TÉCNICO LISBOA

Electric Mobility in Europe for 2030-2040

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Dedicated to my parents...

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Resumo

A mobilidade tem tido uma importância crescente para a humanidade paralelamente aos desenvolvimento tecnológico. A sua influência nas sociedades é elevada dado que afecta o estilo de vida, o tipo e localização de eventos e a oferta de bens e serviços. Além disso, a mobiliddae é um factor crucial para o crescimento económico dos países e regiões dado que contribui para o crescimento de outros sectores de actividade. 90% do combustível usado no sector dos transportes é proveniente do petróleo, sendo responsável por 23% das emissões de gases de efeito de estufa. O sector dos transportes é um dos que deve contribuir para a redução das emissões, como expresso nos objectivos do Acordo de Paris. Os veículos eléctricos (VE) constituem uma altertaniva promissora neste aspecto. Com a combinação de veículos Eléctricos, partilha de viaturas e veículos sem condutor, o número de proprietários de automóveis pode diminuir 80% no futuro, o que resultará num tremendo decréscimo nas emissões de gases poluentes, assim como na poluição e engarrafamentos nas grandes cidades. Com a penetração crescente dos VEs, os produtores de energia e o sector da mobilidade terão que trabalhar conjuntamente para satisfazer a procura de energia para o carregamento dos VEs. Tecnologias de carregamento inteligentes e veículo-rede podem contribuir para a penetração das energias renováveis na rede, dado que os VEs poderão carregar a partir destas fonts. Como uma das grandes empresas no sector energético, Iberdrola pode ter um paperpreponderante no futuro da mobilidade eléctrica. Ao produzir grande parte da sua energia a partir de fontes renováveis ajudará os detentores de VEs a carregá-los com 100% da energia roveniente de fonts renováveis. Além disso, podem satisfazer um serviço de partilha de viaturas com emissões zero de forma a serem atingidas as metas estabelecidas no Acordo de Paris para um future sustentável.

Palavras-chave: Mobilidade, Gases de efeito de estufa, Veículos Eléctricos, Partilha de viaturas, Veículos sem condutor, Futuro sustentável

Abstract

Mobility has been very important in order to improve the civilization of the humankind in the past and its importance is increasing with the improvements in technology. It has a high influence on the society since it affects the style of life, the range, and location of activities, goods and services which will be consumed. Moreover, it is the crucial factor for the economic growth for the countries because mobility helps other sectors to grow. 90% of the fuel used in transportation comes from the petroleum based products; therefore, the global greenhouse gas (GHG) emissions due to transportation is 23%. Transport sector is one of the main sectors which the GHG emissions should be decreased to reach the Paris Agreement goals. Electric vehicles (EV) is a very promising alternative to this task. With the combination of electric vehicles, car-sharing, and self-driving vehicles, the amount of car ownership could be decreased by 80% in the future. This would result a tremendous decrease in the GHG emissions as well as decrease in air pollution and congestion in the big cities. As EV penetration increases, power generation sector and the mobility sector would need to work together to balance the increase electricity demand due to EV charging. Smart charging and vehicle-to-grid (V2G) technologies could increase the penetration of renewables into the grid because EVs could be charged with renewable electricity. As one of the biggest utility company in the world, Iberdrola could place importance on electric mobility in the future. Their high share of renewable energy production will help EV owners to charge their cars with 100% renewable electricity. Furthermore, they could provide zero emission car-sharing service to the customers in order to reach the company goals and Paris Agreement goals for a sustainable future.

Keywords: Mobility, Greenhouse Gas Emissions, Electric Vehicles, Car-sharing, Self-driving Vehicles, Sustainable Future

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Chapter 1

Introduction

Ever since the discovery of fire and using it for providing heat, such as cooking and many other essential purposes, energy hunger of the humankind has been growing. At the very beginning wood was the main source to provide energy to humankind for sustaining their lives; however, this was changed with the industrial revolution and coal was started to be used as an energy source. During the 20th century, oil and natural gas have been used as another fossil fuel alternative to coal. Nowadays, hydrocarbons which are derived from the crude oil, natural gas, and coal are widely used to maintain the life's quality. Industries, such as chemical, petrochemical, plastic, and rubber, are highly dependent on hydrocarbons as a raw material. Most of the hydrocarbons are used as fuels for transportation, electric power generation and for heating since their energy density values are high. These hydrocarbons are a gift to the humankind given by nature if the energy content of the fossil fuels is considered. A single barrel of oil has the energy equivalent of 12 people who are working all year, 8760 hours; in other words, 25, 000 man hours [1].

Fossil fuels have good energy density and they are used to produce electricity in the modern world; however, as a result of this action, they emit a huge amount of CO_2 and the greenhouse gases to the atmosphere. The increase of the concentration of the greenhouse gases in the atmosphere causes an increase of the temperature of the earth since these gases act like a blanket; keeping heat radiation comes from the sun in the world. It can be seen that the temperature of the earth is constantly increasing; moreover, evidence shows that years between 2000 and 2009 were recorded as the hottest decade in the least past 1,300 years. This change in the temperature of the earth is modifying the climate system including lands, oceans and the glaciers [2, 3].

More than nine out of 10 climate scientists agree that anthropogenic CO_2 emissions are the main cause of global warming [4]. The greenhouse effect has been known since the 1800s; Swedish physicist Svante Arrhenius predicted in 1896 that CO_2 emission occurs from coal burning would warm the planet. He was correct with his argument, CO_2 warms the planet and the concentration of it in the earth's atmosphere have nearly doubled since the 1960s [5].

GHG emissions due to transportation are substantially high; since transportation has a high influence on the society. It affects the style of life, the range, and location of activities, goods and services which will be consumed. Moreover, it plays a crucial role in the economic growth of the country due to the fact that it helps to the other sectors to grow more [6]. According to the Environmental Protection Agency (EPA), 27% of the GHG emissions in U.S occurred due to transportation in 2015 (Figure 1.1) [7]. These emissions from transportation come mainly from the burning of fossil fuel used in trucks, cars, ships, trains, and aircraft. Petroleum based products such as gasoline and diesel are used more than 90% of the internal combustion engines (ICE).

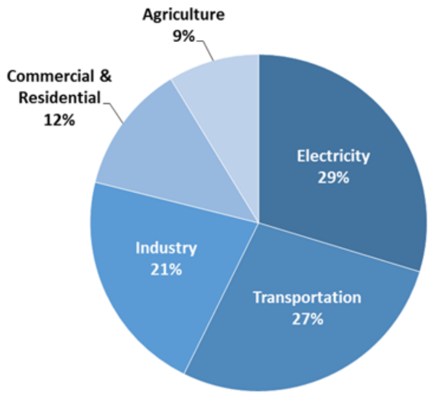

Figure 1.1: Total GHG Emissions in U.S by Economic Sector in 2015 [7]

According to the European Environment Agency (EEA) report on Transport and Environment Report Mechanism (TERM), GHG emissions have decreased in all the main economic sectors between 1990 and 2013 with only one exception which is the transport sector. Over the mentioned period transport emissions increased by 19.4%; if emissions from international aviation are excluded the amount of increase is 13%. In 2013, transportation sector had a share of almost one-quarter of total EU GHG emissions (24.4%). After excluding the international aviation and the maritime, the share of GHG emissions from transport sector drops to 19.8% [8].

Transportation can be divided into two parts; freight and passenger transport. The demand for transportation, the mode of transportation and the type of fuel used to meet that demand determines the environmental impact of the transportation sector. Due to the economic growth and expansion in EU-28 countries, freight transport has increased 22.4% between 1990 and 2007. The modal composition of freight transport determines greenhouse gas emissions; for instance, inland freight transport, rail and inland waterways have lower CO_2 emissions per ton-kilometer (tkm) than road transport [8].The majority of the freight transport was done with road and sea transport with the percentage of 50.6% and 32.9%, respectively. These two were followed by rail transport by 12% of the share and inland waterways with a percentage of 4.4%.

Passenger transport demand is measured in passenger-kilometers. The demand has increased until 2008 and then it stayed stable throughout the years. Between 1995 and 2014 passenger cars were mainly responsible for the increase of passenger kilometers with a share above 70%. Air transport has increased by 1.5% in 2014 and reached a share level of 9.2%. If rail passenger demand was considered, it has slightly decreased during the years and at the end of 2014, it has a share of 6.5%.

Figure 1.2 shows the contribution of different modes of transports to EU GHG emissions in 2013.

Road transport was responsible around 73% of greenhouse gas emissions in 2013; second biggest share belongs to the aviation. Furthermore, passenger cars were responsible approximately 60% of all road transport emissions; whereas, heavy duty vehicles and buses were responsible for 27% of the emissions [8].

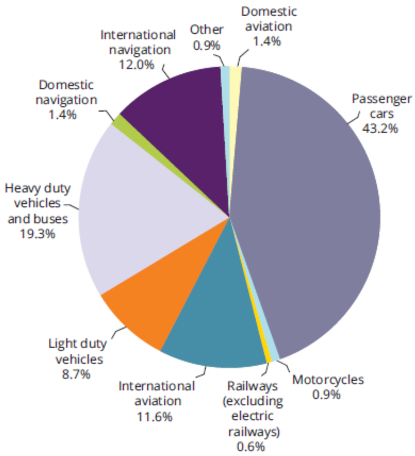

Figure 1.2: Contribution of Different Modes of Transport to GHG Emissions for EU in 2013 [8]

The European Commission has the target of reducing GHG emissions in transport by 60% until 2050 as compared to emission level in 1990. It can be said that the GHG emission levels from transportation were increased approximately 20% since 1990. That makes transport sector only major economic sector in EU where GHG emissions have risen until now. It is estimated that there will be a significant growth in transportation sector until 2050. Between 2010 and 2050, passenger transport is expected to increase about 40%; and fastest growth rate will be seen in the aviation sector. Similarly, freight transport is estimated to increase around 58% while road freight transport will be the highest share of 70%. Current estimates show that climate policies in EU countries would decrease the GHG emissions in transport in 2050 by 8% below the 2010 level mainly due to the technological development in the car industry. Nevertheless, according to this estimation, the GHG emission level in 2050 would still be 15% higher than the 1990 level [9].

Apart from climate change, the impact of transportation on air pollution, noise pollution, and habitat fragmentation is substantial. High volumes of traffic cause important problems in most of the big cities. Transport is the main contributor to dangerous noise levels especially in the urban areas. Moreover, it causes negative effects on ecosystem and biodiversity [9].

When all these negative sides of transportation are considered, significant efforts and crucial changes should be done in the transport sector to accomplish the targets which have been taken by European Commission. There are several ways to decrease the GHG emission; amongst these alternatives, increase the number of electric cars in the transportation sector and use renewable sources for charging applications is one of the most favorable ones.

1.1 Importance of Electrification of Road Transport

Paris Agreement which was announced in December 2015 and was enforced in November 2016, has set a goal of keeping the global average temperature increase of the world below 2 degree celcius as compared to the pre-industrial levels. Since 2 degree celcius increase in global average temperature will affect the life dangerously, the temperature decrease should be limited. As mentioned in the previous part, CO_2 emissions due to anthropogenic activities cause global warming. Transport sector which currently is responsible 23% of global GHG emissions, has substantial impact emissions both in EU and in the World [10].

As it was mentioned before, conventional mobility with internal combustion engine (ICE) vehicles has harmful emissions on environment apart from CO_2. There have been significant improvements in the past decades for decreasing the concentration of pollutants in exhaust gas; from 1990 to 2013 transport emissions of pollutant gases has decreased as follows: NOx 35%, PM_{10} (particulate matter with a diameter of 10 μm or less) 27%, SOx 36%, CO 82% and NMVOCs (non-methane volatile organic compound) 83%. However, poor air quality is still responsible more than 400,000 premature deaths in Europe each year. Moreover, poor air quality shows its effects mostly in urban areas where there is more traffic. For instance, emissions from road traffic are responsible from the NO_2. In EU the annual air quality limit for nitrogen dioxide was widely exceeded in 2013 with a percentage of 93%. There are 3 important pollutants coming from the combustion of fossil fuels in ICE; SOx, NOx and PM. NOx and PM_{10} have declined from all modes of transportation in EU 28 countries in 2000; the only exception was the aviation sector. Due to technical improvements in the transportation sector, NOx emissions decreased 32% after 2000. This trend is also similar for PM_{10} emissions; after 2000 the amount of the emissions decreased around 30%. Similar to NOx and PM_{10}, SOx emissions also depend on the type of the fuel used. Due to the EU regulations in 2000, the emission of this pollutant gas decreased 23% with the exception of the aviation sector [8].

Another dangerous pollution is coming from road transportation is the level of noise. Environmental noise pollution has a negative effect on the quality of life. According to the World Health Organization's study in 2011 showed that around 1 million healthy life-years are lost every year in Western Europe due to the noise pollution from road transport. Road noise (inside and outside urban areas) due to the transportation is one of the most relevant sources according to the strategic noise maps. Around 125 million people are potentially exposed to the noise coming from road transportation. Railways have the second biggest share of the noise pollution [8].

Moreover, transport sector in EU highly depends on fossil fuels with a ratio of 94%. In other words, this means EU economy is strongly dependent outside due to the fact that mobility has a very crucial role in the economy and most of the oil is imported from other countries [11].

Low emission transportation gives an opportunity to Europe to be less independent on imported oil as well as it creates an opportunity for innovation and new job creation. The shift to low emission mobility has already started by using bio fuels and hybrid cars in the traffic more and more; however, it needs to speed up in order to achieve the GHG reduction goals which have set by European Commission. Electrification of road transportation has substantial benefits such as decreasing GHG emissions, local pollutants due to the exhaust gas of ICE vehicles, promotion of energy security and reduce the dependency on imported oil. If electrification of road transport goes hand in hand with decarbonization of electricity supply and with more renewable resource penetration, GHG emissions will be able to decrease tremendously [10].

1.2 Electric Vehicles

Usage of electric vehicles in the transportation sector is not a new phenomenon; it goes back more than 150 years before. Electric motors were discovered in the early periods of the 19th century while trying to get more information about the magnets. In 1900, among the cars sold in the United States; 38% of them were electric, 22% of the cars were gasoline and the rest 40% were steam driven cars. Due to the less driving range and the high cost of electric cars, the popularity of them decreased at the beginning of 20th century and the number of ICE cars increased. Concept of high efficient, clean, smart and interconnected transportation have not been favored until the 1990s. In that decade, mostly due to social, environmental and political concerns, the concept of mobility has started to change in North America and Europe [12].

There are different types of electric vehicles on the market. They can be ranged from electric bikes with pedal assist, forklifts and to full-size electric cars. Electric vehicles can either be pure electric or with hybrid technology such as internal combustion engine with an electric motor. The battery technologies are changing as newer chemical compositions are used in the electric vehicles. Moreover, the type of battery use can be shown differences according to the purpose of the vehicle. For instance, traditional lead acid batteries (Pb-acid) are used for the electric bikes; whereas, nickel-metal-hydride (NiMH) are used for Hybrid Electric Vehicles (HEVs); also, lithium-ion (Li-ion) batteries are used for full Battery Electric Vehicles (BEV) and Plug-in Hybrid Vehicles (PHEV) [13].

Electric vehicles can be divided into 6 different group which are Light Electric Vehicles (LEVs), Industrial Forklifts, Fuel Cell Electric Vehicles (FCEVs), Hybrid Electric Vehicles (HEVs), Plug-in Hybrid Electric Vehicles (PHEVs) and Battery Electric Vehicles (BEVs). Since it will be more focused on the BEVs, HEVs, and PHEVs in the report; LEVs, Industrial Forklifts and FCEVs are not going to be mentioned in detail.

1.2.1 Light Electric Vehicles

Electric bicycles, also called as e-bikes, electric scooters and electric motorcycles are the smallest and the lightest electric vehicle in the market; therefore, they are also called as Light Electric Vehicles (LEV). The components in the LEVs are similar with the full-size EV; however, the size of the components are much smaller than the ones in electric vehicles. In order to charge the battery, the external power source is needed [13].

Electric Bicycles (e-Bikes)

Electric bikes consist of an electric motor and the similar voltage of the battery with a size of 12 V, 24 V, 36 V or 48V. Since it has a lead-acid (Pb-acid) battery, these voltages account for the multiplication of the number of batteries with 12 V which is the voltage level of one Pb-acid battery. These bikes have an electric motor power between 250-750 W. Conventional pedal assisted electric bicycles to have energy from the batteries between 100-400 Wh; while for the bigger size e-bikes, this number can reach up to 1 kWh. The size of the electric motor in this type of LEV is usually regulated by government since there is no need for license, registration, and training needed for this type of vehicles. Therefore, it can be said that larger e-bikes are defined as electric motorcycles. In order to achieve higher performance, 36 V or 48 V electric motors are used in e-bikes. However, when a high voltage of the electric motor is used, the weight of the battery becomes an important factor; hence, nickel-cadmium (NiCd), NiMH or Li-ion batteries can also be used in the e-bikes [13].

Electric Motorcycles

Full-size electric motorcycles are more similar to full-size electric vehicles than the e-bikes. Due to the fact that NiMH and Li-ion batteries offer higher energy density, electric motorcycles are often constructed with these batteries. In addition, NiMH and Li-ion batteries help to improve payload capability and range. The typical electric motorcycle has a battery which has the capacity between 2-5 kWh. 96 V or higher voltage electric motors are used in order to achieve higher performance and higher efficiency [13].

1.2.2 Industrial Forklifts

Industrial forklifts are used in material handling industry in the warehouses. These type of vehicles use the electric power for lifting and moving the freights. Sometimes they are equipped with heavy Pb-acid batteries in order to have the motive force and counterbalance the weight. Electric motors in these vehicles can be operated at 12 V, 24 V, 36 V and 48 V with a battery capacity of 10-75 kWh [13].

1.2.3 Fuel Cell Electric Vehicle (FCEV)

Fuel cells are the electrochemical reactor that converts the chemical energy in the fuels, such as methanol and hydrogen, to the electrical current with higher efficiencies. Moreover, they eliminate the energy conversion steps unlike the internal combustion engines (ICE). Fuel cells involve two electrodes which are an anode and the cathode. The sign of the anode is negative and the sign of cathode part is positive. With the help of the electrochemical reactions, oxidation of fuel at anode and reduction of oxidant at the cathode, electricity is produced. At the end of this chemical reactions, water and heat are produced as by-products [1, 14]. Fuel cells often cannot provide enough current and voltage to sudden changes which are occurred because of driving conditions. Therefore, FCEVs need also a battery in their power train. Batteries used in the fuel cell vehicles have the same characteristics with mild or full hybrid vehicles (which are going to be explained detail in the next section). The efficiency of the whole system is much higher than the conventional vehicles [13].

1.2.4 Hybrid Electric Vehicles (HEVs)

Hybrid electric vehicles can be also defined as dual-powered vehicles; they contain both electric motor and an internal combustion engine. The ability to optimize the propulsive energy of the vehicle effectively by operating the electric motor or combustion engine at the right moments, help HEVs to reach higher mileage and offers more efficient drive which leads to less GHG emissions [12]. Powertrain consist of some main elements which are *electric batteries* , *electric motor*, *internal combustion engine*, *electric current generator*, *some coupling elements* in order to connect mechanical system with the electrical system and *management system* for arranging two different drive system [15]. The dual-mode of operating of electric machine gives the opportunity to work as a generator. This feature of the electric motor is used very efficiently in the HEVs by recovering the kinetic energy while braking phase; which is known as regenerative braking. Whenever driver brakes, the electric motor acts like a generator and converts the forward momentum of the car to electricity. Due to the regenerative braking, a battery of the HEV can be charged. The second way of charging the battery in HEV is charging it with the engine. A heat engine can be powered by gasoline, diesel, compressed natural gas (CNG) or with biofuel. A generator is connected to the heat engine and electricity produced is used to charge the battery [12].

According to the powertrain configurations, HEVs are divided into 3 different categories; parallel, series and series-parallel. The configuration of different powertrains can be seen in Figure 1.3.

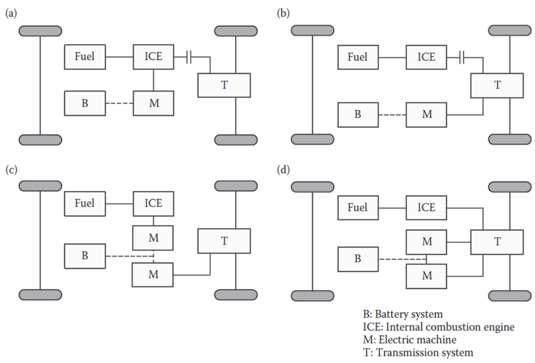

Figure 1.3: Different Power-train Configurations of HEVs: (a) Mild HEV, (b) Parallel HEV, (c) Series HEV, (d) Series-Parallel HEV [12]

Series Hybrid Electric Vehicle

In this type of powertrain, electric machines supply power to the electric vehicle while the ICE gives power to the generator. Electricity produced from the generator is not only used to charge the battery, also is used in the electric motor. It can be seen from Figure 1.3c that ICE is decoupled from the wheels in a series configuration. Since the electric motor supply the traction power, bigger electric machines are used in the powertrain. As a result of this bigger electric motor, energy recovery capability is higher than other types of HEVs [12].

Parallel Hybrid Electric Vehicle

In the parallel configuration, both the ICE and the electric motor are connected to the wheels with two different pathways; electric pathway and mechanical pathway. Depending on the driving type, ICE or electric motor supply the power to the wheels individually or together. In these HEVs, combustion engine, electric motor, and the gearbox are coupled each other by using automatic clutch [12].

Series-Parallel Hybrid Electric Vehicle

In series-hybrid powertrain, two electrical machines and an ICE provide energy to the propulsion system. When this system is compared with the series powertrain, there is two low-power electric machine which can work as generator and motor. Two electrical machines and the heat engine are connected to the traction system via planetary gear system [12].

This powertrain system can be seen in Toyota Prius which Toyota achieved a good number of sales with Prius. The planetary gear boxes help the system works as either parallel or series system. This device allows the car operates as a parallel hybrid so that the electric motor can power the car on its own, or ICE can power the car on its own or they can power both together [12].

HEV technologies show differences also depending on the configuration of the vehicle since the hybrid technology can be applied in a wide range; such as passenger cars, sports cars, trucks, and buses. One of the generally accepted methods of categorizing HEVs apart from their configuration of power-train is to use a ratio of the electric systems power to the overall systems power. By considering this, HEVs can be categorized into 3 different groups; micro hybrids, mild hybrids and full hybrids [12].

Micro Hybrid Electric Vehicles

Micro hybrids are the modest version of the HEVs; they are equipped with a small electric motor. Therefore, their electric rating is between 3 kW and 5 kW. The micro hybrid electric vehicles are capable of start-stop or idle-stop features, which automatically shut down the engine when the vehicle is coasting, braking or stopped according to the type of drive cycle. When the car needs to accelerate, the engine is restarted. Micro hybrids are the simplest version of HEV; however, they can provide a fuel efficiency up to 10%, especially in urban driving conditions [12].

Mild Hybrid Electric Vehicles

Mild hybrids are equipped with bigger electric motor than the micro hybrid vehicles; thus, their power rating is between 7 kW and 15 kW. As a result, higher fuel efficiency can be achieved in this type of vehicles; they can save up to 20% of fuel when they are compared with the conventional ICE vehicles. An electric motor is placed between the engine crank shaft and the transmission input shaft. Due to this added electric motor which can act as a generator also, the vehicle has gained some specialties such as start-stop function, regenerative braking, and additional drive power. Some of the mild hybrid vehicles can also supply a small amount of power to the engine [12].

Full Hybrid Electric Vehicles

The power rating of a full hybrid vehicle is around 30 kW or higher, which makes them having the highest electric portion if it is compared with micro and mild hybrids. Full hybrid vehicles are considered as the vehicles that can run on only ICE, only battery or both of them together. They have the same features with mild hybrids; in addition to that specialties, full hybrid vehicles can operate only with an electric motor. Due to the limited size of the battery pack and the electric engine, full HEVs have the short all-electric range and they have less power output. They can save fuel up to 40% especially in the city driving conditions. Although it brings high efficiency, less fuel consumption, and fewer emissions, full HEVs bring some complexity for manufacturing and maintenance. Therefore, the cost of the cars increase [12].

1.2.5 Plug-in Hybrid Electric Vehicles (PHEVs)

As it can be understood from its name, PHEVs are the special form of hybrid electric vehicles. Similar to HEVs, PHEVs have also both electric motor and the ICE in order to supply power for the propulsion. However, the main difference in this type of hybrid vehicle is that they have a higher capacity to store electrical energy in the battery and the battery pack can be charged from the grid. As a consequence of this, petroleum is no more the only energy source of the powertrain. Since PHEVs have much higher battery capacity, this allows them to cover more kms with the electric-only drive. This range that can be covered only with electric drive is arranged by considering daily needs of the PHEV owners, especially the owners who are driving their vehicles in urban areas. It is estimated that in Europe 50% of the trips are less than 10 km; also, 80% of the trips are less than 25 km. In addition to these data, in the United Kingdom 97% of the trips are less than 80 km. In the United States, 60% of the vehicles cover less than 50 km and around 85% of the vehicles cover less than 100 km. All these data show that a PHEV with a range of 100 km would meet all the range requirements in Europe and America. The powertrain configuration is same like the HEVs; series, parallel or series-parallel [12]. Comparison of Conventional vehicles, HEVs and PHEVs can be found in Table 1.1.

Table 1.1: Comparison of PHEV, HEV and ICE Vehicles [12]

Type of the Vehicle	Stop and Start	Regenerative Braking	Motor Assistance	Electric Driving	External Battery Charge
Conventional Vehicles	Mostly no	No	No	No	No
Micro HEVs	Yes	Minimum	No	No	No
Mild HEVs	Yes	Yes	Minimum	No	No
Full HEVs	Yes	Yes	Yes	Yes	No
PHEVs	Yes	Yes	Yes	Yes	Yes

1.2.6 Battery Electric Vehicles (BEVs)

Battery electric vehicles (BEVs) are fully powered with an electric motor; therefore, there is only electric propulsion pathway in the powertrain. Since it has 100% electric propulsion (Figure 1.4), BEVs have the highest efficiency propulsion system in all types of electric vehicles. They can convert approximately 80% of the electrical energy in the batteries to traction power; whereas, the conventional ICE vehicles can convert only 20-30% of the energy stored in the fuels. In addition to that, less moving parts in the pure electric propulsion increase the efficiency of the vehicle and decrease the maintenance cost. The number of moving parts of BEVs are 20; while, the conventional ICE vehicles have more than 2,000 moving parts [12, 16] .

Due to the 100% electric propulsion system, there is zero tail pipe emission which makes BEVs eco-friendly if tank to wheel GHG emissions is considered. Furthermore, there is no air pollution and noise

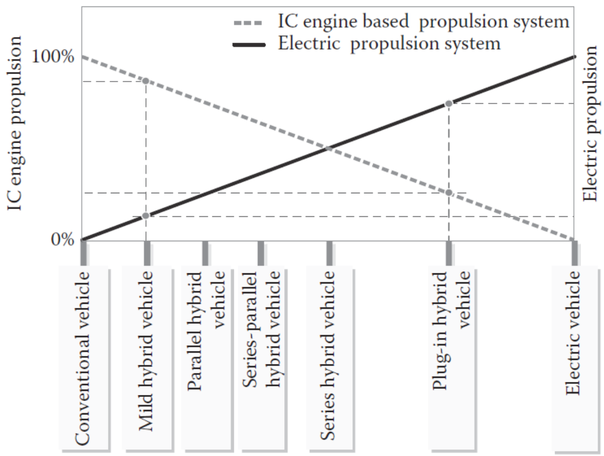

Figure 1.4: Different Vehicle Types and their Conventional and Electrical Propulsion Systems [12]

pollution due to the electric motor. However, when well to wheel emissions are considered, the total carbon footprint of BEVs are highly depend on the electricity in the grid. Since the battery is charged from the grid, the electricity generation method has huge importance. If the BEV is charged with the electricity produced from renewable resources that are the best case scenario for the overall carbon footprint [17].

Although BEVs have lots of advantages over ICE vehicles, the biggest problem or fully electric cars are the limited driving range; which is also called ‘'range anxiety”. Depending on the battery type and size, driving range of BEVs changing from 80 km to 400 km. The powertrain of BEVs consists of the battery pack, power electronic devices and electric motor which can be seen easily in Figure 1.5.

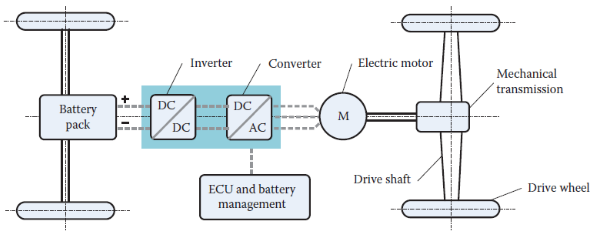

Figure 1.5: Battery Electric Vehicle Powertrain [12]

The most important component of the powertrain is the battery pack. Depending on the usage purpose of the electric vehicle, the chemistry of the battery shows differences. Each combination has distinct advantages and disadvantages in terms of performance, cost, safety and lifetime. The most used battery types are lithium-nickel-cobalt-aluminum (NCA), lithium-nickel-manganese-cobalt (NMC), lithium-manganese-spinel (LMO), lithium-titanate (LTO) and lithium-iron-phosphate (LFP). Most important features of the batteries can be divided into 6 different categories; cost, specific energy (capacity of storing the energy per kg of weight), specific power (amount of power that batteries can deliver per kg of mass), safety, performance, and lifespan. For instance, NCA technology is used for the high-performance cars such as Tesla because its specific power is high. However, the drawback of this technology is its safety; thus, the control system needed for this type of battery chemistry is very important. On the other hand, LFP technology is safer at cell level; however, it provides very low specific energy. This 6 different features of the battery chemistry can be seen in Figure 1.6 [18].

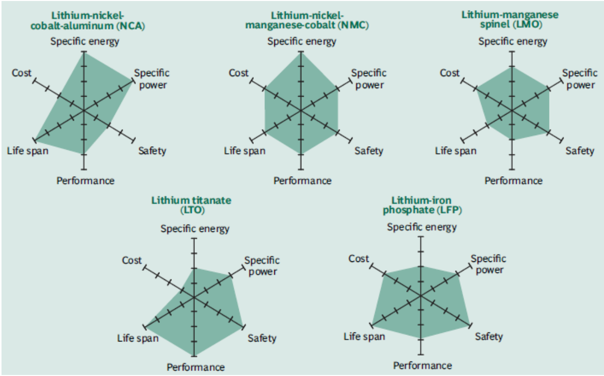

Figure 1.6: Five Principle of Lithium-ion Batteries [18]

1.3 Objectives

The objectives of the thesis are to investigate the future of electric mobility mainly in Europe for 2030 and 2040 and propose a different business model according to these new e-mobility trends to the utility company Iberdrola. In order to reach the goals, detailed literature research is done on the following topics, (i) EV market outlook and future projections on the market, (ii) self-driving vehicle technology, (iii) car sharing applied to EVs, (iv) vehicle to grid (V2G) applications, and (v) fast charging. Furthermore, actions of competitors are investigated in order to obtain information about the possible future business models.

1.4 Research Question and Methodology

The research question for this thesis is; "Which areas in electric mobility can Iberdrola place emphasis in order to achieve their company goals; decrease greenhouse gas (GHG) emissions and have a sustainable mobility for future?".

In order to find an answer to the thesis question, a detailed research is done by following a methodology. According to this methodology, first of all the electric vehicle (EV) market is investigated in detail. The current EV market and the future possible EV market projections are searched. After obtaining some information about the future projections of electric mobility and EVs, a detailed research on the competitors of Iberdrola is done. In this part 7 utility companies are investigated and their actions and future plans about electric mobility are studied. It is seen that most of the utility companies are putting some emphasis on charging infrastructure and smart charging; and some of them gives importance to car-sharing and vehicle to grid applications. In order to obtain information about the different field of electric mobility, car-sharing and self-driving vehicles are investigated. In order to understand the car-sharing, some business models are found. After the detailed research, it is seen that the combination of the three technologies, (i) EVs, (ii) car-sharing concept, and the (iii) self-driving vehicles, promises tremendous new business areas for the future. As the last part of the research, impact of EV charging on the grid and some opportunities in this field is investigated. It is seen that with the high EV penetration, the EV charging will affect the grid. Smart charging and Vehicle to grid technology promise a big advantage for the future and they can be used for eliminating the negative effects of EV charging on the grid. After whole these detailed market research, some possible future markets are decided and some proposals are done to the Iberdrola in order to exist in these possible markets.

1.5 Thesis Outline

The EV market outlook and the future projections about this market can be found in chapter 2. Furthermore, this section includes the information about what are the other the utility companies doing in electric mobility. Chapter 3 investigates the car-sharing concept; there are some business models for car-sharing. In addition to the car-sharing, the reader can find information about self-driving vehicles. In the last section of this part, there are some future possible projections with the combination of car-sharing and self-driving vehicles applied to EVs which can be called as Mobility as a Service or Transport as a Service. In chapter 4, literature research on the charger types and the impact of EV charging on the grid is investigated. Moreover, vehicle to grid, smart charging, and fast charging concepts are also investigated in detail. Chapter 5 gives information about what Iberdrola is doing on electric mobility field. Due to the detailed market research done in the previous sections, a business model is proposed to the company which can be applied in the future in order to increase the penetration of electric mobility and to increase the company's value on ***Sustainable Mobility*** and ***Green and Sustainable Future***.

Chapter 2

EV Market Outlook

This chapter explains the current electric vehicle market and the future projections about the sales of the EVs. The first part in the chapter includes global EV market outlook. It is divided into three section; North American Market, Asia Pacific Market and European Market. Moreover, the policies of some countries were mentioned. Second part gives information about the future projections about the battery prices and the EV sales in the future. The last part of this chapter gives information about the competitors of Iberdrola, what are their activities on E-Mobility.

2.1 Electric Vehicle Markets by Continents

Transition to electrification of road transport has begun a decade ago; however, it gained huge momentum especially in 2016. The total number of electric cars driven on the road has passed 2 million unit threshold. Although 2 million seems a huge number, when all the car market share is compared; the electric vehicle market is only 0.2% globally. In other words, the electric car market is in very early stage [19]. In 2016, the number of electric cars sold worldwide reached a record number with 750,000. Until 2015 United States of America was the leader of the EV market who has the largest stock of electric vehicles on the roads. In 2016, this trend has changed and China took the lead from the United States. Last year, around 40% of the electric cars were sold in China. As a result of this, China has the largest electric vehicle stock in the world; with more than 200 million electric motorcycles, around 3-4 million low-speed electric vehicles, more than 300,000 electric buses [10].

Figure 2.1 shows the evolution of the global electric car stock between the years 2010 and 2016. It can be seen from the figure that Battery Electric Vehicle (BEV) sales have more than Plug-in Hybrid Electric Vehicles (PHEV).

Although the electric car sales hit a record last year, sales in 2016 decreased its pace; that is, the market growth rate of 2016 is 40%; whereas, the market growth rate of previous years is around 50%. The main electric car markets are China, United States, and Europe. In 2016, the number of electric cars sold in China was 336,000. This number is more than double the number of the electric cars sold the United States; 160,000. Number of electric cars sold in European countries was 215,000 last year.

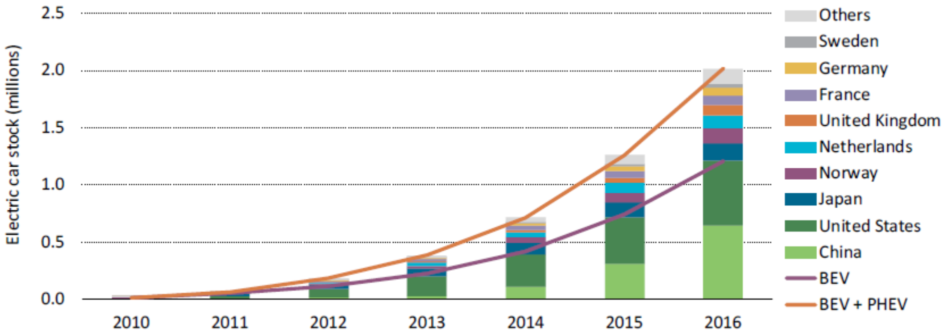

Figure 2.1: Evolution of the Global Electric Car Stock between 2010 and 2016 [10]

In Europe, most of the electric cars registered in 6 main countries which are Norway, United Kingdom, France, Germany, Netherlands, and Sweden. Furthermore, 95% of the electric car registration happened in only 10 countries; Norway, United Kingdom, France, Germany, Netherlands, Sweden, China, United States, Japan and Canada [10]. Figure 2.2 shows the number of sales in these main countries according to the years and according to the type of the electric vehicle; BEV or PHEV.

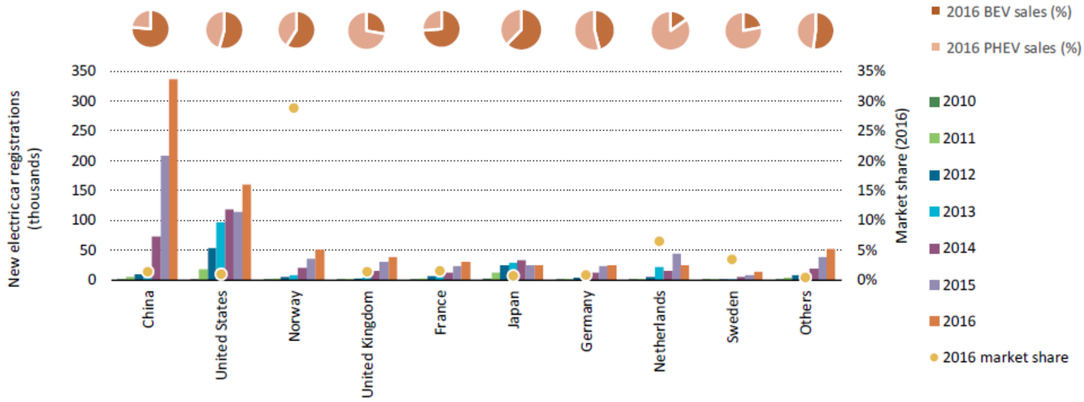

Figure 2.2: Number of Electric Cars Sold, Market Share in Selected Countries [10]

It can be seen from the Figure 2.2 that in 6 countries; China, Norway, United Kingdom, Sweden, Netherlands and France, EV market share is more than 1%. In other words, the share of electric cars sold in those countries over all cars sold in those countries is more than 1%. Norway is the global leader in this field by far with a market share of 29%. This information shows that the deployment rate of electric vehicles in Norway is very high. The second place belongs to Netherlands with a market share of 6.4%. Sweden follows these countries with a market share of 3.4%. The United Kingdom, China, and France have the electric car market share around 1.5%. Furthermore, it gives information about the sale share of BEV and PHEV. It shows that around three-quarter of electric car sales in China and France was BEV; whereas, in Netherlands, Sweden and in the United Kingdom, the majority of the electric car sales was PHEV [10].

2.1.1 North American Market

When the electric car sales in third quarter of 2016 and the sales in 2015 were compared, it can be seen that the EV sales have increased around 62% in North America. Tesla Model S and Chevrolet Bolt are the main EVs which boost this sale increase. Moreover, the sales of battery electric vehicles (BEVs) are higher than plug-in hybrid electric vehicles (PHEVs) [20]. Due to the long range of Chevrolet Bolt, the new Toyota Prius Prime, and Tesla, the sales in North America is expected to increase. Figure 2.3 shows the market share of the electric car models in the United States at the end of the year 2016.

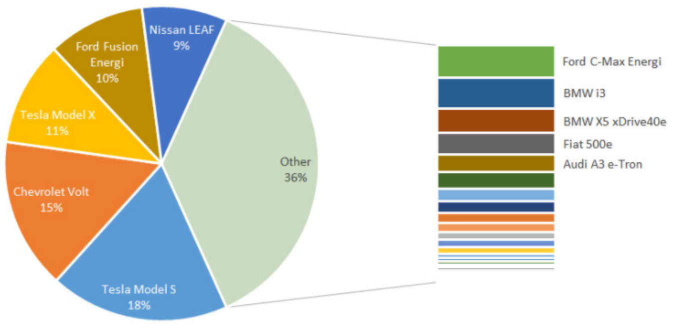

Figure 2.3: Market Share of Electric Car Models in the United States at the end of 2016 [21]

The figure both includes the BEV and PHEV sales in 2016; it can be observed that Tesla Model S has the highest market share. Second place belongs the PHEV model, Chevrolet Volt; of General Motors. Market share of electric cars in Canada can be found in Figures 2.4 & 2.5; the former figure includes the BEV sales only while the latter figure includes the PHEV in the country. The data belongs to the end of the 2nd quarter of 2017 [22]. It can be seen from the figures that Nissan Leaf and Tesla Model S have the highest share of sales in the BEV sector with a share of around 31%. In the PHEV category, Chevrolet Volt has a superior advantage in the market with a share of 59%.

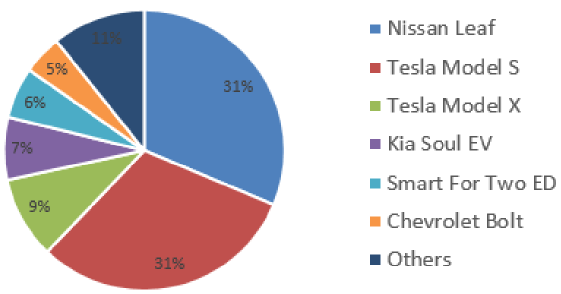

Figure 2.4: Market Share of BEV in Canada at the end of 2nd Quarter of 2017 [22]

Government Policies of United States

According to the White House announcement made on November 3, 2016, the US Department of Transportation is going to take the responsibility to build the charging infrastructure in the country. There will be 48 national electric vehicle charging corridors; with one charging station in every 50 miles. Moreover, in some cities in the United States, a mass EV purchase will be done to the public fleet; such

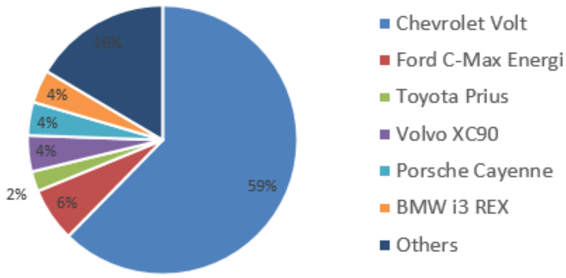

Figure 2.5: Market Share of PHEV in Canada at the end of 2nd Quarter of 2017 [22]

as some EV will be bought for the public bus or police car fleets. It has already started in some cities; for instance, Los Angeles 100 BMW i3s have been bought for the police department in 2016 [10, 20].

2.1.2 Asia Pacific (APAC) Market

China

China market is the biggest market for electric car sector; as it was mentioned in previous sections, in 2016 the number of electric cars registered in the country was 336,000. This number is expected to increase up to 530,000 at the end of 2017 where 80% of the EV sold will be BEVs. This would mean that the share of electric vehicles in China market will rise to 2.1%. The market share of different car segments and models can be seen in Figure 2.6. In the Chinese market, only 6% of the electric cars are non-Chinese brands and the biggest share belongs to Tesla in these non-Chinese brands [23].

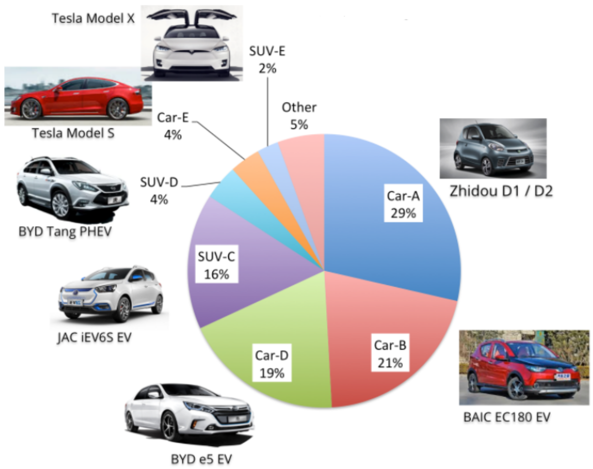

Figure 2.6: Market Share of EV in China at the end of 2nd Quarter in 2017 [23]

Government Policies of China

China has the biggest EV market globally due to its governmental policies. On October 8th, 2016, Premier of China has announced that there will be no more approval for opening of a new ICE vehicle manufacturing facility [23]. This shows that China wants to restrict the ICE vehicle production capacity in the future years. Moreover, the financial and non-financial subsidies for EV has a huge importance in the country. The amount of exemption from acquisition and excise taxes is between $5,000 and $8,500.

In some of the large cities, total or partial waivers for the license plate availability restrictions. In other words, people are encouraged to buy electric vehicles due to the license plate restrictions [10]. Although Chinese government decided to decrease the subsidies for EVs around 20%, the goals for the growth of the EV market is ambitious. It is aimed that the EV share in the country would be 8% by 2018, 10% by 2019 and 12% by 2020 [23].

Japan

Electric vehicle market in Japan didn't show significant improvement during 2016. If the 3rd quarter of 2016 and 2015 is compared, it can be observed that the EV market in Japan decreased almost 60%. The main model which was sold in Japan is Nissan Leaf; sales number of this car is around 12,000 between the first and third quarters of 2016. There are very few newly introduced models in EV market in Japan; therefore, the market stays stagnant. The main reason for that is the attitudes of the Japanese car manufacturing companies. Honda and Toyota gave their priority to the fuel cell vehicles instead of the fully electric vehicle. However, the policy of Toyota towards BEV is changing. They have announced on November 2016 that BEV with a range of 300 km will be on the market by 2020 [20].

Government Policies of Japan

In 2016, a new subsidy program was introduced in the country towards electric vehicle. According to this, number of subsidies will increase as the range of the electric vehicle increase. The maximum limit for the subsidies will be $7,700. For instance, for Nissan Leaf with a 30kWh of battery pack, the incentive will be $3,000 [10].

2.1.3 European Market

Europe started to the first quarter of 2017 very fast. According to the European Automobile Manufacturers Association, the number of rechargeable electric vehicles sold in Europe and number of HEV sold in Europe has increased around 30% and 61%, respectively. This growth was calculated by considering the sales in the first quarter of 2016 [24]. Figure 2.7 shows the market share of BEV models in Europe. It can be seen that Renault Zoe is leading the sales of BEV with 16,820 unit and a share of 26.6%.

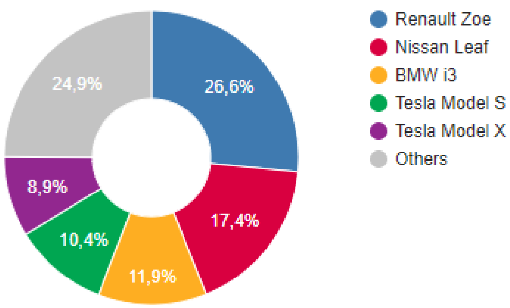

Figure 2.7: Market Share of BEV in Europe in 2017 [25]

For the PHEV sales in Europe, Mitsubishi Outlander Plug-in model is leading the market with 9,294 units and 14.4% of market share (Figure 2.8).

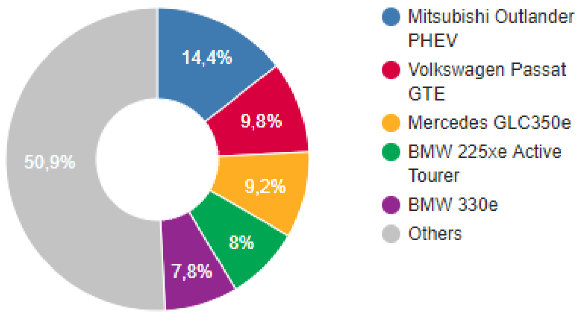

Figure 2.8: Market Share of PHEV in Europe in 2017 [25]

Government Policies of European Countries

When the market share of EVs in each country is investigated, it can be seen that the Norway has the highest ratio with a percentage of 29% (Figure 2.2). Norway has this highest deployment rate of EVs due to the policies in the country. There is no acquisition tax for the electric cars; moreover, 25% of value-added tax (VAT) is exempted at the purchase of BEVs. In addition to these, there are also high variety of waivers applied to the EVs; such as road tolls and ferries. BEV taxes are going to be there until 2020 according to the International Energy Agency report [10].

The Netherlands are pursuing another policy for the taxation. In the country, there is a differentiated CO_2 based taxation which increases gradually until 2020. In 2016, every car owner was obliged to pay a tax according to the km that they cover if they are using conventional vehicle or hybrid vehicle; €6 per g CO_2/km. This rate is aimed to increase in 2017 to €20 per g CO_2/km. Since the BEVs have zero emission, the BEV owners are exempt to pay this amount [10].

The Swedish government has decreased the purchase discount of PHEVs; the amount of this discount was $4,500 in 2015 and it decreased to $2,250 in 2016. However, for the BEVs, there is still purchase discount around $4,500 [10].

Danish government has decided to have a purchase tax discount in 2017. According to this new strategy, there will be a purchase rebate according to the battery capacity of the electric car. The amount of discount will be $225/kWh applicable to a maximum battery capacity limit of 45 kWh [10].

2.2 Future Projections for Electric Mobility

New cell chemistries are still investigated for the batteries in order to improve the performance and decrease the cost. In theory, new cathode materials such as lithium-air could have an energy density around 5,200 Wh/kg; whereas, lithium-ion batteries have an upper limit of energy density around 400 Wh/kg nowadays. Nevertheless, mass production of lithium-ion batteries is 10 maybe 20 years away [20].

Because of the iterative improvements in the active materials and different pack designs, performance of the batteries has already increased 50% between the years 2011 and 2017. There were some promising announcements from the electric car manufacturers. In July 2016, Tesla announced that they were working on a new cell format in order to improve the performance of the electric vehicle. They are using silicon-doped cylindrical format cells to improve the energy density of the anode and reduce the size of the battery. Also, they could achieve better energy density due to the cylindrical shape of the battery. The cylindrical format has a better energy density than the normal configuration since the electrode layers can be packed denser in cylindrical configuration which reduces the size of the battery. Moreover, General Motors (GM) has also announced that Chevrolet Bolt, fully electric vehicle, will have an unexpected high range of drive with single charge, 383 km. That is a huge improvement if the driving range is considered. GM has achieved this feature by using 60 kWh battery pack in Chevrolet Bolt due to the high energy density of this new battery system. In other words, since the energy to weight of the battery ratio is higher, 60 kWh batteries can be easily used in Chevrolet Bolt. In addition to GM group; PSA, French car manufacturer, has announced in September 2016 that the EV can have an extra 50 km extended range due to the redesigned thermal management system in the cars [20].

It is estimated a decrease in the battery cost in the future due to the research, development, deployment of more electric vehicles and the mass market [10]. As mentioned before, battery is the crucial part of an electric vehicle and big portion of the manufacturing cost of EV is due to the battery cost. Since the battery costs are currently high, it results in a high manufacturing cost for the electric vehicles. However, this trend will change soon; in other words, the cost of the batteries has a high potential to decline. If the trend for battery cost for the laptops were investigated, it can be seen easily that the price has fallen to $250 from $2,000 in about 15 years [16]. That means the decrease of the cost is about 14%. Due to the increasing number of EV sales and the increasing technology, the same trend is expected for the EV battery pack cost. Figure 2.9 shows clearly that the decrease of the battery cost for the electric vehicles is around 80%. Cost has fallen from $1,000/kWh to $227/kWh between the years 2010 and 2016 [26].

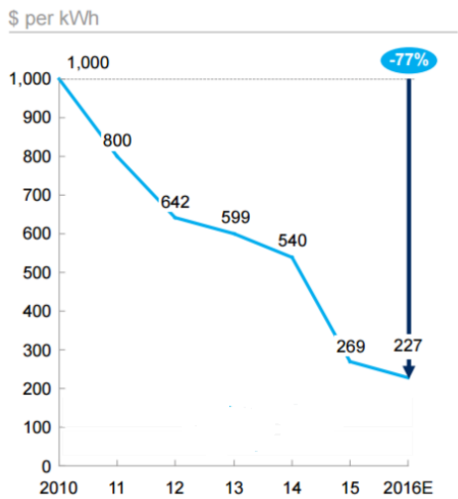

Figure 2.9: Average Battery Pack Price between 2010 and 2016 [26]

While McKinsey & Company claims that the battery pack cost will decrease to $190/kWh by the end of this decade; Tesla states that their battery costs are around $190/kWh since early 2016 [27]. In some sources, it is estimated that there will be a cost parity between ICE and EV in a couple of years in Europe. This projection is due to the unexpected decrease in the battery costs; that is, the battery cost has fallen faster than it was predicted eight years ago [28]. It is stated in the ‘White Paper for the Future of Mobility’ prepared by Bloomberg New Energy Finance that the cost of the batteries will go down until $100/kWh in this decade [6]. Apart from these optimistic projections, it is estimated in IEA’s report on Global Electric Vehicle Outlook that ICE and EV are going to be fully competitive in Europe by 2030 [10]. Moreover, in the paper of ‘Battery Technology Charges Ahead’ prepared by McKinsey & Company, it is estimated that the battery prices will go until $160/kWh by 2025 [29]. Tony Seba mentioned the same type of projections in his book ‘Clean Disruption of Energy and Transportation: How Silicon Valley Will Make Oil, Nuclear, Natural Gas, Coal, Electric Utilities and Conventional Cars Obsolete by 2030’ like Bloomberg New Energy Finance and Tesla. It can be seen in Table 2.1 that the battery cost will fall below $100/kWh around 2023 [16].

Table 2.1: Cost Projections of EV Batteries [16]

Year	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Cost ($/kWh)	500	420	353	296	249	209	176	148	124	104	87	73

When the projection results from Table 2.1 and the real average battery pack cost values for 2015 and 2016 (Figure 2.9) are compared, it can be seen that the real prices are much lower than the projections values. For instance, the average real price for years 2015 and 2016 are $299/kWh and $227/kWh, respectively. These show clearly that the prices are decreasing more than expected. In other words, the battery pack price will be below $100/kWh limit sooner than expected; possibly at the end of this decade [6].

The price limit of $100/kWh is very important for the manufacturing cost of electric vehicles. An EV with a range of 200 miles (322 km) needs 50 kWh battery pack on board [16]. If it is assumed that the battery pack price is $100/kWh, that means the cost of the battery pack for a 200-mile range EV will be $5,000; that is, the EV will become fully cost compatible with an ICE vehicle without incentives.

Electric vehicles are technological products; they are equipped with software and the computers. Tony Seba called in his book, EVs are mobile computer on-wheels [16]. In 2013, Tesla Roadster has covered 30 million miles; also, Tesla Model S had covered also another 30 million miles on the roads. The importance of Tesla Cars had 60 million miles (100 million km) on the roads until 2013 is substantial. With the software system inside all the cars, Tesla could be able to collect valuable data for the future productions and even for the autonomous driving [16]. EVs are mobile and they are connected to the information technology platforms; for example, Tesla Model S can connect to a WiFi or a mobile data (3G, 4G) in order to download updates and patches. With this specialty, EVs are in the same class with smartphones and the tablets. Due to the fact that EVs are information technological products (such as tablets and smartphones), the Moore’s Law can be applied to them. What does Moore’s Law state is micro processor technology improves with an annual rate of 41%. In other words, a computer is 41% better for the same amount of money than previous year; faster, smaller and more powerful [16]. For example, with the same amount of money, people can buy a faster, smaller and a more powerful computer in 2017 than 2016. That is the reason why nowadays microprocessors are 20 times more powerful than they were 20 years ago. It is impossible to compete with the exponentially improving products unless both competing companies have products which are exponentially improving. If the Moore's Law can be applied to one company's product and not to its competitor; that means, the disruption time would be soon for the competitor company. That can be clearly said for the EVs and the conventional ICE vehicles. For instance, in the same time it takes for an ICE car manufacturer to produce a new type of highly efficient gasoline driven car, Tesla could develop two generations of EVs [16].

Due to the technological improvements, living standards are getting improved and the life time of the people increasing. The world's population is around 7.5 billion people nowadays and it is expected to increase up to 9.1 billion people by 2040. Economies of the countries can be measured best by Gross Domestic Product (GDP). GDP is the total value of everything produced by all the people and companies in the country. According to the '2017 Outlook for Energy' prepared by Exxon, World's GDP will be doubled by 2040 if it is compared with 2015 value. During this increase globally, GDP in OECD (Organization of Economic Co-operation and Developed) countries contribute with 60% increase and non-OECD countries will contribute to 175% increase [30]

With increasing GDP, purchasing power all around the world will increase; GDP per capita will be $80,000 in U.S and $50,000 in Europe OECD countries by 2040. As a result of this, the number of middle-class will reach 5 billion people by 2030 by doubling its number [30]

All these predictions show that there will be an increase in the living standards of the people. When the income of people increases, they start traveling and that means more cars on the roads.

According to the projections made by BP, there will be 100 million electric vehicles on the road by 2035 [31]. On the other hand, IEA projects in its report 'Global EV Outlook 2017' that there will be between 9 million and 20 million electric cars on the roads by 2020, and between 40 million and 70 million electric cars by 2025 [10]. Table 2.2 shows the announcements made by the car manufacturers about their EV sale targets for the future.

Table 2.2: List of Goals of some Car Manufacturers on Electric Cars [10]

Car Manufacturer	**Announcement**
BMW	0.1 million EV sales by 2017 and 15-25% of the BMW group's sales by 2025
Chevrolet (GM)	30,000 annual EV sales by 2017
Chinese Car Manufacturers	4.52 million annual EV sales by 2020
Daimler	0.1 million annual EV sales by 2020
Ford	13 new models by 2020
Honda	2/3 of the 2030 sales to be EV (including HEV, PHEV, BEV, and FCEV)
Renault-Nissan	1.5 million cumulative sales of EV by 2020
Tesla	0.5 annual EV sales by 2018, 1 million annual EV sales by 2020
Volkswagen	2-3 million annual EV sales by 2025
Volvo	1 million cumulative EV sales by 2025

As it can be seen from the announcements of car manufacturers that they have a high number of EV sales in the short term. With considering the sale targets, the decrease of battery pack cost and the technological improvements in the microprocessor technologies, it can be expected that the penetration of the EVs to the car market will increase year by year.

2.3 Future Plans of Utilities

When the history of the existence of humankind is investigated closely, it can be seen that the Stone Age didn't end due to the depletion of stones. It is also same for the horse and carriage era at the beginning of the 1900s. People stopped using horses for transportation not because they ran out of available horses. In both cases, a new superior technology came and the old technology had become obsolete. In the Stone Age example the superior technology was the Bronze and in the horse carriage example, this new innovative technology was conventional ICE vehicle [16].

Likewise, the era of conventional way of producing electricity from the fossil fuels will not change due to the depletion of fossil resources (i.e. oil, gas, coal, nuclear). The change will happen because of new emerging business models and services due to the new disruptive technologies in this era such as wind, solar, EV, and self-driving cars [16]. Large scale of electricity production from renewable sources is forcing the conventional grid to change, and it affects the industry substantially. With more penetration of renewables into the electricity market, the wholesale electricity market price is forced to go down. As a result of this phenomenon, the revenue of utilities decreases; because the utilities start losing money from the electricity production. One of the good examples to this case happened in Germany on June 16, 2013. The wholesale electricity price went down minus €100/kWh due to the high generation of electricity from wind and solar. Since the renewable electricity has priority to be sold in the market in Germany, with the excess production from wind and solar forced the prices to go down. In order to stabilize the grid, the cost of electricity went to minus levels [32]. Moreover, according to the financial data of 2013, the German utility company RWE has lost more than $3.8 billion in 2012 due to the sliding wholesale electricity prices. This amount of loss of RWE is quite important for them because it was the first time happened since 1949. For Swedish utility company Vattenfall, the fate was similar also for the year 2012; they have lost $2.3 billion [33]. At the peak year of utilities, 2008, the top 20 power utilities were worth around €1 trillion. At the end of 2013, they have lost almost half of their value. These numbers show that the disruption of traditional, centralized power production is a substantial threat for the power utility companies. Therefore, some changes need to be done for the business models of the utilities [34].

Disruption of the conventional power generation seems inevitable with the increasing amount of electricity production from renewables. However, this change in the electricity market will create different possible future markets for the utility companies. Figure 2.10 shows this possible markets for the utility companies, clearly.

There are also some key trends in the electricity market which the utility companies would benefit; ***trends in power generation***, ***trends in load-balancing*** ,***trends in retail service provision***, ***trends in electric storage***, and ***trends in electric mobility***.

Trends in Electric Mobility

Usage of renewable energy on the roads hasn't been increased yet although there is a high pen-

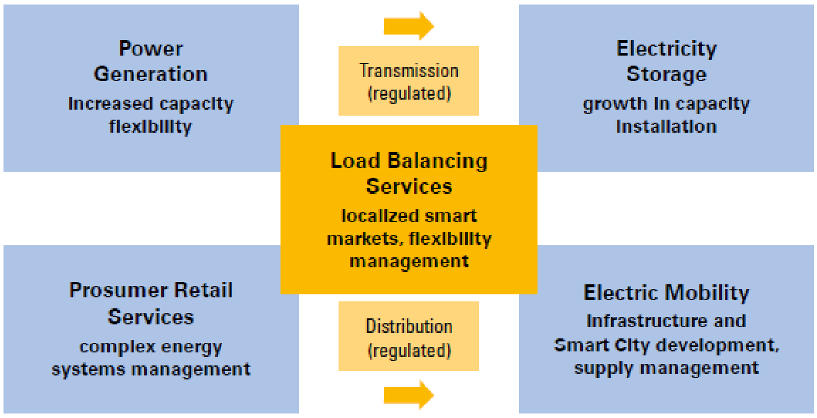

Figure 2.10: Potential New Future Markets for the Utilities [34]

etration of renewables to the grid. Electrification of road transportation is crucial for the sustainable future because of the high emissions from the vehicles. Due to the high battery prices and the battery technology, electric vehicles are more expensive than the conventional ICE vehicles and EVs have the range problem. However, these are expected to change drastically in near future and the EVs will be totally cost competitive with the conventional cars; also, the range problem will not be a problem due to the improvements in the battery technology or due to the new emerging business models such as car-sharing with EVs and car-sharing with autonomous EVs [16].

If it is looked closely, e-mobility might be an important asset for the utility companies' future business models. Utility companies might think to become a 'mobility service provider' as integration of multi modal mobility in people's lives increases. For example, the combination of train-bus-car travels in urban areas will create a good opportunity for the utilities. An example of this kind of model is the car-sharing company Enjoy (Chapter 3.1.4), which operates Italy [35]. Moreover, with vehicle to grid and the smart charging, electric vehicles can be used also as a grid source in the future [34].

2.3.1 RWE (Rheinisch-Westfälisches Elektrizitätswerk AG) / innogy

As the second biggest electricity producer in Germany, RWE gives importance for the electric mobility. According to the information in their official website, RWE sees the e-mobility as a technological change and they believe that this change will create new paths in the energy sector. They offer smart charging infrastructure, IT services and intelligent e-mobility solutions for cities, and private electric car users. There is also extensive research on the integration of electric vehicles into the energy system in order improve the usage of renewables in the grid. With their partners, RWE has developed standards for charging plugs and data which flows between the electric vehicle and the charging station [36]. Type 2 plug is a result of this research and collaborative work. This type of connector is considered as safe for fast charging of electric vehicles. When the vehicle is connected to the charging station, the station sends a signal and lock the plug. After the lock, the customer ID is checked via the system and the charging starts. Type 2 plug charging can be improved by connecting a high-speed internet cable in order to meet the future demands. One of the most important thing that makes RWE's charging infrastructure better is that it supports fast charging with a charging capacity up to 50kW which is 22 times higher than the conventional plug in the houses. During charging, a smart meter records the amount of electricity used and an automatically generated bill shows how much is the customer charged with the electricity that they used. Moreover, EV can communicate with the grid in order to manage charging and arrange the load on the grid. This feature gives high importance to the RWE's charging post because its help will be tremendous for the future applications [37].

In 2015, German based discount supermarket Aldi and RWE established a public DC charging station in one of the Aldi stores in Düsseldorf. The electricity taken from the charger is free and it is provided via the solar panels on top of the Aldi building. The 20 kW power semi fast charging station provides renewable electricity to the electric vehicles [38].

Apart from the charging infrastructure, RWE and Renault have a partnership to produce a residential wallbox ***RWE eBox*** and ***RWE eBox Smart***. RWE eBox is produced for the residential use. It has a power of 11 kW and it can be easily mounted on the wall; depends on the preference, it can be also installed into existing household. The product helps to charge the electric vehicle 5 times faster than the normal power socket [39]. RWE eBox Smart is upgraded version of the regular eBox. The usage area is for towns and regions, utility providers, automobile dealers, companies, etc... The power of the device is 22 kW; that is, it can charge the electric vehicle 10 times faster than the conventional power socket [40].

innogy

Innogy is an energy company which is a subsidiary of RWE (76.8% of the shares belongs to RWE). It was created on 1st April 2016 in order to split renewable, retail and the network business of RWE. E-mobility has a huge importance in their future plans. By thinking the future, they have already made some investments in this field. A new unit which is called eMobility has been launched in January 2017. This new business unit pools all electric mobility activities in one roof. Their aim is to become a leading solution provider for charging in Europe and in U.S. In Europe, innogy already operates one of the largest charging networks with 5,300 charging points in more than 30 countries. COO Retail Martin Hermann said '' Electric mobility is an incredibly important market for innogy. And as a spirit of new beginnings is in the air, it's the perfect time to address this topic: governments and corporations worldwide are making important decisions for the future. By establishing the new eMobility business unit, we can start to react even faster and better to the rapid changes in this future market." [41]. This statement basically shows their ideas about the electric mobility.

RWE is one of the founders of the project ***HUBJECT*** in 2012; and now Innogy is one of the main partners of the project with BMW Group, Daimler, Bosch, EnBW, Siemens and Volkswagen Group. The main goal of the project is to create an eRoaming platform in Europe. In other words, with more than 280 partners all around the world, the project is trying to give B2B service related to the charging of electric vehicles. Since the date of foundation, the project has been trying to connect different market players (i.e. charge point operators, electric mobility service providers, energy suppliers, fleet operators, car sharing companies, service card providers or automobile manufacturers) in order to create a cross-boarding charging network for the EVs. With the help of this eRoaming, EV users can charge their vehicles in any kind of charging infrastructure in anywhere in the world [42].

Like RWE's eBox, Innogy also provides the same technology to the houses. People can mount the eBox in their homes in order to charge their electric cars 5-10 times faster than the normal power socket. Innogy has a new test product from its innovation hub; eCarSharing. In this pilot project, municipalities, companies and private individuals are offered electric vehicles which they can rent them through online platform. Customers can book modern electric vehicles like BMW i3 or Nissan Leaf; and they are charged per minute basis, per hour basis or per day basis (detailed information about the business model will be given in the next chapter). From the Innogy point of view, eCarSharing project will contribute substantially to the Energiewende [43].

2.3.2 EDF

Sustainable mobility has the high importance in EDF's future plans. French based utility company invests in different fields related to electric mobility; (i) design, installation and supervision of charging infrastructures of electric vehicles, (ii) rental and battery fleet management (buses and trucks), (iii) fleet management (companies and local authorities). Sodetrel, subsidiary company of EDF, is highly active in the first field. They are responsible for deployment, technical operation, and maintenance of the charging stations for the electric vehicles. The services that they provide include real time monitoring of the park which can be called also supervision, user services (i.e. consumption and bill monitoring), and remote maintenance. They are also responsible for electric fleet management and on-board energy [44]. In December 2014, they have started a project called CORRI-DOOR. The aim of the project is to install 200 electric vehicle charging stations in France in order to accelerate the adoption rate and the usage of electric vehicles. These 200 charging stations constructed along the busiest roads and motorways and on the outskirts of major cities of France. The distance between two charging terminals is 80 kms and the drivers can charge their electric vehicles with 100% renewable electricity and with fast charging technology in 20 to 30 minutes [45]. EDF's Electric Mobility Division is the coordinator of the project and Sodetrel has the responsibility of specifications, purchasing, installation and operating all the stations. EDF and Sodetrel have partnered with Renault, Nissan, BMW, and Volkswagen for the project. European Commission contributed €5 billion to EDF whereas the total cost of the project was €10 billion [46].

Ombriwatt, a product from EDF ENR Solaire, aims to produce electricity by using solar panels and use that electricity for charging the electric vehicles. The advantage of Ombriwatt is CO_2 emission during electricity generation and powering vehicles is reduced tremendously. It is a parking shelter which protects the vehicle from the sun or bad weathers; and, the roof of the shelter is equipped with PV panels. The produced electricity can be used either to charge the parking EV or to support grid. 30 m^2 of an Ombriwatt unit produces 4,000 kWh of energy; as a result of this, it can prevent 260 kg of CO_2 annually [47].

The second field that EDF is involved related with electric mobility is the rental and battery fleet management (buses and trucks). In 2015, all the buses operate in Paris were ICE vehicle. However, with a 3-year agreement signed in 2014 between Paris Transit Authority and EDF, 4,500 buses of greater Paris network will be clean by 2025; 80% will operate with electricity and 20% will operate with biogas. As a result of this transition, the carbon footprint of Paris Transit Authority will be decreased by 50%. For EDF, the project involves highly research and development for testing the different power trains, batteries and charging systems to achieve this goal [48].

As a three-year pilot project, a new urban transportation model started to operate in 2014 in the city of Grenoble. Toyota, EDF, EDF's subsidiary company Sodetrel, the City of Grenoble, Grenoble-Alpes Metropole, and Cite Lib (local car sharing company) were announced their partnership in order to apply this project in the city. According to the project, Toyota's ultra-compact electric vehicles are used for the public transportation. The first and the last miles are planned to be covered with these EVs. Moreover, with the help of a software or a smartphone application, customers can choose the best roots for themselves. The responsibility of EDF Group is to implement charging stations across Grenoble-Alpes Metropole and the maintenance of these charging stations [49].

Energy storage with the batteries is very important in the energy transition. With the increased battery technology, penetration of renewables into the grid can be increased as well as the energy production for self-consumption. Moreover, battery technology is the heart of the electric vehicles as it was mentioned before. Because of these reasons, EDF started to a partnership with Forsee Power, highly respected and experienced company in the battery market. Through this partnership, both sides are aiming; (i) to involve in the development of new storage options and batteries for heavy electric vehicles, (ii) to perform different research around existing and future lithium battery performance, (iii) to increase the both companies' public awareness in this field [50].

In order to be more active in the private customer market, EDF established Sowee which is a subsidiary aimed entirely the private market. Using Sowee, the customers are able to arrange their domestic electricity consumptions as well as the recharging of electric vehicles with the help of a Sowee device. As a result of this, the responsibility of Sodetrel will be only B2B markets in the electric vehicle infrastructure field [51].

2.3.3 E.ON

E.ON is a German based utility company which has headquarters in Essen, Germany. They are one of the world's largest investor owned electric utility company. In order to find its place in the future change, one of the fields that E.ON gives importance is the e-mobility like its competitors. They put emphasis on providing customer solutions for EVs. According to the press release from E.ON, they announced to have a new strategic e-mobility unit. Their aim is to have the leading role in the European charging infrastructure market. The company has already been offering power wall solutions both private customers and businesses. Apart from these power wall solutions, they are planning to secure the locations for charging stations and to increase the number charging infrastructure on the roads [52]. E-Mobility is getting more and more attention from other companies also. Due to the partnership between E.ON and the major car manufacturers such as Daimler, BMW, Ford, and Volkswagen, number of fast charging stations is planned to increase. 400 sites were identified in Europe in order to implement the fast charging stations. The goal is to implement as much fast charging stations as possible until 2020 [53]. The new mobility funding program from German government will contribute substantially to this process. The company is planning to start with initially 250 charging points and increase this number. Moreover, numerous freely accessible charging points will be installed in rural areas. E.ON sees itself as a partner for municipalities and companies who want to establish their own charging points. With its extensive knowledge and expertise on charging infrastructure, E.ON plans to help to its partners or customers to select the suitable charging points, operate the charging columns, provide suitable payment systems and manage the overall business [54].

In Denmark, E.ON and CLEVER, Denmark based e-Mobility service provider, have made a strategic partnership. Two sides have an experience in installing and operating EV infrastructure in Northern Europe [55]. E.ON has 2,500 charging points in Denmark and over 300,000 charging transactions have been made from these charging points in 2016 [52]. The important goal of this partnership is to implement several hundred ultra-fast charging stations for EVs throughout main European roads. The distance between the charging stations is decided to be 120-180 kms. As a result of this project, several major European cities will be connected to each other with ultra-fast charging stations [55]. Moreover, E.ON has created a phone application which is called EasyPark in Denmark. With using this application from the smartphones, the customers (either have E.ON card or not) can find the available parking spot and the electric vehicle charging infrastructure from the phone. If they have an E.ON card, they can pay the fee for parking separately from the application and pay the amount of electricity that they use from the card. In the other case, if they don't have the E.ON card, they can pay both the parking fee and the amount of electricity that they used from using EasyPark application [56].

E.ON provides to its private customers a card that can be used in 4,000 charging stations in Germany. They offer two different options with different pricing; E.ON Drive Smart and E.ON Drive Basic. The smart version is recommended to the users who use public charging stations more or using a power box at home. With this option, the cost of charging is fixed throughout the month. Basic option is for the customers who use the home charging more. Furthermore, with using smart phone application E.ON Drive, customers can find the nearest charging station and get instant information related to the charging status [57].

In December 2016, the company has announced the partnership with e-bike manufacturer Derby Cycle. As a part of the partnership, Derby Cycle will share its experience with e-bike market and business models related with e-bikes. In addition to that E.ON will share its innovations which are related to cycling. For instance, with the help of E.ON start-ups, new mobility concepts and convenient charging options for the e-bikes can be created [58].

2.3.4 ENEL

Enel is a multinational power utility company which operates around 30 different countries. They have started several different pilot projects about electric mobility in Italy since 2010. With creating strategic partnerships with automobile manufacturers, industry operators and institutions; Enel aims to increase the usage of electric vehicles. In Italy, the company currently has 2,650 recharging stations for electric vehicles, 850 of them is public and 1,800 of them is private. Customers, whether they are Enel Energia customers or not, can use the Enel public chargers with the smartphone application which is called E-go Ricarica. The application gives chance to the customers to charge their EV at the service station visible on the application [59].

According to the press release from Enel on May 2017; Enel and the ALD Automotive Italia have announced their partnership in order to promote and to increase the diffusion of electric mobility. ALD Automotive Italia is the division of French banking group Société Généralé specialized in mobility, long-term car rental, and fleet management. They have offices in Rome and Milan; and in Italy, they operate more than 136,000 cars, light commercial vehicles, and motorcycles. Due to the partnership with ALD Automotive Italia and Enel, customers will be offered solutions according to their needs. For instance, with using E-Go Ricaricar, customers are able to choose the model of the electric car that they want to use. They need to pay only for the kms they have covered by using the smartphone application; in other words, the customers are charged pay-per-use based. Another tailored solution for the customers is E-Go Noleggio a Lungo Termine, which offers to the customers to rent an electric vehicle for a long-term. Apart from these two solutions, the collaboration of two companies offers to their customers E-Go Car Sharing. With using E-Go Car Sharing, customers have a chance to rent a zero emission cars (detailed information about the car sharing service will be given in the upcoming chapter) [59]. In addition to the car sharing service, Enel and Nissan has been working together since June 2016 and they have launched together E-Go All Inclusive in November. It gives opportunity to the customers to buy a package with a fixed monthly fee; Nissan LEAF with 30 kWh battery pack, power box with installation and E-Go app that helps customers to find the closest available charging station and charge their EVs [60].

The alliances with Nissan and Chinese electric vehicle and battery manufacturer BYD was made in June 2016. Enel aims to be one of the key players in Europe on electric mobility and the energy storage with the help of these alliances [61].

In order to develop the charging infrastructure throughout the main European motorways, Enel is working on a project called EVA+ (Electric Vehicles Arteries) with some automobile manufacturers such as Nissan, Renault, BMW, Volkswagen and Austrian utility Verbund. The project is financed by the European commission and aims to build charging stations for electric vehicles along the roadways between Italy and Austria. State of art fast charging columns, which has the same standards like the ones used in whole European motorways, will be used for the project. By the end of 2019, 180 fast charging points are aimed to be constructed; moreover, 30 of these 180 fast charging stations is planned to be finished by 30th September 2017 [61, 62].

An extensive research and experimentation are continuing on Vehicle to Grid (V2G) applications. V2G is a very promising technology which can transform the electric vehicles to the mobile batteries. Due to the double way of electricity flow in the specialized charging infrastructures, the unused electrical energy in the EVs can be fed into the grid in order to stabilize the grid (more information about V2G can be found in upcoming chapters). Enel started its first project in Denmark last year. Collaboration with Nissan, 10 Nissan e-NV200 zero emission van was bought and 10 V2G charging stations were constructed. Like in Denmark, Enel tries its V2G charging infrastructures in the UK. Nine V2G chargers were installed at the Nissan Technical Centre Europe in Cranfield and 1 was constructed in Newcastle University. This year they will continue to test V2G charging stations with 2 new projects in France and Germany [62]. In addition to these, Enel, Nissan, and IIT (Italian Institute of Technology) have announced their collaboration to work on V2G in Italy. A pilot project on corporate car sharing has started at IIT's headquarters in Genoa. Enel provides 2 charging infrastructures and Nissan provides 2 Nissan Leaf and an app management platform which is called Glide to the IIT [63]. Furthermore, Nissan is also launching a new e-car sharing project MOV-E in Italy both contribute the V2G applications and e-mobility in Italy [60].

2.3.5 ENGIE

Engie is a multinational French utility company which has the headquarters in La Défense, France. The fields that they operate are electric generation and distribution, natural gas, nuclear and renewable energy.

The CEO of the company Isabelle Kocher says '' Mobility is a key issue for our major cities, which by 2050 will be home to 67% of the world's population. At ENGIE, we are contributing to the creation of a new form of mobility that is more fluid, cleaner and more economical in cities and regions throughout the world." [64]. This statement shows the company's attitude towards sustainable mobility. The name of their green mobility program is ***Better Mobility TODAY*** which is a part of ***TODAY*** initiative. Engie aims to improve air quality, to reduce noise pollution, to reduce congestion in the cities and to optimize transit network. They are planning to achieve these goals by combining their experience and knowledge on alternative fuels, transport infrastructure, smart transit systems, and upstream design and planning [64].

TODAY is an initiative by Engie which shows everyone that the energy transition has already begun to change people's lives. In order to spread the green mobility throughout Europe, Engie created a mobility program called Better Mobility TODAY. Figure 2.11 shows the details and the fields of the program better. The four main areas about transport sector are; (i) improving existing infrastructure, (ii) encouraging the development of green fuels, (iii) smoothing traffic flow, and (iv) simplifying urban logistics. In addition to these main four areas, intelligent transport systems (ITS), public transport, electric mobility, hydrogen mobility, planning and consultancy, and natural gas for vehicles are important sub-areas that Engie is showing some interest. **Car-sharing**, **electric bus charging infrastructure**, **electric charging networks**, **demand-response aggregation**, **smart charging**, and **renewable electricity for vehicles** are the important topics for electric mobility for the company [65].

Engie offers several solutions in the electric mobility sector. One of them is the electric bus charging infrastructure. The company make the design of the chargers, installs them and make the maintenance. The electricity comes to the chargers are produced by renewable sources. The customers of this solution are usually mass transport operators (both private and public), local authorities and bus manufacturers [66].

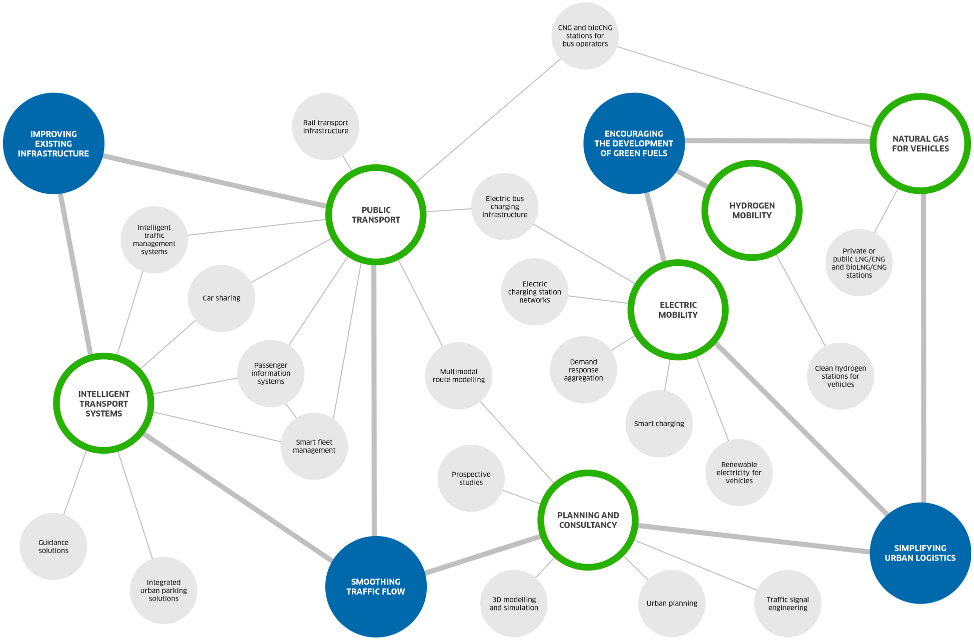

Figure 2.11: Engie's Better Mobility TODAY Program [65]

Second solution that they provide is electric charging stations network. During the past years they have already installed more than 5,000 charging points throughout Europe. The company is making the design of the charging points and the coverage of the geographical area. After the design, installations and commission is done. Maintenance service is given 24/7 to the customers about the charging point. Furthermore, electricity used for chargers are produced from local renewable sources [67]. Engie provides these service with the help of EV Box, a company founded in 2010 in Netherlands. In a very short time, they have become leader in the electrical charging station market by having 40,000 installed charging points globally. They provide charging stations, charging management software and services to its customers which are business, public sector and residential customers. Engie has announced in their press release in March 2017 that they made the acquisition of EV Box. Both Engie and EV Box have same vision on electric mobility; and, with this acquisition Engie aims to combine its globally well-known name, and energy capacities with EV Box's high technology EV chargers [68]. In addition to the EV charging stations network, Engie also provides smart charging solutions to the customers. Smart charging needs the demand-response aggregation services and grid management. With the help of smart charging, the charging time of the electric vehicles can be altered [69].

Another solution is provided with TODAY initiative is car-sharing services. They offer a professional car-sharing service to the municipalities and to the companies which want to establish a car-sharing service to its employees. The car-sharing service that they offer includes; a booking application for company cars, installation and commissioning of charging stations, power supply to the charging stations with electricity produced from renewables, maintenance service, renting of electric cars [70]. According to the press release made in September 2016, Engie and EV Box have aimed to construct 4,000 new charging points for electric cars in Netherlands; 1,800 of 4,000 charging stations will be in Rotterdam. Engie will make the installations, management and operations of these charging stations. Moreover, the partnership between Powerdale, a Belgian company which is specialized in energy control and electrical mobility, and Engie Cofely Luxembourg, a subsidiary company of Engie, has been established in order to install 800 public charging stations in Luxembourg [71].

Recently, Engie has announced that they invest in Gogoro's Electric Smartscooters and energy network technologies. The Gogoro's Smartscooter is an innovative technology which was found in 2011 in Taiwan. Scooters can go with a maximum speed of 95km/h and the range of the battery is 100km. The reason why this scooters are special is they have 2 swappable batteries. The innovative battery swapping system allows users to see the state of charge of battery via smartphone application and also allows them to change the batteries by using the application. Moreover, there are also charging stations which allows users swap the batteries at those locations [72].

Electrabel, a Belgian subsidiary company of Engie, works on smart, comprehensive and universal solution for electric car charging infrastructure which is called CarPlug. With using the CarPlug, the company offers a safe charging solutions in Belgium to the private EV owners without depending on the model of the car. They make the installation of 16 A power supply, a safety socket and detailed set of software in order to monitor the amount of power delivered from the charging station and the charging process by using the smartphone application. Furthermore, CarPlug can give companies the chance to management of charging process and power consumption of entire fleet remotely [73].

2.3.6 Vattenfall

Vattenfall is a Swedish utility company which is fully own by the Swedish government. They operate in several European countries; Germany, Netherlands, Denmark, Finland, Poland, and U.K.

Like its competitors, Vattenfall thinks electric mobility is very important for the future and for decrease the greenhouse gas emissions which occurred due to transportation. They have been involved in E-mobility since 2009 and invested heavily. The company knows that globally more charging infrastructures are needed in order to spread the usage of electric vehicles. Because of that reason, Vattenfall is involving of installation of charging stations throughout Europe. They have already installed fast-charging stations in Stockholm and Uppsala. Moreover, in Netherlands and Germany they operate more than 1,000 public electric vehicle charging stations mainly in Amsterdam, Hamburg and Berlin. These charging stations provide around 200,000 kWh of renewable electricity to the EVs [74]. Nuon, a utility company which belongs to the Vattenfall group and provides electricity to Netherlands, Belgium and U.K, and its partner Heijmans have announced that they won a contract for the south part of Netherlands. They will install and operate around public 2,500 charging points in 65 different municipalities. The installations has already started in March and it is planned to be done until 2018 [75]. Furthermore, Vattenfall offers simple and smart charging boxes for EV owners and businesses. They also work with

Volvo in order to develop world's first diesel hybrid car. The Volvo V60 Plug-in Hybrid emits only 50g of CO_2 per km [74].

With InCharge project, Vattenfall aims to build charging network which allows its customers to access thousands of charging points in Sweden, Germany and Netherlands. The charging network is going to be built with the partners. Companies, local authorities and local power companies can offer electric charging to employees and customers easily with the help of this project. The EV owners are able to charge their cars via using InCharge smartphone application, charging card or RFID-tag [76].

According to the press release in March 2017, Vattenfall invests to the project company Northvolt in order to build Europe's largest lithium-ion battery production factory in Sweden. Construction will start in the second half of 2018 and it is planned to start production at the end of 2020 [77].

The company has announced to replace all of its car fleet in Sweden, Netherlands and Germany with either electric or hybrid cars. More than 3,500 passenger vehicles and light commercial vehicles, 1,700 vehicles in Sweden, 1,100 vehicles in Germany and 750 in Netherlands, are going to be replaced with EVs in 5 years. This announcement shows that Vattenfall supports the movement towards zero emission mobility [78].

Vattenfall has a Research & Development unit which consist of 130 full-time employees. Their main focus areas are smart grids, e-mobility and decentralized solutions for its customers such as energy storage. One of the most important thing that they focus is to use the electric car batteries for energy storage purposes. The EV batteries have a lifetime of 500,000 miles currently. After this lifetime they are replaced with the new ones. However, those batteries only lose 20% of their capacity. Therefore, they can be used for energy storage purposes in order to stabilize the grid [79].

2.3.7 EDP

EDP is a Portuguese utility company which is one of the Portugal's largest business groups. Its headquarters states in Lisbon.

EDP offers some solutions about electric mobility to its customers. One of them is the EV charging stations. EDP makes the installation and the maintenance of the charging stations. These stations can be installed both to the private customers and businesses. In addition to installations of these stations, EDP offers a tariff to its customers for charging their electric vehicles. The electricity used for charging EVs is produced from renewable energy sources. Moreover, if the customers charge their cars in the night time, there is 10% discount from the electricity price [80]. EDP is also a partner company of Mobi.E, a Portuguese program for electric mobility. The Mobi.E program provides to its customers to charge their electric cars with the public charging infrastructures throughout Portugal. With the card and their personal password, customers can use the public chargers whenever they want. Aim of the program is to provide open-access and market-oriented concept, and to spread the usage of electric vehicles [81].

The company has partnership with most of the car manufacturers companies (i.e. Daimler, BMW, Nissan, Renault . . .). According to this partnership if the customers buy EV from these car manufacturers in Portugal and sign-up to electric mobility tariff provided by EDP, first 15,000 km is free. In other words, EDP does not charge its customers with the electricity that they used to charge to their vehicles for first 15,000 km. However, this tariff is valid for first 500 customer who bought their cars in 2017 [80]. Moreover, EDP changed its car fleet with new EVs; 25 new Nissan Leaf was purchased in order to be used for the company employees [82].

A benchmark about what are the competitors of Iberdrola doing in the e-mobility field can be found in Figures A.1, A.2, A.3 & A.4

Chapter 3

Car-sharing and Self-driving Vehicles

This chapter includes information about the car-sharing concept and self-driving vehicles. In the first part of this section there is detailed information about car-sharing. Moreover, some business models of some car-sharing companies can be found. The second part of this chapter consists of information about self-driving vehicles. In the last part of the chapter, reader can find information about the combination of EV car-sharing and self-driving electric vehicles.

Importance of mobility for the big cities is substantial. Every day, people go to their work or school or the places that they need to go with vehicles unless the distances are short. Furthermore, mobility is important for transferring of food and essential goods, and the transportation of waste. The world's population is expected to increase up to 9.1 billion people by 2040. Moreover, 60% of the world's population is going to live in the big cities by 2030. The number of megacities with the population more than 10 million increases substantially. Increase of population living in the cities will bring some problems; such as traffic density, energy consumption, pollution, and congestion. As the number of people in the cities increases, the mobility will become more and more important [6].

Congestion is one of those problems which will boost with increasing the population in the cities. The cost of congestion to the people is not only losing time but also health. Moreover, because of congestion, huge amounts of money in the cities are thrown away. For instance, Los Angeles loses around $23 billion per year due to the congestion problems [6].

Combination of three important technologies could help to prevent these problems in the future; electrification of road transport, shared mobility and autonomous vehicles. In general, the combination of electrification, shared mobility and autonomy with integrated energy systems, public transport and infrastructure will bring lots of advantages to the future cities.

3.1 Car-sharing

The history of first car sharing concept dates back to 1948, Switzerland. It started because of economic reasons; however, it couldn't become popular until 1987 [35]. The modern car sharing programs started in 1987 in Switzerland. After becoming popular in Switzerland, it started to spread in Germany in 1988;

and the idea of car sharing has become popular in North America, Europe, and Australia during the 1990s. As of October 2014, car sharing systems had 4.8 million members all around the world and there were 104,000 vehicles [83]. Figure 3.1 clearly shows that the trend towards car sharing in Europe keeps increasing in an exponential way between 2006 and 2014. Moreover, the projections show that there will be around 15 million members by 2020 [84].

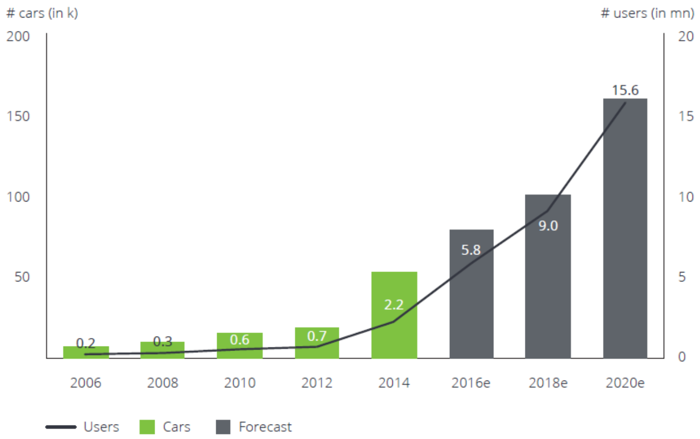

Figure 3.1: Evolution of Car Sharing in Europe [84]

3.1.1 Success of Uber

Although ride-hailing (i.e. Uber, Lyft) and car-sharing target the same customer segment; that is, these two type of services are rival to each other, the success of Uber shows really good that there is a change in people's behaviours about car ownership. In other words, people's behaviors towards the mode of transportation are changing. The most obvious example of this trend can be shown as Uber. According to a survey made by Schaller Consulting in New York, less subway and bus rides were used by the people in New York in 2016. When the statistics of the year 2015 and 2016 is compared, it can be seen that in 2016, people used 19 million fewer rides with the public transportation. People are used additional 72 million rides with application based cars in 2016. In result, the yellow cabs lost 25 million passengers in 1 year period. Moreover, application-based ride-hailing, on-demand servicing (i.e. Uber, Lyft, Juno) have changed the way of transportation. These companies had 50,381 vehicles in New York City and in 2016 they were providing service to 500,000 passengers per day [85].

Uber was founded in 2009 in San Francisco and in shorter than 8 years period their value has risen around $70 billion; they operate in 633 different cities worldwide. None of the technology companies in the history have grown in this pace like Uber. Since they can offer on-demand transportation to the users generally cheaper than the main competitors, taxis; people's attitude towards this type of transportation model has changed since 2009 [86]. They offer several options depending on the country that they are operating. The most two common services that they offer is UberX and UberPool. These two services can be classified as ride-hailing and ride-sharing, respectively. With the UberX service, a peer-to-peer service is established; via using the smartphone application, people who own any type of car and want to provide the mobility service can find do it easily. In addition to that, with the UberPool, they provide the service by putting the people who want to go to the same direction into the same car. They do not own any car fleet in order to provide these two services; however, they have a commission from the driver, typically 25% of the income of the driver goes to Uber. When the price of two services are compared, it can be seen that the UberPool option is almost half the price of UberX [87].

Although their main competitor seems like the yellow cabs and there are lots of arguments between two sides, Uber's main aim is to provide transportation option to the people as cheap as possible. They aim to provide the service cheaper than owning a car; as a result, they aim to increase the sharing economy and decrease the number of car ownership tremendously. The average cost per mile for UberX is around $1.5; whereas, the average cost of ownership of a car in New York City is around $3/mile. Although the cost of ownership of a car shows drastic changes with respect to the cities and the countries, these numbers show that using car sharing can be much cheaper than owning a car in the future [87]. In order to achieve that goal, they are also investing in self-driving vehicles since the combination of ride-hailing and autonomous driving will decrease the cost tremendously.

3.1.2 Advantages of Car-sharing

Car-sharing concept has not only environmental benefits but also it provides people social and economic benefits. According to the press release from DriveNow, a joint venture company between Sixt SE and BMW Group, car-sharing helps to decrease the number of car ownership. Considering a study performed in Vienna last year, around 5 private vehicles can be replaced by one car-sharing vehicle. Due to this reduction in the number of car ownership, 44 million private kilometers with vehicles and 7 metric tons of CO_2 emission is prevented; in other words, car-sharing helped to reduce the CO_2 emission from the private cars around one third according to the study [88]. Moreover, another study which was made in Netherlands shows similar results. It is stated that with the help of car-sharing programs, the number of car ownership is decreased around 30%. The kilometers covered with private cars show some decline similarly, around 15-20% decrease per person per year [89]. As a result of the decline in the number of car ownership, the air quality and the congestion problem in the big cities can be overcome. Furthermore, less money can be spent for the parking infrastructure and road expansions. With the usage of more EVs in car-sharing programs, the greenhouse gas emissions can be decreased tremendously. It also helps people to save more money. Owning a private vehicle is costly enough due to the insurance, taxes, maintenance and the fuel costs. However, with the car-sharing, users do not need to pay for the insurances, taxes, and fuel. As a result of this, people can save more money unless they don't drive every day for long distances. In other words, car-sharing makes sense when the users' general behavior is to make less kilometer with their private vehicles. For instance, car-sharing is cheaper for city-car drivers who drive less than 7,500 km annually in Europe. Likewise, car sharing makes much more sense for the compact-car drivers who cover less than 12,500 km annually [90].

It can be seen from Figure 3.2 that drivers who own a mid-size car and cover less than 16,000 km per year, could consider car-sharing as an option because it would be much cheaper for them. An additional data shows that 46% of the compact-car drivers and 63% of the mid-size drivers cover less km annually

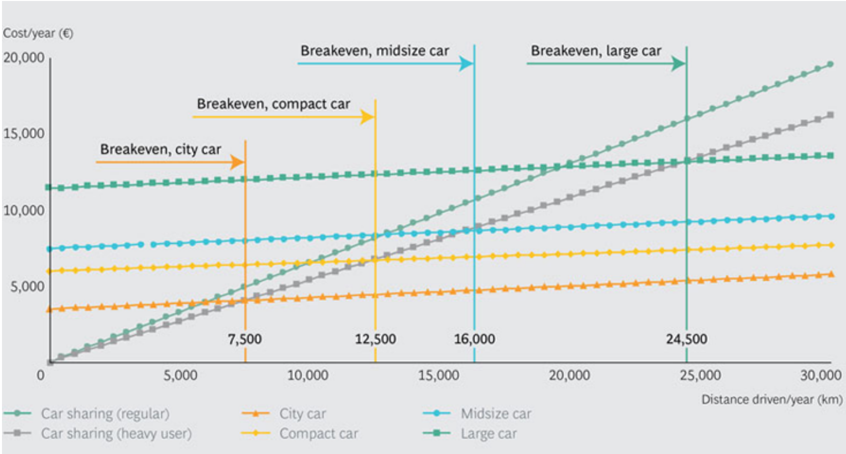

Figure 3.2: Total Yearly Costs of Owned Cars versus Shared Cars [90]

than 12,500 km and 16,000 km, respectively. Furthermore, it can be said that car-sharing will be applied best to the 40% of the city-car drivers and 20% of the compact-car drivers when the usage and driving patterns are considered [90].

Another benefit of car-sharing is from the social perspective. It can be said that car-sharing could be defined as the more responsible version hitch-hiking in today's world. People could find more chance to socialize with people during the trips, and they could find a chance to meet with new people with who possibly they never would have met [91].

3.1.3 Types of Car-sharing

Although car-sharing is one type of car rental, they are quite different from each other. Usually, customers rent the car for daily purposes for the car rentals. The fuel cost and the insurance cost are not included in the overall cost; therefore, customers need to pay additional money for these costs. Furthermore, customers need to make a new contract each time they rent the car. When the car-sharing concept is considered, there are some distinctive features. First of all, the rates are not only daily based. Usually, the cost of the vehicle sharing is calculated by minute based; however, customers can also have the vehicles as hourly based or as daily based. This feature, short-term access, gives customers the huge amount of flexibility. Secondly, most of the car-sharing systems work with membership based. In other words, customers need to register to the website of the car-sharing company. They can have the vehicle via the smartphone application or from the website 10-15 minutes before the pick-up; that is, there is no need for reservation couple of days before. Finally, unlike the car rentals, the insurance and the cost of fuel (or cost of electricity for EVs) are included in the price. The amount of money that the customers need to pay is calculated by the time passed between the accessing moment to the car and the delivery of the car. [9].

Car-sharing is a very general term and there are different types of it; each concept has its own advantages and disadvantages.

Stationary Car-sharing

The stationary car-sharing concept can be divided into two different styles; round trip and one-way.

In the ***stationary round trip car-sharing*** concept, there are fixed stations where the customers can pick up and return the car. Usually, the starting point and the ending point for the car-sharing is the same location. In other words, the customers need to return the car to the starting point. Vehicles can be picked up or can be returned at special parking lots or special parking areas. Zipcar is one of the biggest providers of this kind of car sharing model [92].

In the stationary one-way car-sharing concept, users need to pick up the car from one car parking station and they have the flexibility to return the car to another selected car park area. Fixed infrastructure, such as charging points for the EVs or kiosk for the car-sharing company, can be available at these locations. Autolib', the French company, is one of the largest point-to-point station based car sharing company [92].

For both concepts, it may seem that they have lack of flexibility; however, as an advantage side, customers can find a vast variety of car selection with different brands and different segments. Utilization of this model is high due to the long distance drives and well-planned car logistics. In station based car-sharing system, arranging the logistics is much easier than in free-floating car-sharing system. Because of these features, this type of car sharing is more suitable for replacing conventional car rental system or car ownership [84].

Free-floating Car-sharing

Free-floating car-sharing was introduced first time in 2008 by car2go which was founded by the car manufacturer Daimler. In this concept, customers can pick-up and return the cars anywhere in the city limits (usually in the business areas or airports) or a certain area; there are no dedicated parking lots for these pickups and returns. Customers can return the cars by simply parking them on the street and by ending the utilization. They do not need to pay for parking unless they are not going to continue for utilization. Therefore, in this model, communication with the local authorities and the car-sharing company is very important [84].

The main advantage of free-floating car sharing is flexibility. It is used mainly for the short distances such as going for a shopping or other leisure activities, or as first and the last miles in order to make public transportation more comfortable. A German study on free-floating car sharing has shown that the average distance covered by this model is around 5 km [93]. Furthermore, small to medium-sized cars are preferred usually in order to move in the crowded city conditions easily and to find a parking place easily [84].

There are mainly four important factors in order to be successful with this type of car sharing model: ***(i) location***, in order to attract enough people per car, high population density places should be chosen; ***(ii) pricing***, it should be based on time (usually per minute based or hour based) rather than distance; ***(iii) cooperation***, the communication between the local authorities about the parking spaces should be good; ***(iv) convenience***, the availability of the cars should be enough; that is, the customers shouldn't be wait more to access an available car [84].

Peer-to-peer Car Sharing

As operation model, it resembles the stationary round trip car-sharing; users need to return the cars to the pick-up location. However, the biggest difference from the stationary car-sharing model is private car owners give their cars through an online platform to the customers. In other words, cars used in this car-sharing model are not owned by a central operator. More diverse selection of vehicles (i.e. brands, segments or models) can be reached by users due to the fact that there is no central operator. The cost of having the car is based on a daily basis and the payments are done through a P2P car-sharing operator. There can be an online website or a smartphone application. Furthermore, with the help of online platform, the vehicle-owners and the customers are protected [84, 92].

Figure 3.3 shows the types of car rental and the car sharing models well. It can be seen easily that the car-sharing is perfect for the short distance transportation. For instance, free-floating car sharing is very flexible if it is compared to the other versions of car-sharing due to the fact that members can leave the car whenever they want. However, the distance traveled by this mode of car-sharing is less than stationary and peer-to-peer car-sharing.

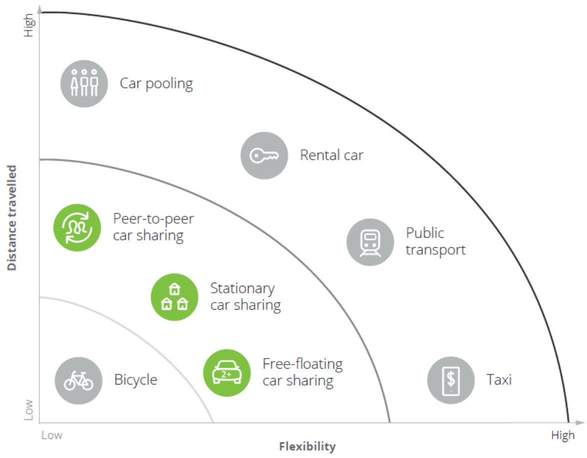

Figure 3.3: Different Types of Car Sharing Concepts among Existing Mobility Alternatives [84]

3.1.4 Business Models for Car-sharing

As the number of people who prefers car-sharing over car ownership increases and the car-sharing concept is becoming more popular, European car manufacturers (i.e. Daimler, BMW, FCA Group) are deciding to involve in the car-sharing business. One of the best examples of this trend can be shown as Daimler and BMW. Both car manufacturers invested highly on the free-floating car-sharing services called car2go and DriveNow, respectively. The main reason behind this change is clear. As the transportation cost with car-sharing or ride-hailing goes down, people's attitude to own a car will change. Because after some point, using these mobility services will be much cheaper than owning a car. After this point, the number of cars sold globally will decrease because of less demand for car ownership. Especially, after the commercialization of autonomous driving, the cost of using car-sharing or ride-hailing services will go down more and an inevitable disruption will happen for the car manufacturers [94].

Most of the car manufacturer's companies are aware of the danger; therefore, they are trying to create another field in order to keep their existence. Car-sharing market in Europe is 50% of the global market; therefore, it attracts the attention of other companies, mainly the European car manufacturers [84].

Car2go

Car2go was founded in 2008 in Ulm as a subsidiary company of Daimler AG. It operates in 8 different countries and 25 different cities in Europe, North America (U.S and Canada) and China. Size of the fleet is 14,000 vehicles and they serve 2,500,000 customers globally. Car2go is very important for the history of car-sharing since they are the pioneer of free-floating car-sharing concept which shows a high increase among people who want to use car-sharing services. Since they are the subsidiary company of Daimler AG, the cars that are provided are Smart Fortwo, Mercedes-Benz CLA, and Mercedes-Benz GLA. In the beginning, car2go was using only electric vehicles in their car fleet; however, due to the low number of charging stations in the cities, they decided to use both conventional ICE vehicles and EVs [35, 95].

One of the success factors that car2go has is that they operate in large-scale mainly in the city centers and other important areas in the city. The company's aim is to provide a high-quality service to the customers with least amount of waiting time for the available vehicles. Users can find the closest available car by using the website or smartphone application. There is no need to reserve the car days before, 15 to 30 minutes before is enough to access to the car. The business model of the company is same in every country; they provide a free-floating car-sharing service and they charge the customers per minute basis. In addition to minute based charging, there are also discounted hourly and discounted daily rental options. Also, users do not need to pay extra costs such as fuel, maintenance, insurance and parking [95]. Customers need to pay a registration fee to be able to use the service, there is no more monthly fee after registering to the website. Furthermore, an extra fee for exceeding km, which is generally 50 km range, is applied to the customers in addition to the rental fees [35].

Figure A.5 shows the business model of the company. The value proposition of the company is to provide innovative and environmentally friendly service to its customers.

In addition to that, car2go provides flexible mobility and convenience to the customers due to the free-floating car-sharing concept. They focus their attention on the young adults who have high awareness about environmental problems and eager to take initiative to new innovative technologies. Moreover, car2go aims to provide mobility services to the young adults who do not own a vehicle; therefore, students are also included in their target group. In order to sustain their business model, strategic partnerships have high importance. The partnership with Europcar gives them the chance to learn fleet management and logistics about car renting. Both companies have benefited from cross-selling and cross-marketing. Furthermore, partnership between the local municipalities are also important in order to obtain a permission to park the cars in the designated parking spots in city centers and the cars can have access to the restricted streets in city center [35].

Enjoy

Enjoy was founded at the end of 2013 in Milan by an Italian oil and gas company ENI. Today they operate in Florence, Milan, Rome, Turin, and Catania. Like car2go, Enjoy's car sharing concept is based on free-floating car sharing. Customers can register through the company website or smartphone application without paying any registration fee; furthermore, there is no fee that members need to pay monthly or annually [96]. They charge users only from the utilization of the car (per minute based cost) and the extra fees per km if the included mileage was exceeded. The fuel cost, insurance, maintenance and parking cost are included in the utilization cost; also, if customers want to rent the car more, discounted hourly prices and discounted daily prices are available [35].

From its business model canvas (Figure A.6), it can be observed that their value proposition is same like car2go; to provide flexible, environmentally friendly and economic mobility service. Key partnerships have huge importance in the business model of the company. For example, Enjoy has important partnerships with Trenitalia (Italian train operator), Fiat Chrysler Automobiles (FCA), CartaSi (credit card company), and with local municipalities.

The partnership with Trenitalia is very strategic for Enjoy in order to provide their service in high quality to the corporate clients which is one of the biggest customer segments for the company. With the help of this partnership, Enjoy customers can get some discount for buying the train tickets or vice versa. Both companies have benefited from cross-marketing and cross-sales, and both of them can reach to wider customer segments. FCA provides the vehicles to the company which is Fiat 500, small cars that give the customers enough convenience to move in big cities. In addition to these partnerships, Enjoy has a partnership with CartaSi, a credit card company. Through this partnership, specific arrangements for the payments and services are arranged. Similar with car2go, Enjoy also have a partnership with local municipalities in order to access parking lots or limited traffic areas in the city center [35].

Car City Club (IoGuido)

Car City Club is a car-sharing company which is run by the city municipalities. They offer two types of car rental options; classical car rental modal and one-way rental modal. The former one is the conventional car rental modal; that is, the customers should return the car in the area that they started to the rental. Unlike the classical car rental modal, in one-way rental, customers can return the car to a different parking area. In both cases, customers need to make reservation before and they need to mention the pick-up location. The company charges its customers with either a fee per km or an hourly fixed fee depending on the type of the rental and the vehicle chosen. Moreover, the fees might show some difference depending on the time of the day. Unlike the previous two companies (car2go and Enjoy), Car City Club charges its customers with an annual fee [35].

The value proposition of the company is to provide a mobility service with a low environmental impact in addition to the public transportation network (Figure A.7). The key partners are municipalities, Italian

Ministry of Environment, FCA and Car Sharing Initiative (ICS) which offers technical, financial and legal support to the local municipalities interested in car-sharing services. Furthermore, the company is having some partnerships with retail stores, shopping malls, and universities in order to provide their customers free parking spots in these areas [35].

Autolib

Autolib is an electric car-sharing company which was founded in Paris in 2011. It is run by public-private joint venture between Paris Municipality and Bollore' Industrial Group. Before establishing Autolib, the Bollore' Industrial Group had not any experience neither in transportation sector nor in car manufacturing sector. They involved only in research and development for new battery technologies [35].

Their car fleet consists of a small car which is called Bluecar. These cars were designed with the help of Pininfarina which is an Italian car designer firm and coachbuilder. The production process of the cars is done with an Italian car manufacturer CECOMP. Autolib offers to its customers one-way station based car sharing services. As of July 2016, they have around 4,000 Bluecars in their fleet; moreover, they have around 1,000 electric car charging stations with around 6,000 chargers. When the charging infrastructure is considered, it can be said that it was the first extensive public electric car sharing system [35].

Figure A.8 shows the business model canvas of Autolib. It can be seen that the value proposition of the company is to provide an efficient and low environmental impact mobility option as a complimentary service to public transportation. Since whole car fleet consists of electric vehicles, zero-emission drive is offered to the customers. The customers are charged by the rental fees which are per minute based and the subscription fees. In addition to the car-sharing service, people can charge their EVs, motorcycles or e-bikes at the Autolib's charging stations by paying subscription fee and usage fee. As it was mentioned before the partnerships are very important for Autolib. Due to the key partnerships with CECOMP and Pininfarina, the production of the Bluecars can be made successfully without any problems [35].

Bee-Green Mobility Sharing

Bee is a car-sharing service which is created by NHP ESCo, a company which works in the green energy sector; they design and manufacture products that produce energy from renewable sources. Bee was created in 2013 in Naples as a first electric car-sharing service created in Italy. Their car fleet consists of Renault Twizy in order to provide a zero-emission drive to its customers. Until 2014 the company provided point-to-point station based car-sharing. However, after 2014, it started to provide free-floating car sharing service. Bee charges its customers with annual subscription fees and rental fees, per minute or per daily based pricing. Similar to the other companies, their customer segment is divided into two; private users and corporate clients.Their value proposition is to provide an efficient and low environmental impact mobility alternative to its customers with low price (Figure A.9). Moreover, Bee has quite important partnerships with other companies. Renault is one of the key partners since they provide the vehicles to the car-sharing service. Due to the partnership with Siemens, installation, and operation of Bee-Points, in other words, the charging infrastructure, is done easily. Moreover, Tom Tom Telematics provides know-how and technology in order to track and trace the cars in the fleet. With the help of ALD Automotive, Bee can have the experience of full operational leasing and fleet management. Apart from these important partnerships, they have agreements with the municipalities like most of the other car-sharing companies. With using these partnerships with municipalities, customers of Bee can park the shared car in the designated areas in city center or can use some restricted streets in the city center [35].

DriveNow

DriveNow is a car sharing company, a joint venture company between BMW Group and Sixt SE. Each of the companies has 50% share in this joint venture. DriveNow provides free-floating car-sharing service to its customers. BMW Group provides the cars (BMW and MINI) and Sixt SE provides the services of car rental know-how, IT systems and the network of stations for the customer registrations [97]. The company was founded in 2011 in Munich and as today they give service in 9 countries in Europe in 13 different cities. The company has 815,000 registered customers as of January 2017. Furthermore, the members can use 5,000 vehicles across the cities; around 20% of these cars in the fleet are electric BMW i3. Due to the BMW i3 fleet, over 200,000 customers could find a chance to drive with zero emission around 6 million kilometers [98]. They provide a service in North America under the name of ReachNow [99].

Similar to its main competitor in Germany, car2go, DriveNow provides free-floating car-sharing service to its customers. In other words, users can pick-up the car at any locations within the city business area zones and leave the car again any parking spot in the business area zone or at airports. Unless they don't choose the parking option in the car, customers don't need to pay for parking. DriveNow charges its customers per minute based. Moreover, there are some special package options in order to give discounts to the customers who want to have the car for hours or days. A subscription fee is also needed to be paid by the customers who are registering the system for the first time. Like its competitors, the insurance, maintenance, fuel costs and parking costs are included in the price [99].

The price range is changing between 30-50 cents/min depending on the type of the car and the city. Due to this competitive price range, DriveNow offers its customers an alternative option for conventional taxi journeys, i.e. airport journeys. According to BMW Group, the average age of its customers who want to buy BMW cars is around 45; whereas, for car-sharing services the average age of the customers who use the service is 32. With DriveNow, they are not only offering a cheap, environmentally friendly mobility solution to its customers but also they are able to reach to non-core customers in the city centers who cannot afford to own an expensive car [100].

eCarSharing

eCarSharing is a new test product from the Innovation Hub of Innogy. It is a car-sharing service and the fleet consist of only BEVs. eCarSharing is a stationary round trip car-sharing concept. Customers need to pick up the car from the charging points and they need to return it to the same point. The electricity that is used to charge the cars is generated from renewable sources. Likewise in the other car-sharing companies, customers need to sign-up through using the online platform. There is no registration fee, the customers only pay for the km they drive. In addition to that, there are also weekend packages where customers can pay €33 per day or €55 for whole weekend. Insurance, maintenance and the electricity cost for charging are included in the price [43].

The value proposition of the eCarSharing is being cost-effective, flexible and providing zero-emission drive to its customers. Apart from private customers, they provide service to municipalities and to the businesses. The service is attractive for the municipalities because they do not need to deal with the administrative of car parking by using eCarSharing. Participants can book BMW i3 or Nissan Leaf via the online platform. Additional payment options are provided for the businesses. Depending on the size of the business, they can choose one of the options to use eCarSharing service [101].

E-Go Car-sharing

E-Go Car Sharing is a service that ENEL and ALD Automotive have founded together in order to provide car sharing services to its customers. They operate in Italy and provide car sharing service to the private customers and corporate businesses. Their fleet includes electric cars and the customers can pick up the cars with using online platform, via internet or smartphone application. In addition to the car rental service, they also offer packages. For instance, businesses can choose a package in which they can use the cars and also E-Go install an electric vehicle charging station based on the needs. Same is applicable also for the private customers; they can choose an appropriate package and make the installation of charging boxes to their homes. Moreover, with using E-Go, the customers can access limited traffic areas in cities in Italy and they can park the cars free in most of the public parking places in Italian cities. Customers are charged by the km that they cover with the car. The payments can be done either with the card that the company provides to its customers or via online platform [102].

3.2 Self-driving Vehicles

Self-driving, also called autonomous driving, technology is improving rapidly. There has been extensive research and development going on in order to improve the technology. The term autonomous vehicle does not only mean a single vehicle with a set of technological capabilities. It means rather several vehicles interact with each other on the road and using an online network in order to share the data globally and learn. Although the fully autonomous driving is a new technology, the advanced driver assistance systems also include part of this technologies. For instance, *adaptive cruise control* was introduced to the car market in the year 2006 in order to adapt the speed of the vehicle and the distance of the vehicle from the car in front by monitoring the road. Likewise, *parallel-park assist* was also introduced in 2006 for most of the cars. It uses cameras and sensors in order to assist vehicle in during parking. *Automatic emergency breaking* was used first time in 2008. With the help of this technology, breaks are activated when the risk of colliding occurs. Moreover, in 2014 *lane-keeping technology* was introduced in the cars. This technology warns the driver when the vehicle goes out from the lane. In addition to these technologies which were introduced a couple of years ago, some new technologies were started to use in the new cars after 2016. *Single-lane highway autopilot* is one of those technologies. It allows vehicle to drive in a single lane by itself without any driver input in highway road. *Highway autopilot* with lane changing helps vehicle to drive on a highway with changing lanes without any driver input. In addition to these, *traffic jam autopilot* enables vehicle to move low-speed, stop and go in the traffic conditions. *Autonomous valet parking* works as an automatic valet; it enables vehicle to spot a suitable parking space and park the vehicle in that spot by itself. Finally, *urban autopilot* enables vehicle to drive itself in the urban conditions; it also pays attention to traffic jams, traffic signals and the intersections [103].

3.2.1 Autonomy Levels of Self-driving Vehicles

As it can be seen from the existing technologies, there are different types of the level of autonomy. These technologies can be divided into 5 levels; from level 0 to level 4. ***Level 0*** means that there is no automation in the vehicle. At all times the driver is in charge of the control of the car. ***Level 1*** can be classified as one function-specific automated. In this type of vehicle, only one type of function is automated at the time. If multiple functions are operated at the same moment, they operate independently from each other without any communication. One example of this type of automation level can be automatic assisted breaking. ***Level 2*** is called two functions automated and combined. In this level, at least two primary control functions work autonomously and together. This level of automation allows driver to leave the control to the vehicle. The driver can leave the steering wheel to the car and take the foot off the gas and brake. The vehicle can achieve to drive by itself without any driver input by combining different automated functions. An example of this technology can be shown as adaptive cruise control with combination of lane management. ***Level 3*** is limited self-driving automation. With this level of automation, the driver can leave the critical functions to the vehicle. In other words, the driver can spend his or her time by doing some other activities in the car without paying attention to the drive. The driver is only expected to be available from time to time for occasional controls; however, they have a sufficient time for taking the control of the car. Google's self-driving car can be an example of this level of technology. ***Level 4*** is the full self-driving automation. This type of vehicles can drive themselves without needing any driver. The vehicles can monitor the road conditions for entire trip and carry out driving with safely with the help of ultrasonic sensors and cameras [16]. Table 3.1 gives the summary of the level of automation.

The most common technology (cameras and the sensors) are used in the self-driving cars is the LIDAR system. LIDAR means the system of laser and the radar together; a conical, hat-shaped device with cameras on top of the car. This system can be seen on top the Uber and Google autonomous cars. The cameras allow to the software to capture 360 degrees real-world data with the cameras; also it fires out laser pulses to surrounding and creates a graphical representation of the real world [104]. The cost of LIDAR system is very high nowadays; almost half price of the self-driving vehicle. However, it is expected that the LIDAR technology will be smaller and the cost will decrease due to the Moore's

Table 3.1: Automation Levels of Self-driving Vehicles [16]

Levels	Example of Automation	Role of Driver	Manufacturers
0	None	Driver has complete control	All car manufacturers
1	Adaptive cruise control, Emergency dynamic brake assist	Driver is in control; however, he or she can leave the control to single function automation	Audi, BMW, Mercedes, Nissan and others
2	Adaptive cruise control, Lane keeping assist, Traffic jam assist	Driver may surf in web, read and text; but, the driver should be ready to take control when is needed	Audi, BMW, Mercedes, Nissan
3	Traffic jam assist, City driverless shuttle	Driver can sleep	Google, Nissan, Tesla
4	Full car automation	No need for driver	No commercialization yet

Law [16].

Figure 3.4: LIDAR System on top of Google's Self-driving Car [104]

Unlike the Google and Uber, Tesla is using a different kind of technology in its cars. The CEO of the company Elon Musk states that the LIDAR system has lots of moving parts; thus, it is not a robust solution for the self-driving vehicles. Tesla vehicles have 8 surround cameras which provide them 360 degrees of vision up to the 250-meter range. Moreover, the vehicles are equipped with 12 ultrasonic sensors and forward facing radar which allows vehicle to operate perfectly in the bad weather conditions [105]. Figure 3.5 shows the technology works on the Tesla cars.

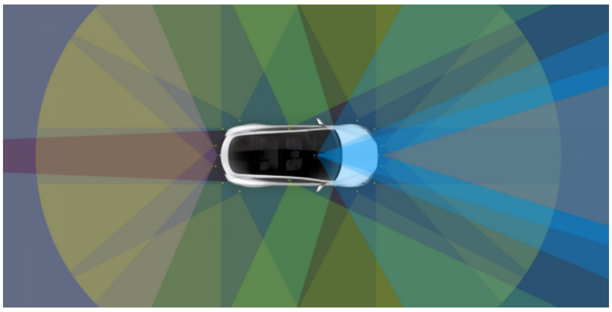

Figure 3.5: Tesla's Self-driving Car Technology [105]

3.2.2 Advantages of Self-driving Vehicles

ICE vehicles are the ultimate waste machines that the mankind has ever invented. The waste that can be produced from conventional vehicles can be divided into 5 different fields; waste of lives, waste of time, waste of space, waste of energy, and waste of money [16]. Autonomous vehicles seem like a proper alternative in order to reduce these negative effects and promote a better quality of life to people.

Waste of Life

The number deaths or fatal injuries due to car accidents are substantial throughout the world. In 2011, more than 30,000 people died on the roads in EU because of accidents [106]. Moreover, in U.S. 32,788 deaths happened in 2010 due to 6 million car crashes. It is estimated that 93% of these crashes are due to human error. According to the World Health Organization, 1.24 million people died in 2010 in the world because of the car crashes; almost half of those deaths were pedestrians, bikers or cyclists. In addition to these, 20 to 50 million people suffer from non-fatal injuries because of the car accidents every year. Globally, deaths occurred due to car accidents are in the first place for the people between ages 15 and 29. When all these numbers are considered, it can be seen clearly that we are not good at driving and cause lots of fatal injuries. Because as human nature, we tend to distract easily while driving, i.e. texting, eating, having a conversation with passengers, etc. ... With the help of mathematical models based on Center for Disease Control data shows that sleepy drivers are the main cause of 15-33% of fatal crashes in U.S. [16].

Autonomous driving has lots of superiority in driving against human drivers. First of all, they have 360 degrees of vision range and the computers cannot be distracted like human drivers. Due to the sensors and the camera, they can even see in the night and they do not have a sleep pattern; thus, they can operate 24 hours of the day without any accidents. Self-driving car technology is not perfect yet; however, they are still better than most of the human drivers. Moreover, due to the technological components of the autonomous cars, they are getting better, faster and cheaper exponentially since they fit in the Moore's Law. In addition to the technological components, the artificial intelligence software in the autonomous cars is also getting better exponentially. They are able to process more data when they compared couple of years ago. One of the most important features of autonomous cars is the ability to learn from the mistakes. Human being tends to make the same mistake over and over again without learning from their mistakes. This is one of the reasons that there are lots of traffic accidents on the roads. Unfortunately, most of the times a bad lesson does not sink in unless the driver experiences it. Unlike the human drivers, autonomous cars can learn from data that all other autonomous cars are collecting due to the online network they have between each other. For instance, an autonomous car can learn from its mistake and avoid to make the same mistake again. Another autonomous car other side of the world can also learn from that car's mistake. This feature will help them to learn quickly and globally, and it will help to decrease the number of accidents on the roads in the future. With the help of autonomous driving, 1 million lives can be saved per year [16].

Waste of Space

More urban space is dedicated to cars than humans in nature. For instance, in North American cities, roads and parking lots occupy 30% and 60% of the total surface, respectively. This number does not contain the number of garages and driveways. When the roads are considered, it can be concluded that the highways are also a huge waste of space. According to UC Berkeley Professor Steven Shladover, cars in the highways only occupy 5% of the road. This number shows how big the waste of space in the highways is. Because cars need lanes which have double the car's width and also more than 2 lanes are needed for cars to change the lane. Driving a car occupies 10 to 100 times more space than any other type of transportation. For example, a car needs 200 m^2 of road space per passenger; whereas, public transportation takes only 2 m^2 per public transportation passenger and walking only takes 3 m^2. Research has shown that the intelligent vehicles can reduce the space needed substantially. An automated vehicle needs 25% less space for changing the lane or overtaking a car. Moreover, with adaptive cruise control technology, the capacity of highways can be improved around 40%. In other words, the self-driving cars could drive closer to each other at high speeds due to the vehicle to vehicle communication on the highways; thus, they increase highway capacity by 3.7 times and they could help vehicles to save fuel (10-15% fuel saving) due to less wind resistance [16]. Furthermore, the self-driving cars can park themselves. This feature allows them to decrease space between cars while parking. As a result of this action, 15% of the parking area can be saved because there would not need a gap for the driver to get out from the vehicle after parking. There would not be needed parking areas in the city centers since the autonomous car passengers can leave the car at the city center and the car could shuttle to a parking spot which is not located in the city center. By saving the space from the parking lots and the roads, these areas can be used for recreational areas in order to increase the number of green areas [107].

Waste of Time

Amount of time that the people spend in the traffic congestion is so much, especially in the big cities with high population. For instance, 4.8 billion hours have been spent in U.S. only because of congestion. Time spent in traffic is also stressful for the people. Due to the high-stress levels, number of some serious diseases also increased. Self-driving cars could free-up the time for the drivers. The drivers could do some other productive activities while traveling in the car, they could work on the task that they need to work or they could sleep. Moreover, self-driving cars will help people to save time during looking for a parking space [16].

Waste of Energy

According to MIT Media Laboratory, 40% of the fuel usage is spent while looking for a place to park for the vehicle. Moreover, 1.9 billion gallons (7.2 billion liters) of fuel is wasted in U.S. due to congestion in the traffic. Self-driving vehicles could help to save fuel for parking because they could park even in small places where the driver think that the car would not fit. Or they can leave the passenger and can park in somewhere else with distance instead of circling in the same area for finding a parking spot. Furthermore, as it was mentioned before, autonomous cars can save fuel in the highways by decreasing the wind drag force due to vehicle to vehicle communication [16].

Waste of Money

In 2012, the traffic congestion cost U.S. $121 billion; moreover, this number is expected to grow up to $199 billion in 2020. According to the World Health Organization, global monetary loss in U.S. due to injuries is $518 billion per year and they cost to the government 1% to 3% of GNP [16].

As it can be seen easily, self-driving vehicles promise tremendous amount of advantages to the human life. The phrase of 'if autonomous vehicles are on the road...' is not valid anymore. It is more the question of when are they going to hit the road. According to the most of the sources, beginning of the 2020s will be the time when autonomous vehicles can be seen on the roads [16]. The obstacle of trust issues is also shrinking with time for the autonomous vehicles. A survey was made by the Boston Consulting Group and the World Economic Forum in 27 different countries and with 5,500 customers about the self-driving vehicles. According to this survey, overall 58% of the people said that they would take a ride with an autonomous vehicle. Furthermore, 69% of the customers said that they would take a ride in partially self-driving vehicle (Figure 3.6). It can be said that around half of the people in Netherlands, Germany, and France are eager to take a ride with both fully self-driving car and partially self-driving car [108].

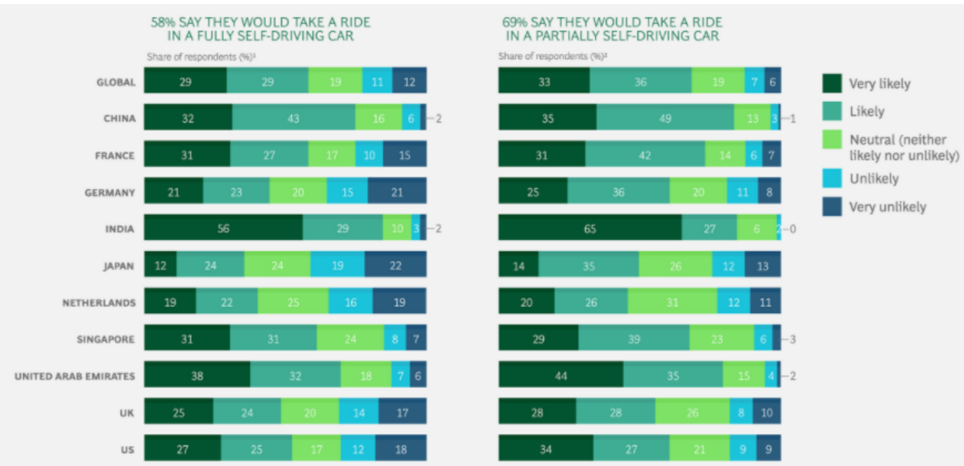

Figure 3.6: Survey made by BCG on the usage of Self-driving Vehicles [108]

People like the convenience of the autonomous cars according to the survey. The first reason that they want to take a ride with autonomous vehicles is that drivers don't need to find a parking spot for the car. They can leave their car and the car can find a parking spot and can park itself. The other reasons are the passengers can be multitasking and do some other more productive things while traveling in the car. Majority of the people also state that they are willing to pay $5,000 or more as a premium feature for the self-driving vehicle. However, the concern of safety and trust to self-driving vehicle still exists. Around half of the people mention that they don't feel safe when the car drive itself on the road. Moreover, 65% of the parents would not let their children take a ride in a self-driving car alone [108].

3.3 Mobility as a Service (Transport as a Service)

The autonomous cars are disruptive due to the fact that they will save time, money and energy at the individual level; also, they will save time, money, lives and energy at society level. Moreover, autonomous car technology will most likely disrupt the automotive industry, the public and private transportation industry, and logistics industry. Nowadays, people own cars just because they need mobility-on-demand; that is, they want to be free and want to travel whenever they want and wherever they want. Most of the people don't really want to own a car since it is costly. Furthermore, the EV technology and the autonomous vehicle technology will be very important in the future. They could overlap with each other like internet and mobile phones did in the past. It wasn't even a decade before that smartphones and the internet disrupt all the other things around them and created 'mobile internet' concept. The Same disruption might most likely to happen with EV and self-driving vehicles. Together they could disrupt the transportation industry and could create a new concept which is called 'Mobility as a Service (MaaS) or Transport as a Service (TaaS)'. With on-demand mobility system, transportation market will expand since more people could use the service such as children, older people, and disabled people. When using the mobility service becomes cheaper than the ownership of the car, people will stop buying new cars and start using this service. The market promises substantial amount of revenue. Therefore, most of the car companies and the technology companies are racing each other in order to take the biggest share from this market [16].

The biggest race to get the biggest share from the market is happening between Tesla, Google, and Uber. Tesla cars have already included the first generation autopilot. With this technology, the cars can change lane in the highway, drive itself with auto-steer in the highway, exit ramps when the signal is on, look for a parking spot, park perpendicularly and parallel, and can be summoned from the garage. In October 2016, Tesla has announced that Tesla Model 3, and new production of Model S and Model X will include a hardware that allows car fully autonomous drive in addition to the first generation capabilities. With this technology the cars are able to drive themselves in heavy traffic, and change lanes without input. However, this does not mean that the cars can drive itself fully autonomous. It rather means Tesla models include the hardware for autonomous driving and it can be enabled after the legalization of fully autonomous drive from the authorities [109]. Like Tesla, Uber is making an extensive research on self-driving vehicles. The company targets to use self-driving technology in its well established ride-hailing service in order to decrease the cost of drivers and to increase the revenues; as a result of this, cost of one ride will decrease tremendously for the customers who are using the service [86]. With combination of self-driving technology, Tesla is aiming to take some of the market shares of Uber by participating in the ride-hailing market with Tesla Network. By using Tesla Network, the Tesla car owners can choose to use their car in ride-hailing network and make money when they are at work or on vacation due to the self-driving technology of the cars. Uber seems to have a huge advantage in that market because they have already had an established system (Uber app). However, Tesla made a huge brand name like Apple in the last years and created loyalty within its customers. Most of the people are eager to use Tesla Network just to have an experience of drive-in Tesla cars. The strength of brand can be easily seen from the sales of Tesla Model 3; people (115,000 people) preordered the car without even seeing it [109].

Teaching to the car to be able to handle every situation needs an extensive processing power and requires lots of teaching. Google has a huge advantage in this field. Its fleet of 60 self-driving vehicles has already covered more than two miles and collected substantial amount of data in the system. Google's cars are collecting data from real world with cameras and radar system. Furthermore, there is an engineer in the cars who highlights the important data while the car is driving itself. However, Tesla has an advantage due to the high number of vehicles sold globally. Its cars have been covered 222 million miles in autopilot mode and during these times they have been collecting data. Due to its online network, Tesla acquired big amount of data [110]. Table 3.2 shows a summary of which companies are investing in the self-driving vehicle technology and what their future plans are.

Table 3.2: Which Companies are investing on Self-driving Vehicles [104]

Company	**Future Targets of the Companies**
Tesla	Tesla cars are equipped already with the autonomous driving hardware and they are waiting for the regulatory approval. Tesla will drive itself from Los Angeles to New York at the end of 2017.
Uber	In September 2016, Uber started a pilot project in Pittsburg. Some Uber cars are equipped with the hardware and they give self-driving car service to the customers. However, the cars still have a safety driver because the autonomous technology fails from time to time.
Google	Google separated its self-driving unit Waymo as another company. They partnered with Fiat and they will start the robot taxi service at the end of 2017.
BMW	BMW is partnered up with Mobileye which was acquired by Intel. BMW is planning to release self-driving cars in China in 2021. Moreover, they will release full electric vehicle with self-driving capabilities in 2021.
Toyota	Toyota's approach towards autonomous driving is more conservative. They are planning to be on the roads in the 2020s.
Volvo	Volvo has partnered up with Uber and invests huge amount of money to the self-driving technology. By 2020, they are planning to have released its fully autonomous vehicle on the road.
Nissan	Nissan is aiming to release its fully autonomous cars in Europe, China, and U.S. in the beginning of 2020.
Ford	Ford targets to have its autonomous vehicle in 4 to 5 years. They are aiming to have a self-driving vehicle fleet for ride-hailing services by 2021. Moreover, these cars will come without a steering wheel, gas pedal and brake pedal.
General Motors	GM has partnered with Lyft, the rival company of Uber. The releasing date is not certain yet; however, they are aiming to have fully electric, autonomous vehicle in the 2020s.
Daimler	Daimler has a target of having driverless trucks by 2020.
Audi	Audi has partnered with Nvidia in order to release its fully autonomous vehicle in 2020.
Honda	Honda is going to produce fully driverless cars by the beginning of 2020.
Hyundai	Hyundai is planning to produce its cars with driverless function by 2020; however, their cars won't have fully autonomous feature until 2030.
Apple	Apple wants to have a market share of self-driving vehicle market also. Thus, they are aiming to produce a self-driving vehicle rather than only producing the software.

As it was mentioned before, self-driving technology, electric vehicles, and sharing mobility is promising lots of advantages for disrupting the existing mobility concept. Combination of these three technologies could combine different fields to each other and could change the game forever. Figure 3.7 shows some key trends in the future mobility systems [6].

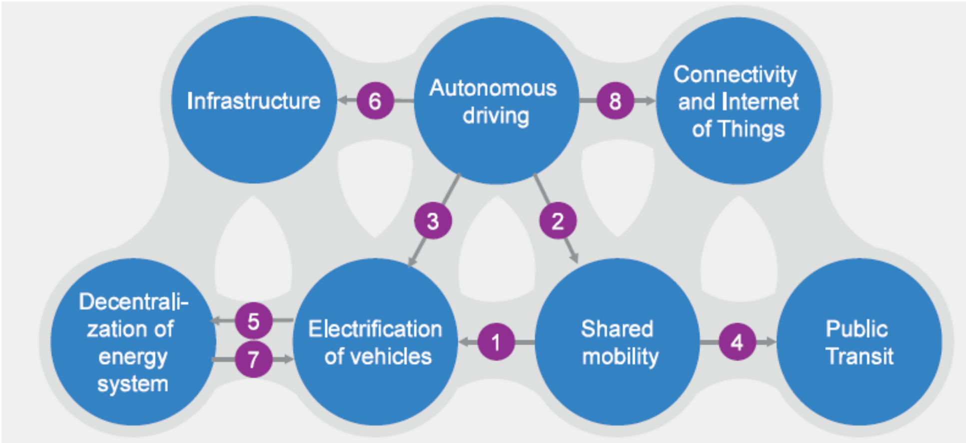

Figure 3.7: Some Key Trends for the Future Mobility Systems [6]

#1: When the shared mobility increases, electrification of the vehicles will increase. Relative to the ICE vehicles, EVs are more expensive mostly because of the battery prices. In their lifetime, EVs can make maximum 500,000 miles which is 2.5 times more than the ICE vehicles. However, people who own an EV rarely drives more than 140,000 miles during the lifetime of the car. As it can be seen from Figure 3.8 that when an EV is driven fewer miles than its capacity, it cannot compete with the ICE. On the other hand, when the EVs are used in the shared mobility, they can cover more mileage and become more cost competitive than the ICE vehicles. Vehicles which are used for ride-hailing services cover around 70,000 miles annually in U.S. which is same value with the taxis. Furthermore, vehicles can be replaced faster with the new versions due to more mileage that they are covering with the shared mobility; and the batteries of the EVs can be used in energy storage as second life batteries. It is known that after the EVs lifetime, the battery loses only 20% of its capacity. Thus, they can still be used for energy storage purposes. Since it is much more cost effective to use EVs in the shared mobility systems, sales of EVs will boost also with the usage of shared mobility services. For every 10% increase in shared mobility could increase the sales of EVs up to 5% between 2015 and 2030 [6].

#2: Autonomous driving technology and shared mobility business models could be combined easily in order to compete with private car ownership. As it was mentioned in before sections, ride-hailing services are already cheaper than the cost of car ownership in some parts of the world. With using autonomous cars in the ride-hailing services would decrease the expenditure of the ride-hail service companies because they do not need to pay for the driver anymore. Thus, their income would increase and they could start offering cheaper mobility service to its customers. The self-driving vehicles could drive itself to the next customer, to a parking lot or to a starting point. Furthermore, with using self-driving, pooled and electrified taxi could offer much cheaper transportation solution (30-60% cheaper per mile when it is compared with private vehicle) to the people as long as people are open to car-pooling [6].

#3: Self-driving vehicles could leave its passengers and park themselves, or they could drop family members to the places where they want to go and then shuttle back to the starting point. It would

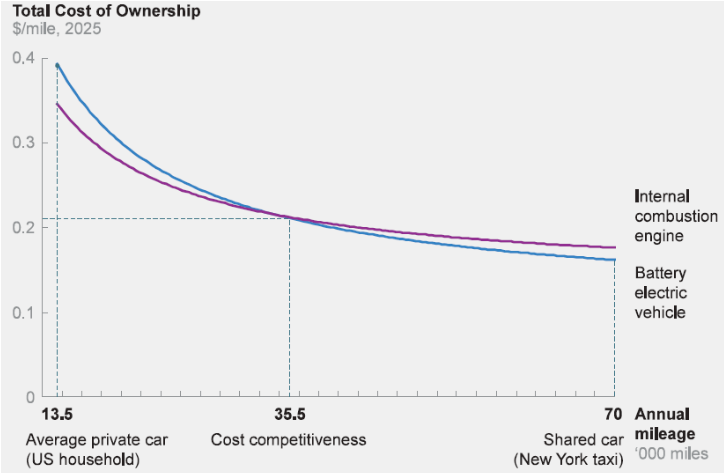

Figure 3.8: Total Cost of Ownership of ICE Vehicle versus EV [6]

likely to increase the mileage of the vehicles while providing on-demand mobility. With this specialty of the vehicles, the number of cars that the families owned would be decreased tremendously. Instead of having 2 or 3 cars in the family, having only 1 autonomous vehicle would be enough. Figure 3.9 shows the comparison between the operating cost of autonomous ICE vehicle and the autonomous EV. Autonomous EVs are much cheaper than the ICE vehicles. The cost of operation is cheaper for the EVs because the finance cost is 90% lower, as well as the maintenance cost is 80% lower and the fuel cost is 70% lower. Thus, self-driving vehicles could increase the usage of EVs [6, 111].

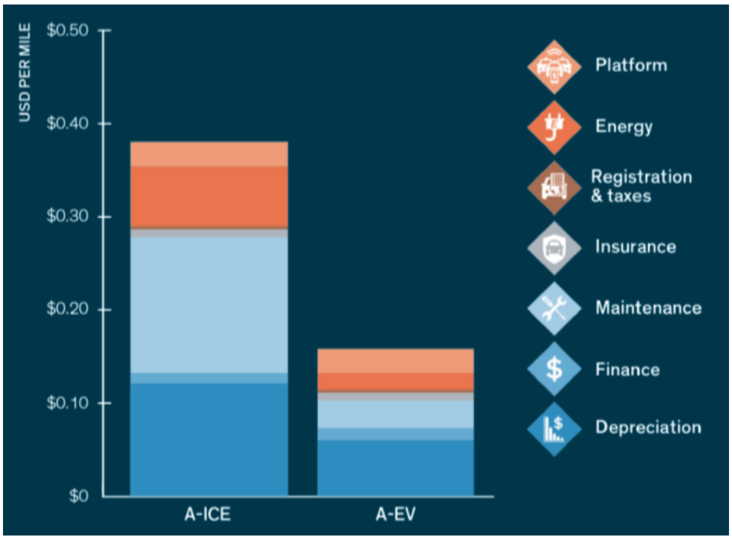

Figure 3.9: Cost of Autonomous ICE versus Autonomous EV [111]

#4: The effect of shared mobility on public transportation seems positive, nowadays. There are some surveys which show that people who use car sharing, use 40% more public transportation than the ones who do not use car sharing. The advantage of car sharing is that it can be served to people as first and last miles transit, connecting homes with public transit network. However, after the legalization of self-driving vehicles, using car sharing or ride-hailing might become much cheaper than the public transportation [6].

#5: When EV production increases and more EVs are sold, the battery production cost would likely to decrease as a result of mass production of EVs. Moreover, research and development on batteries would also be increased. As a result of decrease in the battery cost and enhanced research on battery technology, the storage systems with renewable energy sources will gain advantage, i.e. PV and a battery system at houses. Therefore, more renewable can be integrated into the grid due to the improved storage options [6].

#6: Self-driving vehicles either private or shared could have impact on the charging infrastructure for EVs. Shared EVs would need different type of charging infrastructure such as fast charging stations. When the usage of autonomous vehicles increases, shared EV uptake would increase also as it was mentioned before. Therefore, the utilization of the charging stations would increase at some locations in the cities [6].

#7: The EVs have zero emissions while on the road. However, when the whole carbon footprint is compared, the production style of electricity has a huge impact. EV technology makes more sense and has less greenhouse gas emissions only if the electricity that people charge them is from renewable sources. Share of renewables in the grid is going to be increased more in the future. Electrification of the transportation system could boost the integration of the renewables into the grid due to the smart charging technology [6].

#8: Vehicle connectivity has been increasing during last years. Self-driving vehicles would need more communication between the vehicles and between the charging infrastructures. Therefore, self-driving technology would increase the usage of internet of things more [6].

People want to have mobility-on-demand; they want to have the freedom of traveling wherever they want in any time of the day. The mobility-on-demand concept has been automobiles almost for 100 years. However, it will most likely to change in the future. The concept of having a car shows the status in life is also changing among people. When ‘Mobility as a Service’ or ‘Transport as a Service’ start emerging and become cheaper, people would most likely to abandon their cars and start using these services [16]. In 2021, transport as a service will provide a transportation option much cheaper than owning a car; 4 to 10 times cheaper per mile than buying a new car and 2 to 4 times cheaper than using an existing vehicle [111]. Adoption of the service will start in the crowded cities and expand to the rural areas. It is projected that at 2030, 10 years after the legalization of autonomous vehicles, TaaS will provide 95% of the passenger miles covered in U.S. Fleets of autonomous electric vehicles provide people higher levels of service, faster, cheaper, and safer rides. According to the ‘RethinkX: Disruption, Implications, Choices’ report, an American family will save more than $5,600 annually because of using TaaS instead of owning the vehicle. In the report it is estimated that the annual cost of owning a car is $9,000; whereas, cost of using the mobility service is $3,400 per year. Furthermore, if TaaS pool is chosen as a transportation option, families would need to spend only $1,700 annually. The service will be much cheaper since there will be 40% more utilization (10 times more utilization than owning a car) for using autonomous EVs in the mobility service. The increase in vehicle utilization happens due to the shared mobility. Individually owned vehicles are used only 4% of their lifetimes; 96% of the time they are parked. Due to the autonomous vehicles, on-demand door-to-door mobility service can be used 24 hours; this will bring more utilization than individually owned vehicles. Figure 3.10 shows the importance of cheap transportation on customers. Most of the people would likely to choose to travel with TaaS mainly because it is cheaper [111].

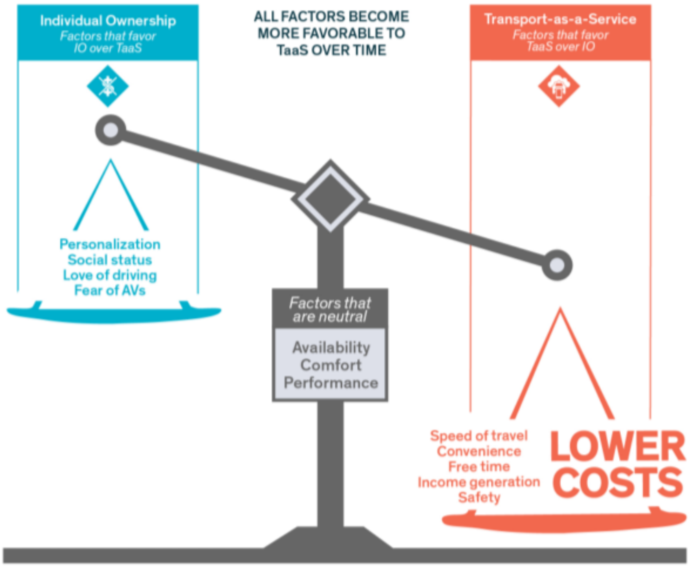

Figure 3.10: Factors that Affect the Customer Choice [111]

As a result of increased utilization and increased usage of TaaS, the number of vehicles used on the roads in U.S. will drop to 44 million by 2030 from 247 million. In other words, the mobility as a service concept will disrupt the automotive industry because fewer people will decide to own a car [111].

Apart from the economic benefits, TaaS will have also huge impact on environment, geopolitics and social life. Since more EVs will be used in the transportation system, CO_2 emissions will decrease. Moreover, air pollution due to the exhaust gases from ICE vehicles will be eliminated. New transport system will improve the air quality and help to decrease the number of deaths because of air pollution. As a negative side of the EV uptake, the electricity demand will increase 18% by 2030; however, energy demand for transportation will decrease 80% due to the higher efficiency of EVs over ICE vehicles. The increase in electricity demand could be compensated by more renewable electricity production. EVs could have the potential of boosting the renewable energy production (Chapter 4). Furthermore, with vehicle to grid (V2G) applications, EVs can act as a mobile battery and support grid when it is needed. In the geopolitics field, TaaS will disrupt the importance of oil in transportation sector; and it will help to increase the energy security of the countries. With more autonomous EVs on the roads, there will not be needed the ICE vehicles. Lithium will be the most important component for the transportation because it is the main part of the batteries. However, lithium reserves are different than the oil reserves. Lithium is a material stock which is needed to build the battery: however, oil is the fuel which is required to operate the ICE vehicles. From the social perspective, TaaS will increase the mobility tremendously. Autonomous vehicles can drive people wherever they want; thus, children, disabled people, and older people can also use the service very easily. It will increase the access to the jobs, education, and health. Besides of these important enhancements, it will free up the drivers time. As a result of this, the time spent on driving could be used more productively and it could increase the GDP of the country substantially. On the other hand, it would cause people in some sectors to lose their jobs due to the driverless cars [111]. However, there is also the negative side of this disruption. There will be some job losses due to the usage of autonomous vehicles. Most of the drivers will lose their job. Furthermore, some monopolies can appear in the transportation sector. Some companies might have big market shares and this might create unbalance in the market. Figure 3.11 shows the summary of positive sides and the negative sides of on-demand mobility service.

Figure 3.11: Positive and Negative Sides of Transportation as a Service (TaaS) [111]

Chapter 4

EV Charging

This chapter gives information about the impact of EV charging on the grid. Furthermore, smart charging and vehicle-to-grid concepts are investigated. Apart from the impact of EV charging, basic information about EV chargers is given; fast charging can be found under the charger types section.

4.1 Impact of EV Charging on the Grid

Electric vehicles are one of the best solutions to decrease the greenhouse gas emissions and air pollution in the cities due to transportation. However, renewable electricity should be used in the cars in order to have overall lowest carbon footprint [9]. Figure 4.1 shows the comparison of lifecycle analysis of different fuel types and electricity that is produced from different sources. It can be seen easily from the figure that if the electricity used for charging is produced from coal, the overall carbon footprint of EVs are worse than the overall carbon footprint of ICE vehicle works with gasoline. On the other hand, if the EV is charged through a renewable electricity, the overall carbon footprint is very low.

Until now, the connection between power utilities and the transport sector has been very weak. However, with the increase of market share of EVs, these two sectors are likely to connect more with each other. In order for this connection to happen, at least 15 years are expected to pass. It is estimated that by 2030 the EV market in some of the European cities will be 4-5%. Moreover, by 2050 the electricity demand is expected to rise due to EV charging up to 25%. With an EV penetration of 80%, the average electricity demand in Europe is expected to rise around 9.5% by 2050. These projections show that the EV charging will have a serious effect on the grid. Most of the EV charging will most likely to happen at homes and businesses or in public charging stations. Therefore, when there are more EVs on the roads, there will be an impact on the low-voltage distribution grids at residential areas and business areas. The operation of the energy market and the grid infrastructure will change. The additional electricity demand needs to be covered with additional power generation, and this additional electricity generation needs to be added to the grid. If this additional needed electricity is produced mostly from the fossil fuels, more GHG emissions will occur and all the positive effects of electrification of mobility will disappear since usage of EVs only make sense when they are charged with renewable electricity (Figure 4.1) [112].

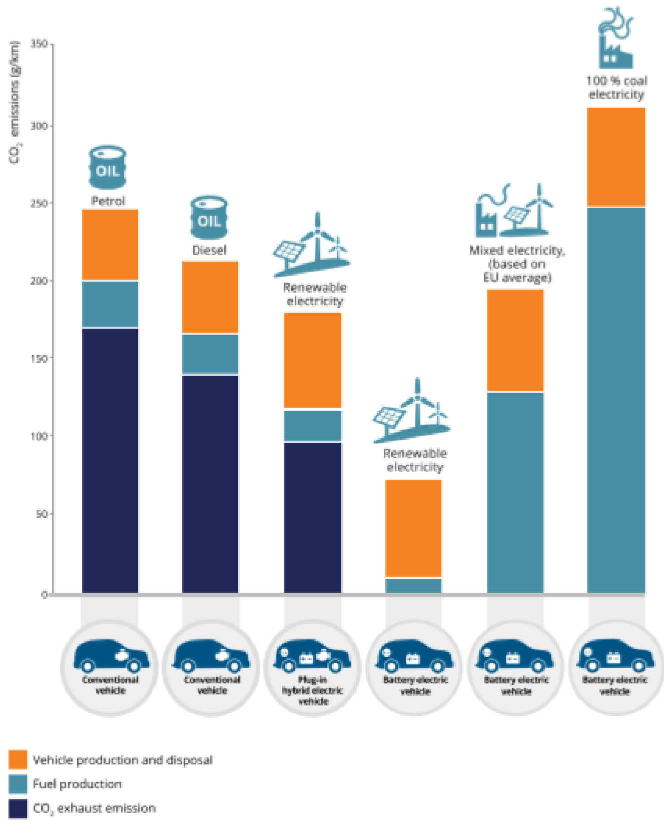

Figure 4.1: Lifecycle CO2 Emissions of different Energy Sources for the Vehicles [9]

According to the report 'Assessing the status of electrification of the road transport passenger vehicles', two different scenarios for the EV penetration is considered; EV mid scenario and EV high scenario. EV mid scenario assumes that the EV penetration will be 20% and 50% by 2030 and 2050, respectively. On the other hand, EV high scenario assumes that the EV penetration will be 30% and 80% by 2030 and 2050, respectively. Figure 4.2 shows the effect of EVs on CO_2 emission in power sector and transportation sector. It can be said that the avoided CO_2 emission in transportation sector due to EV usage is much higher than the additional emissions in the power sector due to increased electricity demand. Furthermore, the additional CO_2 emissions can be decreased due to the renewable electricity production [112].

Smart charging is going to be important when there is more EV penetration in the car market. With the help of smart charging, the charging times can be shifted according to the peak renewable production and the vehicles can be charged with the help of renewable electricity. Furthermore, smart charging would increase the penetration of renewables into the grid because they can be used in EV charging immediately. When there are more renewables in the grid, the additional CO_2 emissions in power sector due to EVs could be decreased and less GHG could be released to the atmosphere [112].

4.1.1 Smart Charging

Smart charging, also called managed charging, is a way of charging the EVs in contrast to uncontrolled and user-driven charging patterns. Charging times are flexible and show differences according to the

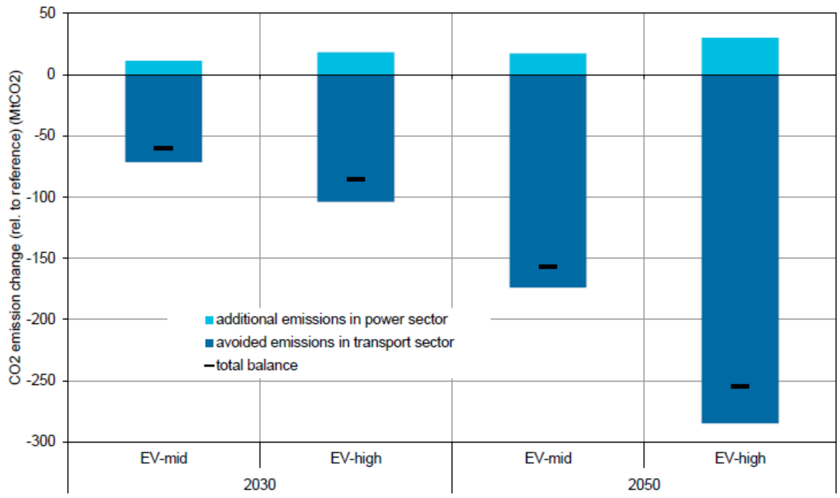

Figure 4.2: Effect of EV Penetration on CO_2 Emissions in Power Sector and Transportation Sector [112]

user's preferences. Most of the people charge their EVs during the night time when they are at home or during the day when they are at work. Usually, electric vehicles are connected to the grid longer than they would need for charging. Smart charging concept postpones the starting time of the charging according to the needs of the grid. The charging patterns and when the EVs are being charged strongly effects the grid. With the help of smart charging, the negative effects of EV charging on local grids can be eliminated. Also it eliminates more GHG emissions. More EV penetration in the future would increase the importance of smart charging technology [112].

There should be enough communication between the grid and the charging infrastructure in order to achieve smart charging. Apart from the communication between the charging infrastructure and the grid, another important issue is the acceptance of the users. People who are using this technology should agree on the terms since with using smart charging they might lose some of their freedom. That freedom is that they are not able to charge their car whenever they want. Furthermore, the users need to understand that their EV might not be fully charged every time since their vehicles are being charged according to the needs of the local grid [112]. In other words, the number of electric vehicles connected to the grid allows different charging strategies and creates flexibility for charging. If EVs are connected to the grid not only at homes but also at the workplaces during the day, smart charging can be applied to more vehicles; thus, a positive impact of smart charging on the grid can be seen more. Due to these factors, the willingness of EV owners to use smart charging approach is very important. EV owners can be incentivized by offering them cheap charging options or some discount through their electricity bills [10].

Specific goals of smart charging can be divided into 3 different categories: network-oriented charging, renewable energy-oriented charging, and cost-oriented charging [112].

Network-oriented Smart Charging

The main goal of this type of smart charging is to avoid the overload of the lines and the voltage drop on the grid. In other words, the congestion and the physical capacity constraints can be eliminated with this type of charging. The charging time of the electric vehicles is shifted to low demand periods (i.e. night time) in order to decrease the intensity of electricity demand of the EVs and to smooth the load profiles. The positive impact of this type of charging is to increase the system stability and grid functionality. Furthermore, investments in infrastructure could be also avoided with the help of this type of charging. On the other hand, there will be seen some negative environmental impacts due to network-oriented charging. In places where the conventional power plants dominate the electricity production in off-peak times, network-oriented smart charging will increase the GHG emissions since the charging will be shifted to these times (off-peak times) and the generation from conventional power plants will increase [112].

Renewable Energy-oriented Smart Charging

As it was mentioned before, the overall carbon footprint of EVs highly depends on the type of the power plant produces the electricity used in charging (Figure 4.1). In most of the systems, there is high PV production during the daytime; and electricity demand during the night times are met with conventional power plants if there is not a wind production. From an environmental perspective, the EVs should be charged during the high renewable electricity generation times in order to prevent more GHG emissions due to the conventional power plants. In addition to that, charging EVs during high renewable energy generation times will boost the use of renewables in the grid. A research on German power sector shows that by arranging the charging patterns of EVs according to the solar and wind production times, the renewable energy used for EV charging can be more than doubled; thus, there can be more renewable energy on the grid. Similarly, a research in Portugal shows that arranging the EV charging times with respect to the PV generation times during the day, will increase the penetration of renewables in the grid substantially [112].

Figure 4.3 shows clearly how the renewable energy-oriented smart charging works. It can be seen that the EV charging demand and the PV generation coincides during the day due to the smart charging. With more penetration of EVs in the car market, smart charging in the PV generation times could avoid the 30% increase in electricity demand due to EV charging [10].

Apart from all those positive impacts, there are also some negative effects of this type of smart charging. Since every country has a different type of energy production mix, for some of them (i.e. the ones who is having wind energy mostly) it might be hard to use this system due to the unpredictable nature of some wind energy. Furthermore, there should be sufficient renewable electricity produced in the future in order to meet the EV charging demand. There might need to have more renewable energy capacities in the grid; thus, this needs more investment [10, 112].

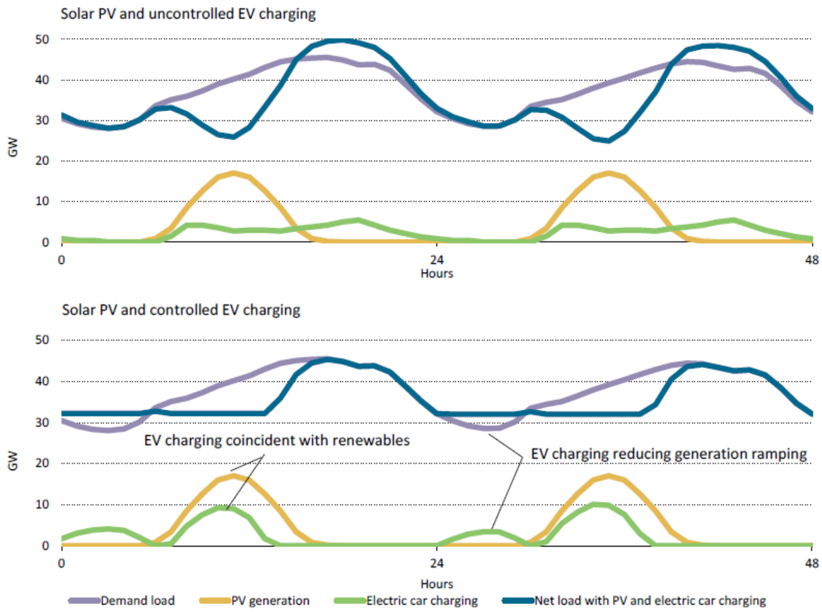

Figure 4.3: Renewable Energy-Oriented Smart Charging [10]

Cost-oriented Smart Charging

EV charging can be done in the periods when the electricity prices are low in order to obtain the minimum cost from the charging. This approach will be beneficial both for utilities and for EV owners. By shifting the charging to these low energy price periods, cost of EV charging can be reduced significantly. In addition to the cheap charging for the EV owners, load patterns can be smoothened by postponing the charging times to the low demand time period. This will bring good economic benefits to the utility companies. Furthermore, with the increase of renewable energy use in the grid, the fluctuation between the high price and the low price will become more frequent. Cost-oriented smart charging could be also beneficial for utilities to arrange the demand in these times in future [112].

An example for the cost-oriented charging can be seen in Figures 4.4 & 4.5. The Figure 4.4 shows the load curves for EV charging (user-driven). It can be seen that if EV charging starts in the evening time when everyone comes back home from work or school, the charging will be too costly due to the peak time.

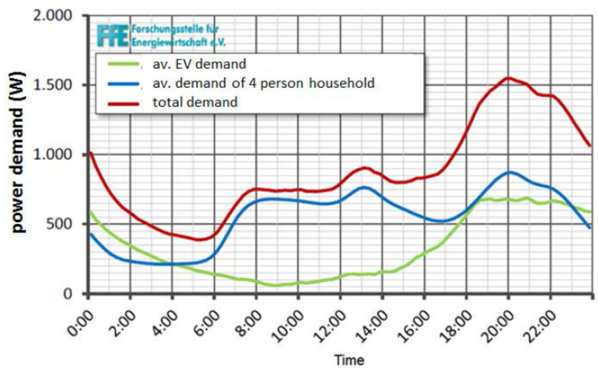

Figure 4.4: Load Curves of EV Charging (User-driven Charging) [112]

However, the high cost of charging can be reduced by using the smart charging (Figure 4.5). The difference can be seen easily in the figure. Due to the shift of charging, the total electricity demand at evening time is reduced and the charging starts after midnight when the electricity is cheaper.

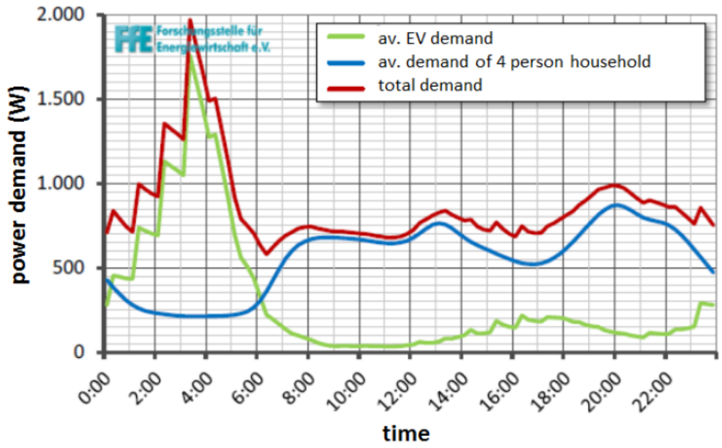

Figure 4.5: Load Curves of EV Charging (Cost-oriented Smart Charging) [112]

However, the negative impacts of this type of charging are similar with the network-oriented charging. If the electricity generation during off-peak times is dominated by the conventional power plants, there will be an increase in GHG emissions due to the high electricity demand during off-peak times [112].

4.1.2 Vehicle to Grid (V2G) Technology

With the increasing penetration of EVs in the future car market, their batteries could be used as a grid source in the future. V2G creates opportunities to generate cleaner power, to have a lower energy cost both for the EV owners and utility companies, and to achieve greater stability in the grid. An average car stays parked 23 hours of one day [113]. Moreover, an average charging time of the EVs is around 7-8 hours with slow chargers. When an EV is considered to be plugged into the grid 96% of its time, this creates a huge opportunity for using EVs as a grid source [111]. EVs could back up the grid when it is needed and they can help for the peak hours shaving by supplying their renewable electricity which is stored in their battery. According to the report 'Rethinking Transportation 2020-2030,' it is expected to be 20 million transport-as-a-service (TaaS) vehicles in U.S. by 2030. When it is considered that these vehicles have a battery capacity of 60 kWh, the total battery capacity of these vehicles would reach 1,200 GWh. The report also states that the peak draws from the grid in U.S. is 475 GW in winter and 670 GW in summer. These numbers show that the EVs can be used in the future electric market to support electricity to the grid [111].

Furthermore, one of the goals of V2G application is to increase the penetration of renewable energy sources in the grid. The cost of solar PV and wind turbines are decreasing and renewable energy production in the future is expected to increase due to the low emission energy policies. Due to the fluctuating nature of solar and wind, penetration of these renewable sources will create instabilities in the grid. V2G has a potential to decrease these instabilities; thus, it could increase the penetration of renewables. For instance, wind turbines stop working at some time of the day. Sometimes this happens not because of non-wind condition but because of the grid. If there is more energy produced than the grid can handle, the production from renewables needs to be stopped. EVs can be a good solution for this situation. With the help of smart charging, these renewable electricity production surplus can be stored. After storing this renewable energy, bidirectional V2G connection helps to supply this energy back to the grid when it is needed [113].

As it was mentioned above with the high percentage of EV penetration, utility companies can use this potential 'on-wheel batteries' in order to stabilize the grid. In order to achieve this, the connection between the grid and the EV should be bidirectional. The EV owners should be able to sell their electricity stored in their EVs when the electricity prices are high. Charging the EVs at low demand times and selling some portion of this electricity stored in vehicle batteries, would create additional income to the EV owners. Most of the EVs are parked between 20:00 and 07:00 during the week days at homes. They are on the move usually between 08:00-09:00 and 16:00-17:00. In addition to these times, they are also parked at workplaces during the working hours. According to the state-of-charge (SOC) of batteries, EVs can either support the grid or charge the battery. Figure 4.6 shows this phenomenon in a simple way. In this type of system, the battery is protected due to the fact that it contains the optimized charging as long as possible [114]. Moreover, the V2G application can be applied to homes as vehicle-to-home (V2H) technology. This approach will provide EV owners a huge advantage. For instance, when an EV owner come back to home from work, he/she would not need to use the grid electricity since the electricity from the grid is more expensive at evening peak times during workdays. Instead of using the grid electricity, the EV owner can use the electricity charged in his/her EV battery. After using this energy for a couple of hours, EV can be charged again with the low-cost electricity or with renewable energy. Furthermore, the utilities would decrease their operating costs. Therefore, a different kind of infrastructure is needed. In the future, these type of bidirectional chargers should be standardized in order to increase the usage of V2G system [12].

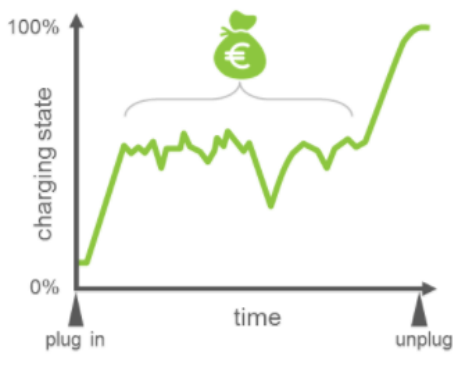

Figure 4.6: V2G Application which will happen most likely in the Future [114]

V2G application is in the research phase nowadays. Some utility companies (i.e. Enel) started some pilot testing with the help of research institutes. There are some crucial steps needs to be done in order to increase the use of V2G, such as the installation of necessary hardware and creating new business models to attract EV owner's attention. Apart from all its benefits, some important issues need to be solved for the V2G. One of the most important problems is the privacy of the customers. In order to arrange the available electricity from the EVs that can be used, the schedule of charging data might need to be obtained by the utility companies. In that case, the protection of these data need to be done properly since from the charging data of the EVs, some valuable information can be obtained about the EV owner such as when they are at home or when they are on vacation. Another issue that needs to be solved is the same as the smart charging. New business models need to be invented in order to incentivize the customers to use the V2G applications. EV owners need to sacrifice some of their freedom of mobility in order to use V2G since they cannot plug off the charger cable whenever they want when the vehicle is supplying energy to the grid [12].

4.2 Electric Vehicle Supply Equipment (EVSE)

Availability of charging infrastructure is one of the key factors in order to overcome 'range anxiety' of some of the drivers for the EVs. The electric vehicle uptake will increase with more charging stations in the cities and on the main roads. This is more like a 'chicken-and-egg' problem since more EV brings more charging infrastructure; likewise, more charging infrastructure will increase the adoption of EV in the vehicle market. There are 3 different types of charging points; private/domestic charging points, semi-public charging points, and public charging points. Private/domestic charging points are the ones at households such as wall boxes. EV users own these type of charging points at their garages. Charging the EV at home with private charging points is common in rural areas due to the fact that people can have their own garage for their vehicles. Semi-public charging points are places on the private ground but they can be accessed by any type of user. Example for this type of charging places are the ones at commercial car parks, shopping malls or leisure facilities. Most of the fast charging stations are semi-public charging points which are installed on the private ground like conventional petrol stations. Public charging points include a stand-alone charging poles. In some countries, municipalities provide this type of charging points. These are slow chargers and customers pay to the specific utility which provides the electricity to the charging point [17].

Figure 4.7 shows that the number of public charging points throughout the world is less than the number of EVs; more than six to one. Moreover, publicly available charging stations are not distributed evenly throughout the countries. The right-hand-side chart in the figure shows the number of fast charging stations. China is the leader with far more number of fast charging stations due to their EV policy [10]. In Europe, there are around 92,000 public charging points. Netherlands is leader for having the highest number of publicly available charging stations with a number of 23,000 [17].

Deployment of the charging stations is very important for the EV uptake in the future. However, there is a problem about who is going to build these charging stations. Currently, coming up with a profitable EV charger deployment is hard because of some reasons such as high initial investment cost, and low and uncertain demand for the public chargers in short term. For instance, the initial cost of a fast charging station results in a net loss of $44,000 for the company who builds it over a ten year period. Likewise, the cost of a slow charger results in around $5,000 over a ten years period [115]. In order to make the deployment of the charging points attractive, some business models need to be created. In most of

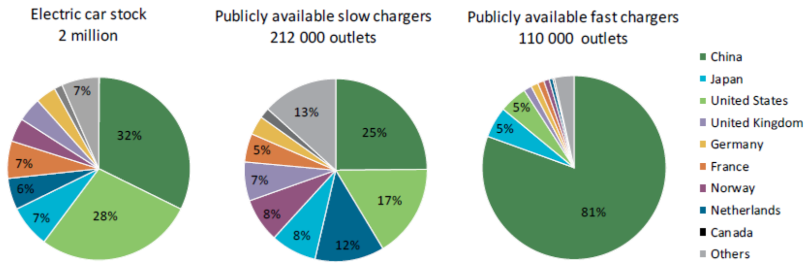

Figure 4.7: Number of EV Stock and Charging Points [10]

the business models, partnerships will be very important in order to install these charging stations. For instance, like the other utility companies doing in the installation of the fast charging station network (i.e. E.ON, Engie), partnerships can be done with the car manufacturers or some local authorities (Chapter 2.3). Since the car manufacturers will need the EV chargers in order for them to sell EVs to the people, creating a partnership between the utility companies and the car manufacturers is one of the promising options. As it was mentioned before, the fast chargers needs high investment cost. Therefore, these kind of partnerships will be useful in order to deploy fast charging stations on the main roads. One example to this can be given as the partnership between BYD and China Southern Power Grid. With the help of this partnership, charging infrastructure in Shenzhen is built [116]. Apart from that, Tesla is following another business model for its charging stations. They make the installation of the fast chargers on the main roads and they provide free charging for the Tesla owners for some years. With this type of business model they are not only trying to increase the number of sales of Tesla's but also trying to increase the number of fast chargers [116].

Charging habits of EVs show a huge difference from the refueling habits of ICE vehicles. According to the data from the EV owners in Norway which has the highest EV penetration in the world, people charge their EVs mostly at their homes and their workplaces by using the slow chargers (Figure 4.8) [10]. The third place that the Norwegians prefer to charge their vehicles is at public chargers, and it is followed by the chargers at the commercial facilities such as shopping malls and retail stores. It can be seen easily from the figure that fast charging is preferred neither primarily nor thirdly. Fast charging stations are preferred on the main roads or highways when the traveling distance is getting bigger. Unless the traveling happens in the city itself, the fast charging is not preferred as a primary charging option [10].

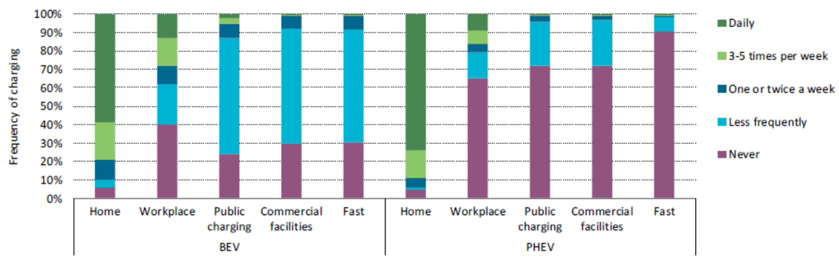

Figure 4.8: Charging Habits of Sample Norwegian EV Users [10]

EV to EVSE (Electric Vehicle Supply Equipment) ratio is expected to be 15 for the public slow chargers and 130 for the fast chargers in the future. Some governments are very active with these issues. In

China, the government supports the local municipalities in order to install charging infrastructure. French government gives some incentives for the installation of home chargers, residential or workplace chargers. These incentives are like a tax credit and their value is up to 30% of the home chargers.They are like a subsidiary for residential and workplace chargers. Moreover, a legislation states that the 50% to 75% of the parking bays in the new buildings or recently renovated buildings should have some conduits in order to make the installation of EVSE between 7 kW and 22 kW. In commercial buildings, 10% of the parking bays should have conduits for the charging infrastructure which has power output of 22 kW. In Netherlands, due to the Green Deal, government supports the joint deployment of public chargers with local municipalities and third party organizations. Norwegian government gives public funding for the fast charging stations at every 50 km on the main roads and for the public charging stations. Likewise Norway, Sweden provides financial incentives for the installation of public chargers. In the UK, people who want to install EV chargers in their homes get 500 British pounds from the government. Likewise, businesses obtain 300 British pounds per installation of one charging points at workplace. Furthermore, these businesses can get a tax break from the government if they deploy a large amount of charging infrastructure. Finally, in U.S, most of the incentives depend on the state. For instance, in Colorado, the state provides incentives up to 80% of the cost of EV charger. Furthermore, in France, Spain, U.S. (the state of California), and Portugal, some important steps have been taken by the governments in order to adapt the law of property in order to increase the installation of charging infrastructure and increase the uptake of EVs [10].

4.2.1 Charger Types

There are 3 different ways of charging an electric vehicle; plug-in charging (conductive charging), battery swapping, and wireless charging.

Plug-in charging is the most widely used charging method; all the commercial charging infrastructures includes this type of charging. There is a physical connection between the vehicle and the charger via a cable. Plug-in charging can be done anywhere (i.e. at home, on public streets or on commercial or private places) as long as there is a charger. Generally, EVs can be charged with a normal power socket that we use at our homes; however, it takes time due to the low current of the sockets at homes. The time needed for the charging at home is approximately 8 hours; thus, the best way to charge the EVs at home is the overnight charging. Different charging infrastructures types help to reduce the charging times. For instance, with fast charging, an EV can be fully charged up to 30 minutes [17].

Battery swapping technique is changing the used battery with the new ones at special battery swapping stations. This is applied to some of the e-scooters in order to eliminate the time passes for charging. However, almost all the electric car models do not support the battery swapping technology since there is no standard type of battery used in the electric cars; type of the battery might show differences with respect to the model or the brand of the car. Furthermore, the infrastructure of the battery swapping technology is very costly [17].

Wireless charging does not require a physical connection between the charger and the electric vehicle. There are three types of wireless charging; inductive, capacitive, and microwave. The last two types of wireless charging are still in an early experimental phase; but, inductive charging is used. The vehicle is charged by the electromagnetic field and the induction due to that electromagnetic field. Since there is no cable due to the non-conductive energy transfer, the risk of electric shocks on the EV owners during charging can be eliminated. Moreover, the non-cable charge can eliminate the electrical and mechanical problems [113]. This type of charging can be seen only as a pilot project in some of the locations; such as charging option for the buses in Belgium, Germany, Netherlands, and the UK. Also, in Sweden, there are some pilot projects for wireless charging for electric cars [17].

Plug-in charging is divided into four 'modes' according to their power and the specialties. Each of the modes has different level of power supply and some of them use different electric current. The grid provides an AC current; whereas, the batteries in the EVs store DC. Thus, there should be a converter either on the vehicle or at the charging station. Usually, EVs have a converter on board that is why it is called sometimes 'on-board charging'. Fast charging stations provides DC; therefore, there is a converter at the charging station. The power level of the charging station depends on the voltage and the current that is supplied by the charging station. Power of the charging stations determines the time that needs for the battery to be charged fully; this level varies between 3.3 kW and 120 kW [17].

Mode 1 Charging

Mode 1 charging is the basic charging type, it allows EVs to use the household socket and cables. It can be found also in the office buildings. The standard power sockets provide 16 A or 2.3 kW power. This type of charging is not used for the electric cars due to the safety issues of the charging; it is hard to assess the quality of charging and the safety of vehicle. It is mostly used for the two-wheelers or 3 wheelers [113].

Mode 2 Charging

Mode 2 charging is for slow charging or semi-fast charging. The connection between the grid and the EV is similar to the mode 1; that is, there is a non-dedicated socket. However, cable is given by the car manufacturer itself. Difference between mode 1 charging is the additional protection which is called "In Cable Control Box (ICCB)". ICCB helps to protect the cable and the vehicle but the main drawback is that it doesn't protect the plug which is one of the components mostly damaged during charging [113].

Mode 3 Charging

Mode 3 is used for slow, semi-fast or fast charging. There is a dedicated EVSE between AC network and the vehicle. This type of charging is used at private or public charging stations and at households as a wall box charger [17]. There is a protection between the equipment which is permanently connected to the grid and the vehicle; it is called "control pilot". The duties of the control pilot are; (i) signaling when the vehicle is properly connected to the charging station, (ii) sending continuous verification about protective earth conductor, (iii) being responsible for the energization and de-energization of the system,

(iv) selecting of charging rate (ampacity). With the help of control pilot, power is delivered when the EV is connected properly and when there is earth-circuit connection. This type of charging is mostly preferred due to its safety features and the potential for smart grid integration [113].

Fast Charging (Mode 4 Charging)

Mode 4 charging or fast charging uses DC in order to charge the EV; thus, it is called sometimes 'off-board charging'. There is an indirect connection to the EV and the grid. There is also an off-board charger where the control pilot conductor extends to equipment permanently connected to AC supply. This type of charging stations are preferred for fast charging because off-board chargers are suitable for DC charging. Since the charger is off-board, a connection is needed in order to regulate DC charging; charger needed to be informed about the type and the state of charge of battery to supply right amount of voltage and current [113]. Fast charging station network has a great potential to reduce the range anxiety of the drivers. With a fast-charging network which is installed on the main roads between the countries in Europe, the range problem of the EVs can be significantly reduced. However, fast charging has some drawbacks. Since fast charging concept uses high current in order to increase the power and to reduce the charging time, efficiency of the charging is very low. Furthermore, fast charging can decrease the lifetime of the battery by reducing the total number of charging cycles. In addition to the technical drawbacks, the installation cost of the fast charging stations is also 3 times more expensive than the slow chargers [17].

Table 4.1 shows a summary of the charger types, outlet power from those charger types and the approximate charging time in order to charge the battery for 100 km range.

Table 4.1: Charger Types and the Time Needed to Charge BEV to have 100 km Range [17]

Power (kW)	Current	Mode	Time needed to charge BEV to provide 100 km driving range	Location
120	DC	Mode 4	10 mins	Motorway service area or assigned charging stations in urban areas
50	DC	Mode 4	20-30 mins	Motorway service area or assigned charging stations in urban areas
22	AC (3 phase)	Mode 3	1-2 hours	Most public charging stations
10	AC (3 phase)	Mode 3	2-3 hours	Household, workplace wall box
7.4	AC (single phase)	Mode 1 or Mode 2	3-4 hours	Public charging stations
3.3	AC (single phase)	Mode 1 or Mode 2	6-8 hours	Household, workplace wall box

Chapter 5

Discussion and Proposals

In the first section there can be information about the activities of Iberdrola on electric mobility field. Furthermore, some possible proposals that can Iberdrola use for different areas in the future can be found in the chapter.

5.1 Electric Mobility from Iberdrola's Perspective

Likewise its competitors, Iberdrola gives importance on sustainability by decreasing the GHG emissions and increasing the use of renewables in the electricity generation. According to the Dow Jones Sustainability index, Iberdrola decreased its GHG emissions by 31% in last five years and by 75% since 2000 [117]. Figure 5.1 shows that most of the power generation of Iberdrola in 2015 was from mostly with gas and less with coal. Furthermore, the share of renewable sources in the power generation is substantial when it is compared with its competitors. This shows that the greenhouse gas emissions for electricity generation are lower than the competitors [118].

Electrification of the road transport has huge importance in their agenda. According to the Iberdrola, electric vehicles could decrease the GHG emissions tremendously as well as the air and noise pollution. Oil dependence will be reduced tremendously when the electrification of road transport is achieved. Furthermore, people can travel longer with a cheaper fuel (in this case electricity) and save more money because electric vehicles need less maintenance. In addition to these, penetration of renewables could be increased due to the night-charging, smart charging or vehicle to grid (V2G) technologies [119]. In order to promote green mobility, Iberdrola came up with a sustainable mobility plan, and 23 initiatives (Figure 5.2). According to this plan, they incentivize their employees to use electric vehicles. For instance, they give assistance up to €4,000 to their employees who want to purchase EV. Furthermore, Iberdrola provides non-refundable loans up to €500 for the EV charging station installations to their employees at their homes. Instead of the €4,000 support from the company, the employees are able to choose to get €6,000 if they accept to carry the company logo on their EVs [120]. Iberdrola offers two different charging options to its EV user-customers; Green Charge, and Smart Green Charging. The green charger is a charging box which can be installed at homes or garages in order to promote charg-

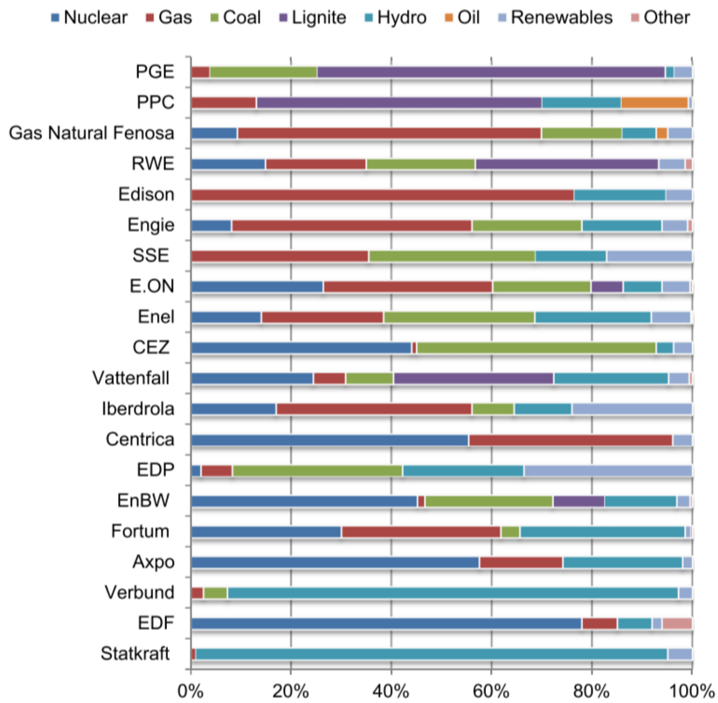

Figure 5.1: Power Generation Mix of Utility Companies in 2015 [118]

ing to the EVs. The company makes the sale and the optional installation of the charger. By purchasing this infrastructure, EV owners can have access to the Iberdrola Green Energy and charge their EVs with 100% electricity [121]. The second product is the smart green charging. By purchasing the second option, the customers have the charge point, two identification cards and they gain the access to the Green Charge app. From the app, they can manage the charging schedule and be able to control the charging. Likewise the first charging station, the charging is done with 100% renewable energy [122].

Figure 5.2: Iberdrola's 23 Initiatives for Sustainable Mobility [123]

Figure 5.2 shows the 23 initiatives of Iberdrola on Sustainable Mobility Plan. It can be seen that for the company employees and business activities there are more initiatives than for the customers. One of the most important in these initiatives is the car sharing program for the business activities. BMW and Iberdrola have announced their partnership in 2015. According to this announcement, BMW provides fully electric vehicle i3 to Iberdrola. Due to this car-sharing service, almost 350 members of staff at Iberdrola who are doing retail business in the four cities in Spain where Iberdrola has the operation (Valencia, Barcelona, Madrid, and Bilbao) can use this service. The aim of the service is to decrease the emissions due to road transport and increase the travel efficiency [124].

5.2 Proposals on Possible Future Business Areas for Iberdrola

5.2.1 Car-sharing Service Provided by Iberdrola

As it was discussed in Chapter 3 that car-sharing concept will change how we use our cars. The advantages of car-sharing are substantial and the car-sharing concept applied to EVs will help to decrease the GHG emissions from the road transport tremendously. It is projected that around 35 million users will drive 1.5 billion minutes annually by 2021 with car-sharing. Furthermore, this will bring a revenue of €4.7 billion. Europe will be the biggest market in car-sharing and it is expected to have revenues around €2.1 billion [90]. These numbers and the projections show that the market share of car-sharing is huge and most of the companies have been already competing with each other in order to take the biggest share. Ride-hailing (i.e. Uber, Lyft) and car-sharing are two rival services that target the same type of customer segment. However, it can be seen from the success of Uber (Chapter 3.1.1) that people's attitude towards mobility as a service is changing. Most of the people who cannot afford to own a vehicle want to use this kind of services. For instance, electric car-sharing service Emov in Madrid gains popularity among its customers. More than 100,000 customers have started using the service only in 5 months. With this subscription number in a short time period, Emov becomes one of the main competitors of car2go which operates also in Madrid. City council of Madrid supports the EV usage in the city by allowing EVs in restricted areas in the city centers and allows them to park free almost everywhere in the city. Due to these reasons, electric vehicle car-sharing services is getting attention [125]. This trend can be seen from the activities of the competitors of Iberdrola (Chapter 2.3). Almost all the other utility companies show great importance on electric mobility; and, some of them has car-sharing programs, such as Enel, innogy, and Engie. Likewise, most of the car manufacturers involve in the car-sharing services. The most well-known two of these car-sharing services are car2go and Drivenow founded by Daimler and BMW Group, respectively (Chapter 3.1.4).

After the detail research done on the prospective future market in the mobility services, and on the activities of some big companies in car-sharing (even though they are mostly outside of the mobility sector), it can be said that it would be a good idea to involve in electric mobility programs as one of the biggest utility company in the world. According to my opinion, car-sharing with EVs would have benefits not only for increasing the penetration of renewables for Iberdrola but also for giving chance to them to exist in different potential future markets. For instance, Iberdrola could be more active in the long-term in vehicle to grid technology (V2G). With having EVs in their car fleet, they could use their batteries as a source for the grid when these cars are not rented by the customers. The renewable electricity stored in these EVs can be used to support to grid and increase the renewable electricity production. Furthermore, it is expected that the legalization of self-driving vehicles will happen either early 2020s or mid-2020s [111]. It is not a coincidence that most of the companies even the technology and software companies, as well as the car manufacturers, are working on autonomous vehicles since the market is big and promising. Also, after legalization of the autonomous driving technology, the difference between ride-hailing and car-sharing will disappear. By implementing an EV car-sharing program before the legalization of autonomous vehicles, Iberdrola would have the advantage of having experience in the field. Furthermore, Iberdrola can create trust, which will have more importance in the future when there are more companies in the car-sharing field, by providing these electric car-sharing service to its customers. That is the reason why big car manufacturers are trying to involve in the car-sharing business. They are trying to use their brand name in this field in order to create this trust among its customers because they all well aware that when the number of people using car-sharing services increases, the number of cars sold annually will decrease. Moreover, with the combination of EVs, car-sharing, and autonomous vehicles, automotive industry will most likely to be disrupted. In order to keep their revenues, most of the car manufacturers are trying to involve in different fields and use their expertise in these fields.

Iberdrola has more advantage than most of the car manufacturers or technology companies in the car-sharing market mostly because of their visions. Due to the less carbon policy that they pursue and their determination on reduction of GHG emissions for a sustainable world, the trust between the car-sharing service provided by Iberdrola and customers can be established easily. Moreover, they have another advantage than the car manufacturers due to the fuel. Since electricity is used as the fuel for the EVs, Iberdrola could choose either rent the cars or use them as a grid source (V2G) according to the grid needs since they own its own car fleet. For example, with the V2G application, Iberdrola can use that electricity in the car batteries when it is needed in order to decrease the expenses of the company during the peak times. The optimization between the charging and renting the car can be done easily. Moreover, Iberdrola is one of the utilities which have high share of renewable electricity production. This will be used to charge the EVs; therefore, less overall carbon footprint from the EV drive can be achieved. Having their own EV fleet would give them the flexibility to charge the vehicles when there is more renewable energy production. As a result of this, renewable energy penetration could be boosted in the grid. Or with using the smart charging technology, the EVs can be also charged according to the peak times on the grid in order to decrease the demand and stabilize the grid during these times.

Some of the business models show that the experience in the car production is not important in order to have a good market share in the car-sharing market. For example, the business model of Autolib (Chapter 3.1.4) is a very good example for this. Autolib is a joint venture which was founded by the Paris Municipality and the Bollore' group which has no experience either in transport sector or in car manufacturing sector. By having important and necessary partnerships, Autolib has a good market share in France in the electric car-sharing and the number of their customers are keep increasing. Another good example is Enjoy (Chapter 3.1.4) which was founded by Italian oil and gas company ENI. Today they have a good market share in Italy with their free-floating car-sharing concept.

Business Model for Car-sharing Service

After the extensive research on the car-sharing concept applied to EV and the future projections of EVs, my proposal would be establishing a car-sharing service. Madrid is a very good candidate to start this service. It can be seen from the success of ride-hailing companies (Uber, Cabify) and some car sharing companies (car2go, Emov) in Madrid, people in the city are eager to use these kind of services due to the congestion and parking problems mainly in the city center. Also, the awareness of people about environment is increasing. Preventing air pollution as well as decreasing the carbon emissions in transportation sector as a result of using electric car-sharing service created by Iberdrola could incentivize people who is living in Madrid. By giving the chance to the people to do something small by using EVs with car-sharing service, would make them feel better and fulfilled because they could have positive impact on nature and environment. Apart from environmental issues, economic part of car-sharing could also attract people in Madrid to use the service. Owning a car is very costly simply because people need to pay taxes, need to pay for maintenance, and need to pay for parking for an asset which they do not use 96% of the time that they have it. Therefore, the value proposition of the electric car-sharing service provided by Iberdrola could be flexible, environmental friendly (zero emission) and economic mobility service for the customers. The car-sharing service is going to offer one-way point-to-point station based rentals, and the EVs are going to be connected to the grid all the time when they are not rented. By using the service, customers are able to have chance to drive EVs in the city centers and restricted streets in some areas in the city. Also, the customers could park their cars at the charging points without paying any fees to the parking. The aim of the car-sharing service is going to be complementary to the public transportation. With using electric car-sharing service, use of public transportation could be increased since the car-sharing program could cover the last and the first miles. Furthermore, by using electric buses and metro in the public transportation, the GHG emissions in road transportation and the air pollution in the city could be decreased tremendously. Due to the competitive pricing of electric car-sharing, the number of car ownership will decrease in the future.

Target customers can be divided into 3 different categories; private users, corporate clients, and the EV owners. Private customer segment includes frequent clients, occasional clients (i.e. tourists), students and young drivers, people who cannot afford to have their own private vehicles, and people who have high concerns about climate change and global warming and want to have a small impact to have a sustainable future. This service can also be given to the corporate clients. It could be similar to the car-sharing service provided by Iberdrola to its employees. However, in this case, the car-sharing service will be provided to other companies who want to access to EV fleet in some certain times or permanently. Apart from these two segments, the last segment will be different. Iberdrola has already an application which is called Green Charger. The car-sharing app could involve Green Charger app in itself. With combining these two apps, EV users could charge their own EVs at the Iberdrola charging points in the city. Due to this feature, Iberdrola could reach a wider range of customer segments. When two different applications are combined in one smartphone app, it would be much easier for the customers to use it. For example, a customer who owns a private EV could not only use the car-sharing service but also use Iberdrola chargers with paying only one subscription fee. Moreover, with this convenience and combining two different customer segment, Iberdrola could sell chargers to the EV owners while offering them the car-sharing service.

The channels that Iberdrola could reach to the customers is going to be the online website, smartphone application, and the customer service call center which is going to be available 7/24. Furthermore, the customer relationships will be achieved by automated services by using the website or smartphone, and by using the call center.

Customers are going to be charged by the minutes; the time between they start using the vehicle until the time they end the rental. There will be an option for parking the car and do their work, and then start using the same car again by choosing the proper option during the rental. Or they can end the rental when they leave the vehicle. Moreover, there will be different payment options or discounts according to rental of the EVs such as hourly or daily. The customers need to reserve the vehicle around 15-20 minutes before the use. This will give Iberdrola enough time to arrange smart charging or V2G application by knowing when the vehicle is going to be rented. In other words, the EVs are going to be connected to the grid all the time when they are not used for the rentals. There is going to be one-time subscription fee to the system. The customers who are already registered one service, car-sharing or EV charging, are able to have the chance to use the other service without paying an extra fee. Furthermore, there will be an extra payment per km when the customers exceed a certain mileage. There will also be usage fees from the EV charging for the EV owners.

Essential key activities that the electric car sharing service provided by Iberdrola are going to be car rentals. In addition to that, fleet management and the maintenance of the vehicle should be done as well as make the vehicles ready by recharging them via a team. There should be 24 hours online customer service which helps to the customers related to any kind of problems. Marketing and creating new partnerships for the future will be very important. Furthermore, maintenance and the development of the website and the smartphone app is going to be very important in order to provide easy, simple and attractive service to the customers. For the development of these channels, feedbacks from the customers will have a huge importance.

One of the most important key resources for the service is going to be vehicle fleet. Moreover, the importance of the service team who is going to do the maintenance, relocate the vehicles and charge the EV battery is going to be substantial. Another key resource is going to be the website and smartphone application as well as the call center. The management team is going to be responsible for the fleet management. Finally, designated parking areas near to the Iberdrola charger will also be an important key resource.

Since it is very costly and not feasible to have the know-how of EV production, and battery production, the key partnerships are going to be very important for Iberdrola. In order to have its own electric vehicle fleet, there could be an agreement between a car manufacturer and Iberdrola. For instance, there could be a partnership with the car manufacturer SEAT, a Spanish car manufacturer company. Moreover, partnership with the local municipalities is going to be necessary in order to have a permission in the restricted areas to the traffic in the city centers and to have free parking for the customers. Like the business model of car2go, there could be a partnership with a car rental companies (i.e Europcar, Avis, etc. . .) in order to use their expertise in this field, such as arranging the fleet, vehicle logistics and make the vehicles ready for the next rental. There should be also an agreement between the insurance companies since there might be some issues due to improper use of the vehicles. In addition to these, an agreement between retail companies, retail stores, universities and other promotion partners, would create flexibility for the customers. By installing charging stations and car-sharing stations to these points as well as the airports, stadiums, and shopping malls, customers could reach to the car-sharing service easier and the number of people using the service could be increased easier. For example, having these EV stations around crowded areas (i.e. shopping malls, stadiums, and university campuses) would create great comfort to the customers.

Cost structures of this service will be directly connected to the key activities and the key resources. The cost is going to occur from maintenance and cleaning of the vehicles (personnel cost) and the vehicle fleet acquisition. Moreover, there will be payments to the partners such as insurance contracts, municipality taxes, and for parking. In addition to these costs, there will be some other costs due to improper use of vehicles by the customers and the costs for development and maintenance of the website and the smartphone application. The business model for this electric car sharing service can be seen in Figure 5.3.

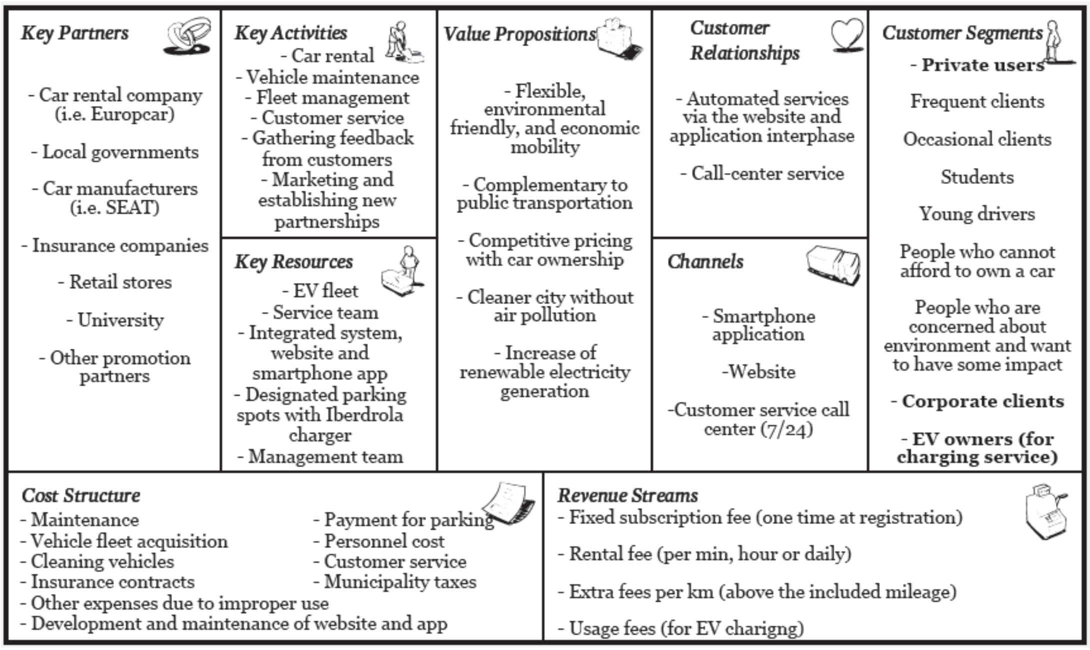

Figure 5.3: Business Model Canvas for Car-sharing Service Provided by Iberdrola

5.2.2 Smart Charging and V2G by Iberdrola

As it was discussed in the previous chapter (Chapter 4), the impact of EV charging will be high in the future with the increased use of EVs. There will be an increase in the electricity demand. The renewable electricity should be used to charge the EVs in order to prevent the additional GHG emissions due to increasing electricity demand. Smart charging will be very important in order to decrease the additional GHG emissions. Moreover, it could boost the penetration of renewable electricity into the grid and it could have the potential to be used as a peak shaver tool. In other words, the charging time of the EVs can be shifted from the high demand times to the times when the demand is not high. This will help not only to increase the share of renewables in the grid but also to decrease the GHG emissions due to additional power plant operation to stabilize the grid. Moreover, Iberdrola can decrease its operation cost with smart charging because of the more stable grid. Smart charging is not only helpful for Iberdrola but also helpful for the customers. By charging their vehicles in the fewer demand times, the EV owners will pay less to the charging and save more money. Like the smart charging, V2G technology promises a bright future in electric mobility. As it was explained in Chapter 4, V2G technology uses the electric vehicles as on-wheel-batteries. In theory, the idea is very simple; renewable electricity is going to be stored in the EV batteries and this energy will be used in order to support the grid at the peak times if the EV is not used at the same time. By using V2G technology, additional power plants will not need to produce electricity; thus, the GHG emissions will decrease. Furthermore, there will be more renewable electricity in the grid because it can be used in a wider range. Another application of V2G can be seen at residential houses. For instance, when an EV owner come his/her home, EV can support the electricity to the home for about an hour instead of using the grid electricity. This will decrease the electricity demand at the evening times when everyone comes home from work and uses the electricity. Furthermore, when the people with a PV at their rooftops are considered, the benefits for them will be more since they can charge their car battery with solar power and then use this for the home appliances when the electricity is expensive. Due to these advantages, most of the utility companies started to make some research about V2G application. For instance, Enel has a pilot project with Italian Institute of Technology (IIT) and Nissan.

These two technologies, smart charging and V2G, are very promising and the benefits of these technologies are unquestionable. However, both of them have the same problem when it comes to use it. The customers need to accept the use of these technologies because they will sacrifice their freedom of mobility for some certain level. For instance, they are not able to charge their EV whenever they want. Or let's say they are using the V2G technology and feeding electricity to the grid, they cannot unplug their car at that moment if they want to stop charging. In order to incentivize the customers, some features via the smartphone application can be used. Iberdrola has been providing the smart charging option to their customers who have EVs. With the help of this feature, the customers can arrange the starting and the ending time of charging by themselves. In my opinion, this feature can be enhanced and could be put into the same smartphone application, which is used for car-sharing, as an option to the customers who own EVs. The customers can be incentivized by providing them cheap electricity for charging their EVs through smart charging. Furthermore, Iberdrola can use the smart charging technology with their EV fleet used for car-sharing. With the proper optimization and the data collected from the rentals, some of the vehicles' charging patterns can be shifted to another times when there is more renewable electricity or less demand to electricity. Likewise the smart charging, V2G can be also added into the same application that the customers are using for car-sharing. EV owners might have some doubts about V2G application in the beginning since they need to sacrifice their freedom. However, it can be overcome easily. For instance, there can be two different options for the EV owners in the app; flexible option and higher benefit option. With the flexible option in the app, customers can unplug their vehicle whenever they want by informing Iberdrola some time before; for instance, 15 mins or 30 mins before. With the higher benefit option, EV owners who have pretty the same schedule every day (i.e. from home to work and from work to home) can give permission to Iberdrola to access their charging data. According to their typical charging patterns every day, Iberdrola use this data in order to arrange the bidirectional charging. In order to incentivize the customers, they can be rewarded through the app. Iberdrola will save money at the high-peak times due to the less operation cost from the additional power plants. Some of this money could be paid back to the EV owners as a service cost for using their car battery. For instance, the EV owners could get some discounts for their electricity bills, they could have the chance to donate that amount to some other renewable energy projects or social projects, or they could be awarded with free kilometers. Free kilometers means the EV owners using the V2G technology could be awarded with free charging, and this free electricity which is going to be used for charging could be shown as free kilometer in the app. While deciding these free kilometers, Iberdrola could consider the amount of electricity which was taken from the vehicle with V2G plus the service cost. In my opinion, rewarding the EV owners with free kilometer concept would be very effective since the reward would be more tangible to the customers when it is compared with 'kWhs' and it would be more attractive than the money. Customers would be awarded according to the options they chose; flexible option and higher-benefit option. The ones who chose the flexible option could be awarded less than the ones who chose the higher-benefit option.

With the V2G, people who own EVs should be targeted first since the impact of V2G can be achieved with high number of EVs. Apart from the EV owners, using electric car-sharing fleet in the V2G application is going to be important. Due to the data collected by the car rentals, at certain times of the day when the electricity demand is high, these EVs can support the grid. The optimization of renting the EVs or using them as a grid source can be done instantly according to the needs of the grid. However, the car-sharing customers shouldn't be left in unpleasant situations (i.e. no available vehicles for the car-sharing customers when most of the vehicles are used for V2G) in order to keep the trust between the service and the customers at a good level.

5.2.3 Repurposing the used EV Batteries

The battery life of the EVs is around 500,000 miles; or from the time perspective 5 to 7 years. After reaching either 500,000 miles or year limit, the batteries need to be replaced with the newer ones. An EV battery still keeps 80% of its capacity after replacement; therefore, it shows great potential to be used for storage purposes. According to the study done in German Renewable Energy Federation (BEE) in Berlin revealed that old EV batteries can be either recycled or reused by households or utilities [126]. A report by Bloomberg New Energy Finance on second-life use of EV batteries projects that there will be 29 GWh used batteries coming from the EVs by 2025. New storage systems could cost around $1,000/kWh;

whereas, repurposing the used EV batteries as storage is expected to cost much cheaper by 2018. Vattenfall is one of the utility companies who is interested in the second-hand use of EV batteries [127]. In Germany, they involve in a project with BMW and Bosch in order to construct a stationary energy storage facility. The storage facility can store 2,800 kWh of energy and it can supply 2 MW of power back to grid [79]. In addition to Vattenfall, some car manufacturers are also trying to involve in this field such as Tesla, Mercedes, and Renault. After replacing the EV batteries, the batteries are repurposed and sold to the customers as stationary household storage device by these car manufacturers. According to the estimation made by Renault, these second-hand EV batteries can be used for 10 more years as home storage [128]. In my opinion, it would be beneficial for Iberdrola to repurpose these second-hand batteries. The batteries either could be sold to the customers in order to be used as home storage or could be used to be built a stationary storage facility for Iberdrola. In either case, Iberdrola could have benefit out of this. Due to the smart home service which is provided by Iberdrola, repurposing these EV batteries and provide them to the customers would be easy. Furthermore, it would be a good option for the partner car manufacturer company and for Iberdrola. Since car-sharing will increase the mileage of the EVs that Iberdrola has, the replacement time of these car batteries will be faster than the private EVs. Therefore, batteries from these EVs could be used more efficiently by repurposing.

Chapter 6

Conclusions

Paris Agreement which was signed between 197 United Nations Framework Convention on Climate Change parties, has set a goal of keeping the global average temperature increase of the world below 2 degree Celsius as compared to the pre-industrial levels. CO_2 is one of the most abundant greenhouse gas (GHG) in the atmosphere and CO_2 due to anthropogenic activities are the main contributor to the global warming and greenhouse effect. Transportation sector impacts the GHG emissions substantially by emitting 23% of these gases to the atmosphere globally. Mobility is one of the crucial factors for the economic growth for the countries; therefore, the change in the transport sector should be done carefully. Electric vehicles (EVs) are one of the most promising solution to this change. With the electrification of the road transport, which causes approximately 73% of the GHG emissions, the GHG emissions could be decreased tremendously. Moreover, road transport also causes air and noise pollution especially in the crowded metropolitan areas. Using EVs in these crowded areas will help to decrease the air pollution problems as well as the congestion problems in the cities.

One of the most important advantage of EVs is that the tank-to-wheel emissions of the EVs are zero. Furthermore, the harmful emissions from internal combustion engine (ICE) vehicles such as CO_2, SOx, NOx, and PM (Particulate matter) are avoided by using EVs as a main source of transportation. Second advantage is that the dependency to petroleum can be decreased. With stopping the use of petroleum in road transportation, the energy security of the country will be increased tremendously because 90% of the fuel used in transportation is either gasoline or diesel and it is mostly imported. Another positive impact of EV usage is the energy cost saving. Since the EVs have much higher efficiency than the conventional vehicles, more energy can be saved. Furthermore, due to the low price of electricity when it is compared to oil, more money can be saved. Apart from the energy cost saving, the EV owners could also save money from the maintenance of their vehicles. Since EVs have 20 moving parts, the maintenance cost would not be high as ICE vehicles which have around 2,000 moving parts. It is expected that the most of the cost for maintenance would most likely to occur due to the change of tires.

Tank-to-wheel emissions of EVs are zero; however, when the overall carbon footprint of the EVs are considered, the source of electricity used for charging matters. If the EVs are charged with the electricity which is generated from coal, the overall carbon footprint of the EVs will be much higher than the overall carbon footprint of gasoline vehicles. Therefore, renewable electricity should be used for charging the EVs in order to obtain the positive impact of EVs. Two technologies, vehicle to grid, and the smart charging, would help the penetration of renewable energy into the grid. With smart charging technology, the charging times of the EVs can be shifted some other times in order to balance the grid and shave the peaks as well as to use the renewable electricity surplus (if there is any) for EV charging. With using the V2G technology, this renewable electricity stored in the EV batteries can be used to achieve a more stable grid. Because there will not need to use the additional power plants to meet the changing electricity demand throughout the day. Furthermore, the EV owners can plug their cars when they arrive home after work and can use the renewable electricity in their EV batteries for couple of hours. This would help not only decrease the electricity demand at evening peak time but also help EV owners to be more sustainable as well as help them to save more money by not using the electricity when the price is high. Likewise, this will help Iberdrola to decrease its operation cost and increase their revenues at those peak times.

Way of mobility has changed at the beginning of 1900s, from using horses to using ICE vehicles; and in the future, a change will most likely to happen from ICE vehicles to EVs. International Energy Agency expects that there will be between 9 million and 20 million electric cars on the roads by 2020, and between 40 million and 70 million electric cars by 2025. Since it is needed electricity to charge the EV batteries, there will be an increase in the electricity demand in the future. Power generation sector and the transport sector will need to work together in order to stabilize the electricity demand. In other words, the boundaries between these two fields will disappear with the increase penetration of EVs. Furthermore, with the combination of electrification of road transport, shared mobility (car-sharing), and self-driving vehicles, the understanding of mobility will change. The combination of these three main pillars will disrupt the mobility concept that we have been using for more than a century. It will bring a new concept which is called 'Mobility as a service' or 'Transport as a Service'. According to this new mobility understanding, the number of car owners will decrease since the cost of using the service will become much cheaper than the cost of car ownership. People want the freedom of mobility; the freedom that gives them the flexibility to go anywhere at any time with a comfort. This was owning a car in the past century. When the mobility as a service will become cheaper than the cost of ownership of a vehicle, people most likely to choose these services because they could save more money. As the number of cars on the roads decreases, the congestion and air pollution problems of the cities will be solved.

After the detailed research done on the electric mobility, Iberdrola could put more emphasize on the electric mobility field for the future. In my opinion, a service of electric car-sharing to its customers as well as EV charging service, would help Iberdrola to be more active in this field to reach the company goals; decrease the GHG emissions and have a sustainable mobility. Furthermore, Iberdrola can use the advantage of disappearing the boundaries between mobility sector and the power generation sector by providing the electric car-sharing service. Iberdrola could use the renewable electricity in the batteries of their EV fleet when it is needed to stabilize the grid due to the smart charging and V2G. The optimization between renting the EVs or using the electricity in the EV batteries for grid can be done by considering the renting patterns of the customers.

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Appendix A

Complementary Figures

A.1 Benchmark about Competitors of Iberdrola

	Strategies on E-Mobility	Dedicated Company (Subsidiary) or Business Unit	Projects	Partnerships
EDF	The importance of E-mobility is very high in their agenda. They aim to spread the usage of electric vehicles globally. Therefore, they involve the installation of EV chargers.	Sodetrel (Subsidiary company)	CORRI-DOOR	Renault, Nissan, Volkswagen, BMW, Toyota
		Electric Mobility Division (Business Unit)	A Project between Paris Transit Authority and EDF	
		EDF ENR Solaire (Subsidiary company)		Cite Lib
	EDF knows the importance of energy storage to increase the renewable energy penetration. Thus, they give importance on energy storage.	Sowee (Subsidiary company)	A pilot project between City of Grenoble, Grenoble-Alpes Metropole, EDF, Sodetrel, Toyota and Cite Lib to improve transportation in Grenoble.	Grenogle-Alpes
				Paris Transit Authority
				City of Grenoble
				Forsee Power
E.ON	They aim to have the leading role in the charging infrastructure market in Europe.	E-mobility Unit (Business Unit)	E.ON and the car manufacturer companies have announced their partnership to build fast charging infrastructure network. 400 charging point locations were already decided. The aim is to implement as much stations as possible until 2020.	Daimler
				BMW
	E.On aims customer solutions for EVs.			Volkswagen
	E.On aims to be active in e-bike market with the help of the partnership with Derby Cycle.			Ford
			E.On and CLEVER has announced their partnership. They will install and operate EV infrastructure in Northern Europe. They aim to install several hundreds of fast charging stations in the main roads with 120-180 km distances.	CLEVER
				Derby Cycle
ENEL	ENEL aims to be one of the key players in Europe on electric mobility and the energy storage		EVA+ (Electric Vehicles Arteries); by the end of 2019, 180 fast charging stations are planned to be installed.	ALD Automotive
				Nissan, Renault, BMW, Volkswagen
			Project on V2G in Denmark	
			Project on V2G in UK	BYD
			Project in collaboration with Nissan and IIT in Genoa about V2G	Italian Institute of Technology (IIT)

Figure A.1: Benchmark about Competitors of Iberdrola

Engie	Engie aims to improve air quality, to reduce noise pollution and congestion in the cities and optimize the transit network.	Better Mobility TODAY (Initiative)	Engie and EV Box aims to install 4,000 new EV chargers in Netherlands.	EV Box
		TODAY (Initiative)		Powerdale
		Engie Cofely Luxemborg (Subsidiary)	Due to partnership between Powerdale and Engie Cofely Luxembourg, it is decided to install 800 public charging stations in Luxembourg.	Gogogro's Electric Smartscooter
		Electrabel (Subsidiary)		
		Engie Lab		
Vattenfall	Vattenfall gives hgh priority to zero emission mobility. Installation of charging infrastructure is very important in order to spread EV usage.	Nuon (Subsidiary)	Installation and operation of 2,500 charging points in south of Netherlands	Heijman
				Volvo
			InCharge	
			Replacement of their car fleet with Evs	
			Northvolt and Vattenfall are planning to build Europe's largest lihium-ion battery production factory.	
			Replacing 3,500 cars in their fleet with EV.	
EDP	They aim to spread the usage of EVs. Thus, they involve in installation of charging infrastructure.		Mobi.E	Daimler
				BMW
	They involve in project called Mobi.E in order to increase the number of EV chargers.			Nissan
				Renault
RWE/Innogy	Innogy is the subsidiary of RWE and is responsible from the renewables, retail and network business. Therefore, all the previous activities of RWE on e-mobility are done by Innogy after this separation.	eMobility (Business Unit)	HUBJECT	Aldi
		Innovation hub (Business Unit)	In 2015, Aldi and RWE established some public charging stations in the car park of the store in Düsseldorf.	Renault, Nissan, BMW, Daimler, Volkswagen
				Bosch
	Innogy sees electric mobility as an incredible important market.			EnBW
				Siemens
	Innogy aims to be the leading solution provider for charging in Europe and U.S.			

Figure A.2: Benchmark about Competitors of Iberdrola cont'd

	R&D Projects	M&A Activities in E-mobility Field	Products & Services	# of Charging Points
EDF	Testing different power trains, batteries and charging systems for electric buses		Rental and battery fleet management (buses and trucks)	4,000 (France)
	Development of new energy storage options and batteries for heavy electric vehicles		Design, installation, maintenance and supervision of charging infrastructure	
	Perform different research around existing and future lithium battery performance		Fleet management	
			Ombriwatt	
E.ON			EasyPark (In Denmark)	2,500 (Denmark)
			E.ON Drive Card (In Germany)	
			Installation, maintenance and operations of the charging infrastructure.	
			Power Wall	
			E.ON helps to its partners or customers to select the suitable charging points, operate the charging columns, provide suitable payment systems and manage the overall business.	
ENEL	An extensive research and experimentation on V2G applications		E-Go Ricarica	2,650 (In Italy)
			E-Go Noleggio a Lungo Termine	
			E-Go Car Sharing	
			E-Go All Inclusive	
			E-Go application	

Figure A.3: Benchmark about Competitors of Iberdrola cont'd

Engie	Research about smart charging and its applications	EV Box	Improving existing infrastructure	5,000 (Europe)
		Gogogro's Electric Smartscooter	Smart Charging	
			CarPlug	
			Car Sharing; professional car sharing service to the municipalities and the companies which want to establish a car sharing service to its employees	
			Design, installation and maintenance of the EV chargers	
Vattenfall	Smart grids, e-mobility and decentralized solutions	Northvolt	Installation, maintenance and operation of EV charging stations	1,000 (Germany and Netherlands)
	Energy storage		Smart charging boxes	
	Using car batteries (after their lifetime) as energy storage			
	Trying to develop a first diesel hybrid car with Volvo			
EDP			Installation and maintenance of the charging stations	
			Some special tariffs for the customers in order for them to charge their Evs	
RWE/Innogy	There is extensive research on the integration of electric vehicles into the energy system in order improve the usage of renewables in the grid.		Residential wall box	5,300
			Smart charging infrastructure	
			Installation and maintenance of the charging stations	
			IT services	
			eCarSharing through an online platform, fleet consists of only BEVs	

Figure A.4: Benchmark about Competitors of Iberdrola cont'd

A.2 Car-sharing Business Models

Key Partnerships

- Europcar
- Local governments
- Company customers (refueling agreement)
- Insurance companies
- Fuel distribution companies

Key Activities

- Car rentals
- Vehicles maintenance
- Fleet management
- Customer service
- Marketing

Key Resources

- Vehicle fleet
- Service team
- Integrated system, website and application
- Designated parking spots (where applicable)

Value Proposition

- Free-floating car sharing service with a large scale fleet
- Innovative and environmental friendly transportation service
- Flexibility and mobility
- Convenience, usability and accessibility of vehicles
- Smart ForTwo (gasoline and electric powered) vehicle fleet

Customer Relationships

- Automated services through the website and application interfaces
- No permanent engagements

Channels

- Website
- Smartphone application
- Customer service call center
- On site marketing campaigns and information points

Customer Segments

- Private users
  - Frequent clients
  - Occasional clients
  - Students
- Corporate clients

Cost Structure

- Vehicle fleet acquisition
- Maintenance
- Fueling and cleaning vehicles
- Personnel costs and customer services
- Insurance contracts
- Other expenses related to improper use of the service
- Municipality taxes

Revenues

- Fixed subscription fees (only upon registration of new users)
- Rental fees (per minute, hour or daily rate)
- Extra fees per kilometre (above the included mileage per trip)

Figure A.5: Business Model Canvas of car2go [35]

Key Partnerships

- ENI
- Trenitalia (Italian train operator)
- FCA (vehicle supplier)
- CartaSi (credit card company)
- Other commercial companies and suppliers
- Local municipalities
- Insurance companies

Key Activities

- Car rentals
- Vehicles maintenance
- Fleet management
- Customer service
- Marketing and establishing new partnerships

Key Resources

- Vehicle fleet
- Service team
- Integrated system, website and application

Value Proposition

- Free floating car sharing rentals
- Fiat 500 fleet (design appeal, iconic car, four sits)
- Flexible, environmental friendly and economical mobility service
- Integration with train services

Customer Relationships

- Automated services through the website and application interfaces

Channels

- Website
- Smartphone Application
- Customer service call center
- Co-marketing with Trenitalia

Customer Segments

- Private users
  - Occasional users
  - Frequent users
- Corporate clients
  - Trenitalia loyalty program clients, including corporations

Cost Structure

- Vehicle fleet acquisition
- Maintenance, fueling and cleaning vehicles
- Personnel costs and customer services
- Insurance contracts
- Municipality taxes
- Other expenses related to improper use of the service

Revenues

- All-inclusive rental fees (per minute, hour or daily rate)
- Extra fees per kilometre (above the included mileage per trip)
- Cross-selling (Trenitalia partnership)

Figure A.6: Business Model Canvas of Enjoy [35]

Key Partnerships

- Municipality
- Car Sharing Initiative (ICS) and Italian Ministry of Environment
- Car manufacturers (FCA), fuel distributors, insurance companies
- Retail companies, universities and other promotion partners

Key Activities

- Car rentals
- Vehicles maintenance
- Fleet management
- Customer service

Key Resources

- Vehicle fleet
- Service team
- Integrated system, website and application
- Exclusive parking areas

Value Proposition

- Mobility alternative, integrated with other public transportation modes
- Economical, accessible and environmental friendly service
- Traditional and one-way car rentals
- Varied fleet of vehicles, for different customer needs

Customer Relationships

- Self-service automated services through the website and application interfaces
- Optional call-center service

Channels

- Website
- Smartphone application
- Customer service call center

Customer Segments

- Private users
- Corporate clients
- Public entities

Cost Structure

- Vehicle fleet acquisition
- Maintenance
- Fueling and cleaning vehicles
- Personnel costs and customer services
- Insurance contracts
- Other expenses related to improper use of the service

The company is partially financed by the Italian Ministry of the Environment

Revenues

- Annual subscription fees (or optionally an activation fee per use)
- Fixed rental fees (hourly or daily, according to the period of the day and type of vehicle chosen)
- Fees per traveled kilometre

Figure A.7: Business Model Canvas of Car City Club (IoGuido) [35]

Key Partnerships

- City of Paris
- Other 40 french municipalities surrounding Paris
- Bollorè Group
- Bluecar
- Pininfarina
- CECOMP
- batScap

Key Activities

- Car rentals
- Vehicles maintenance
- Fleet management
- Customer service

Key Resources

- Bluecar vehicle fleet
- Autolib stations, kiosks and reception center
- Integrated information system, website and application
- Management and service team

Value Proposition

- First large scale public electric car sharing service company
- One way point-to-point rentals
- Efficient and low environmental impact mobility alternative, complementary to public transportation services
- Flexibility, availability and economic efficiency when compared to car ownership

Customer Relationships

- Automated services through the website and application interfaces
- Customer service call center

Channels

- Reception center and Autolib's kiosks
- Website
- Smartphone application
- Customer service call-center

Customer Segments

- Private users
  - Frequent users
  - Occasional users
  - Tourists
  - Young drivers
  - Households
- Corporate clients
  - Small
  - Medium
  - Large
- Owners of electric vehicles (charging services)

Cost Structure

- Vehicle fleet acquisition
- Instalation of Autolib stations, kiosks and reception center
- Maintenance, cleaning and recharging
- Development and maintenance of website, app and information system
- Personnel costs and customer services
- Insurance contracts
- Other expenses related to improper use of the service

Revenues

- Private user plans
  - Subscription fees
  - Rental fees (per minute)
- Corporate clients
  - Service packages
  - Additional fees per minute and per extra driver subscription
- Charging service plans for electric vehicle owners
  - Subscription fees
  - Usage fees

Figure A.8: Business Model Canvas of Autolib [35]

Key Partnerships

- Siemens
- Renault (electric vehicle supplier)
- TomTom Telematics
- ALD automotive
- Local partners (installation of Bee-Points)
- Insurance companies

Key Activities

- Car rentals
- Vehicles maintenance
- Fleet management
- Customer service
- Gathering customer feedback

Key Resources

- Electric vehicles fleet
- Bee-Points (private parking spots with recharging plugs)
- Service team
- Integrated system, website and application

Value Proposition

- First exclusively electric car sharing service company in Italy.
- Free float service for rental of exclusively electric cars (Renault Twizy models)
- Efficient and low environmental impact mobility alternative
- Flexibility, availability and economic efficiency when compared to car ownership or other car rental services
- Competitive pricing

Customer Relationships

- Automated services through the website and application interfaces

Channels

- Website
- Smartphone application
- Customer service call-center

Customer Segments

- Private users
  - Locals
  - Tourists
- Corporate clients

Cost Structure

- Vehicle fleet acquisition
- Installation of Bee-Points
- Maintenance, cleaning and recharging
- Development and maintenance of website, app and information system
- Personnel costs and customer services
- Insurance contracts
- Other expenses related to improper use of the service
- Municipality taxes

Revenues

- Annual subscription fees
- Rental fees (per minute or daily, no mileage limit)

Figure A.9: Business Model Canvas of Bee-Green Mobility Sharing [35]