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GROWTH STRATEGY FOR EV's CHARGING NETWORK

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1. INTRODUCTION

1.1 THE TERM "EV's"

Electric cars are a variety of electric vehicle (EV). The term "electric vehicle" broadly includes any road-, rail-, sea-, or air-based vehicle that is at least partially powered by electricity. Recent advancements in battery technology have led to an expansion of the road-based electric vehicle market in the form of public transit such as buses and personal or shared vehicles(*Technological Learning in the Transition to a Low-Carbon Energy System - 1st Edition,* 2019). On that note, electric vehicles are gaining popularity and becoming more affordable. According to the drive train configuration, electric vehicles can be classified as Battery Electric Vehicle (BEV), Hybrid Electric Vehicle (HEV), Plug-in Hybrid Electric Vehicle (PHEV) and Fuel Cell Electric Vehicle (FCEV).These terminologies have become widely accepted and according to this norm and a short analysis of the working principles for each drive train class, are mentioned below:

- **Battery Electric Vehicle (BEV)**: Battery electric vehicles (BEVs) are fully powered by electricity. They make use of an electric propulsion system and rely on energy delivered by a battery pack. The battery Electric vehicle is charged externally at charging stations and by recovered braking energy (regenerative braking). The type of battery chemistry and design varies across different BEV models, but lithium-based batteries are currently dominating. BEVs have several advantages over the currently dominating fossil fuel combustion engines. Besides having no tailpipe emissions and no direct reliance on fossil fuels, BEVs have higher vehicle efficiencies and better acceleration(*Technological Learning in the Transition to a Low-Carbon Energy System - 1st Edition*, 2019).
- **Hybrid Electric Vehicle (HEV) and Plug-in Hybrid Electric Vehicle (PHEV)**: PHEVs use both engine and motor powertrains like in a HEV. The difference is that PHEVs use electric motor as the main drive, and hence, they require a larger battery than the standard HEVs. PHEVs start in electric mode, runs on battery and when the batteries are low in energy, the engine starts to charge the battery and thereby extends the electric range. PHEVs can also recharge their battery from an external source. Carbon footprint of PHEVs is less than the HEVs (Vidyanandan, 2018).
- **Fuel Cell Vehicle (FCV)**: This type of EVs has the potential to significantly reduce dependence on fossil fuels and lower harmful emissions that burden climate change. FCVs run on hydrogen gas rather than gasoline and emit no harmful tailpipe emissions. The Fuel cell has the following constituents. The Power control unit governs the flow of electricity. The electric motor propels the vehicle more quietly, smoothly, and efficiently than an internal combustion engine and requires less maintenance. The Fuel Cell Stack converts hydrogen gas and oxygen into electricity to power the electric motor. The High-Output Battery stores energy generated from regenerative braking and provides supplemental power to the electric motor. The Hydrogen Storage Tank stores hydrogen gas compressed at extremely high pressure to increase driving range. FCVs look like conventional vehicles, but use cutting edge technologies. The heart of the FCV is the Fuel Cell Stack. The stack converts hydrogen gas stored onboard with oxygen from the air into electricity, which powers the vehicle's electric motor (Muniamuthu et al., 2018).

Basic arrangement of few EV configurations is shown in the following figure.

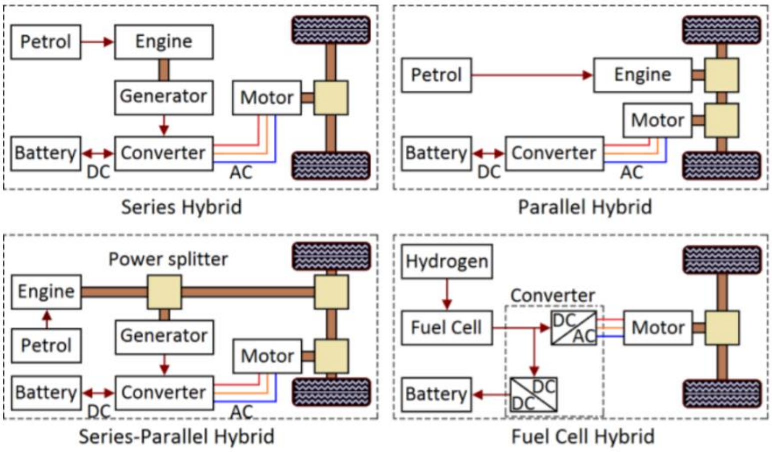

Figure 1. Architecture of various EV configurations (Ehsani et al., n.d.)

1.2 THE PRINCIPLE OF OPERATION OF THE EV

Based on the components used in EV, the internal energy transfer mechanism can be described by three critical units: energy conversion system, electric power converter, and energy storage. The energy conversion system includes the electric machine, which operates as a generator or a motor, depending on the energy flow. The energy storage is a significant part of storing the excess energy (regenerative braking and recharged electricity) and maintaining the system when confronting a greater energy demand. Also, various converters channel the bridge between each component from the energy source to storage or the opposite(Lie et al., 2017). In general, the electric vehicle drive system includes:

- High-voltage battery with control unit for battery regulation and charger
- Electric motor/generator with electronic control and cooling system
- Transmission including the differential

The various components are presented in detail in the following figure.

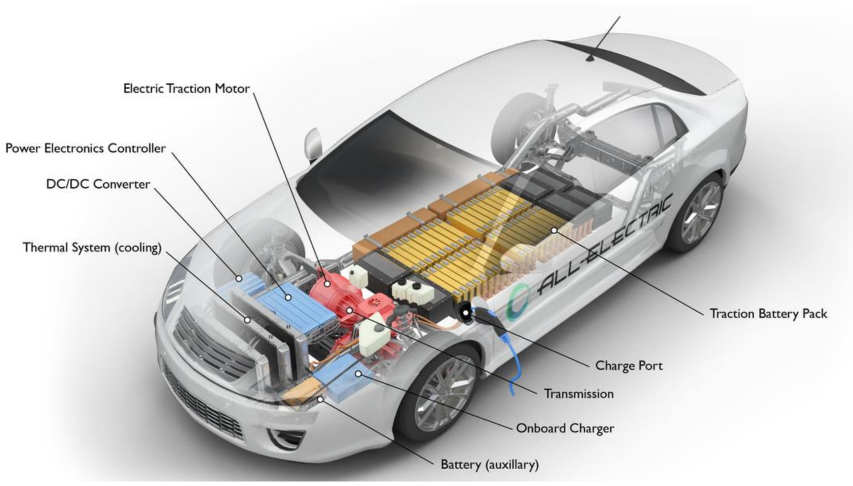

Figure 2. Typical components of BEV drive train

1.2.1 Electric motors

Electric motors are critical components of the drivetrains of electric vehicles. Over the past few years the majority of traction drive systems have converged toward containing some form of a permanent magnet machine. There is increasing tendency toward the improvement of power density and efficiency of traction machines, thereby giving rise to innovative designs and improvements of basic machine topologies and the emergence of new classes of machines. The basic types of machines used in electric vehicles (EVs) are (Agamloh et al., 2020):

- **Direct current (DC) machines**: DC machines are the first type of machines used in electric vehiclesdue to the simplicity of the speed and torque control. However due to the need of frequent maintenance (replacement of brushes on the commutator), their implantation is nowadays restricted in small electric vehicles (prototypes) and bikes.

- **Induction machines (IM)**: Squirrel cage induction machines have a rich history as the most widely used machines in industry. With their simplicity, low cost and ruggedness, they are a good candidate for most applications including traction. The main advantages of these machines include construction simplicity, low cost and ruggedness high peak torque, good dynamic response, and very low maintenance requirement in all aspects of operation.

- **Permanent magnet synchronous machines (PMSM)**: The majority of the machines currently used in vehicles are permanent magnet machines. The increasing requirements of high efficiency, high specific power, and highpower density caused a shift toward permanent magnet machines, such as the departure from the traditional induction machines previously used in the Tesla Model S toward permanent magnet-based technologies in the Tesla Model 3. PMSM's efficiency can reach up to 99%, due to the lack of windings on the rotor, which are replaced by permanent magnets producing a constant excitation field.

- **Switched reluctance machines (SRM)**: SRMs, which developed in 1838, are now increasingly being considered for automotive applications while efforts are on-going to improve their performance. For EVs low torque ripple is important, particularly in EV configurations where the electric motor is the main propulsion device. During the last several years, there has been significant research toward low torque ripple designs, increased performance and power density. For further improvement, the insertion of magnets into the stator poles was also implemented, giving rise to a new class of machines that are being actively researched.

1.2.2 Power electronics

The power electronics refers to converters and inverters (DC/AC converter, AC/DC inverter, AC/AC, and DC/DC converters) implemented in different scenarios. For an EV, the characteristics of the power electronic system are crucial for achieving high efficiency and energy savings, which include various features depending on selections of power semiconductor devices, converters/inverters, controlling strategies, packing methods of individual units, and the integration of the whole system (Deng et al., 2020). Some studies have introduced a multilevel converter coupled with the cascaded cell for higher propulsion demand to integrate the supercapacitor to improve the efficiency and the energy capacity (Lu et al., 2007).

The power electronics system is depicted in the following figure.

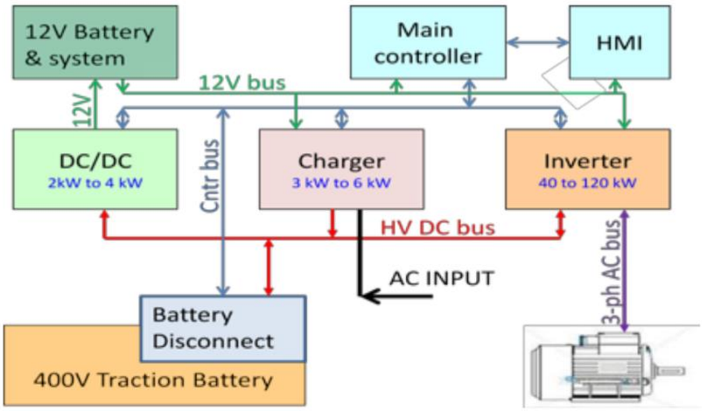

Figure 3. Power electronics system(Emadi et al., 2008)

The sizes in kilowatts and voltages are examplesthat fits small to medium personal EV or HEV. The 400V battery is the energy storage of the entire system; it may be charged by the on-board charger (AC/DC) using a regular outlet or larger fast charger, external to the vehicle. Battery disconnect is a safety device collocated with the battery. It connects or disconnects both, the positive as well as the negative pole of the battery from the rest of the system. Power electronics and converters in PHEVs can be found as inverters for air conditioner, inverters for starter/generator (for the combustion engine only), inverters for traction motor and DC/DC converter for the battery.

1.2.3 Battery

The battery in an electric vehicle stores electrical energy that the electric motor uses to power the vehicle. Most electric vehicles use lithium -ion batteries. These have certain advantages over most other battery types, including higher energy storage capacity and longer lifespans. However, current battery systems tend to be both heavy and costly. Furthermore, even if batteries are used according to the manufacturer's instructions, they lose capacity over time as a result of ageing and repeated charging cycles. Developing improved battery technologies is a major priority for further research and development (EEA, 2020).

A number of electrochemical batteries capable of powering EVs exist today. The popular chemistries include: Lead-Acid, Ni-Cd, Ni-MH, Li-ion and Li-metal. Energy storage capabilities of these batteries are shown in the following figure.

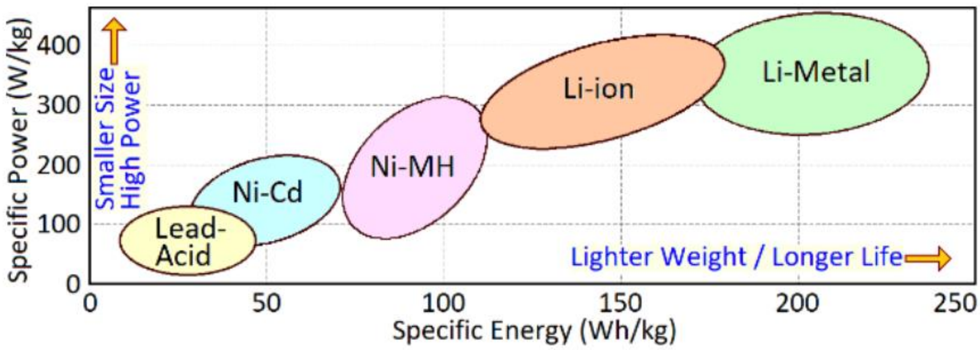

Figure 4. Power and energy capabilities of different batteries (Tarascon & Armand, 2001)

EV batteries are deep cycle (DC) batteries as against shallow cycle (SC) batteries typically used for automobile start, light and ignition (SLI) applications. DC batteries have thicker positive electrode plates but with relatively less surface area available to take part in electrochemical reactions. DC batteries cannot release large power very quickly as they are designed to provide relatively steady power over sustained periods of time. DC batteries can be discharged down to 30-20% of SOC (state of charge) for over thousand cycles, whereas shallow cycle batteries are usually discharged up to 70-60% with limited cycle life of less than 500. The average usable capacity of an EV battery over a ten-year life span is in the range of only 50-80%.

Table 1. Battery parameters of some current EVs (Grunditz & Thiringer, 2016)

Model	Total Energy (kWh)	Usable Energy (kWh)	Usable Energy (%)
i3	22	18.8	85
C30	24	22.7	95
B-Class	36	28	78
e6	61.4	57	93
RAV4	41.8	35	84

The desired attributes of a battery from electric mobility perspective are:

- High specific energy for longer drive distances
- High specific power for good acceleration
- High safety features, wide operating temperature range
- Contains low toxic materials
- Capability of fast charging
- Long life and affordable price

Moreover, in terms of energy storage technologies, supercapacitor (SC) or ultracapacitor can be an attractive option to extend the storage capacity of the electric vehicle. Compared with other storage devices, SC provides higher power densities. SC also could exhibit a longer charge/discharge lifecycle (500,000 times), while the lead-acid and lithium-ion batteries have an average lifecycle of 1000 and 2000 times, respectively(Lie et al., 2017).Nevertheless, research indicates that the downside of SCs is the low energy density, although new technologies and materials for SCs, have shown that the SCs potentially achieve over 400 Wh/kg, comparable to the energy densities of Li-ion batteries (Fărcaş et al., 2009).

1.3 EV's IN THE EUROPEAN UNION

BEV models have had a constant presence in the Europe's automotive market providing a wide range of options even during the first years following the recent technology's market introduction. The number of models has been steadily increasing until 2014 when this trend was stabilising up to day reaching almost 4.5% market share in Europe (including PHEVs). PHEV models on the other hand, after a minimal initial market presence in 2010, have been increasing until today surpassing BEV regarding EV M1 models. The BEV and PHEV market shares' evolution between 2010 and 2019, including passenger cars and other vehicles, are presented in the following figure.

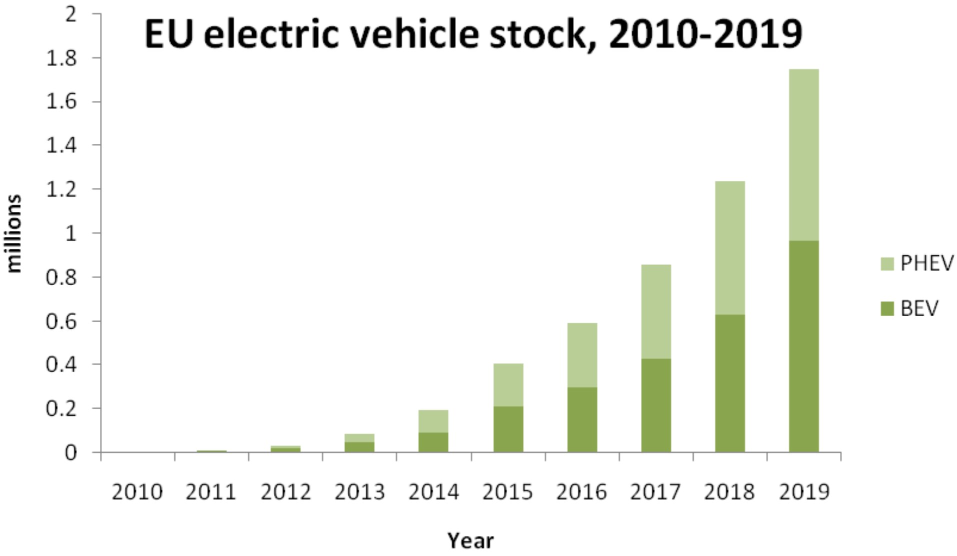

Figure 5. IEA, Global electric car stock, 2010-2019*(IEA, Paris)*

The 0.51 million electric vehicle sales in 2019 represent a 40% growth from the previous year's stock and it doubled since 2016. Some underlying reasons explain this trend are('Global EV Outlook 2020', 2020):

- **Car markets contracted**: Total passenger car sales volumes were depressed in 2019 in many key countries. Against this backdrop of sluggish sales in 2019, the 2.6% market share of electric cars in worldwide car sales constitutes a record. In particular, Europe (at 3.5%) achieved new record in electric vehicle market share in 2019.
- **Consumer expectations of further technology improvements and new models**: Today's consumer profile in the electric car market is evolving from early adopters and technophile purchasers to mass adoption. Significant improvements in technology and a wider variety of electric car models on offer have stimulated consumer purchase decisions. The 2018-19 versions of some common electric car models display a battery energy density that is 20-100% higher than were their counterparts in 2012. Further, battery costs have decreased by more than 85% since 2010. Also, it is important that automakers have announced a diversified menu of electric cars, many of which are expected in 2020 or 2021. For the next five years, automakers have announced plans to release another 200 new electric car models, - in contrast to the number of models until 2017 presented in the following figure-, which ranged from about 60 different models, many of which are in the popular sport utility vehicle market segment.

As it can be observed in the following figure, the following countries present the highest numbers in order of total number of EV registrations forming the European top-10: Norway, the United Kingdom, Germany, the Netherlands, France, Sweden, Belgium, Switzerland, Austria, and Spain. It should be highlighted that the top-5 countries in terms of total EV registrations account for more than 80% of all EV registrations in Europe (Tsakalidis & Thiel, 2018).

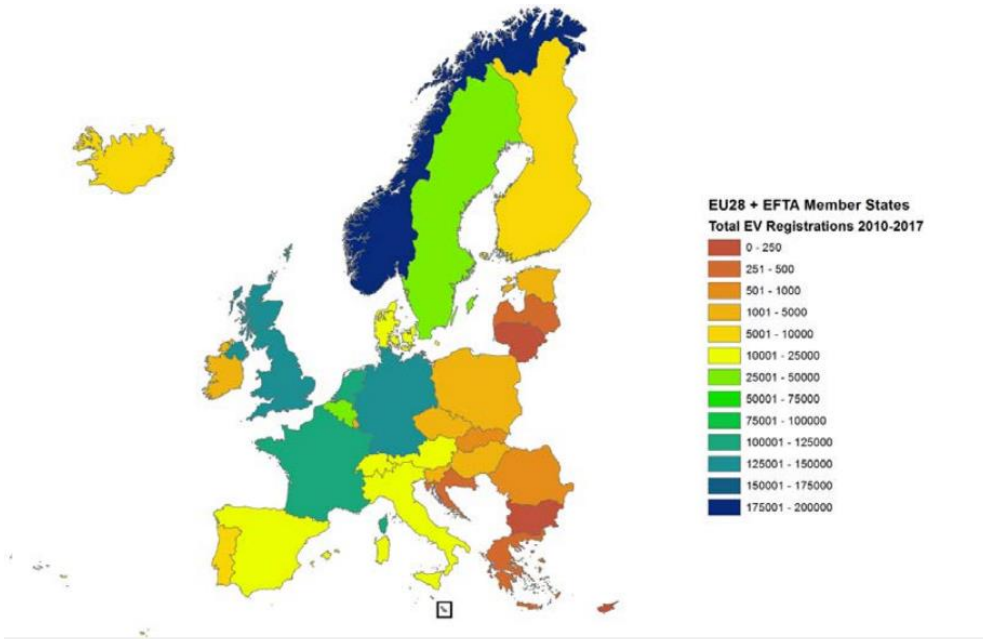

Figure 6. Levels of total EV registrations in Europe per country between 2010 and 2017 (Tsakalidis & Thiel, 2018)

The number of different EV models that were available in Europe from 2010 to 2017 are presented in the following figure.

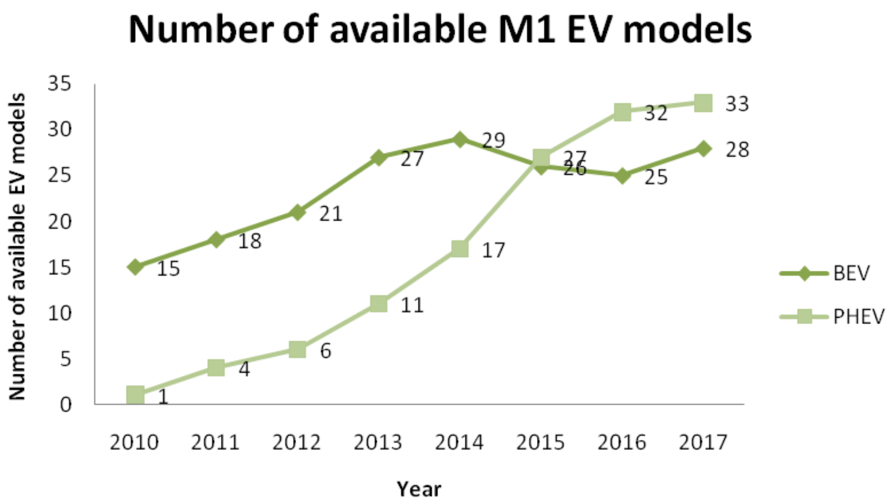

Figure 7. Number of available M1 EV models in Europe (Tsakalidis & Thiel, 2018)

Transport modes other than cars are also electrifying. Electric micromobility options have expanded rapidly since their emergence in 2017, with shared electric scooters (e-scooters), electric-assist bicycles (e-bikes) and electric mopeds now available in over 600 cities across more than 50 countries worldwide. The most important sector of transportation, which was also electrified, is public transport, with the purchase of new buses having increased significantly in 2019, and is projected to increase even more in the next years.

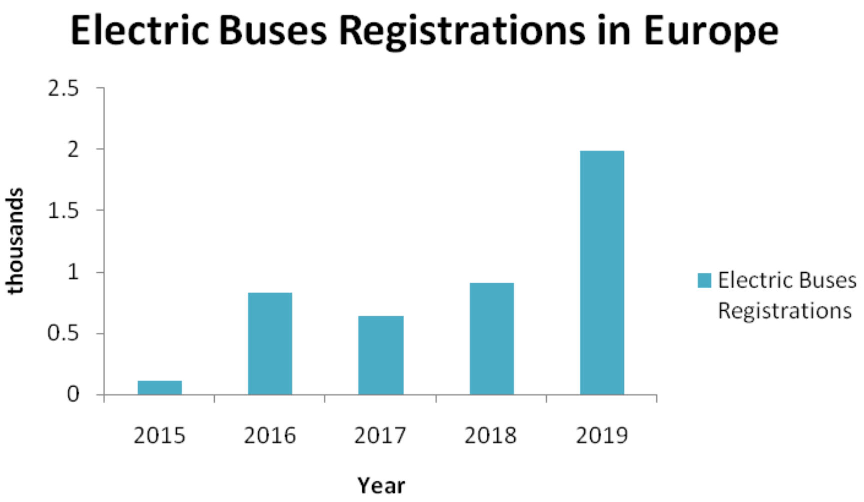

Figure 8. New electric bus registrations in Europe, 2015-2019

Regarding 2020, registrations of electric cars in Europe jumped 57.4% in the first quarter of 2020, but still only accounted for 4.3% of total registrations, according to the latest study of European Automobile Manufacturers' Association (ACEA) (https://www.acea.be). Electric car sales in the EU, UK and EFTA countries reached 130,297 in January-March. More specifically, Germany extended its lead over Norway in terms of new electric car registrations, with a 63.3% rise, while sales in France increased by 145.6% and Norway's declined 12.4%.Overall, automotive manufacturers are moving towards the development of more EV models (BEV and PHEV) in order to meet the demands of EU 2018 laws, on cutting carbon dioxide (CO_2) emissions by 40% between 2007 and 2021, and then by a further of 37.5% by 2030.

1.4 ADVANTAGES – DISADVANTAGES

As mentioned above, electric vehicles are steadily gaining popularity due to the major technological strides, although there are some serious concerns regarding their drawbacks. The main advantages and disadvantages of electric vehicles can be divided into four major categories: economic, technology, social, environmental aspect.

1.4.1 Advantages

When comparing electric vehicles to conventional ones, the price of fuel is almost eliminated and the currently fastest method of charging electric vehicles (DC fast charging) allows for an almost full charge (up to 80%) in around20 minutes. Electric vehicles come with fewer maintenance requirements (fewer moving parts and no exhaust system) and therefore the maintenance costs are lower as well. Also there is potential for tax credits, due to reducing the environmental footprint. These savings can lead to shorter payback period regarding the purchase cost of the EV.

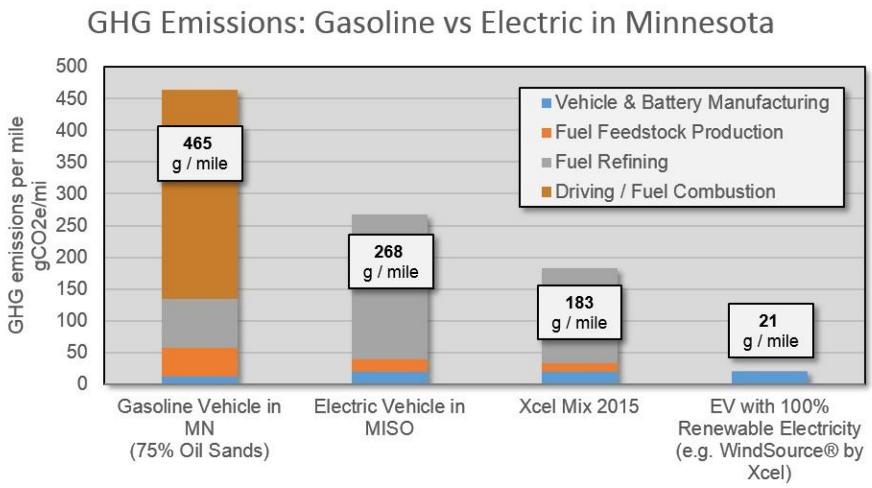

Figure 9. CO2 emissions reduction, depending on the energy mix used for manufacturing and charging of EVs in Minnesota, USA (Argonne National Laboratory; MN House Research Dept.; Xcel Energy; MISO. Figure authored by Great Plains Institute. April, 2016)

From technological aspect, electric vehicles offer superior power-to-weight-ratios compared to traditional cars. Furthermore, electric motors provide constant torque over time, can be rotated in high speed (up to 25,000 RPM) and can reach maximum torque as early as the first revolution; resulting in higher acceleration (i.e. Tesla Roadster 2020 can reach 100 km/h in 1.9 seconds). These characteristics of an electric drive motor mean that a complex transmission is not required.

Also, from social aspect, noise pollution is detrimental to human health, and the ICE vehicles are among its most significant sources, while electric motors which power EVs are almost silent. According to (Parizet et al., 2014), even those EVs that produce artificial sound to notify pedestrians, are way quieter than diesel engines. Moreover, it is extremely rare for a battery-powered car to explode on impact, and because heavy battery packs significantly lower an EV's centre of mass, the car is less likely to rollover(Muniamuthu et al., 2018).

Regarding EVs' environmental benefits,it is well established that EVs have zero (BEVs) or insignificant (PHEVs) exhaust emissions, which results in much less environmental pollution. There is also a trend towards more eco-friendly production and materials for EVs, i.e. Ford Focus Electric is made up of recycled materials and the padding is made out of bio-based materials and Nissan Leaf's interior and bodywork are partly made out of recycled materials. Also, in the case of charging an EV using renewable energy sources (or a green energy mix), there is an even further reduction of greenhouse gas emissions.

1.4.2 Disadvantages

Economic challenges are the major drawback of EVs right now, where high selling price of EVs have obstructed the mass adoption of EVs. Due to low EV adoption rate, high initial investment and low profitability of public charging infrastructure may downturn its economic performance and sustainability of its business model.

Also, from a technological point of view, the manufacturing of energy storage system in EVs is still not economically justified, while thermal instability of Li-ion batteries under extreme environmental conditions is yet to be addressed. Moreover, energy density of current battery technologies is still much lower than fuel, resulting in limited driving range. Also, there is a rapid wear of the battery and replacement is required every 3-10 years, resulting in high costs (comparable to the total vehicle's cost).

Moreover, from social aspect, range anxiety has raised negative perceptions of the society towards EVs, given that EVs have limited range, long charging time and insufficient charging stations which are still in the development stages. Nevertheless, research results on wireless charging have shown that the installation of coils (working as a transformer's primary winding) along busy highways could be a viable solution, powering the installed coil inside the EV (working as a transformer's secondary winding) while driving. Additionally, EVs are very silent at low speeds (below 30 km/h) and can be dangerous for pedestrian, especially vulnerable ones as visually impaired people (Parizet et al., 2014).

Although EVs produce zero tailpipe emission, environmental challenges of EVs include greenhouse gases emitted from power generation to recharge the batteries. Europe's plan is to reduce the CO2 emissions per capita from the current 45 tons per year to 0.7 tons per year by 2050(European Commission, 2018) and this goal can only be achieved if the energy mix used for EV charging has a significant proportion of renewable energy sources. Moreover, it has been shown that manufacturing process and disposal of the batteries after its service life may also cause harmful pollution to the environment (Faizal et al., 2019).

1.5 EV CHARGING TECHNOLOGIES

The field of electric vehicle (EV) charging systems is rapidly evolving with numerous standards, types, connectors, and terms used to describe chargers. The generic term used to describe the piece of equipment used to charge an electric vehicle is 'electric vehicle supply equipment' (EVSE). EVSE can be further categorized into three levels that relate to their output power capabilities. Level 1 and level 2 EVSE both supply alternating current (AC) to an electric vehicle's on-board charger and level 3 systems supply direct current (DC) to the EV. The use of the term 'charger' for levels 1 and 2 is misleading, as they are not technically chargers. They supply AC electricity to the EV where the on-board charger converts the AC to DC, which charges the batteries. EVSE also provides important safety features for both users and charging equipment (Jar et al., 2016).

Figure 10. Connectors and Inlets for EV charging(Chau & Li, 2014)

The battery management system (BMS) is another vital component in an EV charging system. It is responsible for thermal management, cell balancing, over charge and over discharge monitoring of the battery pack. An EV battery pack is not made of a single battery; instead, many individual cells are combined to form a bank. A single cell may only have a small safe working voltage range and it is important to ensure it stays within this range. This is particularly important with variants of lithium ion batteries commonly used in EVs. Over charge and over discharge can result in disastrous consequences including reduced battery life or total battery failure causing fires. It is the job of the BMS to monitor the battery cells to ensure they all stay within normal operating voltages and temperatures. The BMS also balances individual cells by redistributing charge from cells of higher electric potential (voltage) to lower potential cells. BMS's use numerous techniques to manage the battery pack. The BMS is also responsible for the voltage and current requests from the charger. This includes both the on board charger for levels 1 and 2 or the off board charger for level 3 EVSE. Multiple charging profiles (constant current, constant voltage etc.) are available to charge a battery.

Table 2. EV charging levels and capacities

Level	Connector	AC/DC	Max. Voltage (V)	Max. Current (A)	Power (kW)
1	Type 1	1 phase AC	230	16	3.7 to 7.4
2	Type 2	3 phase AC	230/400	32	7.4 to 22
3	CHAdeMO	DC	500V	125	>50

2. ENERGY SYSTEM IMPACTS

2.1 INTRODUCTION

Decarbonisation of power systems has been a topic under discussion during the last decades due to the imminent depletion of oil reserves all over the world. One of the strategies to pursue this objective is framed within the electrification of transportation. Electric vehicles are considered as a promising alternative to reduce the dependence on fossil fuels and counteract the hibernation effect (Arias-londoño & Montoya, 2020). According to a statement published by the European Commission, transportation is the second largest factor in greenhouse gas emission, which produces a quarter of greenhouse gas emissions in the European Union (EU) (Zou et al., 2020). On that note, it is believed that the large penetration of EVs can help reduce the greenhouse gases emission, increase the energy efficiency, enhance the integration of renewable energy, and so forth. Although the large penetration of EVs will inevitably increase the load of grid and that raise concerns about the instability of the grid (which may result in synchronous generators tripping and power outages) and the increase of CO2 emissions from the fossil fuel power plants, which will maximize their production in order to balance the increased load, research results on the impact of EVs in the grid operation seem promising and maybe the advantages of their integration on the power system will outrage the disadvantages or concerns.These advantages originate from the double role of the electrical vehicle's battery, which can be used as power source or load. Through the microprocessor of the power converters of the vehicle, the battery becomes a controllable load that could be optimally controlled at convenient time frames storing and injecting energy.

Nowadays, a significant number of EVs use power grids around the world to charge and sometimes to discharge their batteries.In general, vehicle-to-grid (V2G) describes a system in which plug-in electric vehicles, such as BEVs, PHEVs or FCEV, communicate with the power grid to sell demand response services by either returning electricity to the grid or by throttling their charging rate (Robledo et al., 2018). The model of vehicle connected to grid is presented in the following figure.

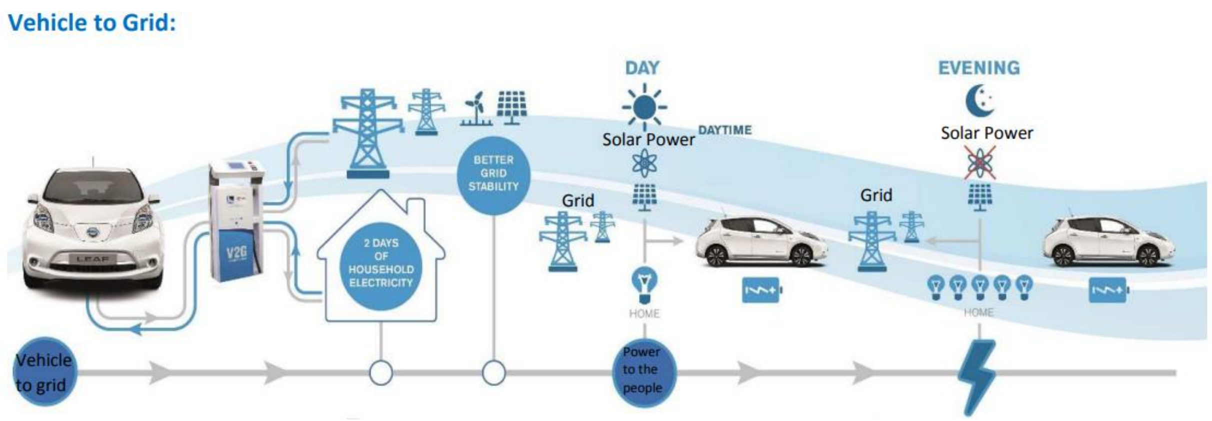

Figure 11. Schematic of EV connection to grid (Zou et al., 2020)

The electric vehicle to grid (V2G) interaction technology can improve the utilization of renewable energy and stabilize its grid connection. At the same time, renewable energy can be used for a microgrid nearby, or incorporated into a large grid, to effectively address the volatility of renewable energy sources. The research conducted in(Shi et al., 2020)have shown that the proposed strategy can increase the absorption ratio of renewable energy while orderly guiding the charging and discharging of EVs in peak-load reduction and valley filling and thus, lower operating costs under various practical constraints.

2.2 IMPACT OF ELECTRIC CARS ON THE DISTRIBUTION AND TRANSMISSION GRID

The impact of EVs as an emerging electrical load for power grid has drawn increasing attention most recently. The possible challenge for power grids lies in that the penetration of large number of EVs may trigger extreme surges in demand at rush hours, and therefore, harm the stability and security of the existing power grids. Also, the risk of overloading local transformers is particularly high during peak hours. Some studies suggest that higher penetration rate of electric vehicles increase transformers' loss-of-life factor, due to overloading (Stoeckl et al., 2011).

Nevertheless, there are some major opportunities with the ever-expanding number of vehicles which will be plugged in the grid. In (Anastasiadis et al., 2019) the impacts of large EV deployment to selected distribution networks are evaluated. The results indicate that the node voltage levels are within the accepted minimum-maximum range in the case of Smart Charging Strategy (controlled charging that follows the load demand curve and EVs are charged at low demand hours). However, Dumb Strategy (EVs begin to charge as soon as they are connected to the charging spot) leads to large voltage deviations that exceed the acceptable limit (±10%) even for a small number of vehicles. In other words, a proper charging strategy can mitigate the voltage problems and allow higher levels of EV penetration in the case of Smart Charging Strategies.Moreover, as distributed energy storage, EVs can also act as a backup power for renewable energy sources. For instance, EVs could store the excess power capacity from large utility scale wind power plants during the night and then release it to the grid during the day where the load is high.

The interconnection of EVs in distribution grid urges the need to further examine several issues such as the impact on the grid, the way that EVs should charge/discharge and the limitations of this process as well as the benefit or not of the Distribution System Operator in such conditions.

2.3 THE IMPACT OF SHIFTABLE LOAD ON THE POWER SYSTEM

As previously mentioned, the V2G project allows vehicles to provide power to help balance loads, by "load leveling" (shifting the load at night when total demand is low) and "peak load shaving" (sending power back to the grid when demand is high).

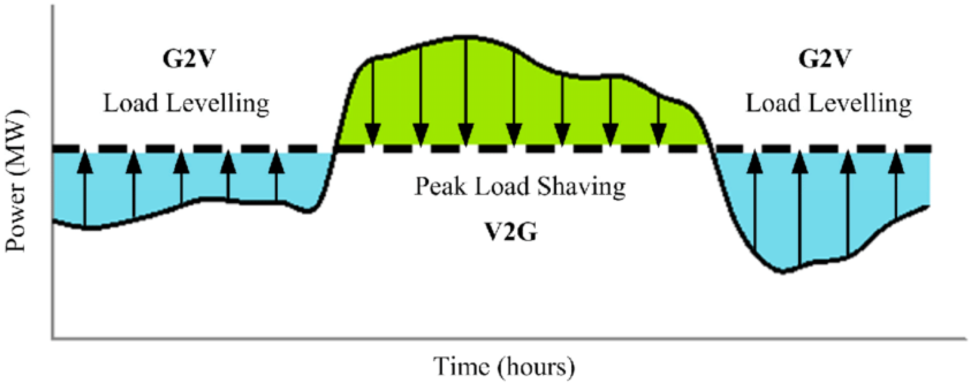

Figure 12. The concept of peak load shaving and load levelling(Tan et al., 2017)

Peak load leveling can enable new ways for utilities to provide regulation services (keeping voltage and frequency stable) and provide spinning reserves (meet sudden demands for power). These services coupled with "smart-meters" would allow V2G vehicles to give power back to the grid and in return, receive monetary benefits based on how much power given back to the grid. In (Pillai & Bak-Jensen, 2010), it has been proposed that such use of electric vehicles could buffer renewable power sources such as wind power, by storing excess energy produced during windy periods and providing it back to the grid during high load periods, thus effectively stabilizing the intermittency of wind power. Some see this application of vehicle-to-grid technology as an approach to help renewable energy become a base load electricity technology.

Also, V2G technology could potentially play a significant role in electricity price arbitrage. More specifically, power system utilities can gain many benefits from the applications of distributed energy resources that include (Shang & Sun, 2016):

- Increase energy efficiency and reduce energy costs
- Avoid or defer investment in the expansion of transmission and distribution system
- Approve system resilience, especially critical loads and vital services

Time-based pricing mechanisms (e.g., time of use, real time pricing or dynamic pricing) have been used by many utilities to shift load demand. Plug-in hybrid electric vehicle, with both battery and gas tank, can serve as a distributed energy storage device of both electric and chemical energy. From owner's perspective, the potential monetary benefits from arbitraging and from providing ancillary services can offset some of the operation costs. An example of this time-based shift of the load is illustrated below. The simulated microgrid consists of wind turbines (renewable energy source)and diesel engines (fossil fuel power plant).

Assuming that electric vehicles are charged during the day with the highest residential load from 18:30 to 21:30, when the residential area has a high load, the scheduled operation becomes insufficient. The access of the electric vehicles will cause the load of the microgrid system to surge, and the output ofdiesel engines will increase, which will also increase the operating cost of the system. However, from 23:00 to 2:00, there is less electricity demand in residential areas, and the output of wind turbines is sufficient, is the best time period to charge the EV batteries, which later during the high load will support the grid, in order to decrease the power input from diesel engines and inject green energy to the grid, which was previously stored in the batteries.

3. EUROPEAN AND NATIONAL POLICY ON E-MOBILITY

3.1 HOW THE EUROPEAN POLICY ENCOURAGES THE GROWTH OF EV's

Leading electric vehicle markets employ a variety of measures at national and local levels to address key barriers to consumer adoption such as financial benefits to bridge the cost gap between electric vehicles and conventional cars, charging infrastructure to increase convenience, and information activities to raise awareness. The following section provides an overview of selected national and local measures being used to foster electric vehicle uptake across the 15 European metropolitan areas selected for analysis.

Many electric vehicle promotion activities are used at national and local levels, and fiscal support measures and charging infrastructure deployment are among the more prominent ones. To bridge the cost gap between electric vehicles and conventional cars, national or local governments often provide consumer incentives in the form of one-time subsidies, tax breaks on vehicle purchase and operation, or preferred or free access to certain road infrastructure. Parking and charging benefits addressing the cost factor are mostly deployed at the local level. The rollout of charging infrastructure—publicly accessible as well as home and workplace charging options—aims at increasing the convenience for electric vehicle owners recharging their vehicles. Local and national promotion actions include financial support programs targeted at specific consumer segments, ranging from homeowners and companies to public bodies(ICCT, 2020).

Beyond fiscal measures and charging infrastructure, many additional information and local action planning activities are also being more broadly deployed. To increase the awareness about electric vehicles, campaigns frequently including tailor-made information are common measures at local or national levels. In addition, the adoption of electrified municipal fleets helps to increase the technology's visibility. Strategic plans and legal regulations regarding electric vehicle sales volume or share—nationally and locally—serve as the underlying framework in driving electrification.

The following table gives an overview of the 20 policy measures selected for this analysis. Some of these measures apply to both national and local levels. Policies that are not applied throughout the whole metropolitan area but implemented in certain municipalities or boroughs are also included. The analysis covers policies for the year 2018 to assess the potential link to electric vehicle sales for the same year. Selected policies introduced in 2019 also are highlighted to indicate policy developments since the 2018 electric vehicle data collected. The effect of Europe-wide measures, such as the regulation of the CO_2 emissions of newly registered vehicles, and of the policy-stimulated development in non-European electric vehicle markets on the availability and cost of electric vehicle models are briefly discussed in the conclusion.

Table 3. Selected promotion actions assessed as part of the analysis (ICCT, 2020)

Electric vehicle purchase and operation	Electric vehicle charging infrastructure	Electric vehicle strategies, procurement, and public awareness
National **1.**BEV purchase benefit PHEV purchase benefit **2.**BEV registration tax benefit **3.**PHEV registration tax benefit **4.**BEV ownership tax benefit **5.**PHEV ownership tax benefit **6.**EV company car benefit for employee	**National** **1.**Public charger promotion **2.**Private and workplace charger promotion	-
Local **1.** EV parking benefit **2.** EV charging benefit	**Local** **1.** Public charger promotion **2.** Private and workplace charger	**Local** **1.** EV goals **2.** Public EV procurement

3. EV infrastructure use and access benefit	promotion **3.** EV curbside charging program **4**. EV ready building codes **5.** EV charging interoperability requirements	**3.** EV information and awareness raising

<u>ELECTRIC VEHICLE PURCHASE AND OPERATION</u>

Promotion actions addressing vehicle purchase and operation are largely focused on breaking down the cost gap between electric and combustion engine vehicles. The analysis considers one-time subsidies and tax benefits on vehicle purchase as well as tax breaks for operating a vehicle in private ownership as well as company-owned cars, usually applied at national the level. Further measures addressing the affordability of electric vehicles included in the analysis focus on parking and charging benefits as well as preferential charges for using road infrastructure or access to restricted urban areas as applied at the local level.

<u>ELECTRIC VEHICLE CHARGING INFRASTRUCTURE</u>

Providing sufficient options for recharging an electric vehicle at convenient locations is a key to drive electrification. Extending the public charger network is mainly aimed at increasing their visibility and the consumer's convenience for recharging an electric vehicle, as well as reducing potential mental barriers. Workplace and home charging play an important role in charging an electric vehicle in the direct living environment. In addition, curbside installations can provide charging in dense inner-city or residential areas where charging options are limited. Building codes can establish electric vehicle infrastructure requirements for new or redeveloped construction projects, preparing for the growing numbers of electric vehicles and improving access for consumers opting for an electric vehicle. Next to the physical charging infrastructure, mandating open access and interoperability in charging infrastructure plays in important role in increasing consumer acceptance and stimulating further uptake of electric vehicles.

3.2 LEGAL FRAMEWORK AND FINANCIAL SUPPORT FOR EV's

3.2.1 EU Guidelines on Electromobility

The electrification of the mobility sector of the EU is defined by a series of guidelines that are adjusted to the national legislation of each member state. According to Directive 2014/94/EU on Deployment of Alternative Fuels Infrastructure, each Member State shall adopt a national policy framework for the development of the market as regards electric vehicles and the deployment of the relevant infrastructure. The national policy framework shall contain the following elements:

- An assessment of the current state and future development of the market as regards alternative fuels in the transport sector, including in light of their possible simultaneous and combined use, and of the development of alternative fuels infrastructure, considering, where relevant, cross-border continuity.
- Ensuring that a number of recharging points accessible to the public are put in place by 31 December 2020 in order to ensure that electric vehicles can circulate at least in urban/suburban agglomerations and other densely populated areas, and, where appropriate, within networks determined by the Member States. The number of such recharging points shall be established taking into consideration, inter alia, the number of electric vehicles estimated to be registered by the end of 2020, as indicated in their national policy frameworks, as well as best practices and recommendations issued by the Commission. Particular needs related to the installation of recharging points accessible to the public at public transport stations shall be taken into account, where appropriate.
- Ensuring and facilitate the deployment of recharging points not accessible to the public.
- The recharging of electric vehicles at recharging points accessible to the public shall, if technically feasible and economically reasonable, make use of intelligent metering systems.

- Measures necessary to ensure that the national targets and the objectives contained in the national policy framework are reached,
- Measures that can promote the deployment of alternative fuels infrastructure in public transport services.
- Designation of the urban/suburban agglomerations, of other densely populated areas and of networks which, subject to market needs, are to be equipped with recharging points accessible to the public.
- Consideration of the need to install electricity supply at airports for use by stationary airplanes.

3.2.2 Greek Legal Framework

The existing legislation - valid at the time of creation of the current report - focused on the charge point technical specifications and defined the operation of charge point operators, the charge point types and specifications, publicly accessible charge point licensing and categorization the charging infrastructure according to its location and accessibility rights. However, it did not define a complete framework for the e-mobility sector.

The latter is achieved by the new legal framework that is currently under consultation (June 2020). In the following paragraphs the legal framework is described, based on the provisions of the new legislation as well as provisions from current legislation.

The newly introduced legal framework sets the basis for the development of the e-mobility sector in Greece. It defines specific targets for the CO2 limits of certain vehicle categories and for the supply of light vehicles on a national level. These targets are part of the National Climate and Energy Plan (NCEP), which aims for 30% penetration of EV sales by 2030. The targets refer to the vehicles of the public sector, including vehicles of regional and local authorities and are mentioned in the following tables. The following tables present the targets set for CO2 emissions and clean light vehicle sales.

Table 4. Targets for CO2 emissions limits of light vehicles as were set in the new legal framework

Vehicle category	*Until 31st of December 2025*		*From 1st of January 2026*	
	CO_2 (g/km)	**Real Driving Emissions (RDE) as a percentage of the emissions limits**	**CO_2 (g/km)**	**Real Driving Emissions (RDE) as a percentage**
M1	50	80%	0	-
M2	50	80%	0	-
N1	50	80%	0	-

Table 5. Minimum target for clean light vehicles set for Greece

	Until the 31st of December 2025	*From 1st of January 2026*
Greece	**25.3%**	**25.3%**

4. STRATEGY MANAGEMENT FOR EV's CHARGING POINTS (EVCP)

4.1 ELECTROMOBILITY BUSINESS ECOSYSTEM

New business models are required for e-mobility solutions because of the differences between electric and conventional Internal Combustion Engine (ICE) driven transport. Most EV are still more expensive to buy than ICE equivalents, and come with perceived operational limitations such as range, the need for education about how and where to recharge, and little experience of residual value. However, they also have some major advantages, being cheaper to operate (in terms of re-fuelling and servicing costs), quieter, with better acceleration and zero tailpipe emissions at the point of use which supports wider air quality and emissions policy as well as CO2 reduction. Some consumers may perceive recharging at home or work when the vehicle is parked anyway, as easier than the existing ICE refuelling methods. Therefore, business models for the holistic e-mobility system are envisaged to promote a wider value proposition, which includes environmental and social considerations in addition to traditional financial concerns.

With this holistic approach comes a range of new stakeholders with differing motivations, opportunities, threats and likely conflicts of interest, which affect their behaviour within the e-mobility system (Bakker et al., 2014). Where their interests differ, their attitudes to financial return also differ. For example, some stakeholders such as grid operators act to mitigate the risk of further costs for grid reinforcement by aiming to control recharging behaviour, whereas electricity providers may seek to seize the commercial opportunity for increasing energy sales. Bakker described e-mobility in terms of an evolving socio-technical system where the conflicts between stakeholders' interests coupled with the stability of the existing ICE market make for an uncertain development path. Therefore, continuing reliable policy support will be necessary in the medium term to enable e-mobility to flourish in order to deliver the environmental benefits required.

The main players in the e-mobility ecosystem can be divided up into natural groups taking the end customers as a starting point. There are for instance suppliers of hardware, providers of vehicles and customer facing CPOs. Below are the main players of the e-mobility ecosystem listed and described in summary.

CPOs

CPOs handle the operation and maintenance of the charging point, focusing on the customer interface and providing a charging service that lives up to customer's requirements.

Location owners

Location owners in public charging infrastructure vary across markets. Traditional fuelling stations are key players, often partnering with CPOs to provide their location for installation of a charging point.

Power suppliers

Power suppliers are among the most active players in the e-mobility eco-system.

Vehicle manufacturers

All major vehicle manufacturers have some stake in the e-mobility ecosystem. Among them Renault, Nissan, Audi, Jaguar and Mercedes have EV models available. Their interest in the market is based on the fundamental need of charging solutions to drive sales of EVs. Many therefore act in the market in the form of partnerships, while Tesla have established their own charging network.

Charging point hardware manufacturers

The manufacturing of the hardware used at private and public charging stations can be done either by a player with a background in other technical hardware solutions, but also from a player with background in EV charging.

Networks & Platforms

To reach interoperability among CPOs, players in networks and platforms, provide software to CPOs to allow for standardized payment solutions and interfaces. Through their business model, network and platform players can cover large geographies with their platform, essentially helping fulfil customer requirements such as charging alternatives for long distance trips.

Others

Other players in the eco-system include construction players who construct the infrastructure surrounding the charging station, grid players and fleet owners. Furthermore, regulators, EV organisations and universities play a role in the overall development of the market through research or issue-based projects.

More detailed information regarding the role of those players in the electromobility business ecosystem will be presented in section 4.2 of this chapter.

4.2 BUSINESS MODELS IN THE E-MOBILITY PUBLIC CHARGING SEGMENT

The last section showed that there are a large number of players with different legacy platforms trying to enter and do business on the e-mobility market. The e-mobility business model legacy platforms provide a good picture of available business models in the entire e-mobility market seen from a value chain perspective. In order to address fossil free corridors there is a need to look more closely at public charging, where the main issue is the poor business case, particularly long distance en route charging which requires investment in expensive fast charging technology. In any viable business model addressing the public charging segment it is therefore critical to:

- Find more revenue sources
- Lighten the investment burden
- Set up a large enough and importantly scalable networks
- Find strategic locations with easy access to large potential customer flows
- Meet EV customers ever more demanding requirements on offering, ease of use, payment, waiting times etc

In the current early development phase of e-mobility there are several business models that have emerged trying to cope with the challenges above. Below some of the main business models are described and how they are made operational focusing on different segments with different competitive strategies. The set of selected business models displayed include(GREAT, 2019):

"All Charge" business model: Seamless charging provide both public charging and private charging solutions combined

Table 6. "All Charge" business model

"ALL CHARGE" – BUSINESS MODEL	
Characteristics	Setting up and running a complete charging service spanning private and public segments with the private business as customer base
Value Proposition	Seamless Charging Service towards EV owners
Delivery	Through partnerships and alliances across the value chain for HW and Public network
Market	All market segments, private customer base is key
Revenue model	"All inclusive" Charging typical but can include various levels
Competitive advantage	Operations, brand, customer service and network scale
Opportunities/Challenges	▪ Installed grid customer base ▪ One charge shop ▪ Digital and V2G solutions ▪ Cost of National network

"Destination" business model: Use destination businesses to attract customers for the public charging infrastructure

Table 7. "Destination" business model

"DESTINATION" – BUSINESS MODEL	
Characteristics	Using a well-established destination business as a means to attract customers/volume where the public charging becomes an add on service
Value Proposition	Providing an opportunity based public charging service in combination with a destination B2C business
Delivery	Partner with CPO typically or build up proper network
Market	Public market segment, typically short distance
Revenue model	Revenue derived from charging sometimes conditioned by using destination business including discounts or voucher solutions
Competitive advantage	Brand of core business and customer relationship
Opportunities/Challenges	▪ Unlimited number of destinations ▪ Destination owners willing to invest ▪ Destinations change over time

"Location" business model: Use public charging as a means to attract customers in strategic transport locations and reap revenues also from established co-located typically a retail business.

Table 8. "Location" business model

"LOCATION" – BUSINESS MODEL	
Characteristics	Use Public Charging as a means to attract customers in strategic locations and reap revenues also from established co-located typically retail business
Value Proposition	Providing a Public en route fast charging service and a travel related B2C business
Delivery	Partner with CPO typically or build up proper network
Market	Public market segment en route fast charging
Revenue model	Revenue derived from real value of fast charging services as well as established co-located business with healthy margins
Competitive advantage	Strategic location, advanced charging service offering, co-located services, brand
Opportunities/Challenges	▪ Fast Charging Point technology ▪ Price levels remain relatively high ▪ Grid distribution capacity may require significant additional investment ▪ Battery Technology advancement diminish demand for en route fast Charging

"Collaborative " business model: provide a solution for en route charging

Table 9. "Collaborative" business model

"COLLECTIVE" – BUSINESS MODEL

Characteristics	Addressing the heavy Public Charging investment by taking a collective approach sharing investment costs
Value Proposition	Providing a Public en route fast charging service scalable to meet future requirements
Delivery	Partner with strategic location owners along highways
Market	Public market segment en route fast charging
Revenue model	Revenue derived directly from fast charging or leasing agreements with location owners and promoting EV´s
Competitive advantage	Financial strength, long term location agreements, advanced service offering
Opportunities/Challenges	▪ Include as integral part of EV offering ▪ Drive EV demand (and profits) ▪ Charging Price levels may remain relatively high for fast charging ▪ Demand for en route long-distance charging will take time to develop

It is important to remember that these business models are not mutually exclusive but rather are implemented in parallel by several players in the market.

Procurement Contracts / External Funding

When a private sector decides to deploy a network of charge points for EVs on its territory, it may decide to execute a procurement contract for the construction of the network and, when appropriate, one for their operation too. This is the case when the private sector is fully supported by external funding (governmental, EU, etc.). In this model, the procurement contract does not transfer any risk from the private sector to the contract holder: The contract holder is remunerated by the private sector for the provided services (construction and/or operation of the charge points). For operation, the CPO receives the majority of the royalties with the rest going to the private sector. There is also an option for the private sector to pay a flat fee to the CPO.

In conclusion, there are two possibilities:

1. The private sector executes a procurement tender for the construction but operates the network on its own
2. The private sector executes a procurement both for the construction and operation of the charging network.

4.3 STRATEGY

4.3.1 Electric Vehicle Charge Points (EVCP) value chain

A successful integration of EVCP in the wide electricity network requires a thorough look into the operational aspects of the charging infrastructure value chain.

In charging networks, the list of the main stakeholders comprises of EV drivers purchasing electricity for EV charging from a power retailer via a CPO or via an e-mobility Service Provider (e-MSP).

The CPO is responsible for the maintenance and operation of the charge points, while e-MSP's role is to enable access to a variety of charge point networks in a geographic area. Generally, e-MSPs help EV drivers find charge points, start charging events and pay with various methods. In many cases, CPOs and e-MSPs are usually the same organization.

A CPO is a market player, purchasing energy from energy suppliers and delivering it to end-users, i.e. the EV drivers. In the vast majority, the largest CPOs are generally energy companies, including retailers, or entities owned by energy companies suggesting that there is a case for charging point operation to be directly linked to retail of electricity.

Other stakeholders having a role in the EV charging value chain and may act independently or not, are:

- Energy market regulators: Regulators are managing electricity tariffs, setting rules to ensure the reliability and robustness of the electricity grid by ensuring the financial health of utilities and defining the conditions under which the grid infrastructure can/must be upgraded.

- A Clearing House: A clearing house ensures that payment transactions are automatically processed, following a set of check and validation rules. The basic idea is that a Clearing House gives ''Roaming Support'' for every e-MSP for the clients to be able to use any charging station.

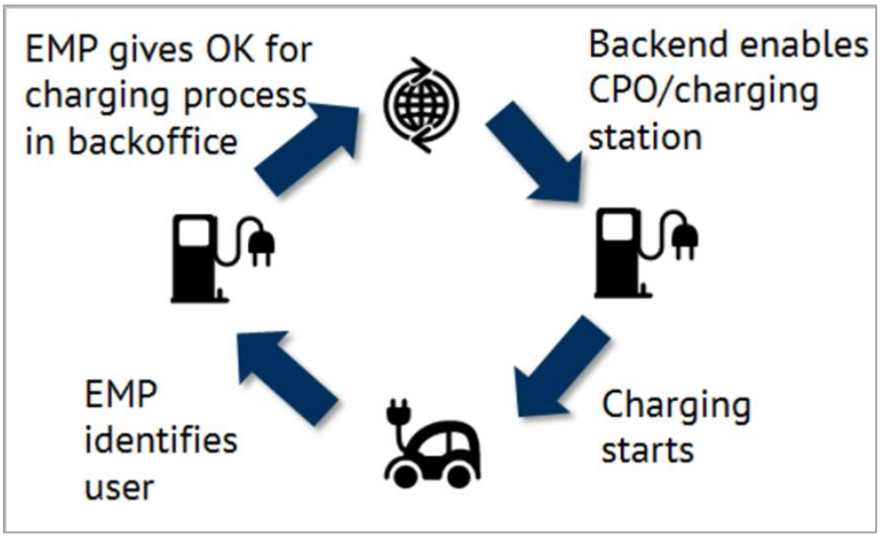

Figure 13. Process to initiate charging including the role of actors involved (Energy Brainpool)

4.3.2 Billing methods

At the very early days of the market the simplest billing strategy was unmetered, free charging where there was no money transfer from the EV-owner for the purpose of the charging services received. In practice, different stakeholders (e.g. municipalities, cities, commercial businesses, pilot projects) were often offering charging free of charge to vehicle owners.

This is no longer the case in most countries. For example, the city of Amsterdam, has already abandoned the principle of free charging since April 2012. Concerning the remaining payment methods, a distinction can be made between two main types.

- The cost of the charging can be paid for before the actual charging process takes place. This category of payment methods is referred to as 'prepaid' since it entails a financial transaction pre-charging.

- The payment takes place after the charging process has taken place. This payment method is better known as 'postpaid' and relates to payments via cash, card, billing and by mobile. Post-paid methods for billing are more complex, in the sense that they require more data communication and hence entail more software related costs. Besides the two main payment categories, the vehicle owner can also be billed for the charging services by all kinds of combinations of prepaid and postpaid methods.

4.3.3 Prepaid Methods

If the customer makes the choice to pay before the actual charging process takes place, he will be confronted with one of the following payment methods:

- **Subscription**: The owner of the electric vehicle pays a fixed amount in order to be given access to certain charge points for a certain period, mostly 6 or 12 months. This is a very simple payment method since the identification of the subscribed user is the only requirement. However, this method also entails some major issues. Some users will be paying too much for their electricity used for charging while others will be paying far too little.

- **Pay as you go (PAYG) –** ad-hoc access: When referring to "ad-hoc access", we refer to the ability for any person to charge an electric vehicle without entering into a pre-existing contract with a CPO. In this case, the owner of the electric vehicle pays in advance to obtain a level of credit. After charging, this credit is debited, and the remaining balance is determined. This payment method follows a similar approach as the prepaid cards for mobile phones. There are two potential ways in which the relevant credit can be treated:
    a. at the start of the charging, the charging station communicates with the EV service provider to verify the owners' identity and the remaining balance of the payment card. After the charging, the data concerning the extracted electricity is sent back to the EV service provider, who recalculates the remaining credit.
    b. the data concerning the owners' identification and the level of credit is stored on the device for identification (e.g. RFID card, mobile phone for NFC). After charging the authentication device is updated. Even though it is a more complex and costly charging system, this method of payment is already being used by different operators of charging infrastructure (e.g. Elektromotive, POD Point, Ville de Paris). There are also some means of payment on the market who fit the 'Pay as you go'-principle that rely on a prepaid mobile wallet, linked to a back-office system. The virtual wallet can be recharged via the bank account (internet banking), maestro or even by a third party (e.g. employer)

4.3.4 Post-Paid Methods

Alternative to prepaid methods, charging services can be paid after the actual charging process has taken place. The available billing concepts within this category are listed below:

- **Cash:** The owner of the electric vehicle pays for the electricity by using cash. This payment method shows some similarities with the current payment method at petrol stations. In Belgium, Total is experimenting with inter alia, cash payments for charging within its Plug To Drive network. However, while the value of the electricity used for charging is rather small, the costs for collecting, storing and employing somebody to retrieve the cash are relatively high. It will thus be cost ineffectual to give customers the opportunity to pay using cash.

- **Card:** In this case, the owner of the electric vehicle pays for the electricity by using his credit card. Also, this method shows some similarities to the current payment method at petrol stations.

- **Pay by mobile:** In this case, the owner of the electric vehicle sends an SMS to a dedicated number, indicated by the CPO. The telecom operator of the CPO then charges the mobile phone operator of the EV owner with the relevant amount. Although, it is very convenient to pay by mobile phone, this system is not a plug-and-play system. This payment method entails additional administration costs as there needs to be extensive communication between both the EV service provider and the mobile phone companies of both the CPO and the EV owner.

- **Domestic electricity bill:** Since most customers already have a domestic electricity account, it may be convenient for EV owners to pay the costs for charging their EV through their domestic electricity bill. In this case there will is a clear need for a Clearing House since the standard electricity supplier of the vehicle owner is not necessarily the dedicated electricity supplier of the public charging point.

5. EV's CHARGERS LEASING METHOD - CASE STUDY

5.1 INTRODUCTION

Leasing of EV chargers provides a convenient, low cost option for many customers including commercial real estate owners with parking garages, multi-use buildings, shopping malls and supermarkets. Most of the leasing customers pass through their lease costs to their tenants as operating costs, thereby avoiding the need to tie up their cash, take out loans, or put their charging assets on their balance sheets. At the same time the development of an EV charging grid can offer new revenue opportunities through parking fees, advertising, and internal brand development. Some of the main advantages of the leasing method regarding EV chargers are:

- Allows the customer to conserve cash and free up capital for other priorities
- Pass monthly costs through to tenants as an operating cost
- Bundle equipment, extended warranties, shipping, installation, and other services into one low monthly payment
- Avoid capital charges and covenant impacts by keeping off balance sheet

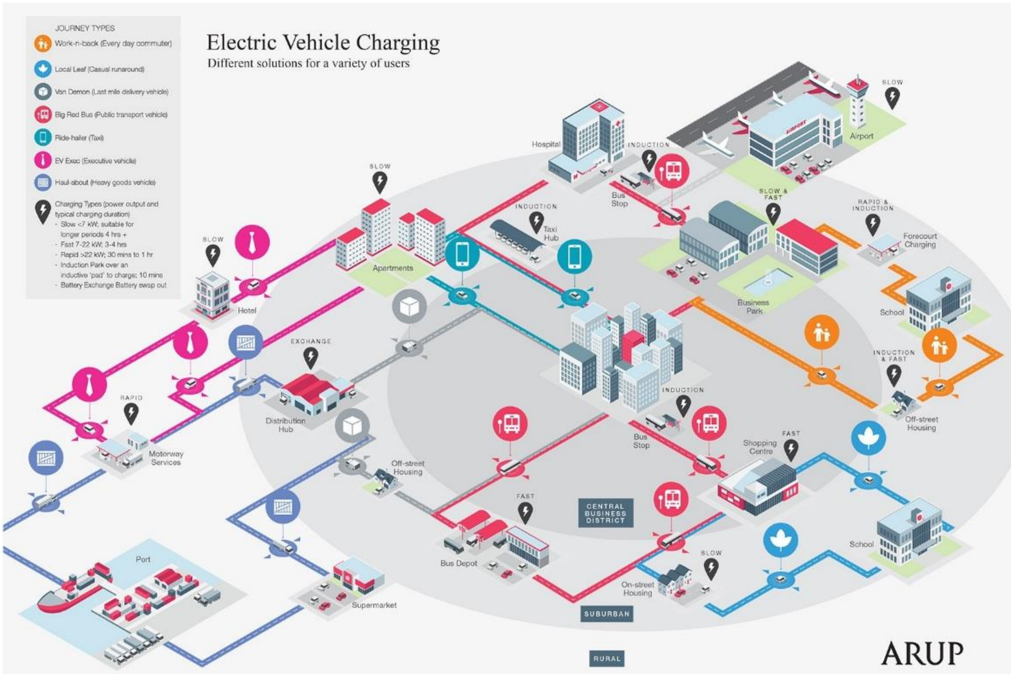

Figure 14. Electric vehicle charging plan

So, in general, leasing a number of EV chargers with a fixed monthly investment is great for businesses who either require a large investment to implement charging infrastructure, or have the opportunity to generate revenue from customer, public or residential charging.

From the various methods mentioned above, the one proposed in this work, includes the payment of the installation of the charging network by the CPO and the payment of operating and maintenance (O&M) costs by the customer. In that way, the CPO makes profit by the difference between the price that the supermarket pays and the actual cost for O&M.

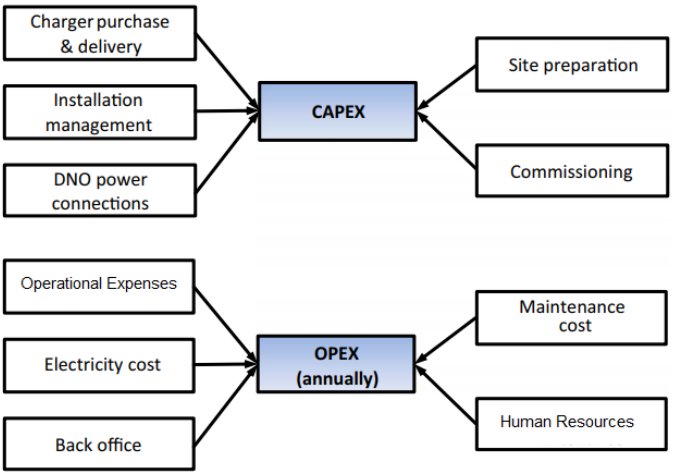

Figure 15. Sources of costs arising from offering an EV battery recharging service. Revenues arise from the leasing and O&M income.

The main economic indicators that will be analyzed later in the model that has been developed, are defined below.

CapEx (which refers to Capital Expenditure) is incurred when a business acquires assets that could be beneficial beyond the current tax year. For instance, it might buy brand new equipment or buildings. Also, it could upgrade an existing asset to boost its value beyond the current tax year. CapEx is also known as a Capital expense.

OpEx (which refers to Operational Expenditure) consists of those expenses that a business incurs to run smoothly every single day. They are the costs that a business incurs while in the process of turning its inventory into an end product. Hence, depreciation of fixed assets that are used in the production process is considered OpEx expenditure. OpEx is also known as an operating expenditure, revenue expenditure or an operating expense.

Net Present Value

Net Present Value (**NPV**) is the value of all future cash flows (positive and negative) over the entire life of an investment discounted to the present. NPV analysis is a form of intrinsic valuation and is used extensively across finance and accounting for determining the value of a business, investment security, capital project, new venture, cost reduction program, and anything that involves cash flow.

$$NPV = \sum_{t=0}^{n} \frac{R_t}{(1+i)^t}$$

R_t : Net cash inflow-outflows during year t

i : Discount rate

t : is the time of the cash flow

Internal Rate of Return

Internal Rate of Return (**IRR**) is a metric used in capital budgeting to estimate the profitability of potential investments. The internal rate of return is a discount rate that makes the net present value (NPV) of all cash flows from a particular project equal to zero. IRR calculations rely on the same formula as NPV does.

$$0 = NPV = \sum_{t=0}^{n} \frac{C_t}{(1+IRR)^t} - C_0$$

C_0 : Initial investment

C_t : Cash flow in year t

Benefit Cost Ratio

The benefit cost ratio (**BCR**) compares the present value of all benefits with that of the cost and investments of a project or investment. These benefits and costs are treated as monetary cash flows or their equivalents, e.g. for non-monetary benefits or company-internal costs.

$$BCR = \frac{\sum_{t=0}^{N} \frac{C_t(Benefits)}{(1+i)^t}}{\sum_{t=0}^{N} \frac{C_t(Costs)}{(1+i)^t}}$$

5.2 BUSINESS DESIGN OBJECTIVES

The basic assumptions made in order to design the proposed financial model are presented in this section. The present study, as well as the prices assumed below, refers to the case where the public charging network is installed in the parking lots of a large chain of supermarkets, consisting of 300 stores and has an estimated annual turnover of over 1,000,000,000€.

The proposed study and installation of the charging points, concerns fast AC type 2 chargers, 22kW each. These chargers are suitable for customers of supermarket stores, who drive urban electric vehicles, such as cars or scooters/motorcycles. On the other hand, drivers of vehicles such as taxis or trucks/buses, are not recommended to charge their vehicles to the proposed charging points, as the best practice suggests charging those vehicles to rapid DC chargers, with power more 50kW.

Regarding the CAPEX and OPEX of the installation of the proposed chargers are illustrated below:

Table 10. CAPEX Analysis

Charging Points CAPEX				
a/a	Company Setup	Numer/Pcs	Cost	Total
1	Charging Stations	300	1,200	360,000
2	Media Chargning Stations	-	-	-
3	Installation materials & extras	300	600	180,000
4	Mounting structures	300	300	90,000
5	Installation cost (accomodation & perdiem)	300	200	60,000
	TOTAL		**2,300**	**690,000**

Company CAPEX				
a/a	Company Setup	Numer/Pcs	Cost	Total
1	Office desk & furnitures & deco	-	-	-
2	PC & Electronics	2	500	1,000
3	Technical tools for CP Installations	2	2,500	5,000
4	Electric Vans for technicians	2	-	-
	TOTAL			**6,000**

CONSULTING				
a/a	Position	Monthly Fee	Months	Total/Year
1	CONSULTING SERVICES IT /backend design	lumpsum		30,000
2	MARKETING SERVICES	lumpsum		25,000
	TOTAL			**55,000**

According to the CAPEX analysis above, the **total CAPEX** of the EV charging plan is calculated to be around **751,000 €** for the CPO (and around 1,096,000 if the Supermarket pays CAPEX, including a 50% profit in above charging points CAPEX).

Table 11. 1st year OPEX, including Human Resources

HUMAN RESOURCES				
a/a	Position	Salary (Gross)	Months	Total/Year
1	Director	2,200	14	30,800
2	Development Director	2,200	14	30,800
4	Software Engineer	1,300	14	18,200
5	Technician 1	1,000	14	14,000
6	Technician 2	900	14	12,600
10	Administrative Assistant	800	14	11,200
11	Marketing - Billing Dpt	1,300	14	18,200
	TOTAL	**12,100**		**135,800**

Table 12. 1st year OPEX, including Operational Expenses and Offices

OPERATIONAL EXPENSES - OFFICES				
a/a	Position	Monthly Fee	Months	Total/Year
1	Offices	800	12	9,600
2	Utilities	150	12	1,800
3	Accounting	500	12	6,000
4	Software Licenses (1 per year)	-	1	-
5	CRM	200	12	2,400
6	Leasing Car Sales 1 - EV	500	12	6,000
7	Leasing Car Sales 1 - EV	500	12	6,000
	TOTAL	**2,650**		**31,800**

According to the OPEX assumptions above, the **total OPEX for the 1st year** of the chargers installations is calculated to be around **167,600 €**. Another key hypothesis made in the study is that the amount of OPEX increases by a certain percentage per year, as shown below:

Table 13. OPEX percentage increase per year

OPEX year 1	–
OPEX year 2-3	+5%
OPEX year 4-5	+10%
OPEX year 6-7	+10%
OPEX year 8+	+10%

In addition, the assumptions made about the economic analysis are that inflation is 0.2% and the discount rate is 6%. Also the basic assumptions regarding the customer's costs and incomes, are shown below.

Table 14. Basic assumptions of the projected scenarios (Supermarkets side)

Basic Assumptions		
Charging Points	320	Units
Media Chargers	-	Units
Total Chargers	320	Units
Profit per session	0.65	€/session
profit per charge	0.15	Euro/kWh

Costs & CAPEX/OPEX		
CAPEX 1st year	1,165,000	Euro
OPEX 1st year	117,320	Euro/y
OPEX year 2-3 (+5%)	123,186	Euro/y
OPEX year 4-5 (+10%)	135,505	Euro/y
OPEX year 6-7 (+10%)	149,055	Euro/y
Increase in OPEX after y. 8	10%	%
Leasing	1,300	€
Charger O&M Costs	300	Euro/y/point

Income Assumptions		
Charges 1year	30	Hours/y/point
Charges year 2-3	300	Hours/y/point
Charges year 4-5	900	Hours/y/point
Charges year 6-7	1,800	Hours/y/point
Sessions year 1	60	sessions/point
Sessions year 2-3	600	sessions/point
Sessions year 4-5	1,800	sessions/point
Sessions year 6-7	3,600	sessions/point
Marketing profits	-	Euro/Media charger/y
Indirect products	-	Euro/charger/year

5.3 SENSITIVITY ANALYSIS

Sensitivity analysis (SA) investigates the relations between uncertain parameters of a model, and a property of the observable outcome, which represents some critical features of the modelled system. SA has been used for various parameterization tasks of models of financial or engineering systems, such as finding essential parameters for research prioritization, identifying insignificant parameters for model reduction or parameters clustering (Charzyńska et al., 2012).

The process of recalculating outcomes under alternative assumptions to determine the impact of a variable under sensitivity analysis can be useful for a range of purposes (DJ Pannell, 1997), including:

- Testing the robustness of the results of a model or system in the presence of uncertainty.
- Increased understanding of the relationships between input and output variables in a system or model.
- Uncertainty reduction, through the identification of model inputs that cause significant uncertainty in the output and should therefore be the focus of attention in order to increase robustness (perhaps by further research).
- Searching for errors in the model (by encountering unexpected relationships between inputs and outputs).
- Model simplification – fixing model inputs that have no effect on the output, or identifying and removing redundant parts of the model structure.
- Enhancing communication from modellers to decision makers (e.g. by making recommendations more credible, understandable, compelling or persuasive).
- Finding regions in the space of input factors for which the model output is either maximum or minimum or meets some optimum criterion, e.g. Monte Carlo analysis. Monte Carlo simulations are used to model the probability of different outcomes in a process that cannot easily be predicted due to the intervention of random variables. It is a technique used to understand the impact of risk and uncertainty in prediction and forecasting models.

- In case of calibrating models with large number of parameters, a primary sensitivity test can ease the calibration stage by focusing on the sensitive parameters. Not knowing the sensitivity of parameters can result in time being uselessly spent on non-sensitive ones.
- To seek to identify important connections between observations, model inputs, and predictions or forecasts, leading to the development of better models.

Conducting sensitivity analysis provides a number of benefits for decision-makers. First, it acts as an in-depth study of all the variables. Because it's more in-depth, the predictions may be far more reliable. Secondly, It allows decision-makers to identify where they can make improvements in the future. Finally, it allows for the ability to make sound decisions about companies, the economy, or their investments.

But there are some disadvantages to using a model such as this. The outcomes are all based on assumptions because the variables are all based on historical data. This means it isn't exactly accurate, so there may be room for error when applying the analysis to future predictions. However, in the context of the present study, sensitivity analysis is an effective tool for extracting results from the projected data.

5.4 Customer Side: Leasing or buying EV charging points?

Rather than focusing on individual future projections for energy demand, the approach taken here considers the projection of the EV market growth over the years. The following financial corresponds to a life cycle analysis over a 10-year period. The time period of the financial analysis is selected according to the average lifespan of a charging station, which is predicted around 10 years, according to industry experts (IRENA et al., 2019).

5.4.1 Scenario 1: Leasing EV charging points

During this scenario, CPO pays for CAPEX and OPEX costs and Supermarket pays only for leasing and O&M costs. This being the case, the calculations and the results of the financial indicators of the EV charging plan, are shown below:

Table 15. Leasing EV charging points calculations and results

LEASING EV CHARGING POINTS (CPO pays CAPEX and OPEX, Supermarket pays leasing and O&M)

Key Input data

Year	Description	Unit	Cost/ Benefit
1	Income	EUR	13,920
2 & 3	Income	EUR	139,200
4 &5	Income	EUR	417,600
6 & 7	Income	EUR	835,200
1 to 5	Leasing	EUR	416,000
-	O&M	EUR	96,000
	Inflation	%	0.2%
	Project Lifetime	years	10
	Discount Rate	%	6%

Results

Description	Unit	Value
Net Present Value (NPV)	EUR	**647,340**
Benefit Cost Ratio (BCR)		**3.5**
Internal Rate of Return (IRR)	%	**12.38%**

Discounted Cash Flow Calculations (yearly) [in EURO]

Operation Period	0	1	2	3	4	5	6	7	8	9	10
Operation Year	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Benefits		13,948	139,478	139,757	418,435	419,272	836,870	838,544	840,221	841,902	843,585
OPEX	- 256,000	-512,000	-512,000	-512,000	-512,000	-512,000	-153,600	-153,600	-153,600	-153,600	-153,600
Gross Profit	**-256,000**	**-498,052**	**-372,522**	**-372,243**	**-93,565**	**-92,728**	**683,270**	**684,944**	**686,621**	**688,302**	**689,985**
Investment costs	0										
Net Cash Flow	-256,000	-498,052	-372,522	-372,243	-93,565	-92,728	683,270	684,944	686,621	688,302	689,985
Discounted Cash Flow	-256,000	-469,861	-331,543	-312,542	-74,112	-69,292	481,679	455,527	430,795	407,405	385,284

5.4.2 Scenario 2: Buying EV charging points

During this scenario, Supermarket pays for CAPEX, 70% of the OPEX and O&M of the charging points to the CPO. This being the case, the calculations and the results of the financial indicators of the EV charging plan, are shown below:

Table 16. Leasing EV charging points calculations and results

BUYING EV CHARGING POINTS (Supermarket pays CAPEX and 70% of the OPEX)

Key Input data

Year	Description	Unit	Cost/ Benefit
1	Income	EUR	13,920
	OPEX	EUR	117,320
	CAPEX	EUR	1,165,000
2 & 3	Income	EUR	139,200
	OPEX	EUR	123,186
4 & 5	Income	EUR	417,600
	OPEX	EUR	135,505
6 & 7	Income	EUR	835,200
	OPEX	EUR	149,055
-	O&M	EUR	96,000
	Inflation	%	0.2%
	Project Lifetime	years	10
	Discount Rate	%	6%

Results

Description	Unit	Value
Net Present Value (NPV)	EUR	**317,958**
Benefit Cost Ratio (BCR)		**1.3**
Internal Rate of Return (IRR)	%	**8.91%**

Discounted Cash Flow Calculations (yearly) [in EURO]

Operation Period	0	1	2	3	4	5	6	7	8	9	10
Operation Year	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Benefits		13,948	139,478	139,757	418,435	419,272	836,870	838,544	840,221	841,902	843,585
OPEX	- 58,660	-213,320	-219,186	-219,186	-231,505	-231,505	-302,655	-302,655	-332,921	-366,213	-402,834
Gross Profit	**-58,660**	**-199,372**	**-79,708**	**-79,429**	**186,931**	**187,767**	**534,215**	**535,889**	**507,301**	**475,689**	**440,752**
Investment costs	-1,165,000										
Net Cash Flow	-1,223,660	-199,372	-79,708	-79,429	186,931	187,767	534,215	535,889	507,301	475,689	440,752
Discounted Cash Flow	-1,223,660	-188,087	-70,939	-66,690	148,067	140,311	376,601	356,397	318,287	281,560	246,113

The comparison between the aforementioned scenarios is illustrated below, using the IRR and NPV indicators. It can be clearly seen that IRR is almost double in case of the leasing method and NPV is almost triple in case of leasing method. A safe conclusion is that leasing method is always better for the Supermarket chain.

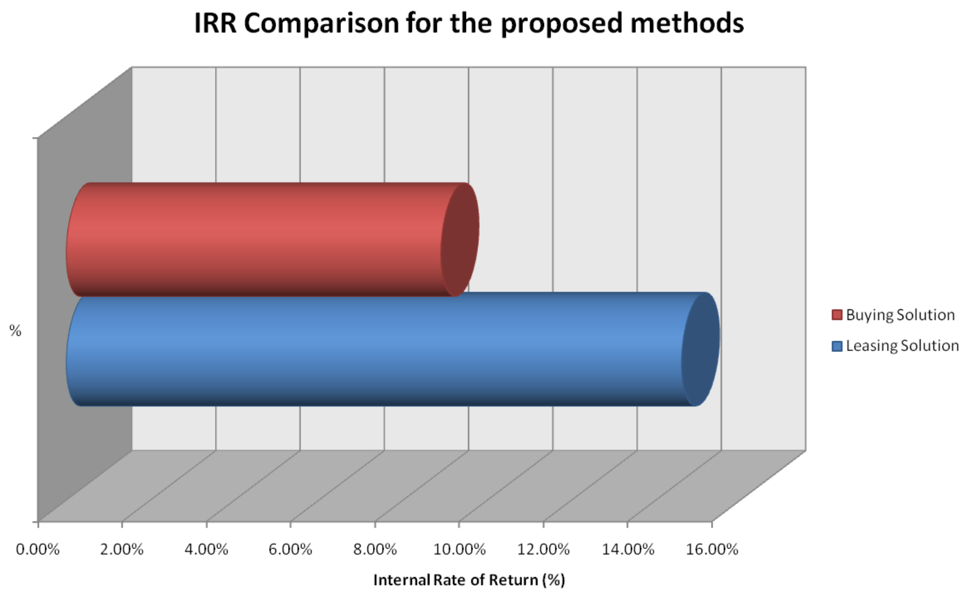

Figure 16. IRR comparison for the proposed methods

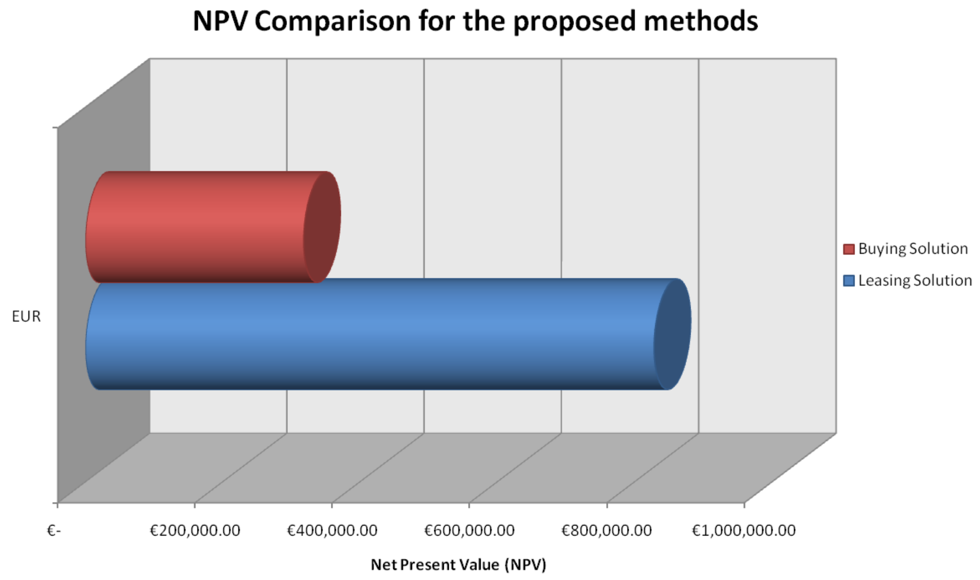

Figure 17. NPV comparison for the proposed methods

5.5 CPO Side: Leasing, but how much?

Regarding the best selection of leasing price, a sensitivity analysis was conducted setting the initial leasing price to 1080€/year/point and the price step to 50 €/year/point. The calculations and results are illustrated below.

Table 17. Basic assumptions (CPO side)

Costs & CAPEX/OPEX		
CAPEX 1st year	751,000	Euro
OPEX 1st year	167,600	Euro/y
OPEX year 2-3 (+5%)	175,980	Euro/y
OPEX year 4-5 (+5%)	184,779	Euro/y
OPEX year 6-7 (+5%)	194,018	Euro/y
Increase in OPEX after y. 8	10%	%
Charger O&M Costs	150	Euro/y/point

Income Assumptions		
Charges 1year	30	Hours/y/point
Charges year 2-3	300	Hours/y/point
Charges year 4-5	900	Hours/y/point
Charges year 6-7	1,800	Hours/y/point
Sessions year 1	60	sessions/point
Sessions year 2-3	600	sessions/point
Sessions year 4-5	1,800	sessions/point
Sessions year 6-7	3,600	sessions/point
Leasing profits	1080	Euro/year/point
Marketing profits	-	Euro/Media charger/y
Indirect products	-	Euro/charger/year
Charger O&M INCOME	350	Euro/y/point
Increase in O&M INCOME after y. 5	60%	%
Annual Revenues	**1,430**	**Euro/year/point**

Table 18. Sensitivity analysis on the leasing price. The model automatically selects the revenues that correspond to a minimum IRR of 15%, which is indicated below by a red line.

Initial	1,080
Step	50

SENSITIVITY			
Annual Leasing per Charging Point (€)	NPV (€)	IRR (%)	Annual Revenues per Charging Point (€)
1,080.00 €	124,073.07 €	11.97%	1,430.00 €
1,130.00 €	187,432.60 €	14.89%	1,480.00 €
1,180.00 €	250,792.13 €	17.73%	1,530.00 €
1,230.00 €	314,151.66 €	20.51%	1,580.00 €
1,280.00 €	377,511.19 €	23.22%	1,630.00 €
1,330.00 €	440,870.72 €	25.89%	1,680.00 €
1,380.00 €	504,230.25 €	28.51%	1,730.00 €
1,430.00 €	567,589.78 €	31.08%	1,780.00 €
1,480.00 €	630,949.31 €	33.62%	1,830.00 €
1,530.00 €	694,308.84 €	36.12%	1,880.00 €
Min Annual Revenues per Charging Point for IRR>15% (€)			1,530.00 €
Selected Annual Revenues per Charging Point			**1,530.00 €**

Table 19. Leasing EV charging points calculations and results (CPO side)

CPO: LEASING EV CHARGING POINTS

Key Input data

Description	Unit	Cost/ Benefit
Income 1year	EUR	414,000
Income year 2-3	EUR	414,000
Income year 4-5	EUR	414,000
Income year 6-7	EUR	123,000
CAPEX 1st year	EUR	751,000
OPEX 1st year	EUR	167,600
OPEX year 2-3 (+5%)	EUR	175,980
OPEX year 4-5 (+5%)	EUR	184,779
OPEX year 6-7 (+5%)	EUR	194,018
Inflation	%	0.2%
Project Lifetime	years	5
Discount Rate	%	6%

Results

Description	Unit	Value
Net Present Value (NPV)	EUR	**250,792**
Benefit Cost Ratio (BCR)		**1.3**
Internal Rate of Return (IRR)	%	**17.73%**

Discounted Cash Flow Calculations (yearly) [in EURO]

Operation Period	0	1	2	3	4	5
Operation Year	2020	2021	2022	2023	2024	2025
Benefits		414,828	414,828	415,658	414,828	415,658
OPEX	-	-167,600	-175,980	-175,980	-184,779	-184,779
Gross Profit	**0**	**247,228**	**238,848**	**239,678**	**230,049**	**230,879**
Investment costs	-751,000					
Net Cash Flow	-751,000	247,228	238,848	239,678	230,049	230,879
Discounted Cash Flow (DCF)	-751,000	233,234	212,574	201,238	182,220	172,526

Based on the previous analysis, the point of optimization of the corporate earnings and the profits of the CPO is achieved at about 15-20%. This assumption is based on the maximization of the benefits of the investor or the bank, the maximization of the CPO who will operate the charging points for the upcoming years, as well as on the maximization of the benefits for the client (the CEO of the supermarkets). In our case, the optimization of IRR between CPO and the client is achieved for **1,180 €/year/point** or a total revenue of **1530 €/year/point**.

The above selection of leasing price results in an IRR of 12.96% for the client, which is satisfying, considering the financial size of the Supermarkets, as mentioned in chapter 5.2.

Table 20. Client's financial results, in case of leasing the EV charging points

LEASING EV CHARGING POINTS (CPO pays CAPEX and OPEX, Supermarket pays leasing and O&M)

Key Input data

Year	Description	Unit	Cost/ Benefit
1	Income	EUR	13,050
2 & 3	Income	EUR	130,500
4 &5	Income	EUR	391,500
6 & 7	Income	EUR	783,000
1 to 5	Leasing	EUR	354,000
-	O&M	EUR	105,000
	Inflation	%	0.2%
	Project Lifetime	years	10
	Discount Rate	%	6%

Results

Description	Unit	Value
Net Present Value (NPV)	EUR	**630,296**
Benefit Cost Ratio (BCR)		**3.7**
Internal Rate of Return (IRR)	%	**12.96%**

Discounted Cash Flow Calculations (yearly) [in EURO]

Operation Period	0	1	2	3	4	5	6	7	8	9	10
Operation Year	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Benefits		13,076	130,761	131,023	392,283	393,068	784,566	786,135	787,707	789,283	790,861
OPEX	- 229,500	-459,000	-459,000	-459,000	-459,000	-459,000	-168,000	-168,000	-168,000	-168,000	-168,000
Gross Profit	**-229,500**	**-445,924**	**-328,239**	**-327,977**	**-66,717**	**-65,932**	**616,566**	**618,135**	**619,707**	**621,283**	**622,861**
Investment costs	0										
Net Cash Flow	-229,500	-445,924	-328,239	-327,977	-66,717	-65,932	616,566	618,135	619,707	621,283	622,861
Discounted Cash Flow	-229,500	-420,683	-292,132	-275,376	-52,846	-49,269	434,655	411,095	388,812	367,736	347,803

6. CONCLUSIONS

As mentioned before, the transport sector is facing the challenge of reducing its overall carbon footprint and becoming less dependent upon fossil fuels. In particular, the European Commission has adopted a roadmap towards 2050 that aims to reduce transport related carbon emissions and dependency on imported oil by 60%, relative to 1990 levels (European Commission, 2018). Because such reductions are particularly difficult to achieve in aviation, shipping and long-distance haulage, even further emission reductions will probably be needed in automobility. After a number of failed attempts in the past, EVs are now a serious option. The success of the transition toward electric mobility, however, will not depend upon car manufacturers alone. Cooperation among a broad set of stakeholders is needed in order to produce affordable vehicles, as well as to develop an early market and the necessary charging infrastructure. In this direction, the development of a public network for charging EVs (such as in malls, shops and supermarkets) is considered important. Thus, the present study focuses on the study of a projected charging network in the parking lots of a supermarket chain, in order to promote the general development of charging infrastructure.

Concluding the above study, it is proposed that the CPO should cover the costs of purchasing and install of the public chargers and undertake the operation and maintenance services, in exchange for the collection of monthly leasing fee for the installed chargers. As a result, in the aforementioned model, the initial risk as far as the CAPEX is concerned is minimal.

In this way, setting the leasing revenues properly, the financial ecosystem between CPO and the supermarket chain will result in an IRR range which will guarantee the satisfaction of both parties. Also, the supermarket will benefit in terms of marketing and customer services in a relatively new technological field, while CPO will maintain the proposed profits throughout the operation of the installed charging points.

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