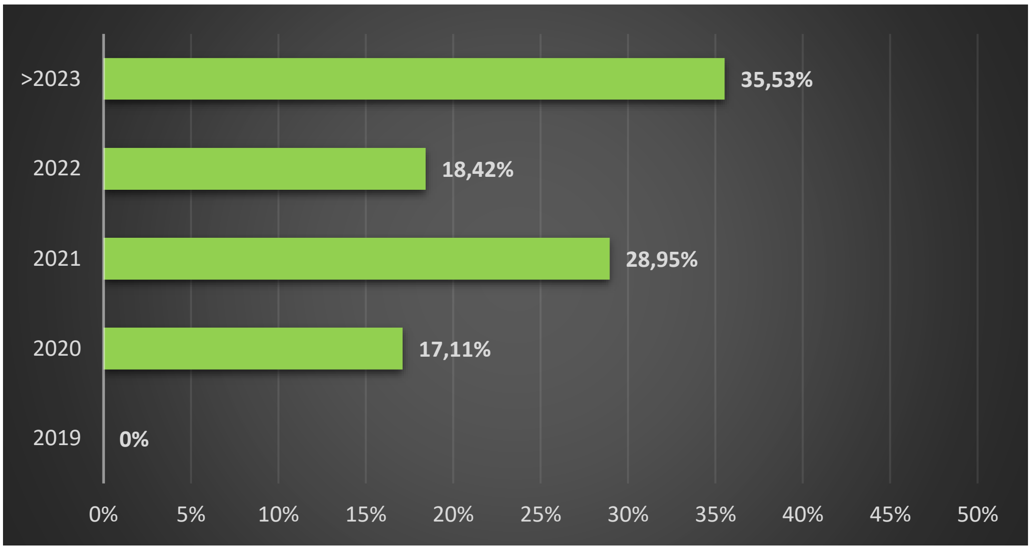

Figure 58. User consideration about infrastructure

Analyzing the correlation between questions we see that the great majority of people who think a range above than 2023 are exactly the people who do not use the public charge and specifically the fast charge. Therefore, the users that do not travel for medium-long distance.

16. What do you consider most important to choose where to stop to charge your electric vehicle on-road? Order from most to least

In this occasion there is no common opinion for all respondents and the valuation is quite similar, the most valued aspects to choose a specific charging facility on the road are the closeness and the accessibility followed by the service level. Finally, and with certain disadvantage we find the variety of services.

This question is very related with the 14 where the participants also consider the added services as the lowest valued factor.

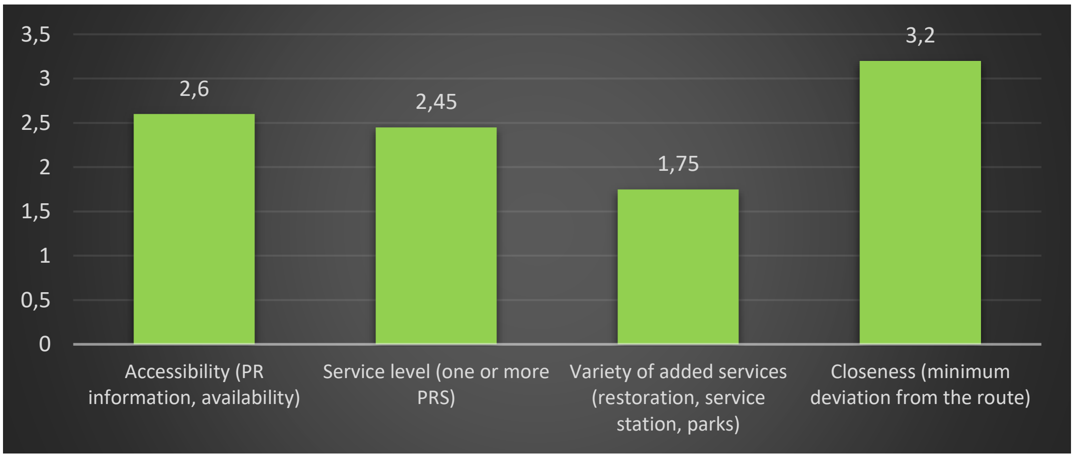

Figure 59.User consideration about charging station characteristics

6.4. CONCLUSIONS

This market research has shown us different important insights from energy utility employees with some degree of knowledge on the EV sector and electric mobility. The evaluation of the survey is good considering the high number of respondents and their degree of participation. Therefore, we can account that the results are very representative.

All respondents had an electric car and even two in some cases. In addition, their degree of satisfaction is very high, which can be traduced as a choice of electric mobility respect to conventional combustion vehicles.

Although it has already been evaluated and commented on in section 2.5.2, the number of electric vehicles in recent years has experienced a relevant increase, a fact that is reflected in the year of purchase of our respondents. Another parameter that reflects the graphs of section 2.5.2 is the vehicles that predominate among the users surveyed.

The main factor that makes the user to decide for the electric vehicle is environmental awareness and fuel costs. Data that largely reflects the commitment of users with energy efficiency, sustainability and environmental protection.

On the other hand, the parameters that most limit the introduction of the electric vehicle continue being the so-called "range anxiety" and the high investment costs with respect to the conventional vehicle. Additionally, technological maturity and the lack of variety of models have been strongly displaced, due to the increase in supply and therefore competitiveness.

As expected, the main place of electric charging is still home, although users express great concern and interest in public charging and, more specifically, on the fast and ultra-fast mode.

The main services that the user values are reliability of the service, closeness and accessibility. On the other hand, the variety of added services is relieved to second place.

Finally, it should be noted that there is a wide variety of opinions regarding the moment when an optimal public charging network allows complete travel of the national territory, although the vast majority affirms that it will be necessary to wait more than 4 years to do so.

However, the high degree of uncertainty in technological advances, in the business models and the action plans of the main companies that are working on the development of infrastructures make it impossible to determine when this transition will take place towards the desired electric mobility.

The results obtained in the survey are closely related to those analysed in the“ Encuesta Nacional de Usuarios del Vehículo Eléctrico” [89] , this coupled with the high range of participation and the number of the survey we can conclude that it is a survey of high value and representative.

In conclusion, the survey has been very satisfactory and has allowed us to analyse the end user point of view, which otherwise would not have been considered on the research and can be used as rules or constraints for the charging network design.

7. CONCLUSIONS

In this master thesis all the objectives set out in the beginning have been addressed with success.

The first step developed was to allow the reader to be aware of the current electric mobility sector, introducing the components of the electric vehicle, mainly the battery and the BMS, charging technologies, charging modes, etc. In addition, the main advances and future technologies in this field were commented.

Next, we analyzed the Spanish outlook and in particular its main problems: the lack of coordination among administrations and private initiatives, the need for more measures and policies that actively encourage electric mobility and, finally, the absence of public recharging infrastructure, specifically, fast and ultra-fast charge interurban infrastructure. There is also a very relevant correlation between the charging infrastructure and the electric vehicle stock in Spain.

Once this problem has been raised, this project has been presented as a useful tool in the starting point of the development of this charging network, a point that we are currently in. The whole project will allow the reader to plan the deployment of the charging network and make the right decisions for the selection of the locations in an efficient way and optimizing the resources. On the other hand, it should be noted that this project has been started from zero, so there were no previous references or methodologies in use. In addition, the phase of obtaining data and analyzing sources has been especially critical when starting this project.

For the planning and design of the network, different location models have been introduced, since they have been considered as the best candidates in the approach to siting and sizing problem of charging stations. Within this type of model, the choice of model has been developed considering different possibilities that meet the established considerations. And selecting the option that best suits the parameters of the problem, the interurban network in Spain, as well as the specific characteristics of the different models

The Flow Capturing Location Model has been selected as the best option. Furthermore, an improvement has been introduced, with the objective of considering the so-called "range anxiety" that allows to take into account specific parameters of the electric vehicle such as autonomy. In addition, the election of the most optimal algorithm for the solution of this problem has also been studied. Highlighting the relevance of heuristic algorithms due to their good behavior in the NP-hard problem, as is the case of ours. Within these, the Genetic Algorithm has been proposed as the main algorithm for the solution due to its great adaptability, its capacity to improve the solution and other features.

In addition, we have studied different tools for the development of the network. Many of these tools will be used as inputs or constraints to the model. On the other hand, with the objective of considering the EV users' opinions, habits and driving patterns, a survey of high value and representativity has been designed. Its responses have allowed us to know the needs and concerns of EV drivers in Spain.

Finally, we conclude that the development of the interurban charging network is a critical path to sustainable mobility and must be carried out in an efficient and organized way, by guaranteeing maximum demand coverage. To achieve these objectives, it is necessary to have a great coordination at the technological, economic and policy level.

"The secret of change is to focus all your energy not on fighting the old, but on building the new." Dan Millman

8. FUTURE WORKING LINES

The proposed future work can be divided into complementary but distinct tasks.

I. Development of a complete model

The first proposed work is the development of a full model following the steps proposed in this research. This model will have a high degree of complexity due to the fact that it will involve a complete analysis of the entire national territory for the optimal development of the fast and ultra-fast public charging network and the corresponding data management.

Once we have developed this complete model, we can compare its results with other methods reviewed in this work.

II. Introduction of distribution network constraints in the model

In this first step of analysis and modelling we have not considered network constraints such as LV transformer idle capacity, power losses, flows and others specific parameters of the grid. It is very important to define that the correct introduction of electric mobility will suppose a change on networks, especially in urban networks, that has to be considered in future models.

In this same line, the mapping of the distribution network at the national level incorporating the LV Transformers and the CUPS is especially relevant for the future grid. This tool can represent a great advance in the coverage of the demand, guaranteeing the security of the network and finally asses the needed reinforcements. This analysis has already been implemented in several countries around Europa and it is considered a priority although in Spain this information is not standardized yet.

III. Database Management

The set of data necessary in the whole development of the model will be managed through an internal database with the aim of managing all the necessary documentation for: the deployment of the network, the formulation and development of the model and extra information, necessary for the correct decision making.

This database has already been created and documentation has begun to be implemented, but this source must be managed throughout the development of the interurban charge project.

IV. Implementation of the analysed tools

Some of the proposed tools are in the development phase or pilot project, so it is very important to advance and implement their results for future progress of the network. In particular, the development of the web mapping tool and the SIM data management tool.

V. Updating the users survey

The survey has offered multiple results on the concerns of users and the future needs of the network. Therefore, it would be sensible to carry out the same or a similar survey in order to update the opinions of the drivers once a comprehensive fast charging network has been deployed and to verify if the concerns have been mitigated.

9. WORKPLAN

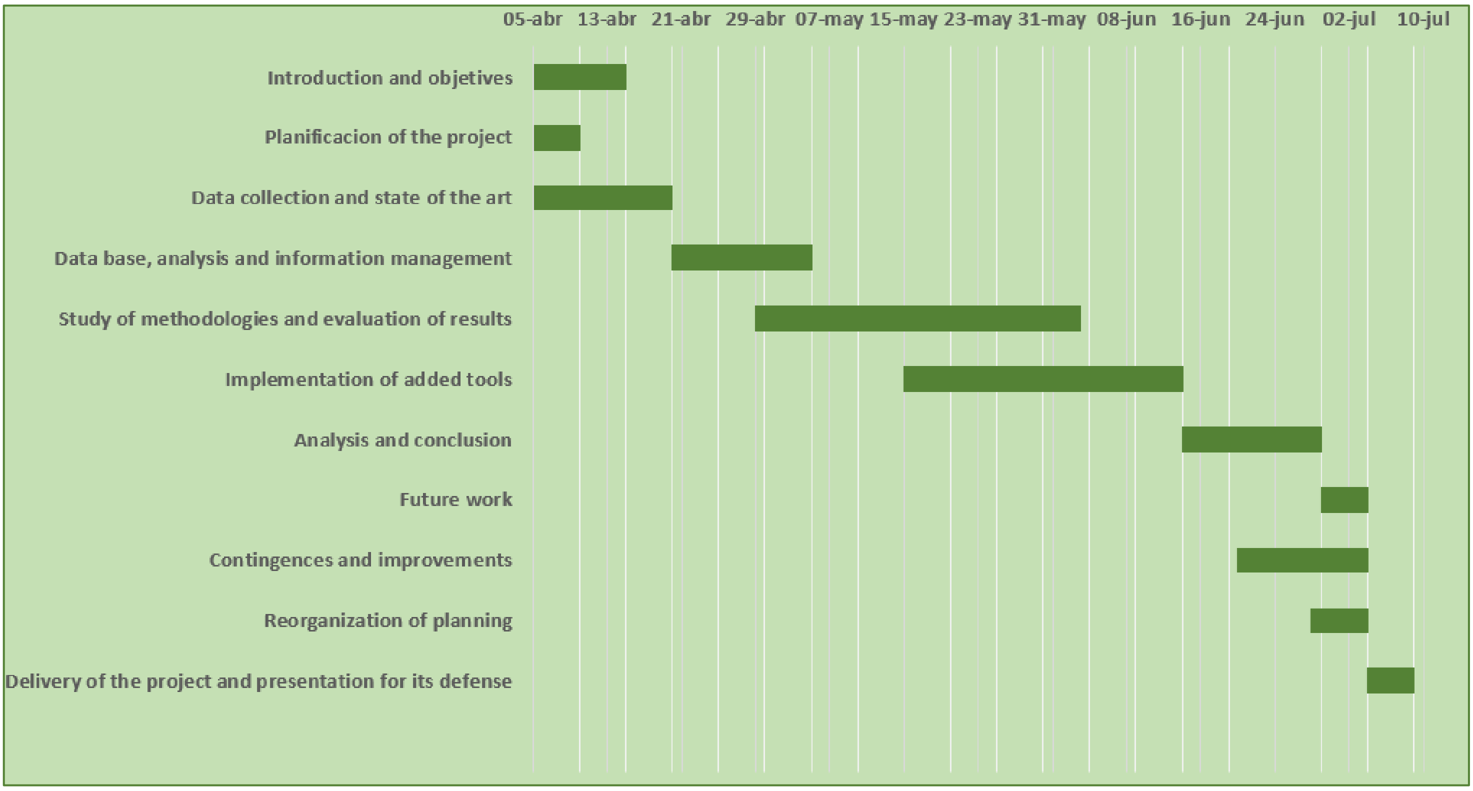

Figure 60. Master Thesis work plan

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ANNEXES

ANNEX A. NOMENCLATURE AND ABREVIATIONS

AC - Alternative Current

BMS - Battery Management System

CCS - Combined Charging System

CHAdeMO - CHArge de MOve

CO - Carbon monoxide

CO2 - Carbon dioxide

CP - Charge Point

CUPS - Universal Supply Point Code

DC - Direct Current

DSO - Distribution system operators

EREV - Extended range electric vehicle

ERS – Electric Road Systems

EV - Electric Vehicle

FCLM - Flow capturing location model

GA - Genetic algorithm

ICE - Internal combustion engine

HEV - Hybrid electric vehicle

NEMA - National Electrical Manufacturers Association

NMVOC - Non-methane volatile organic compounds

NOx – Nitrogen oxide

MCLM - Maximum Covering Location Model

MILP - Mixed-integer linear programming

O-D - Origin-destination

PHEV - Plug-in hybrid electric vehicle

SAE - Society of Automotive Engineers

SOC - State of charge

SOx - Sulphur oxides

TAM - Tour Approaches Model

ANNEX B. SURVEY DATA SHEET

- **Survey**

Answer Period: 25-05-2018 to 20-06-2018
Platform: (https://www.surveymonkey.com/)
Respondents search: Invitation through an email with a link to the URL.
Participants profile: EV Users.
Number of surveys: 83, the 72,3% of contacted people.
Privacy: anonymous.
Type of questions: answers, multiple choice and ranking choice.
Average completion rate: 100%.
Average time spent: 7 minutes and 1 second.
Length: 19 questions.
Costs: time spent on learning survey techniques, survey design, data collection, interpretation and report.