Electric Mobility Charging Network – Environmental Impacts and Challenges

Portuguese Case

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Thesis to obtain Master of Science Degree in

Energy Engineering and Management

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May 2019

Acknowledgments

I would like to thank the Norwegian Electric Vehicle Association that gave access to the results of "Norwegian BEV Owner survey 2018".

The respondents from the survey that I created and distributed are thanked.

Declaration

I, Afonso Casaleiro Domingues, declare that all the work presented in this thesis is original work of my authorship and fulfils the requirements on the Code of Conduct and Good Practices of Universidade de Lisboa.

Abstract

To prevent major irreversible environmental changes, the European Commission has set that member's economies should decrease their carbonic emissions by 80% to 95% by 2050. Portugal has created a plan to reach these goals in which the Electric Vehicle is key to neutralize the emissions from the Transportation sector, studied in this thesis. To understand the Portuguese Electric vehicle market, a survey was conducted with worrying results on the user's perception of the public charging infrastructure showing that most users (83%) are displeased with its performance. The survey's results are compared with the Norwegian's EV Association, the biggest in the world, demonstrating that the Portuguese market is still in early life stage. The Portuguese plan to the economy's decarbonization is studied and helps formulating the carbonic assessment. The results show that the Portuguese plans to lower Green House Gas emissions can meet European proposal if the country's economy is able to stay competitive. A different scenario in which Portuguese development is much slower and less adaptative shows that the emissions are not lowered enough to meet European program. A brief economic assessment is also conducted to understand the user's economic differences in charging in different countries and owning an EV in Portugal alongside with the traditional thermic vehicle showing that EV ownership can already be economically favourable depending on the utilization conditions.

Keywords

Electric Vehicle, Green House Gases, Environmental Impacts, Sustainability, Carbon Neutral, Energy Distribution

Resumo

Para prevenir que as alterações climáticas sejam irreversivelmente danosas, a Comissão Europeia propôs que os seus membros diminuíssem as emissões carbónicas entre 80% a 95% até 2050. Portugal criou o Roteiro de Neutralidade Carbónica 2050 para alcançar tais objetivos. Este Roteiro integra o Veículo Elétrico no sector de Transportes para neutralizar as suas emissões. Este sector é estudado na presente tese, e para conhecer o mercado português do veículo elétrico, nomeadamente a rede de abastecimento, foi conduzido um questionário com resultados preocupantes sobre a perceção publica da mesma, mostrando que a maioria dos utilizadores (83%) está descontente com o seu desempenho. Os resultados do questionário são comparados com a Associação de Veículos Elétricos Norueguesa, a maior do mundo, mostrando que o mercado português se encontra ainda em fase embrionária. O Roteiro de Neutralização Carbónica é estudado e serve de base para formular uma avaliação carbónica. Os resultados mostram que os planos de diminuir o impacto ambiental estão em concordância com os europeus, se a economia portuguesa se mantiver competitiva. Um cenário diferente mostra que uma economia menos evolutiva e adaptativa não chegará para cumprir os objetivos europeus. Uma breve avaliação económica é feita para perceber a diferença económica de carregamento elétrico em diferentes países e compra de um veículo elétrico em Portugal face ao tradicional veículo térmico, mostrando que um VE pode já ser economicamente competitivo dependendo da utilização.

Palavras-chave

Veículo Elétrico, Gases de Efeito Estufa, Impactes Ambientais, Sustentabilidade, Neutralidade Carbónica, Distribuição de Energia

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Acronyms

GHG – Green House Gas(es)

EV – Electric Vehicle

ICEV – Internal Combustion Engine Vehicle

PHEV – Plug-in Hybrid Electric Vehicle

ICE – Internal Combustion Engine

BEV – Battery Electric Vehicle

NEVA – Norwegian Electric Vehicle Association

1. Introduction

1.1. Environment Challenge

The quality of the atmosphere has been a concerning issue for a long time. Human evolution has continuously put pressure on the surrounding environment for centuries. The first industrial revolution allowed fast and massified production granted by the steam engine which increased the average economy and at some extend the population's quality of life. In the XVIII century, the mass production, transformation and transportation of several products and goods was a major factor on the increase on natural growth of the human population. The spreading of the steam engine together with the population expansion increased dramatically the pressure on the environmental systems to absorb all the pollution product of human evolution. In figure 1 it is visible the correlation of the environmental pressure of such demographic expansion in the last centuries.

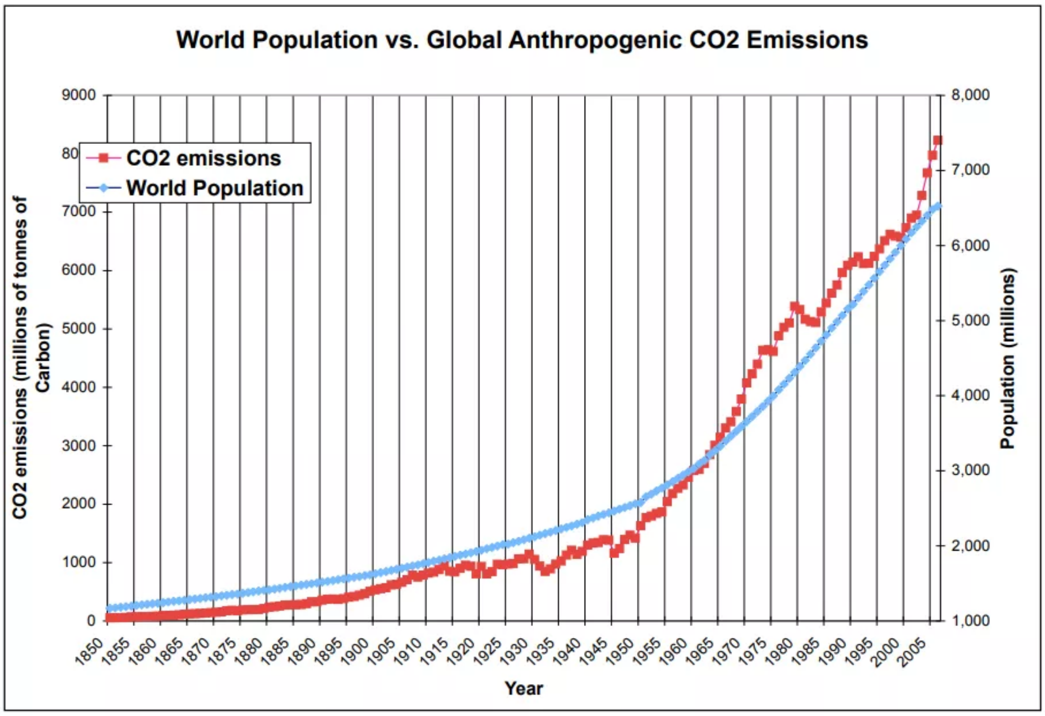

Figure 1 - CO_2 emissions and population evolution (source: https://overpopulation-project.com/solutions/)

The increase of concentration of pollutant gases in the atmosphere, has been having consequences on human behaviour since it directly influences the biological systems. There are several health problems related with air pollution [1,2]. The awareness for the environment grew and so, evolution lead humankind to avoid and rethink conducts known to pollute. Governments' role in global acknowledgement of pollution as a problem is key as these can use law-based tools to catalyse changes in processes prospecting lower global emissions of Green House Gases (GHG).

Nations have gathered several times to discuss ways to surpass environmental issues in the last years. These meetings are to discuss and plan strategies of human sustainable development hence improving life quality not only for present but also for the future. European Commission has set some targets so its members could develop plans to decarbon their economies with means to prevent an increase in global temperature higher than 2ºC. Resulting from the agreements made in such meetings like the Conferences of Parties, Portugal has structured plans to pursue the effort of keeping the temperature less than 2ºC higher than in pre-industrial times.

As part of the European effort to lower global emissions, Portugal has presented, in 2018, its plans to eliminate carbon emissions from the economy. The *Roteiro para a Neutralidade Carbonica 2050* [3] (RNC 2050), proposes three scenarios in which Portugal could merely follow the European trend, or it could be pioneer in changing its economy setting an example not only for the other European countries, but also the rest of the world. There is a third scenario which would be the worst-case scenario in which Portugal does not even follow the European trend and evolves unsustainably. The program suggests great changes in every economy sector to lower overall emissions by 85% to 90% from 2005 to 2050.

1.2. Purpose of thesis

With the development of humankind, the pressure on Earth's biological systems is predicted to increase as it has been happening for centuries. The consumption of energy as a vehicle (channel) to subsistence is meant to increase considering that developing countries' consumption per capita is much lower than developed countries. Knowing that developing countries have greater populations, their progress suggests great ascend in energy consumption and as a reaction pollution is also predicted to keep on rising.

In the European Commission's "Roadmap for moving to a competitive low carbon economy in 2050" [4], it is shown that in 2005 every main sector has decreased by some degree its GHG emissions comparing with 1990, except for the transportation sector which has increased by 30%. The goal presented if for the sector to decrease its emissions in 54% to 64% by 2050.

Electric vehicles have existed for a long time, but only in the past 10 years these technologies are gaining popularity and confidence from the user. Some concerns from the user's perspective have included anxiety range which is the anxiety felt by the driver about the low autonomy these vehicles may have. Since urban areas constrict the average driver's trip to a short distance, it becomes very reasonable that ordinary drivers can maintain their lifestyle with an EV in urbanized areas if some planning is done, mainly on the vehicle's recharge strategy.

The electrification of the light passenger vehicle, specifically in Portugal and its major cities like Lisbon, is a challenge at several dimensions. The replacement of the traditional gasoline vehicle for an electric one does have large potential to decrease Portuguese emissions but also to decrease the high dependency on oil and oil products. The massive electrification of road transportation transfers the energetic pressure from oil to electricity and so, the electric grid must adapt. Some considerations will be made on the Portuguese electric power system, but its deep analysis is not part of the scope of this report. This shift is highly important to decrease the Portuguese dependency in imports of oil products which represented almost 112% of the total final consumption of energy in 2016 [5].

This thesis goal is to study the Portuguese perspective facing the charging infrastructure of electric vehicles to understand the environmental impacts and challenges of the electric mobility supply system. This thesis focuses in Portuguese urban areas like Lisbon, but the analysis and survey could be more appropriate to analyse at a national level.

As the EV adoption and market evolution is totally dependent on the end user, it was established that understanding the consumers' perspectives was very important. After a state-of-the-art analysis on this field, in November 2018, a survey was constructed and distributed to Portuguese EV owner specific online forums. The major goals of the survey were to understand who the Portuguese early buyers of EV are and their perspective on the public charging infrastructure. The results from the Portuguese survey are compared with the ones from the yearly run survey by Norwegian Electric Vehicle Association (NEVA).

The RNC 2050 is analysed and a carbon emissions assessment is run on the transport sector using two different scenarios based on the RNC 2050 as these represent the Portuguese plans to lower carbon emissions in 80%-95% by 2050. Using the scenarios and results from the carbon assessment, some considerations are made on the future of the charging infrastructure in Portugal, based on the pretended evolution of the EV market.

As the work conducted is based on the consumer, a conservative economic assessment is made to evaluate the costs of ownership and utilization of an EV over an ICEV. The comparison is made between two real models that represent the most sold models from the same category both electric and thermal.

1.3. Structure

This report is structured as follows, the first chapter introduces the project and its purpose. On the second chapter, literature is reviewed with aim to better understand what has already been studied and put in practice in the electrification of the roadway vehicle, the impacts that this change can have and different surveys already conducted on this subject are analysed to better understand the information needed from a new survey. The third chapter is focused on the evolution of the Portuguese charging structure and its EV market. The system is analysed, and the conditions and objectives of the survey conducted is explained. In the fourth chapter an analysis is conducted on the Portuguese predictions for future carbonic emissions, specifically the intentions of decarbon the economy by 2050. In the fifth chapter the results are discussed and analysed with further understanding on the future of the Portuguese charging structure based on the plans to 2050. In the sixth chapter a brief economic assessment on owning an EV in Portugal with a summary of the charging costs in different countries is presented. In the seventh chapter, final conclusions for this thesis are presented as well as ideas that have arisen during this thesis that can be further explored. The thesis references come afterwards, followed by the survey and its results in the annex section.

2. Literature Review

2.1. Consequences on economic sectors

The Green House effect occurring on Earth is a precious biological tool essential to maintain life on the planet. This effect depends on a balanced amount of Gases (GHG), the higher the concentrations, the easier it is for the energy to remain on the Earth's crust, evidenced by heat. The United Nations Framework Convention on Climate Change (UNFCCC) has listed the gases that are able to retain energy on the atmosphere[1]. The most important (most emitted or most effective) are CO_2, CH_4, N_2O, HFCs, SF_6 and CFs. Even though CO_2 is by far the most emitted, others have significant impact since their ability to store heat is higher than CO_2.

The objective is to prevent mean temperature from rising to dangerous values and for that to happen, the emissions of such gases must shrink by adapting world economies to thrive with zero or nearly zero emissions. The International Energy Agency (IEA) has found that in 2016, the global emissions from the transportation sector are almost double than the 1990's values and that 74% of those emissions are explained by road transportation [6].

Pollution emissions from human presence have increased since the first industrial revolution. Different gases are mostly emitted by different activities, and so the tactics to lower the total emissions are complex.

In this thesis two of the most emitting activity sectors are analysed. Both the energy and transportation sector are studied. For the transportation sector the electrification of the private passenger vehicle is studied with focus on the public charging structure and the adoption of this new market. The energy sector, as the most emitting, is studied by association and some suggestions are made for its future development.

With an outlook to more sustainable economies, the replacement of traditional ICEV vehicles for EV implies some assessment on the electricity that is used to power the new vehicles. For that reason, some brief study is done on the Portuguese electrical generation and distribution. The energy sector has shown to be the most emitting globally, responsible for almost 60% of CO_2 in 2010, seconded by the transportation sector with 16% as shown in figure 2.

In [7], the authors analyse the differences on the energy sector of each country and make some considerations on the improvements of the sector and their impact. In [8] compares the usage of ICEV, PHEV and EV in different electric generation mixes, assessing the GHG emissions on these situations. In [9], a global assessment on how electricity production mixes affect the specific carbon intensity of each country. The authors of [10] study the massive introduction of EV in the Portuguese fleet concluding, in such case, the GHG emissions would decrease due to the renewable rich mixture of the generation and the impact EVs would make on the grid could be manageable with a low increase in renewables production.

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[1] *Source: https://unfccc.int/process/transparency-and-reporting/greenhouse-gas-data/greenhouse-gas-data-unfccc/global-warming-potentials*

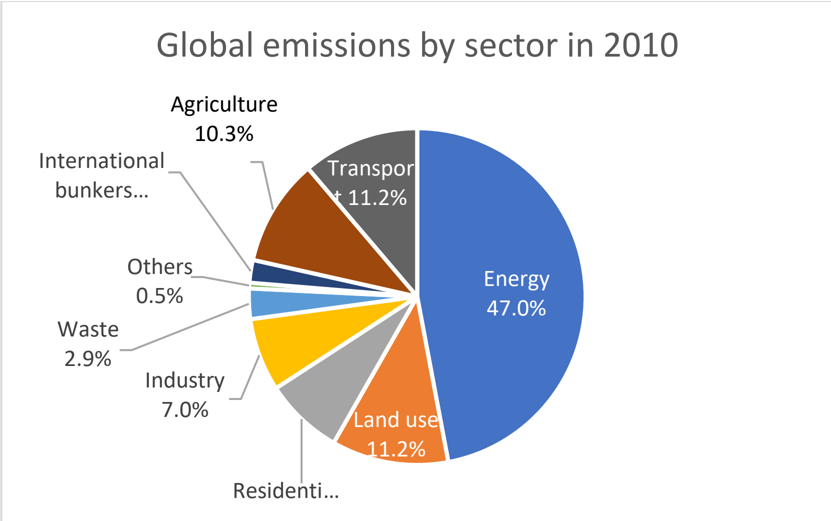

Figure 2 - Global emissions by economic sector in 2010 (source: FAOSTAT)

2.2. Existing and Developing Technologies for Electric Mobility

Transportation sector is one of the main emitters of GHG globally. According to the IEA, the Transportation sector has been the second responsible for global emissions of CO_2 both in 2014 and 2017 [6,11], with Electricity and Heat production being the primary emitter almost doubling the transports quantity.

The mainstream of the transportation sector has worked with the same technologies for over a century. In roadways, the ICE is used for propulsion. In railways either electricity, diesel ICE or even steam can be found in use. In sea, transportation is attained by diesel ICE. Airways which have shown great growth the past decades, are driven by the jet engine which also depends on petroleum-based fuels. As most of the transportation sector depends on combustion of oil products, the electrification of the sector, or parts of the sector is highly important in order to decrease the emissions of GHG. The authors of [8,12] study the impact that electrification of the light passenger vehicle would have on local and global emissions.

The study done in [12] concludes that even for highly carbonised electricity generation like China, the emissions transferred from the vehicle’s exhaust pipe to the power plants can, in some cases, be beneficial for public health. In [8], the emissions for each country’s power generation help to understand where emissions are globally lowered by replacing ICEVs by EVs. The potential for lowering emissions exists but will depend on the energy sector, as the authors in [9] conclude, the emissions can decrease by improving the efficiency of power plants, prioritizing natural gas instead of coal generation and by installing renewable power plants.

Electric propulsion for the road vehicle is growing with the purpose of replacing ICEV. The study run in [13] compares the ICE with the electric motor which has better efficiencies due to the high losses in heat than the thermal option. Tailpipe emissions are also an important measure for improvement, since high concentration of thermic vehicles can locally create dangerously high pollution levels. In [14] it is studied the difference in emissions of small particulate matter ($PM_{2.5}$) from exhaust and non-exhaust sources, which can be applied to an

ICEV-EV comparison since the EV does not have exhaust emissions. In [15], the author studies the health effects of $PM_{2.5}$ concluding that the concentration of this particulate matter in breathable atmosphere has negative impact on human health, particularly cardiopulmonary diseases.

The main setback of electric vehicles has always been the electricity storage. Most used technology used for storage nowadays is the battery which are charged on the electric grid or through a generator for later use.

Fuel cells can convert hydrogen in electric power that can be used to power the electric motors of a vehicle. In [16], the authors examine the early buyers for this technology and compares the results with the early buyers for EV. The standardization of fuel cell vehicles requires a hydrogen production and distribution grid which does not exist yet to a large extend. Comparisons made in [17,18] of the impact of this technology with ICEV, concluding that for fuel cell electric vehicles to replace ICEVs, the hydrogen production processes have to be conducted in a strict range of conditions otherwise the impact of the hydrogen production will overkill that from the gasoline or diesel combustion engines. In [19] a similar assessment for the Portuguese electrical grid is made, concluding that the processes and grid need yet to improve to achieve lower emissions than the ICEV.

Supercapacitors are also a possibility for storage, but due to the high power/low energy capacity, these are better used as complements with other energy storage tech [20–22]. In vehicles where high power is quickly needed, like performance vehicles or work vehicles with moving parts different than the transmission (forklifts, cranes) or even in vehicles with short and non-flexible courses for example public buses, the supercapacitor could be a very interesting option to consider when buying the vehicles, due to the much longer lifetime than batteries and shorter charging periods.

The battery electric vehicle (BEV) has been the technology most manufacturers invested to replace the ICEV for a near future. As no other technology shows signs of being a better solution in a near future for massively replacing the thermal private light passenger vehicle, the focus is being given to the improvement of battery configuration or the charging process in order to improve both autonomy and charging time.

Improving the battery pack could lead to higher energy density and specific energy, leading to a higher autonomy of the vehicle. Improving the lifetime of the battery is also important, since the manufacture process of these devices is a significant part of the vehicle's energy and raw material needs, it is important to increase the usage before disposing or recycling. In [13] it is found that the battery production can be responsible for 30% to 50% of the total emissions for the whole vehicle.

The end life stage of a vehicle is something to consider, and while the vehicle and powertrain are easily recyclable or even reusable, the batteries have been found to be much harder to do so [23]. The difficulty on recycling Li-ion batteries comes from their complex structure. In comparison with lead-acid batteries, Li-ion have many more different materials in their composition, making it harder to recover them separately while maintaining the process economically viable. Another difficulty found by the author is cross contamination on recycling lines meaning that either Li-ion batteries have entered lead-acid recycling lines or the opposite. Not only the recycled materials are going to be contaminated but also mixing battery types in recycling lines represents a real danger with fires and explosions already being reported. Since li-ion batteries have many different topologies, their chemistry compositions can be quite different, requiring different recycling lines. The author, Gaines, points at identification of the batteries on the manufacturing process, to help the disposal and recycling of the device, suggesting that when massive amounts of batteries reach their end life, it will be easier to reach an environmentally and economically advantageous process of recycling [24].

Some solutions are being studied for the afterlife of big battery packs used in transportation to postpone final disposal and recycling. While these battery packs are not as capable for storing energy to power a vehicle, they can be used statically to store energy for different reasons. A stationary use for these lower capacity batteries is ideal since weight and volume should not represent as much of a problem. In [23] the authors study the potential of giving vehicle batteries a second life to support the electricity distribution infrastructure with environmental and economic benefits. Profitability of processes that can absorb all future batteries for second life usage is questioned in [25] but concludes that for most cases is a sustainable step to add in the device's life.

The charging process of a lithium battery is also being improved with more and more powerful charging stations that can discharge energy in such way that its duration can already be compared with filling up a petrol tank.

Although Portugal only has 50kW power stations (considered the fast charging stations), there are already 350kW stations operational around the world for light passenger vehicle usage. The main issue with very high-powered stations is the temperature disturbances in the battery pack. The higher the power received by the battery, the higher the temperature will rise which can damage the device, shortening the lifetime of the lithium-ion batteries. The battery management systems that can withstand such powers have to be able to disconnect the power connection if temperatures rise to dangerous levels, otherwise a fire hazard would be at hands.

Different companies like Tesla and NIO have been exploring the possibility of battery swapping consisting in replacing the car's battery with a charged one instead of charging it while inside the vehicle. This process is very quick, and it would be easy for vehicles to be built to take advantage of this process, since the battery packs are usually the bottommost part of the vehicle to improve weight distribution.

Wireless charging has shown to be very interesting due to the dynamic possibilities of vehicle charging. With this technology, the vehicle can be charged while being driven which eliminates autonomy anxiety. In [26–29] this technology is studied with positive results showing that the power transfer efficiencies are as high as 95%, and due to a lower autonomy need, the battery packs could be reduced by up to 48%.

As an effort to increase public approval and speed up change, several governmental agents have shown intentions to ban ICEV either to be sold or used. Table 1 gathers some dates governments have announced to ban ICEV in their countries. Some cities have decided to go greener sooner and entered the C40 Cities commitment that gathers 27 major cities around the globe that plan to be zero emission by 2030.

Table 1 - Nationwide plans to ban new ICEV sales

Country	**New ICEV sales ban**
Norway	2025
Austria	2025
India	2030
Netherlands	2030
Scotland	2032
UK	2040

2.3. Review of existing markets

2.3.1. Background

The electrification of the roadway is becoming an important step to decrease the ecological footprint of each country. Since there are still problems with public perception on EVs when comparing with thermic vehicles, it is important to understand how public acceptance on EV evolves and how to boost it. As no larger organization has taken drastic decisions, each country decided its own path on this acclaimed change. For a future global strategy, it is critical to study each countries approach to incentivize the EV market.

The EV market has been globally developing since 2000 when there was no mass-produced electric model. Nowadays, not only there are several global models but also the manufacturers are investing large amounts of money in research and development to design vehicles in congruence with the customer needs and environmental laws. Many manufacturers delayed their entrance in the EV market due to discredit on public's adoption, but the electrification of vehicles has been present and developing for almost 20 years. The knowledge that oil based vehicles need to end is general not only for environmental and health reasons, but because oil itself is getting harder and more expensive to pump out of the earth crust.

Public's acceptance has always been a challenge in finding a technology that can replace the internal combustion engine. Electric motors have shown to be a good solution due to the higher efficiency, higher power and torque per volume, and longer RPM range when comparing with ICE. The energy storage systems have been the main setback and reason for apprehension since batteries have always seemed the best solution but meant serious changes in vehicle utilization for the final user. Either batteries had to evolve so the changes in user's life were not so dramatic, or some other technology for energy storage had to rise.

There were two important models in the EV market that showed not only the buyers, but all stakeholders of automobile industry that EVs were able to be a match for ICEVs. The first was the Toyota Prius, globally available for public consumer since 2000. A hybrid electric vehicle that uses electric motors to increase fuel efficiency on the ICE based vehicle. The Prius has dominated the global hybrid market every year since its market entrance.

The second important model is the battery electric vehicle Nissan Leaf which first appeared in 2010 and dominated the Portuguese market except for 2012 and 2013 which was a dramatic period for EVs, explained by the economic crisis, registering a concerning crash in total sales of almost 70% in 2012. Both these models have shown manufacturers that early investment in these new technologies pays off.

2.3.2. Norway

Norway has been the pioneer in electrification of their national fleet. This conversion process goes back to 1990 when the first incentive was created by the government: exemption to purchase taxes. Several other incentives have been conceived since, creating awareness on environmental issues and giving confidence to the consumer to acquire an EV. In [30] the author analyses the performance of Norway's incentives for the consumer to buy an EV, concludes that at a regional level, the quality of the charging structure is the best incentive. In [31], the author studies the development of the charging structure and concludes that a good structure is key for the consumer to trust the EV by decreasing range anxiety.

Norway can be considered a case study due to early and strong incentive for EV adoption. These strategies have generated the highest EV market share on the planet. Holtsmark considers that the incentive program of Norway is way too expensive to be functional, so it should be shut down immediately and not adopted by any other country [32]. The authors worry that the incentives only cause people to get a second vehicle besides the ICEV, instead of actually replacing their thermal vehicles. As Norway has economic power to support these experimental incentive strategies, these could be seen as research. Compiling data very important to explain the evolutions of the market and understand the future of different countries. The Norwegian EV association is the largest and it runs a yearly survey together with the more than 45,000 EV owners which is an important way to gather information on the country's EV market.

The Norwegian BEV Owner Survey 2018 [33] has shown very interesting results even though only 21% of the associates have fully responded the survey which might explain why 40% of respondents own a BEV for less than a year, showing that long time owners do not responded as much.

The percentage of households with one or more ICEVs has decreased from 77% to 63% from 2015 to 2018 respectively, lowering one of the main concerns of Norwegian program which is that users only got EVs as a second car and never gave an opportunity for fully replacing their ICEVs as their daily transport. In figure 3 and 4 the number of vehicles per household in 2018 and the evolution of households with one or more ICEVs are respectively presented.

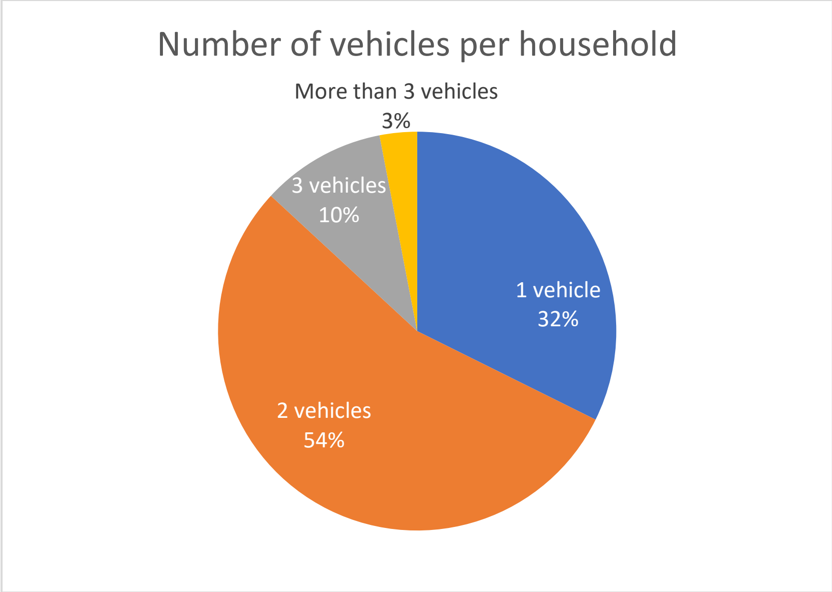

Figure 3 - Number of vehicles per household (source: NEVA survey 2018)

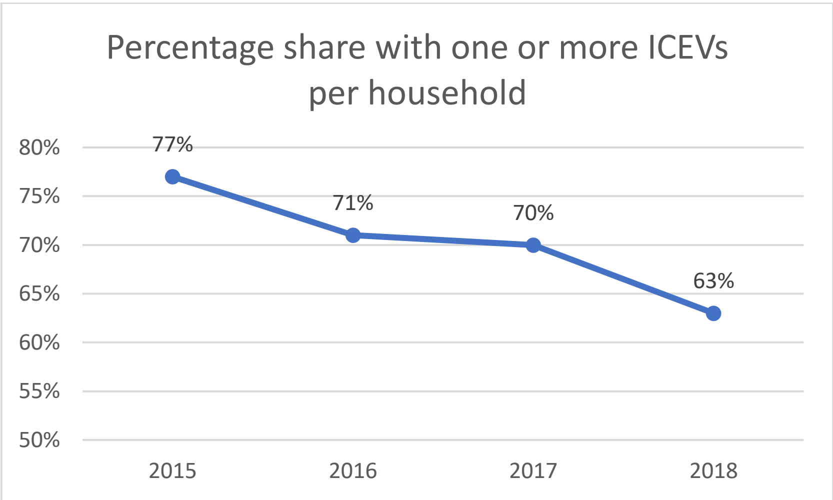

Figure 4 - Percentage share of households with one or more ICEVs (source: NEVA survey 2018)

One other noticeable evolution in public consumer trust on EV is the amount of people that recognise that an EV is qualified to drive for quite long distances. Figure 5 presents the evolution of people that used their EV for holiday trips, with at least one overnight stay.

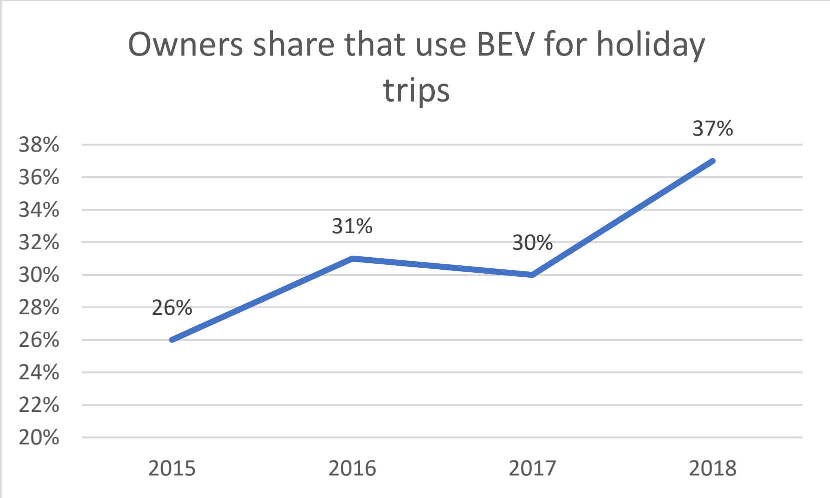

Figure 5 - Owners that use their EV for holiday trips with at least one night over (Source: NEVA survey 2018)

Only 4% of the respondents claim to use an ICEV on a daily basis, while 82% use their BEV. The main reasons for not using the BEV when needed are Range, Need of a towing hitch and few charging possibilities. This result could show opportunity to the EV market, since only one EV model has been certified to tow trailers so far.

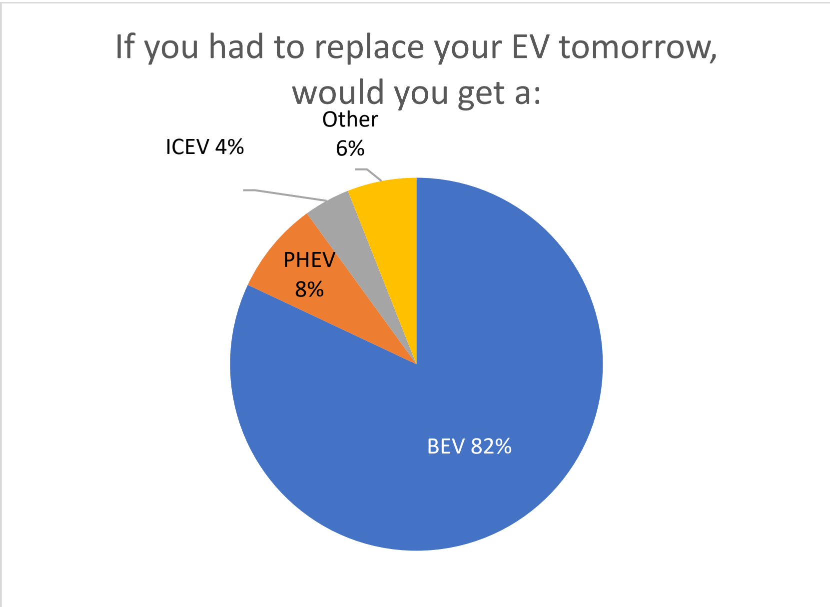

Figure 6 - Answers to the question "If you had to replace your EV tomorrow, you would get a:" (Source: NEVA survey 2018)

The main reasons chosen by users to buy their BEV are Low operating costs, free toll roads and environmentally friendliness of EVs.

Only 3% of the users have run out of power in their batteries for the last year with almost half of those cases being explained by the loss of range due to cold temperatures.

When asked if they had to replace their current EV, 82% responded they would replace the current EV with another EV as represented in figure 6. This response leaves room to improvement, but it is quite significant that only 4% would choose an ICEV after having some experience with an EV. This value could have been lower if a time or usage limit was set so to exclude answers from users that are not familiar with the routines of an EV.

2.3.3. People's Republic of China

China's automotive industry is the largest in the world, and the growth potential is enormous. Comparing with the average developed country of over 500 vehicles, China's car ownership was 125 per thousand habitants [34] in 2015 while the worlds average is was 183.

With the largest population on earth, China has a big issue with environmental pressure that 1400 million people create in their territory. In 2017 almost 60% of the population lived in urban areas[2], where pollution is much more concentrated. This has created several problems, particularly with air quality. Forbes[3] has published that Shanghai, Beijing and Guangzhou are all on the top 10 of most polluted cities. China is trying to lower pollution by incentivizing electric vehicles, lowering the exhaust emissions on urban centres.

In [35], the authors say that an EV is more polluting in the production phase, which can be lowered by further advances in the battery technologies and development of steel recycling industry in China which has almost been inexistent. Wang talks about the incentives and the interest of the government in dropping emissions [34]. The authors analyse the importance of each incentive given to thrust the EV market and conclude that charging infrastructure is one of the great delays on China's market, mainly because people cannot easily charge their vehicles in private areas. In 2019, the same author in [36] studies scenarios with different policy to propel EV market, and [37] studies the effect that dual-credit policy has on the adoption of electric vehicles in different regions of China. This policy is based on attributing credits to manufacturers who produce (1) fuel efficient vehicles and (2) purely electric vehicles.

The authors of [38] studied, in 2014, the problems found in the development of an EV market even with subsidies and other incentives. The conclusions were pessimist and very unclear about the near future of EV in China. In 2016 the same authors wrote [39] in which they explained why the sales rose in such way that turned possible to fulfil the goal of 5 million EVs on the Chinese roads by 2020. They explain that even though EVs are being sold, the real numbers might be lower than announced due to possible large-scale fraud caused by some monetary incentives given directly to manufacturers instead of the final costumer.

The discussion about EV penetration in China, a rising star in this market, only makes sense if preceded by analysing China's electrical generation. China is the bigger coal producer and importer on the planet, with no exportations. China's consumption is more than 48% of the global value and a big part of this goes to the energy sector [40]. The electricity generation depends 65.5% on coal generation. The persistence on coal can be

[2]*Source: http://www.stats.gov.cn/tjsj/ndsj/2018/indexeh.htm*
[3]*Source: https://www.forbes.com/sites/jamesconca/2018/08/23/the-ten-most-polluted-cities-on-earth/#2b90be8218cc*

explained by the large national production and the still expanding electrical demand. Feed-in tariffs for coal power plants are enforced differently onto each province. Some tariffs were created in the last 15 years to incentivize power plants that produce less harmful exhaust gases [41].

Even with surprising results on renewable installed power, the electrical grid emits too much GHG for EVs to be a better alternative to ICEVs. In [12] the authors analyse the impacts of EV deployment, and conclude that for now the electrification of fleet is not globally beneficial in terms of GHG, but it should not be discouraged because the electrical grid is evolving to a less emitting one, but also because decentralizing emissions can be crucial in some urban areas of China where air pollution is above danger levels. The authors of [17] did an overall similar study for fuel cell vehicles with similar conclusions. The electric grid is still too carbonated for a decrease in global emissions from EVs.

In [42] the authors notice some big differences in the interest for EV technologies between China and the United States of America. When asked, Chinese potential buyers have more tendency to choose a BEV than USA's. The demographics between potential buyers in these two countries is also very different, in USA only 1.3% of first-time buyers were found, against almost 60% in China. Age and education degree are higher in the USA. In China the social status from buying an expensive vehicle is more relevant, which gives a small advantage to BEVs which are usually more expensive than the comparable ICEV. In Chinese urban areas there are several limitations to licensing plates, due to excessive traffic. As an incentive, local governments from bigger cities are highly facilitating the plate licencing for New Energy Vehicles, thus making much easier to get authorization to buy a vehicle if it is a BEV/PHEV.

2.4. Surveys done in different studies

Electric vehicles have existed for over a century, but their presence in the markets have only been significant after 2010 when several manufacturers started to present new models. Since late XIX century (when the first lead-battery electric vehicles were sold to public [43]) the technology and infrastructure has evolved quite substantially.

Beginning in 2010 the electric vehicle has started to become quite popular and thus EV market has grown considerably. The entrance of Nissan's Leaf in 2010 in the markets has shown the public that manufacturers could have great interest in stepping back from oil dependent vehicles. Both governments and manufacturers seem to have some interest in disseminating electric vehicles and demonstrate the average driver that an EV can not only decrease human impact on the environment but also be economically favourable to the owner. As public acceptance of EVs has shown to be quite demanding, it is crucial that public's opinion is understood and studied by the manufacturers and governments.

Being a new market, there are several commercial, governmental and academic interests in studying and understanding its evolution. A good way to understand public's perspective on EVs is by conducting surveys. As this report includes a survey directed to Portuguese EV drivers, some other surveys were then previously studied to better understand (1) how could the survey be correctly conducted and (2) what knowledge was at fault in this area.

The article [44] studies the behaviour and experience of the user during a 6-month period in which they were given an EV to drive on a daily basis. Being an extensive study, the information to collect would be higher than a regular survey to capture the public's opinion on EV, and so, this study made three different information collecting periods (beginning, middle and end of the experience). Not only the participants would have an interview, answering questionnaires but they would also have to keep record of their involvement by keeping a travel and charging diary for small parts of the 6-month period. The travel diary should include all trips the user would have done, even if another transportation mode were used to better understand how the EV has been used and what for. The charging diary kept by the vehicle itself, only registered charges after an adaptation period to the car and the charging systems. The questionnaires used a 6-point Likert scale to evaluate how comfortable the driver was with the state-of-charge of the battery in different situations and when he planned to charge. Main conclusions from direct participants' answers were:

- The amount of people that considers public charging structure indispensable decreased from 86% to 62%, after adaptation time
- Most people (87%) thought the charging process was easy
- 78% of participants were not distressed by the increase in charging time, when comparing with an ICEV

In [42] the authors compare surveys run both in the United States of America and in China. The questionnaires were directed to people looking for a new vehicle, with no a priori selection for EV or ICEV. The intention was to understand how deeply the participants were considering buying an EV and their willingness to pay for these vehicles, when comparing with a traditional one. This survey was conducted by presenting descripted options for the respondent to choose between those options. The aesthetics of the vehicles were put out of the picture, by presenting the same image for all options available, this way the authors were able to evaluate only quantifiable and directly comparable criteria. The objective was to give participants near real life choices of different vehicles with realistic prices and specifications. One important aspect of the construction of this survey is to limit possible argumentation of the respondent, by leaving no grey areas. The respondent should always understand what is being asked, but also the train of thought conceived with the questions should always be approached in the answers. The authors also briefly explain a couple of exclusion criteria to prevent non-relevant answers for example of people who are not paying enough attention or do not fully understand the questions.

3. Case study of Portugal

Portugal is a very good candidate for an early expansion of the EV market. The electrical grid is responsible for quite low emissions when comparing with the rest of the world due to high power installed in renewables [9]. Portugal has an extensive quantity of hydropower plants throughout the territory but also, several investments were made in the past 20 years in wind power. Wind power plants are very useful in the Portuguese case because these have their production peak hours during demand's valleys (night time). This energy is usually consumed in some hydropower plants that are able to pump water back upstream. This pumped hydropower system can be used as an energy storage system, but is also important to manage water storage, since Portugal has a dry season with very low precipitation that lasts for 6 months or more. The dry season and the geographic location of Portugal also mean that these renewables can have a broad spectrum of functioning. For example, in figure 7 it is noticeable that the emissions rise almost 65% from 2016 to 2017 which is explained by a low precipitation resulting in a dry year. The variability of renewables is high, and the effects can be instantaneous (Photovoltaics and Wind) or tenacious (Hydropower). Further investment in a broad spectrum of renewables should lower instability of each renewable source.

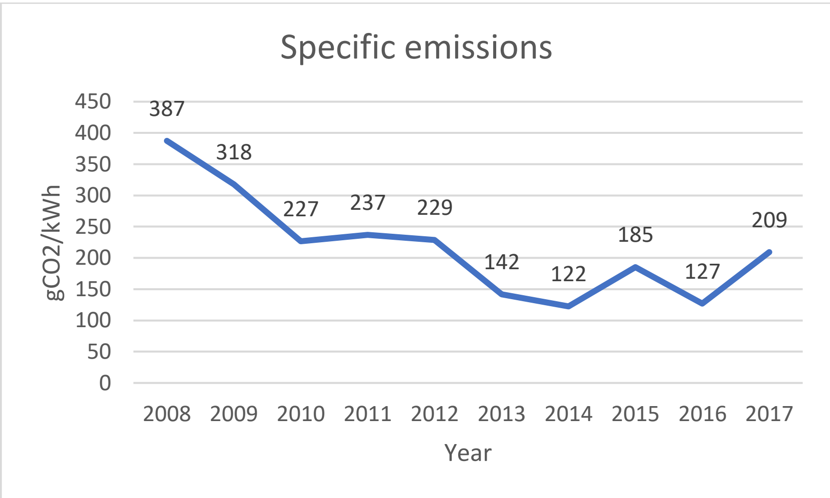

Figure 7 - Specific emissions from Portuguese electrical generation grid (Source: EDP)

The EV market has started to be significant in Portugal in 2010 just like in many other developed countries chosen to launch EV models. In figure 8 we can see the evolution of EV models in Portugal. Starting 2017 Tesla has entered the Portuguese market and from then on, the market has kept expanding.

Incentivizing the end user has been the main strategy for Portugal, in contrast with the early Chinese strategy of incentivizing the manufacturers. The nation's incentives to those who prefer an EV when buying a vehicle are:

I. 3000€ for the first 1000 PEVs of each year for individual buyers and 2,250€ for companies, in vehicles that cost less than 62.500€
II. Automobile tax (ISV) exemption for BEV and discount for HEV

III. Exemption of circulation tax (IUC) for BEV
IV. Exemption in value added tax for companies (IVA of 23%)
V. Free public slow and medium charging (up to 22kW)

As public's acceptance and knowledge on EVs is growing, the registered growth in sales is increasing every year and so, the government understands that incentives are lesser needed to keep public buyer interested in personal vehicle electrification.

Due to rising acceptance and pricier models, in the beginning of 2019 Portugal has limited the subsidies given when buying a new EV by their price. Vehicles more expensive than 62.500€ do not receive the financial incentive from the government when buying an EV for being considered luxury vehicles. Since Tesla vehicles are considerably more expensive in Portugal than others in the market, most models cannot claim the subsidy.

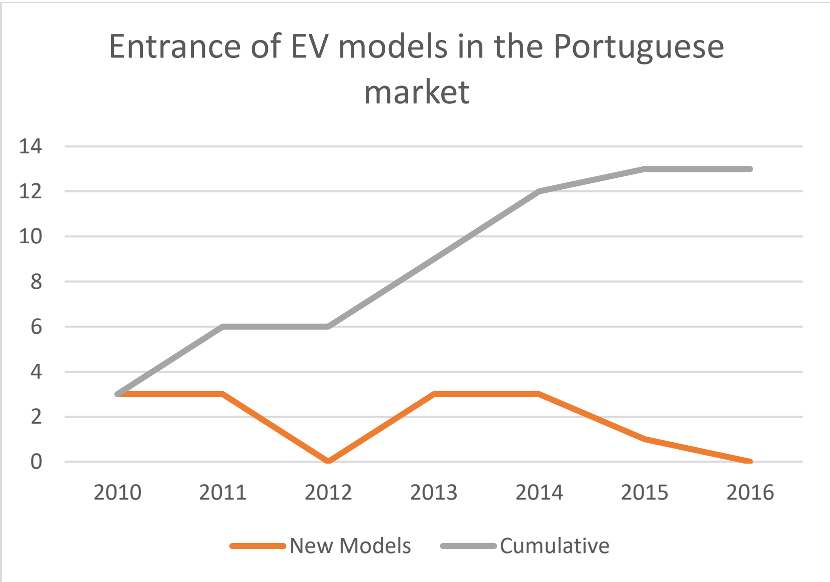

Figure 8 - Portuguese EV market evolution concerning existing models. Both new models and total electric models are shown (Source: ACAP)

3.1. Description of Portuguese charging system

Starting in 2011, Portugal has structured its charging structure by creating the market regulator which attributes licences to 1) built and operate charging structure (OPC – Operador de Posto de Carregamento), and 2) sell energy through charging terminals (CEME – Comercializadores de Eletricidade para Mobillidade Elétrica). As in many other countries, the main investor for this structure is the regulator, which is a public company. The Portuguese regulator has around 560 charging stations to date, 60 of which are fast charging stations, and until end of 2018 they were all free of charge, in an effort to incentivize public's acceptance on EVs.

In November 2018, fast charging points started to be paid and managed by energy traders (CEME licence owners) with different pricing strategies. There are around 10 energy traders currently exploring fast charging points with several others that are qualified to do so but are not running any charging station yet. The remaining 500 charging points are still free to charge as an incentive for new users.

The Portuguese system's evolution is very similar with other countries' with a developing EV market: charging has been free for several years, and for the last few years, governments have slowed down the incentives, including removing the free charging which indicates maturity from the structure and sufficient user number for profitability of the charging grid.

3.2. Present survey

3.2.1. Characteristics of the survey

In November 2018, a survey was conducted to support this thesis. The questionnaire was presented to EV owners in Portugal. Google Forms was used as a platform for the questionnaire which was presented to EV owners throughout specific web-based forums for EV owners. The spreading of the survey was carefully made since it was desired that only owners would answer, and most forums for this subject contain a high quantity of people that do not own an EV but are interested in the subject from which many of them might be near future buyers. The aim of this survey is to gather information about the demographics and behaviour of the Portuguese EV owner and its perspective and opinions on the current state of the charging structure. The survey is present in Annex I just as it was presented to the EV user.

This survey was shared with the EV community in early November of 2018, when the public fast charging stations started to be paid and explored by energy traders. Since it was too recent for respondents to have well-formed opinions, no questions were included in the survey concerning these changes.

Considering previously studied surveys, there was an attempt to create ways to filter out people who may have not understood the questions asked or did not pay enough attention to the questionnaire. In ref [40] the authors created specific questions that allowed filtering for not understanding the question if certain answers were given. In this same study the inquire was timed and if the process was too quick, it meant that the thinking and answering could have been compromised and those answers were not considered.

Google Forms do not allow time count for responding questionnaires, so there was an initial idea of excluding people who have driven less than 10.000km due to a lack of fully developed charging habits and structured opinions on public charging structure. The question "How many km does your EV have?" was included in the survey, but no respondent was excluded from it. Since EV is usually driven inside urban areas where you might take quite some time to cover 10.000 km, but all in all the distance driven is usually very short leading to the possibility of people with low distances driven but with matured charging habits. From the total 64 valid and complete responses, no filtering was made.

The survey conducted in this academic work is compared with the one that the Norwegian Electric Vehicle Association (NEVA) does yearly together with Norwegian EV owners. The Norwegian questionnaire is not conducted only to associates but to everyone that owns an EV, to achieve a higher response rate. The reason for this comparison is the maturity of the Norwegian market that has no match anywhere else responsible for a very high quantity of EV owners and thus, respondents to the questionnaire.

3.2.2. Results

3.2.2.1. Demographics

There are several studies made that confirm that the demographics of New Energy Vehicles is not uniform across the population [16,33,42,44,45]. Table 2 presents a comparison in demographic parameters between NEVA's survey and the one conducted for this work in Portugal. The Norwegian results are from the 2018's yearly survey conducted with users that own at least one EV (not exclusively members of the association). The only parameter not measured by the Norwegian association in 2018 is the income of the EV owner. In [45] the authors use the results from the NEVA survey from 2014 to better understand the EV owner population and their decisions comparing it with new vehicle owners. This allows a comparison with new EV owners and new ICE/PHEV owners. The authors correlate the EV buyer with high income due to high prices of these vehicles and lower price sensitivity with new technologies. This study has shown that only 37% of EV users have incomes lower than 56,000€ (550,000 NOK), while for new vehicle users 60% have incomes lower than that same value, showing a very noticeable difference for EV new owners. A representation of Portuguese income is represented in figure 9 in which is noticeable that the majority of buyers receive less than 50k€.

Table 2 - Demographic comparison of the Portuguese and Norwegian 2018 and 2014 results (Source: NEVA and [45])

Education	**NEVA survey 2018**	**NEVA survey 2014**	**Portuguese Survey**
Superior Education	75.00%	76.00%	75.00%
Gender			
Male	76.00%	81.00%	90.63%
Female	24.00%	19.00%	9.38%
Age			
Higher than 44	60.00%	47.00%	
Higher than 40			62.50%
Income			
Higher than 50k€		63.00%	
Higher than 30k€			59.38%

The survey presented in this thesis reports 75% of superior education in the Portuguese EV population, which is the same value for Norwegian respondents in 2018. A majority of male users is noted, higher than Norwegian that has a more mature market. The Norwegian market itself has been evolving to a more even gender distribution. The majority of owners is aged higher than 40 or 44 respectively for Portugal and Norway.

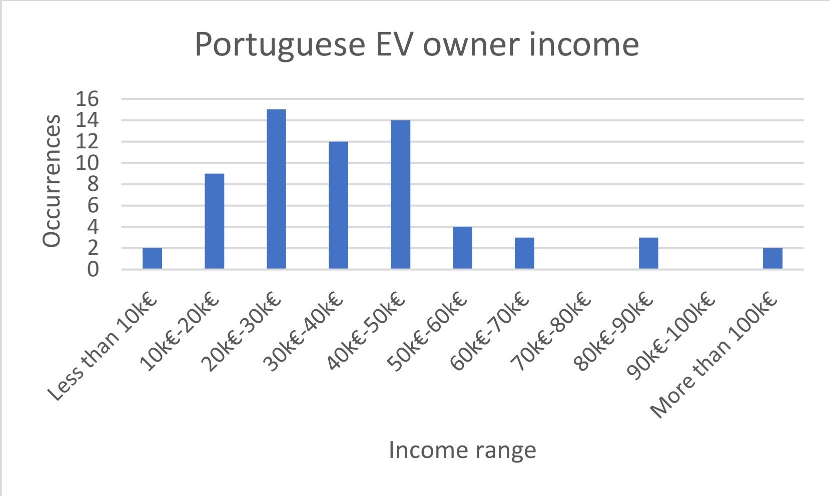

Figure 9 - Income distribution of the Portuguese EV owner

Regarding income, only 18.75% of the Portuguese respondents earn more than 50k€ per year which is considerably lower than the Norwegian number of 63% earning more than 56k€ per year. Since both countries have such a different purchase power parity, the average income for the Portuguese EV owner is found at around 35k€ which is 4 times higher than the national's minimum wage. According with OCDE values[4], the Portuguese and Norwegian average incomes are close to 30.000€ and 50.000€ respectively which lead to closer shares in EV users as seen in table 2, confirming the idea that the regular EV owner tends to have higher income.

The sectorization of EV buyers by age and education can be explained by the difference in income with younger and less educated people. Any private vehicle is seen as quite an investment in Portugal, and the electric ones still have higher initial costs when compared with an equivalent thermal vehicle. Higher education might lead to higher conscientization for environmental issues and willingness to pay for technologies that might decrease pollution.

3.2.2.2. Structure perspective

A user that already has habits and routines of charging its EV, does not fully depend on the public charging infrastructure. A large charging load should be fulfilled through a home charger box or even a regular socket. The low prices of home charging are an important factor for the user since it allows much cheaper price per kilometre driven if comparing with the predominant technology. More distant routines may require charging at work, but as NEVA's survey shows, only 11% of the inquiries drive more than 100km/day and 28% of people charge their vehicle more than once a day. This shows that either the vehicles used in Norway have relatively low autonomies or that people charge their vehicles even with medium-high state of charge. Recent models have autonomies higher than these values allowing drivers with more than 100km/day to charge every two or three days.

[4] Source: https://data.oecd.org/natincome/net-national-income.htm

This is very much representative of the larger Portuguese urban areas (Lisbon and Porto), where the commute is relatively short. The average distance per drive is approximately 20km and the total daily driven distance is 60km [46] and so there is not a daily need of charge for recent models.

The questionnaire run for the present thesis has revealed that 69% of EV users have installed some kind of home charging device, with 45.5% of those using it on a daily basis. Only one out of 44 respondents have claimed not to be satisfied with its home charging device. From the respondents that have not acquired a home charger, 70% have not even considered it when buying the EV, suggesting lack of information from the salespeople, manufacturers or EV associations. Main reasons for not buying a home charger were 1) the ability to charge with a regular socket, (2) high price of the device and/or installation and (3) 20% of them answered that they were able to charge their vehicles out of their homes. This means that 4 out of 64 people rely only on public charging structure for their charging needs.

It has been found that 80% of the Portuguese owner takes advantage of home charging at least every 3 days, with almost 50% using it daily. In figure 10 it is presented the distribution of home charging frequency.

Concerning the public structure, 49% of the respondents have claimed to use a charging station at least once a week. 81% claims to charge in different stations and the main reasons for that are 1) different daily routes, 2) already occupied stations by EVs and non-EVs and 33% justify 3) with faulty equipment. Figure 11 presents the distribution of public charging frequency from Portuguese owners.

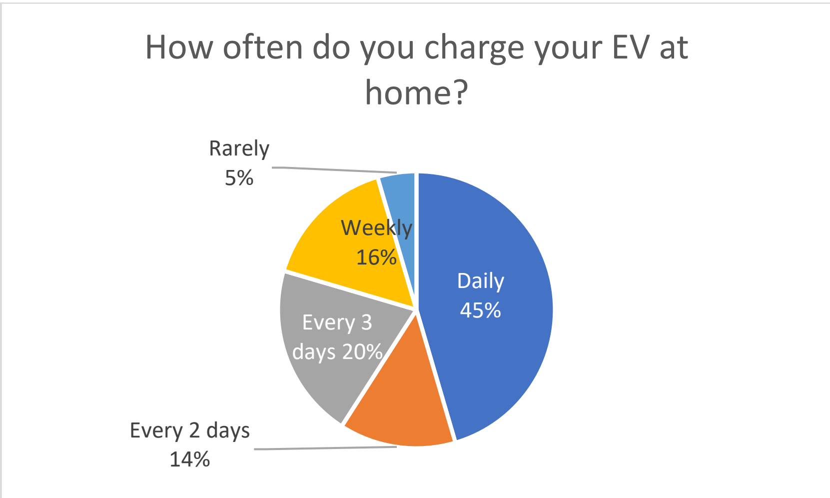

Figure 10 - Answers to the question "How often do you charge your EV at home?"

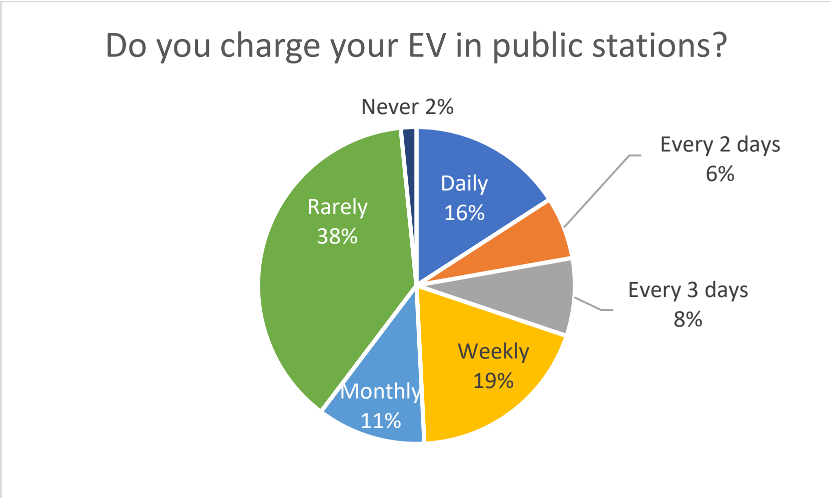

Figure 11 - Answers to the question "Do you charge your EV in public stations?"

When asked about their general opinion on the public's charging structure most respondents answered that the structure's performance was either poor or very poor. The possible answers proposed simulated a 4-point Likert scale {Very Good, Good, Poor, Very Poor} with a more specification for the grid's case. The proposed answers were respectively "Well functioning, despite some occasional issues explained by the novelty of the structure", "Relatively well functioning. Most of the grid works well even though there are some chronic problems in some stations", "Poor functioning, several stations with problems" and "Very poor function with too many problems in working stations and/or stations permanently non-functional". In figure 12 the distribution of answers to the question "What is your opinion on the performance of the charging structure?" are presented.

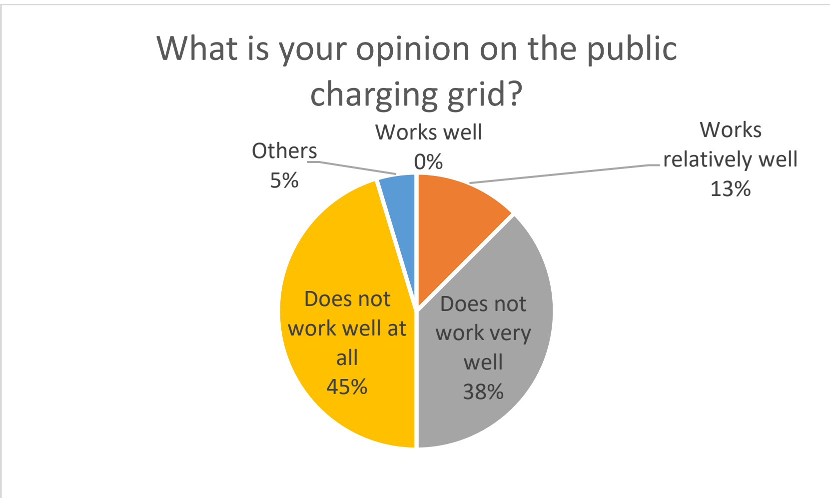

Figure 12 - Answers to the question "What is your opinion on the public charging grid?"

The results from such question are alarming with only 13% of people answering the equivalent of "Good" performance, with zero respondents selecting "Very Good" equivalent as an answer. Almost half of the users answered the equivalent of "Very Poor" performance, the worse possible choice.

When asked about the future end of free charging, only 2 out of 62 people felt misrepresented, while 42% of respondents felt anxious for the free charging to end believing that the grid's problems will decrease but also, paid charging shows maturity from the EV market.

When confronted to the question "Would you be interested in using your EV to support the electrical grid by selling energy during peak hours at higher prices than you have bought it?" only 19% answered No, while the rest has rest answered either Yes or Maybe.

3.2.3. Discussion

The literature points a bundle of different reasons for most effective incentives for EV adoption. As authors in ref [7,35] conclude, a properly developed charging structure is one of the strongest reasons for public's acceptance of the EV which means that an abundance of functioning well spread-out stations is needed so the potential buyer can have confidence in the EV market's future and consider it when choosing a vehicle to buy.

The slow adoption of EV market can be related with the lack of belief in its future development and the expectation of huge future development of technologies related with EV, that could bring the users' behaviour closer to the ICEV's.

Normal (slow and semi fast) charging structure has different importance than fast charging structure. It is important to study these separately for understanding the roles of such charging stations.

The existence of fast charging stations (higher than 22kW) is key and its spreading must be very well planned. The high price of these stations compared with regular chargers, constrain its dissemination. These chargers not only are much pricier but also require much higher power from the grid for lower time periods each use, making them more uncomfortable to control from the electrical grid's perspective. Their importance is to establish and maintain a connection between places that are far away enough for the average EV to drive it without charging.

Regular charging points (up to 22kW) are required in different places. These should be placed in amenities or parking areas where the users might leave their vehicles parked for quite some time. Regular charging points should be in urban areas whereas fast charging points are indispensable in highways. It should not be comprehended that a fast charging station has no place in densely urbanized areas, but that their importance goes beyond that.

For example, Portugal has planned to link north with south using roadways for EVs. A trip of Porto-Lisbon is around 300km which is approximately the same as Lisbon-Faro. Most EV's are not capable of doing this trip without charging and this is where the fast charging stations come convenient, because the driver can charge the vehicle for a short time with good charging rates. Some manufacturers claim 60 to 80% in an hour of fast charging which is quite faster than what regular charging can offer although it is still very far away from filling up a fuel tank. In Portugal all fast stations have 50kW, but there are companies that already produce stations able to charge up to 350kW with several chargers operational obviously with much quicker charging times.

One possible issue with fast charging is the vehicle's possibility of accepting such cables and such power. Some vehicles (mostly models with lower capacity batteries) cannot connect with a fast charging station due to cable incompatibility. It also should be considered that fast charging and discharging increases battery's temperature and owners of vehicles without active temperature control for their batteries should be prudent when using these chargers. High speed charges are responsible for heating the battery which is very closely correlated with battery ageing [47–49].

Survey's answers about home charging suggested that the manufacturers of such devices should be symbiosed with vehicle manufacturers or take advantage of EV associations to spread information. It is not worrying that only 69% of EV owners have home charging devices, but it is worrying that 70% of those who have not acquired one have not even considered home charging as a solution. The acknowledgement of home charging as an answer for most charging needs should be more generic. Home charging allows the lowest prices and long charges during the night that might help the electrical distribution grid.

Some accidents have happened during vehicle home charges without proper equipment. NEVA's survey report that 5% of respondents have experienced burnt sockets which represents a dangerous fire hazard and 27% have experienced their fuse going off. It is important that the user is informed and understands that the power and energy that a vehicle requires does not make it comparable with any household appliance. The user should understand that without proper equipment and installation, the regular socket might not be completely safe to use as a charging point. Since most people leave their vehicles to charge overnight while sleeping, the fire hazard is even more dangerous due to a long reaction time in case of an actual electrical fire.

It seems acceptable that people are not sure about using their battery packs to sell energy back to the grid since this subject yet needs more studying. Even though the user can make a direct profit from selling energy at peak hours, the cost of the battery charging cycle is not considered in these situations thus making it hard to concisely evaluate the benefits for the user. It is very important that the owner of the vehicle is benefited from this behaviour to incentivize this useful electrical support. Without any benefit for the user, like profit, such system will not get adopted.

It is a positive sign that these many users (66%) are willing to consider selling energy from their vehicle's batteries since the usage of EVs to supply energy during peaks and fill the valleys of the daily energy demand has high potential to integrate renewable production in a more consistent way and help control grid's parameters.

The results here discussed are as valid and representative of the Portuguese market as the questionnaire. To ensure representativity, there were collected a significant amount of valid (complete) answer sets (n=64). The sample collected was totally random without any filtering of answers received, and it was given total freedom to the inquires to answer or not the questions when presented to them. All complete sets of answers (without unanswered questions) were accepted. The representativity of the collected sample is suggested by the demographic similarities between resultant from the survey here presented and the one used as reference which represents the largest EV association in the world.

4. Carbon Assessment

4.1. Background

The European Council has announced in 2011 [4] that to reach EU's objective of minimizing climate change to a temperature rise of 2ºC, the European Union's GHG emissions would have to decrease 80%-95% from the 1990 values by 2050. This plan would include the effort needed to decrease global emissions in 50% by 2050, accounting the impact of developing countries which are presently the ones with higher potential to increase their emissions and emit the most.

The emissions from EVs are generally considered null due to the inexistence of exhaust gases. This approximation might be acceptable for small scale studies that account only local pollution. Even in these cases, the electric production must be far enough away from the considered areas, so the pollution levels are not considerably affected by the electricity generation. Electric vehicles have pollutant emissions as long as electric production and distribution is not 100% emissions free.

Since emission limits are created based on a tank-to-wheel model, car manufacturers announce their electric vehicle's emissions as zero, keeping the same line of thought. For a better understanding of the emissions of an EV, a life cycle assessment has to be considered. A life cycle assessment considers 3 main stages of the vehicle's life: production, usage and disposal.

The production period of an EV is quite comparable to the ICEV's. The main differences reside on the powertrain and the large battery packs existing in the electric vehicle. Manufacturing a combustion engine is different than an electric motor and the cables used to connect such motor to battery are substantial. In [50] the authors make a very complete review on what has been studied on this field and conclude that the differences in the production phase are neglectable due to the major differences in the utilization phase. In [51] the authors conclude that the environmental impact of the battery of an EV accounts for 7 to 15% of the total vehicle's production. The extra components surrounding the battery (steel box, cabling, wiring boards) sum up to more than 20% of the impact, depending on the assessment method. The authors also conclude that the usage phase creates much more impact than the differences in the production phase.

The utilization period of the vehicle can be considered emissions free (just like manufacturers announce) if only tank-to-wheel is considered. Considering Well-to-Wheel, the emissions from the electrical generation and distribution must be considered. To understand the impact of this phase the duration of it has to be defined just like the emissions from the electrical generation. In [51], Notter studies the difference in hard coal power generation and hydropower concluding an increase of 13.4% or a decrease of 40.2% to the ICEV emissions. The duration of the vehicles used is the expected lifetime, for which it might use more than one battery packs (in ref [51] it uses 2). In [50] it is concluded that for coal power generation, only high-efficiency ICEVs perform better than BEVs, while the average ICEV is still more polluting than the electric competitor.

When considering disposal of vehicles, the spotlight comes down to the battery pack just like in production phase. Since most of the vehicle is made from the same plastics and materials, only the powertrain and battery pack differ from one to another. The evolution of batteries in vehicles has allowed much higher power and energy densities. Three main battery technologies have been used in car manufacturing: lead-acid battery used in ICEVs to power the starting motor, Nickel-metal hydride and lithium ion popularized in hybrid and pure electric vehicles, respectively. As batteries evolved, their structures turned more complex making it harder to recycle.

Lithium-ion batteries not only have a much wider range of materials in their composition, but these materials are not standardized, meaning that the cathodes are made from different materials, depending on manufacturer's preference. In [52], authors propose four changes in the battery recycling industry that would facilitate and incentivize Li-ion processing: 1) Separation of technology by labelling the devices and making different processing lines for each kind of battery; 2) developing cathode separation methods; 3) battery standardization; 4) well-built regulations. The authors also recognise that the current lack of lithium ion batteries in end-of-life state does not boost the recycling industry. In [24] the same author concludes that recycling of Li-ion batteries is still complicated due to the complexity of the device but also the diversity in possible materials. Standardization and design to recycle would facilitate the end-of-life recovery and recycling. The interest will increase as batteries evolution slows down and production and disposal of devices rise. In [53] the authors claim savings of up to 51.3%, 70% and 70% for virgin materials, energy and CO_2 emissions respectively if manufacturing Li-ion batteries depends on recycled products. The main problems with recycling these batteries are uncertainty of their future composition and the economic feasibility of the recycling process. The technologies associated with recycling Li-ion batteries are still expected to evolve in future years when a large number of vehicles reach end-of-life stage.

As part of the European effort, Portugal has developed its plan to change the various economic sectors to a more sustainable evolution. These plans are based in three different scenarios that have different degrees of adaptation to a more sustainable economy. The scenarios used by the Portuguese Environment Agency are described as follows:

The first scenario represents the worst-case scenario in which the adaptation level is very low, and economic evolution exists only due to the need of replacing outdated and defective technologies, meaning that changes are pushed by the need of replacement.

Second scenario represents a case in which the Portuguese economy simply follows the European trend without any major innovations but is able to change its economy to a slightly more sustainable one.

Third scenario pictures Portugal as an innovator. This is the best-case scenario presented, proposing all the best changes to a sustainable economy reaching the wanted results to prevent major climate changes.

In this thesis a carbon emissions assessment has been put together to understand how profoundly emissions would change on the transportation sector with the proposed changes by the RNC 2050. The evolution of electricity generation is considered for more accurate results. The objective from this emission's assessment is to understand what will change in Portuguese economy to adapt its transports to a low carbon scenario and what will be the course of evolution of the electric vehicle charging structure.

Predictively, the first and third scenarios propose the best and the worst conducts for the development on both the transportation and energetic sector. The first scenario proposes very low adoption on EV and passive transportation. The energetic generation does not change significantly in this scenario and so, the future emissions are considered as todays. The third scenario plans for a total electrification on private light passenger vehicles and a decrease on GHG emissions from electric generation of 98% by 2050.

In the course of the emissions assessment, two scenarios based on the ones presented in RNC 2050 are going to be used, namely the first scenario representing "Business as Usual" and the third which is characterized by "Sustainable Development" which will be the names given to each scenario.

4.2. Proposed Model

Using RNC 2050, some changes can be predicted in the transportation and energy like the increasing share of circulating EVs and the decrease of the specific carbon emissions for the generation. The Portuguese Environment Agency (APA) developed the RNC 2050 in which predicts that by 2050, 100% of the Portuguese light passenger fleet will be electric, and the electricity generation is responsible for -98% of GHG emissions, considering 2005's values. These improvements on the economy are considered for the "Sustainable Development" scenario. Table 3 represents a more complete set of the goals set in the RNC 2050.

Table 3 - RNC 2050 goals for the transportation and energy sectors (Source: RNC 2050)

Year	2020	2030	2040	2050
Electrification of private passenger vehicles		33.3%		100%
GHG Reduction on Electric Generation	-38%	-83%/-84%	-93%/-94%	-98%

To complete the assessment, the 2020 EV share is 1% and for 2040, a linearization with values from 2030 and 2050 led to 66.66%.

For the "Business as Usual" scenario, the electrical generation will remain as carbonised as it was in 2016 while the EV share is chosen to be a third of the high adoption scenario reaching only 33.33% in 2050.

With these two scenarios it will be possible to understand what will be needed from the electrical structure to power these vehicles, but also the change in emissions. The totality of emissions is considered for both the EVs and the ICEVs present in the fleet until 2050.

To understand the vehicle impact on atmosphere, the number of vehicles running in Portugal is accounted by the Portuguese Association of Vehicle Commerce (ACAP) [54] which shows the evolution of private light passenger vehicle in the country since 1974. The total Portuguese fleet has grown almost 700% from 1974 to 2016, with neglectable number of electric vehicles. In 2016 the considered vehicle count is approximately 460 per thousand people. Only light passenger vehicles were considered since these are expected to be the easiest and first segment to replace the ICE transmission due to lighter weight and shorter routes. ACAP's report not only has the count of active vehicles but also the yearly sales which will be useful to structure a couple of scenarios of EV adoption.

As shown in figure 13, the light passenger fleet has shown positive growth although very low for the last 8 years, with growths of less than 1% most years or even decreasing fleet numbers for 2012 and 2013. It is very important that the evolution of the number of vehicles is understood to reach reliable results. In face of the past evolution, trendlines were calculated both linearly and quadratically for a broader range of results, using the past data of the Portuguese fleet from 1990 to 2016.

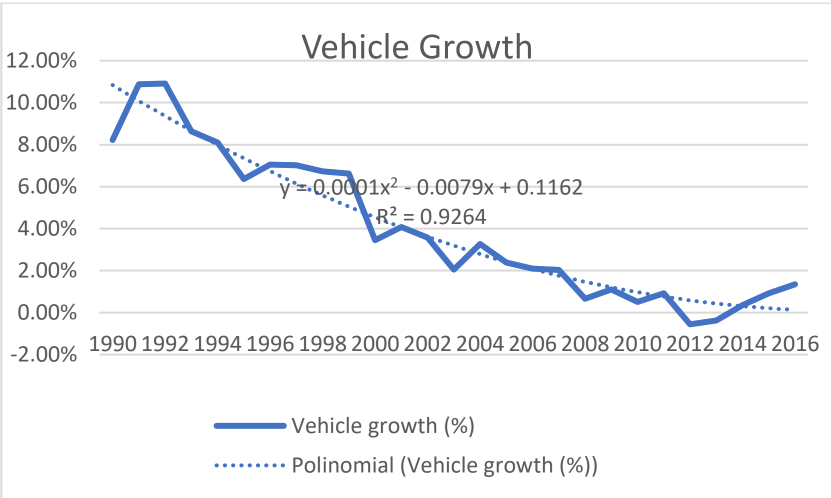

Figure 13 - Vehicle Growth in Portugal with Quadratic trendline

Although a prediction of the evolution of the Portuguese fleet numbers is made, the results should be looked at with high criticism due to an upcoming change of paradigm on private transportation in which Portugal may be part of. The electrification of vehicles may help push this perspective that the private vehicle is still needed but, in less situations, and because of that, owning a car is not always the best option. Renting, sharing, leasing vehicles, together with a boarder spectrum of transportation options decreases the need of reliance in owning a vehicle. For this reason, and since Portugal already has reached 560 cars per thousand habitants, a value close to most developed countries, the continuous increase of vehicle number might be unrealistic. Using linear and quadratic trendlines, the resulting changes in the fleet are -15% and 10% for 2050, respectively. The linear trendline might represent the development of the described decrease in car ownership while the polynomial might represent a more business as usual case.

The first stages of EV spreading are occurring in the urban areas not only due to a better charging structure support but also driven distances. Usually urban population has shorter commutes, even though might spend longer periods in traffic. For this reason, the yearly distances driven per vehicle considered in this study are reported in [46] which has found the distances driven and the number of trips per day in urban areas in 2017. The distances driven are expected to have increased over the years, and so, for conservatism the distances found for 2017 are considered for the whole period of this study.

For the electric vehicle, the efficiencies were taken from the two most popular models in Portugal (Leaf and Zoe) and averaged [55]. These vehicles charge in the Portuguese electrical grid. The emissions from electrical production and distribution in Portugal were collected from IEA's website.

Just like the considered efficiency from EVs is the average of the two most sold models in Portugal, the emissions from ICEV for the next 30 years is considered the average of four representative models chosen by their efficient engines: Ford Ka+, Toyota Aygo, Volkswagen UP! and Renault Clio. The last model is the most sold in the country and its emissions are higher, but close to the rest of the chosen models allowing some room for further development on engine efficiency.

4.3. Results

The results from the carbonic assessment from "Business as Usual" and "Sustainable Development" are present in tables 4 and 5, respectively. These tables represent the evolution of emissions for the decades of 2020 until 2050. The baseline set is the emission values from 2005 since it is the base for the European goal to decrease emissions.

Table 4 – Carbonic Assessment from "Business as Usual" scenario with linear and quadratic fleet evolution

	Emissions (kton CO_2)		**Reduction from 2005**	
Year	Linear	Quadratic	Linear	Quadratic
2005	9795.69		-	
2020	4986.58	4961.40	-49.09%	-49.35%
2030	4384.60	4672.76	-55.24%	-52.30%
2040	3817.15	4448.97	-61.03%	-54.58%
2050	3284.21	4264.79	-66.47%	-56.46%

Table 5 – Carbonic Assessment from "Sustainable Development" scenario with linear and quadratic fleet evolution

	Emissions (kton CO_2)		**Reduction from 2005**	
Year	Linear	Quadratic	Linear	Quadratic
2005	9795.69		-	
2020	57.48	12.99	-99.41%	-99.87%
2030	102.89	79.11	-98.95%	-99.19%
2040	71.15	66.96	-99.27%	-99.32%
2050	22.86	29.69	-99.77%	-99.70%

4.4. Discussion

To understand the future emissions of the transportation sector, the evolution of the Portuguese fleet numbers had to be forecast. As growth has been decelerating, it is unclear if the fleet will continue to increase or stagnate and decrease in future.

The recent spreading of different ways of transportation, namely shared transportation, the improvement of public transportation and the governments will to EV, which are still more expensive than their equivalent thermal vehicles, may push the population to different transportation solutions rather than owning vehicles. This could lead to a decrease in vehicles per household, but it is still very uncertain on how Portuguese adoption of different transportation is going to evolve.

Due to uncertainty on the fleet growth, two different trendlines were created using the history of vehicles from 1990 until 2016. For a more optimistic and sustainable case, a linear trendline was created which predicts a lowering in the private vehicle number from 4.6 million in 2016 to 3.9 million in 2050, a number close to the 2002 real fleet size. The second trendline generated was quadratic with a more business as usual results, with small decrease in 2020 and 2030, but a significant rise in 2050, ascending to almost 5.1 million vehicles.

By analysing the results from the sustainable scenario, it is clear that the proposals made by the Portuguese Environment Agency are more than enough to meet the decreases of 80%-95% in GHG emissions in the transportation sector. When comparing the reduction from 2005's emissions it is noticeable that the difference of more than a million vehicles created by the two different trendlines on fleet evolution, becomes almost neglectable for low enough electrical emissions like in "Sustainable Development". This small enough difference in emissions from a 3.9 million and a 5.1 million vehicles fleet points to a much stronger parameter responsible to lower transportation emissions: electric specific emissions. This optimistic scenario shows that for a decrease of 98% in specific emissions, the usage phase of an EV is almost non emitting when compared with the emissions from an ICEV.

As part of evolution of the electricity generation all around the world, the specific emissions tend to lower in the future due to lower costs in renewable sources and higher environmental awareness, leading electric infrastructures closer to the one projected by RNC 2050 with very low carbon emissions. An electrified transportation sector will have all its emissions dependant on the energy sector.

Although it is important to understand if the energy sector of a country is already low carbon enough for EVs to decrease the sector's emissions, it seems more interesting to catalyse public adoption on EVs. Electrification of the private vehicle can be quickly achieved through legislation, but governments are, so far, only incentivizing so that the adoption is organic for the end user.

As transportation sector electrification is much more dependent on consumer will to change vehicle, governments should focus on lowering the carbon intensity of the electrical production without neglecting the EV incentive. The energy sector is much more emitting than the transportation and it has consequences on different sector's due to electricity usage. As electric specific emissions lower, the population that is educated for the subject is more easily attracted to the electrification of their vehicles as an environmental measure.

The scenario "Business as Usual" characteristics has much different results. As the specific emissions from electricity generation are the same as in 2016, the total emission values can never reach such low values as the "Sustainable Development" scenario. This parameter is kept constant through all the assessed period because Portugal already has quite a good share of installed power in renewable energy and according to IEA, Portuguese specific emissions only decreased 5% from 1990 to 2016, legitimating the tendency of no evolution in specific emissions for this scenario. EDP values are more optimistic showing a decrease of almost 50% from 2008 to 2016 as shown in figure 7. It was considered that the IEA data was more reliable due to a representativity issue from EDP since their data can represent only the company's generation and not the country's.

The "Business as Usual" scenario is represented with only a third of the final adoption on EVs and two thirds of ICEV. As a strategy for lowering the emissions to the defined goals, this scenario would not have been enough with maximum decreases of 66% from the 2005 values in CO_2 emissions with the linear trendline which represents a decrease in number of circulating vehicles. In this scenario, the difference between the linear and quadratic trendline approach is noticeable on the results. This is explained by both a considering value of electrical generation emissions and 66.66% share of ICEVs in the total fleet.

It seems important to notice that with high emissions on energy sector, the number of vehicles circulating can damage the country's emissions while on the second scenario the differences caused by 1million vehicles is neglectable.

5. Prospective Scenarios and results discussion

The predictions made in the previous chapter led to a duality of results, in which Portugal could accomplish its plans to lower carbon emissions with the “Sustainable Development” scenario or it could not, considering the “Business as Usual” scenario.

5.1. Sensitivity analysis

It is important to notice that the “Business as Usual” scenario failed to succeed on lowering emissions by 80%-95% reaching only 66% decrease in 2050. It is clear that a difference of 1 million vehicles can make a significant disparity in emissions by 2050 (10% difference from 2005 results) as can be seen in table 4. On the other hand, “Sustainable Development” scenario has reached near zero emissions, with a 99.77% decrease of emissions for the linearly evolution fleet, over achieving the carbon decrease pretended for 2050. This over decrease in emissions represented by this scenario is not in any way negative, for the contrary.

A brief sensitivity analysis is run for the current assessments’ results to understand which parameters are the most relevant to improve and invest on at first. This analysis is meant to comprehend the power of each parameter in the results and predict some results in case of slight changes in the basilar parametrical predictions made in RNC 2050.

During the sensitivity analysis conducted, only the proposed parameters are going to change once each time. The rest of criterion are to stay constant and equal to the considered in each scenario. For an easier examination, only one trendline is considered for the evolution of the fleet size. As linear behaviour leads to a less populated fleet, those are the values considered, due to a belief in expansion on public and shared transportation which will discourage people into owning a private vehicle.

5.1.1. Business as Usual Scenario

The internal combustion engine has been object of improvement for a hundred years since it has been globally commercialized. In the last 20 or 30 years, legislation has pushed manufacturers to improve their engines’ efficiency by taxing high volume, high fuel consumption and high emissions vehicles.

Electric vehicles have been in the global market for a decade and improvements on their efficiency have appeared not only directly on the electric motors, but on the whole transmission system, for example with regenerative breaking.

The electrical production and distribution are complex processes due to the controlled parameters of electricity measurement. Renewable integration has shown to be challenging due to their instability which is then passed through the distribution grid. Thermal powerplants allow easier control with more stable results and for that reason these are still needed to help stabilize the Portuguese grid. Achieving a carbon low (or even free) electricity distribution is the goal and the carbon emissions associated with it have potential to decrease.

The number of light passenger vehicles circulating in the country is the reason for the carbonic emissions studied. A different sized fleet will be responsible for lower or higher emissions which will be studied in this sensitivity analysis.

As more traditional vehicles are replaced by EVs, the higher the potential to lower global emissions and the closer Portugal is to reach 80%-95% decrease in emissions from 2005. For this reason, an adjustment of the EV adoption is studied in this low penetration scenario.

ICE emissions, EV efficiency, electricity emissions, fleet size and EV adoption rate will be the five parameters used in the sensitivity analysis of this “Business as Usual” scenario. These are going to be tweaked for a better judgment on which are most significant to reach the proposed goal of decreasing the emissions by 80%-95%.

For the ICEV emissions efficiency, a decrease in emissions per km is expected since most manufacturers and consumers are not fully on board with electrical only transportation and still invest in developing the thermal engine. For this reason, it is proposed a change in CO_2 emissions per km of -5%/decade. The base value is the average of four vehicles, used in the carbonic assessment. The first decrease is done in 2020, and the total value drops from 114gCO_2/km to 93g CO_2/km in 2005 and 2050 respectively. The results are presented in table 6.

Table 6 – Results from sensitivity analysis of “Business as Usual” for an improvement of 5%/decade on ICE emissions

Year	**Emissions (kton CO_2)**	**Reduction from 2005**
2005	9795.69	-
2020	4737.25	-51.64%
2030	3970.69	-59.46%
2040	3310.71	-66.20%
2050	2745.70	-71.97%

This scenario considers two thirds of the fleet being ICEVs, and so the efficiency of such engines can be quite significant for a high decrease in total emissions of CO_2. To reach the minimum proposed decrease on 2005 emissions, the efficiency of the thermal engine would have to decrease 14% every decade, from 114 gCO_2/km to 62 gCO_2/km in 2005 and 2050. To achieve the maximum proposed decrease in emissions, the efficiency of the thermal engine would have to increase 56% every decade, allowing it to produce only 4 gCO_2/km in 2050. This is questionable since these emission values are not realistic and the main idea is to lower emissions by 80-95% from 2005 to 2050, but not stagnate once these goals are reached. The objective is to neutralize all emissions produced worldwide and stabilize the GHG levels in the atmosphere in an effort to not disturb the natural equilibrium and avoid climate changes in which the proposed goals by RNC 2050 are just a step instead of the final destination. As ICE is a pollutant machine and eliminating all its exhaust emissions is not possible, the aim should be to replace these with a cleaner technology like the electric motor, instead of keep developing slightly less pollutant engines.

As electric vehicles penetrate the market, the technologies evolve to bring higher efficiencies to the energy management systems. As this is still a very recent market, when compared with the traditional vehicle, an improvement of -10%/decade on its efficiency is proposed. The proposed change is from 16.3 kWh/100km to 10.7 kWh/100km in 2005 and 2050 respectively. The results are presented in table 7.

Table 7 - Results from sensitivity analysis of "Business as Usual" for an improvement in EV efficiency of 10%/decade

Year	**Emissions (kton CO_2)**	**Reduction from 2005**
2005	9795.69	-
2020	4986.58	-49.09%
2030	4358.14	-55.51%
2040	3744.97	-61.77%
2050	3153.16	-67.81%

By tweaking EV efficiency for a 10% improvement on the powertrain, the emissions stay quite similar to the original scenario, showing that this parameter is not key for reaching the proposed goal of a decrease in 80%-95% in emissions. Reaching the minimum proposed would be impossible only using this parameter, reaching a maximum of 70% for infinite efficiency on the electric motor, meaning that it would do 100km with 0 kWh, which is still impossible. This parameter does not allow reaching proposed goals unless the EV share in total fleet rises.

Following world's trend, Portugal is expected to keep lowering its emissions related to the energy sector. As a midterm between the -98% planned and a no decrease in emissions, a decarbonization of -20%/decade is proposed. The initial and final values are 184 g CO_2/kWh and 75 g CO_2/kWh respectively. The 2050 value is still an order of magnitude higher than the final value for the best-case scenario "Sustainable development". Results from this sensitivity analysis are presented in table 8.

A decrease of 20% in electricity's emissions seems to have had little impact on the total reduction with the values from 2005. This can be explained by the fact that the share of ICEVs is still very high and seems to be the dominant CO_2 producer. Achieving 80% decrease from 2005 emissions in 2050 would be impossible using this parameter only, confirming the importance of ICEV as a polluter. A maximum decrease of 70% would be achieved for 0g CO_2/kWh. Just like the EV efficiency has shown, total emissions can only decrease using electricity specific emissions if the EV share is higher in the Portuguese fleet.

Table 8 - Results from sensitivity analysis of "Business as Usual" for an improvement on electrical specific emissions of 20%/decade

Year	**Emissions (kton CO_2)**	**Reduction from 2005**
2005	9795.69	-
2020	4986.58	-49.09%
2030	4317.51	-55.92%
2040	3650.22	-62.74%
2050	3005.55	-69.32%

The number of vehicles in circulation is the forth parameter in study. The size of the fleet is highly important since the assessment is about emissions from light passenger vehicles. A smaller fleet will have lower emissions but at what extent? In "Sustainable Development" scenario fleet size seemed neglectable for the Portuguese case due to 100% EV share and very low (almost zero) emissions from the electricity generation. The proposed decrease in the fleet size is of 20%/decade which decreases the fleet from 4.2 million in 2005 to 3.1 million in 2050. The results are presented in table 9.

Table 9 - Results from sensitivity analysis of "Business as Usual" for a decrease in fleet size of 20%/decade

Year	**Emissions (kton CO_2)**	**Reduction from 2005**
2005	9795.69	-
2020	3989.26	-59.28%
2030	3507.68	-64.19%
2040	3053.72	-68.83%
2050	2627.37	-73.18%

In this scenario which keeps the 1/3 share of EV, the emissions go down mainly because of the decrease in ICEVs. In order to achieve the minimum planned 80% reduction of 2005 emissions, the fleet size would have to decrease 41% every decade from the original linear trendline, reaching a total of 2.3 million in 2050. To reach the maximum planned 95% reduction, an 85% yearly reduction would be needed, reaching less than 600.000 vehicles in 2050. These results seem very unlikely for a country with high dependency on private vehicles, showing that downsizing the fleet size by itself represents an improbable solution. Such a solution would require extreme improvement on public transportation in order to generalize its use.

The estimate of EV adoption rate seems very conservative and creates a great gap between each scenario. A change in the adoption rate is proposed with an increase of 25%/decade from the assessment results. This means that, by 2050, instead of 33%, 41.7% of EV is achieved in the whole Portuguese fleet. The results from this increase in EV share are presented in table 10.

Table 10 - Results from the sensitivity analysis of "Business as Usual" for an increase in EV share of 25%/decade from previous values

Year	**Emissions (kton CO2)**	**Reduction from 2005**
2005	9795.69	-
2020	4986.58	-49.09%
2030	4269.79	-56.41%
2040	3582.62	-63.43%
2050	2928.23	-70.11%

The increase of 25% in EV adoption did generate some lowering in the total fleet's emissions, but still far from the European goal. To reach the desired 80%, the EV adoption would have to be 110%, meaning an EV share of 70% in 2050. Tweaking only this parameter the top limit of the European goal would not be reached, peaking at 90% decrease in 2005 emissions by 2050 which can be explained by the necessity of improvement in the electricity generation and distribution grids which are responsible for the remaining emissions.

5.1.2. Sustainable Development Scenario

In this scenario, there are only three parameters analysed. The electrical specific emissions are very important and have shown in the assessment that almost zero electric emissions lead to almost zero total emissions for a completely electrified fleet. The alterations proposed in this sensitivity analysis mean that the electrical sector does not evolve as quickly as the transportations', reminding that only one parameter is changed each time. The potential of EV adoption is also studied in this analysis. A lower EV adoption and its impact on the final carbonic emissions is studied.

There are some criteria that did not qualify to be studied in this sensitivity analysis. The EV efficiency could change the results, but it does not seem realistic nor reasonable that future vehicles will consume more energy. Even if such increase in energy consumption were to happen due to an increase of consumption in surrounding gadgets, the emissions would be neglectable due to a 2050's almost zero electrical emissions. For the same reason it does not make sense to study the impact of a decrease in ICE's efficiency, as the manufacturers have invested so much for the last decades to improve its efficiency. The 2050's full electrified fleet would eliminate any effects of this very improbable decrease in efficiency.

The fleet size is not studied in this sensitivity analysis since it has already been studied at an interesting extent in table 5 by the two different evolution models used for the fleet size: linear and quadratic, creating a final difference of over a million vehicles. In conclusion, the fleet size does not create significantly different emissions during the usage phase if total electrification of fleet and very low electricity emissions are considered.

The EV share in the Portuguese fleet is key to reach low emissions, since the ICEV's efficiency has limits due to the use of a carbonated fuel. The goal of 100% electrified fleet in 2050 might require prohibition to buy and use ICEVs which has not been announced in Portugal. For that reason, an adoption of -20%/decade is proposed for the initial parameter, present in table 3. This means that instead of 100%, only 80% of the fleet is electric by 2050. The results from this sensitivity analysis is presented in table 11.

Table 11 - Results from sensitivity analysis of "Sustainable Development" for a reduction in EV adoption of -20%/decade

Year	**Emissions (kton CO2)**	**Reduction from 2005**
2005	9795.69	-
2020	4953.18	-49.44%
2030	3559.21	-63.67%
2040	2175.23	-77.79%
2050	889.23	-90.92%

A decrease in 20%/decade in EV adoption will lead to a considerable amount of ICEV in the Portuguese fleet by the end of the study, resulting in considerably higher emissions comparing with the initial assessment. The emissions in 2050 have increased almost 40 times and the emissions decrease is now between the limit proposed by the EU, instead of exceeding it. The limit of lowering emissions would be reached for a 45%/decade decrease in EV adoption, meaning an EV share of 55% by 2050. The emissions would have been 85 times higher than the initial assessment and the reduction of emissions from 2005 would only be 80%.

To electrify the light vehicle fleet and lower the carbon emissions it is needed that the electric specific emissions are low enough. In this case, a 20%/decade increase in specific emissions is proposed leading to an emission increase from 3.68 gCO_2/kWh to 4.42 gCO_2/kWh in 2050, which is still a very low value, considering the present values. The results are presented in table 12.

Table 12 - Results from sensitivity analysis of "Sustainable Development" for an increase in electric specific emissions of 20%/decade

Year	**Emissions (kton CO2)**	**Reduction from 2005**
2005	9795.69	-
2020	4946.45	-49.50%
2030	3269.23	-66.63%
2040	1588.89	-83.78%
2050	27.44	-99.72%

As emissions are still very low in absolute values, the results show an emission reduction of 99.7% from 2005's values. Such low emissions together with a totally electrified fleet result in neglectable emissions, when comparing with a thermic fleet. The only way this parameter would reach the limits of EU objectives was by increasing emissions by more than 2000%, in which the emissions for previous decades would be unrealistic with almost 2500g CO_2/kWh in 2020. This considers the same evolution on the electricity generation as proposed by RNC 2050.

5.2. Combined Discussion

The public charging infrastructure is an important criterion for the EV market to spread and grow. The plan to electricize the Portuguese fleet reaches 100% in 2050 for light passenger vehicles which is much more significant than recent numbers. In 2016 the EV share on the total fleet was 0.03%, so the major steps on such change are still to come.

Critically, the evolution of the public charging infrastructure must, at some extent, keep up with the market penetration, to keep the consumer's needs satisfied. The ratio between charging stations and EVs should not deviate from present numbers, so that the users and potential buyers of EV feel secure about owning an EV.

A rough estimation of the evolution of charging structure is here conducted for a better understanding on how many stations should be installed in future years. There are some approximations to keep in mind with the estimation conducted, the first being that the evolution of EVs itself is just a proposal still needing quite some work to achieve, since in 2016 only 0.03% was accomplished to electrify the whole Portuguese fleet by 2050. Second approximation is used due a lack of data, since the number of circulating or sold EVs is only available until 2016 and the number of charging stations is for the present year, creating a gap of 3 years: in this estimation, it is considered that for 2016 the number of charging stations is half of what it is today, resulting in an average of 5.6 EVs per normal charging station and 46.7 EVs for quick charging station. The third approximation is that the ratio of EV/station is going to stay constant during the next years in which the EV market will evolve and mature so much. This is quite conservative since it has already been concluded that as the consumer's behaviour matures, the need for a public structure lowers since the charging needs are based on home charging devices [44] which would lead to a higher EV/station ratio in 2050 than in 2016. The last approximation has already been used as a prediction in this thesis, which is the linear evolution for the Portuguese fleet, leading to a final decrease of 15% in 2050 to 3.9 million vehicles.

*Table 13 - Prediction of charging stations, using 2016 predicted ratios. *Real value*

	Predicted values			
Year	**EV count**	**Regular Charger (Portuguese ratio)**	**Regular Charger (Norwegian ratio)**	**Quick Charger**
2016	1401*	250	77	30
2020	44652	7968	2464	956
2030	1425540	254379	78672	30525
2040	2725347	486322	150405	58359
2050	3899420	695828	215200	83499

So, using the same ratios found in 2016 (using an approximation for the number of chargers as half of the number in February 2019) the prediction on public charging infrastructure until 2050 is presented in table 13.

To fulfil the charging needs of the EV fleet growth proposed in the RNC 2050, the public charging infrastructure has to keep pace and increase to the values presented. All these results are conservative and discussable. The regular charging points can be lowered by the growing maturity of the consumer that, with time, will rely more on home charging instead of public stations. The quick charging points are highly important in highways and long roads to enable EVs to drive between far away points (more than one full charge of their vehicles) without having to wait several hours to fil their batteries with energy in regular charging stations. As explained before, quick chargers also have room to be installed in other places, the more populated with EVs, the better.

The results from the survey reveal bad functioning on the current charging stations which could lead to the idea of need higher investment in more structure per vehicle. Comparing with the Norwegian market in which there were around 45,300 users (which could have more than one EV) in 2018 with less than 2500 charging stations[5] in 2019, which leads to a ratio of more than 18 users per regular charger, confirming not only that with maturity of the consumer, a high part of the charging demand is taken care at home and that the Portuguese performance problem is not due to low amount of chargers but maybe low maintenance of the stations or low maturity of its users. Part of the higher ratio of users/public chargers can be explained by a higher share of individual homes in Norway, while apartment buildings are more common in Portugal which can difficult home charging opportunities.

Considering the Norwegian rate of chargers per EVs of 18, Portugal would only need 216,600 chargers by 2050 instead of almost 700,000 proposed in table 10, representing a considerable difference of almost 70%.

[5] *Source: https://info.nobil.no/index.php/english*

6. Economic Assessment

The whole EV market evolution is dependent on public's acceptance which is still reliant on the performance of these vehicles. Due to lower charging times and autonomies, the consumer still feels discouraged to invest in EV. From the Norwegian case, a conclusion can be taken, which is that the consumer has to feel somehow incentivized to prefer an EV instead of ICEV when buying a new vehicle. The economics of buying a new vehicle is a very important factor for choosing the model. Electric vehicles are still more expensive than their thermal equivalents if considering only initial investment. In this chapter, the costs of owning an EV are accounted and compared with an equivalent ICEV.

6.1. International Home Charging Costs

Charging an EV is a big part of owning one and many times should be planned to fit the users' needs without creating any disruptions in their habits. Charging an EV can be done in three different ways, regular public chargers which are still free in several countries as encouragement for consumers to adopt EV, quick public chargers are the most expensive and fastest way to charge an EV, and home charging devices which are the long term cheapest form of charging and in many cases, the most beneficial for the user and the grid.

Regular public charging is meant to be present in urban areas so that users can charge while doing long tasks, for example during their work period, while shopping, or other long activities.

Quick public charging stations are most important in highways and long roadways to enable EVs to make long drives without multiple hour stops to charge their batteries. These stations are expensive to install and harder to run since their power demand is high which might unbalance the electrical distribution grid.

Home charging on the other hand has much potential to improve the electricity grid functioning since in most cases it can be scheduled for usage during electric valley hours. This is beneficial for the user that can take advantage of lower prices of electricity but also for the management of the electricity grid that ends up with a less deep demand valley, flattening the daily production and consumption profiles.

Public EV charging systems are mainly composed just as the Portuguese. The market regulator is usually a public company that provides companies with licences to operate charging stations but also licences to trade electricity to EV drivers. In many countries the incentive degree still allows some public charging to be free, just like the Portuguese case in which regular charging is free and quick charging has been free until November 2018.

In paid systems the market is free and regulated meaning that every electricity marketer can determine its own prices with regulator's supervision, resulting in different charging strategies and different prices at the end of the charging process. The location and utilization rates of any charging station can be a decisive factor for the pricing strategy. The big variance in charging stations cost make it difficult to evaluate the cost of charging in public infrastructure. Most countries still have incentives that allow some public charging to be free. Some different charging strategies include energy count, time count and price per utilization. These can be used alone or combined, depending on the energy trader's approach.

Since public charging can vary so much within the same country, a comparison of home electricity prices is made and the total cost of the charging process. In table 6 prices of electricity in some different countries are presented together with the total cost of charging a 40kWh battery pack considering a conservative 85% efficiency in the charging process. Due to a broad charging cost in public stations, only home charging is considered. Only regular prices are contemplated without valley discounts. For a valley price consideration, the Portuguese case will be considered in subsequent chapter.

Table 14 - Prices of Electricity per country with total cost of charging a 40kWh battery with 85% efficiency on the charging process (sources: Norway Statistics, Eurostat)

Country	**Price of Energy (€/kWh)**	**Total Home Charging Cost for a 40kWh battery pack (€)**
Norway	0.127	5.98
Germany	0.295	13.88
Austria	0.197	9.27
United Kingdom	0.184	8.66
France	0.175	8.24
Netherlands	0.171	8.05
Switzerland	0.176	8.28

Germany that has one of the priciest kWh in the world, represents the worst-case scenario, enables the user to completely charge a 40kWh battery pack with 14€. Considering the EV efficiency as the average of the two most sold vehicles in Portugal (Renault Zoe and Nissan Leaf) as 16.3kWh/100km, this charging cycle allows the user to drive around 245 km, resulting in 5.7€/100km, which is lower than an ICEV with regular fuel prices. Keeping in mind that such value for km is for Germany which has almost double the electricity price than the other countries presented in table 11. For example, in the United Kingdom, the cost of 100km is around 3.5€.

The superiority of the EV over the ICEV in terms of price per km might not be verified for countries that subsidize their fuels, for example like Angola or Venezuela which for this or other reasons have not yet started developing EV markets.

6.2. Owning an EV in Portugal

As said before, Portugal is a good candidate for developing an EV market due to the great environmental benefit supported by the low carbon electricity generation and potential to lower even further. Despite the environmental advantage, Portuguese population have generically low incomes, when compared with the prices of a new vehicle.

Portugal has created taxes to selectively benefit lower capacity and emission ICEVs, being one of the countries with the most expensive vehicles in Europe due to these high taxes. As engine capacity and emissions from engines increase, the price for the end consumer gets higher and higher. The taxation is achieved in two parts, at the investment moment, attributing a Vehicle Tax (ISV) and yearly with the Circulating Tax (IUC). This taxation highly benefits environmentally friendly vehicles with low consumptions and low emissions.

In the Portuguese case, different electricity prices are considered taking advantage of the valley lower prices. This will allow further understanding on the difference in variable prices for the electric vehicle.

6.2.1. Initial Investment

The novelty of the market and the additional cost of a battery pack keep the final price of an EV higher than the equivalent thermic model, which is still a reason for consumers to avoid the electric choice when it comes to buying a new vehicle. Regardless of that, Portugal has ended up with a different incentive strategy from other countries which usually distribute subsidies to the consumer that choses an EV. Although Portugal does that as well for the first 1000 EVs bought every year, probably the greater incentive is the exemption on ISV and IUC which are based on emissions and capacity of engines – since there is no thermal engine on an EV, these vehicles are exempted.

Taking for example Renault, that produces two comparable models, the electric ZOE and the thermal Clio. The total cost of the ZOE is presented with both methods of battery acquisition, rental and purchase. Battery renting is also included in the following chapter of variable costs, allowing a comparison between both acquisition methods. The models presented are used for this comparison due to their representativity in the Portuguese vehicle market: Clio was the best seller model in 2015 and 2016 and has continuously been one of the best sellers in the country, while ZOE has disputed the best electric seller award with Nissan Leaf ever since these models entered the market. Zoe is chosen over the Leaf because it is from the same maker as Clio and it allows two different battery acquisition strategies: purchasing and renting.

In chapter 3.1 all current incentives in the Portuguese market are presented and these should be considered for the assessment. The first 1000 EVs bought yearly receive 3,000€ or 2,250€ (depending if the buyer is private or a company, respectively) incentive from the government if the vehicle cost is lower than 62,500€, which makes the ZOE qualified for the subsidy. The IVA is deductible for companies and shall be considered as well: total deduction for electric vehicles and 50% for thermic vehicles.

In table 15 the prices of the considered models are presented. There are three prices presented, the first is what the manufacturer sells the vehicle for, meaning the price without any government incentives; second price is considering incentives for private user and finally company prices with deduction of IVA.

Table 15 - Initial cost of 40kWh Zoe and Clio, both from Renault (source: Renault Portugal)

Model	Price Without Incentives (€)	Price for private user (€)	Price for Companies (€)
Zoe 40 – Battery rental	22,284.55 €	19,284.55 €	15,599.10 €
Zoe 40 – Battery purchase	29,284.55 €	26,284.55 €	20,989.10 €
Clio TCe 75	14,669.08 €	14,669.08 €	12,982.14 €

This remarkable difference of at least more than 40% in initial investment might explain why many consumers are driven away from the electric models. The battery pack, if bought, would represent an additional 7,000€, leaving the vehicle's price tag close to 30,000€ without incentives, double the thermic option.

As explained before, it is important for the EV owner to have proper equipment in the household to charge the vehicle's battery pack. Even if not using a device to increase power output, proper protection should be installed in the socket to prevent melting or even electrical fires. This represents a single investment for the EV that has a lifetime longer than the vehicle's. Several home chargers are available in the Portuguese market, with prices around 900€ for a 11kW mono phase or 22kW tri phase. Lower prices can be found for lower power. Despite this, the only recommendation this thesis does is to have proper equipment to charge the vehicle, in which it is included a regular socket that can withstand 2kW. For this reason, the cost of a home charging unit is not considered in the present economic assessment.

6.2.2. Variable Costs

To assess the variable costs, there is a need to define a time period and the distance driven per year. Considering a vehicle's lifespan of 10 years and 15.000km driven per year, the calculations are made. Due to a lack of real results, the announced 5.9L/100km efficiency of the Clio is considered. The prices of gasoline considered are the average of 2018, resulting in 1.559€/L [56]. From the yearly distance driven considered, the announced cost is result in 99€/month for the battery pack rental.

The difference in taxes is presented in this comparison since it should be considered as an advantage for the electric model which is exempted from paying it. The costs of household electricity are 10 and 20 cents per kWh, for valley hours (night-time) and peak hours (daytime) respectively.

As for the maintenance of each vehicles it is acceptable to consider lower values for the electric vehicles since the ICE requires oil changes and other maintenances, inexistent in the EV. The regenerative breaking can also decrease the periodicity in maintenance of EV's break system, decreasing the yearly costs. Despite these differences in maintenance, a very conservative perspective is considered, as no numeric data is available, the maintenance costs of each model is considered equal, and for that reason will not be present in the following assessment.

6.2.3. Economic Assessment

For the models and values defined, the difference in variable costs of private and company ownership are represented in table 16. The electric vehicle with battery rental does have higher variable considered costs than the thermal counterpart. If battery is included in the initial cost, the variable expenditures are significantly lowered. The conservatism of EV values such as maintenance are reminded. The economic difference in maintenance between the ICEV and EV can reach hundreds of euros due to fluid exchange and maintenance on friction parts like the engine and gear box, only present in the ICEV.

Table 16 - Yearly variable costs of Renault's Zoe and Clio with electric charging during night and day for 15000km driven

Yearly Costs (€)	Zoe 40 – Battery rental	Zoe 40 – Battery purchase	Clio TCe 75
Distance driven (km)	15000		
Gasoline	-	-	1,379.72 €
IUC	-	-	103.00 €
Battery rental	1,188.00 €	-	-
Electricity charging (daytime prices)	489.00 €	489.00 €	-
Electricity charging (night prices)	244.50 €	244.50 €	-
Total (daytime prices)	1,677.00 €	489.00 €	1,482.72 €
Total (night prices)	1,432.50 €	244.50 €	

The fuel and electricity prices are considered constant which is also unrealistic since fuel prices are expected to rise in the future due to more expensive drilling, for example with offshore platforms. Electricity prices may increase more moderately than oil due to a growth in competitivity of renewable sources, comparing with fossil fuelled generation.

Being an assessment for the Portuguese case, it could be argued that the variable costs of electricity charges could be decreased by using regular public charging stations that are still free to incentivize market growth, but as these are an incentive that might be removed in the next few years, such charging method is not acknowledged.

Considering the higher cost of an EV with battery rental in such conditions, there is no payback period, since the electric option has higher initial investment and higher variable cost, making it always more expensive in such conservator conditions.

The battery rental option represents approximately the same variable cost as the thermal vehicle in table 16. With this manufacturer, the option of rental is good not only due to a significant initial price decrease but also by shifting the fears of low battery lifespan from the buyer, allowing more confidence on the vehicle long term performance. Due to a quite close variable costs and a significant variance of initial investment, no payback period has been calculated for the battery rental case. For a 10-year lifetime, the battery rental ends up being more expensive than buying the battery pack which costs around 7,000€, boosting the vehicle price to almost 30,000€. With a total 150,000km on the same battery pack, the performance might be compromised if abusive use occurred during the usage period.

When considering battery purchase the variable costs are considerably lower and so, a payback period is calculated. The discount rate considered of 4% is the recommended value by the European Commission as "the reference parameter for the real opportunity cost of capital in the long term" [57]. By using a discount rate on the yearly variable costs to improve the results quality, future savings are less valuable than todays.

Table 17 - Savings of buying ZOE 40 with battery purchase over Clio for private owner

Year	Savings	Year	Savings
0	-11,615.47 €	7	-4,183.64 €
1	-10,424.88 €	8	-3,278.88 €
2	-9,280.08 €	9	-2,408.93 €
3	-8,179.31 €	10	-1,572.44 €
4	-7,120.88 €	11	-768.12 €
5	-6,103.16 €	12	5.27 €
6	-5,124.58 €	13	748.91 €

In table 17 the yearly savings from buying a ZOE with battery included comparing with the Clio are given as a private owner. For this comparison, all previous approximations are considered together with night time charging routine to decrease the variable costs. The results show that, if seen as an economic investment only, the payback period is 12 years for the comparison made between these two models which is close to the average lifetime of a vehicle in Portugal. The battery pack is expected to be in good shape if taken care properly and no abusive use occurred during that period.

The selected EV has a 40-kWh battery which allows around 250 of autonomy with efficient driving. At the end of 12 years, the vehicle has driven 180,000km which accounts for 720 charging cycles, giving some room for further usage since Li-ion batteries are able to run more than 1000 cycles while maintaining an acceptable amount of capacity (higher than 80%) [23].

If a collective ownership is due, the initial price difference is lower with the same difference in variable cost. The payback period is studied and presented in table 18.

Table 18 - Savings of buying ZOE 40 with battery purchase over Clio for company ownership

Year	Savings	Year	Savings
0	-8,006.97 €	5	-2,494.65 €
1	-6,816.38 €	6	-1,516.08 €
2	-5,671.58 €	7	-575.13 €
3	-4,570.81 €	8	329.62 €
4	-3,512.38 €	9	1,199.57 €

In this second case, for company ownership, the payback period found is only 8 years, lower than the considered lifetime of vehicle. When the payback is reached, only 120,000km have been driven, corresponding to less than 480 battery cycles, much less than the capabilities of a Li-ion battery when used properly. This allows either a much longer usage of the vehicle or disposal of the same with a second life purpose for the battery pack.

The EV's economical advantage is the low price per km, comparing with the thermal option. For higher driven distances, it is questionable if the global economics of the EV improves. For a yearly of 27,500km driven, the cost of battery rental is 119€, which improves the cost of the battery very much. Table 19 presents the variable costs of the same vehicles but for a higher driven distance. For both night and day charging, the rental is economically beneficial, for around 1,000€ and over 2,000€ in the battery rental and purchasing cases, respectively.

It is reminded that the average distance driven per year in Portugal is much lower than the considered in table 19, but as EVs are more economically viable with higher distances driven, people that drive longer distances should be more attracted to these vehicles. For 27,500km driven yearly, the difference between the Clio cost and the ZOE with battery rental is enough to calculate its payback period. Table 20 presents the payback periods for the four modes of acquisition the ZOE.

Table 19 - Yearly variable costs of Renault's Zoe and Clio with electric charging during night and day for 27500km driven

Yearly Costs (€)	Zoe 40 – Battery rental	Zoe 40 – Battery purchase	Clio TCe 75
Distance driven (km)	27500		
Gasoline	-	-	2,529.48 €
IUC	-	-	103.00 €
Battery rental	1,428.00 €	-	-
Electricity charging (daytime prices)	489.00 €	489.00 €	-
Electricity charging (night prices)	244.50 €	244.50 €	-
Total (daytime prices)	1,917.00 €	489.00 €	2,632.48 €
Total (night prices)	1,672.50 €	244.50 €	

Comparing the two different battery usage models, it is clear that for the driven distances chosen, rental is economically weaker than purchasing which is only true for all the assumptions made throughout the assessment. Giving the two options for the consumer allows higher market penetration since it allows the user to choose between a higher initial investment or higher variable investment. Battery leasing not only allows lower initial investment but might decrease owner's apprehension by having a manufacturer's warranty of battery quality. Since confidence in battery's capacity over time is still a considerable concern for consumers, rental can decrease users worries by shifting potential problems to the manufacturer or the battery rental company.

Table 20 - Payback period for all four modalities of acquiring the ZOE comparing with the Clio

Payback Period (year)	ZOE with battery rental	ZOE with battery purchase
Private Owner	6	6
Company Owner	3	4

Analysing the payback periods from acquisition of these electric vehicles, it is clear that the taxation incentives are much more favourable for companies than for private owners. Such unbalance might have pushed the government to directly attribute a higher allowance to the private owners that, in March 2019 have changed the incentives to the values presented in this thesis (3,000€ to private owners and 2,250€ to companies). These advantages for companies might be part of incentive plan to attract businesses capable to create jobs and developing Portuguese economy.

For a higher yearly distance driven, like 27,500km, the differences between battery leasing and purchasing become closer, almost neglectable allowing the buyer to evaluate the differences in these two acquisition modes without the economics of it. The 1000 charging cycles are achieved during the 9th year meaning that all for modalities of vehicle acquisition would reach their payback periods with batteries in good condition, conditioned that there was no abusive use of the battery pack.

The distance driven of this last assessment is 27,500km since it is the highest distance allowed by Renault's simulator while maintaining the same leasing period. The simulator allows renting up to 40,000km per year, but with a shorter leasing period. The selected period for battery leasing is 7 years. After this period the leasing shall be renegotiated.

7. Conclusion

7.1. Conclusions

In this thesis the Portuguese charging infrastructure is reviewed. A revision of what has been happening is done together with the end user, through a survey conducted with Portuguese EV owners. From these, one can conclude that the EV market in Portugal is still in a very infant stage and it is hard to predict how it will evolve. There has been a lack of quality and thought out planning in Portugal for the transportation development that only now is being developed. The charging structure has shown to have performed poorly which could be explained by a lack of effort in maintaining the existing stations and/or by a low maturity of the user. The responses pointed to lack information given to new users on domestic charging and a severe lack of performance on the existing public infrastructure.

An assessment on the carbonic emissions from the transportation sector was conducted with two different scenarios, based on the RNC 2050, created by the Portuguese Environment Agency. The best case scenario fulfilled with distinction the goals proposed by the European Union of reducing CO_2 emissions in 80%-95%, showing a decrease in emissions higher than 99.5% in 2050, confirming that, for the transportation sector, the proposed changes in Portugal, are enough to lower emissions to desired levels. The "Business as Usual" did not fulfil the needed emissions change and so, a sensitivity analysis was conducted to better understand which parameters can make a stronger impact on the final emissions and how far could each parameter decrease the emissions by itself. Main conclusion from the sensitivity analysis is that realistically all parameters need to evolve together and that there is not a strong one, if the others are unevolved.

A projection of the evolution of the national charging infrastructure is done based on the proposed economic evolution in RNC 2050 to decrease the economy's pollutant emissions by 2050 as a conjoint effort with the rest of the European Union. The results from these projections reinforce the low maturity of the Portuguese system, but also show that the lack of a detailed plan for the future of the transportation sector decreases the reliability of prediction results which can explain some major differences with the Norwegian system. Main conclusions from this projection and the comparison with the Norwegian market is that the Portuguese system still needs to evolve and mature to better understand what is needed and how it will improve.

An economic evaluation is done to assess the benefits of owning an EV in comparison with an equivalent ICEV. An EV model with two different battery acquisition methods was chosen and for the average driven distances and vehicle lifetime, leasing battery is not economically better than an ICEV. Private ownership of an EV with battery purchasing only becomes economically beneficial after 12 years of usage, which should not represent any concern on lifetime or performance, if proper utilization of the battery is made. Even though this represents around the same duration of the average lifetime of a Portuguese vehicle, the battery pack should have still much capacity and durability, allowing an increase of lifetime of the whole vehicle. The increase of vehicle lifetime is a very sustainable change, since the production of vehicles, thermal or electric, creates high impact on the environment and a lifetime increase would represent a lower production demand.

Major limitations of these thesis have to do with the low sample of survey's responses collected that have shown once more the underdevelopment of the EV market in Portugal. Such concern is reduced by the similarities with the Norwegian survey's results. In some parts of this thesis some approximations are considered which could have been avoided if (most times) current data was available. An articulation with the Portuguese charging infrastructure regulator would strengthen the results and projected path for the infrastructure.

7.2. Future Work

Further investigation in the following points would complete this thesis.

7.2.1. More complex projections on electrical emissions from renewables

Just like electric vehicles are considered by manufacturers as non-polluting, electricity produced from renewable sources is considered zero emissions. Different sources of renewable energy create different impact on the environment, but none of them is completely impact free. Accounting the production and disposal emissions from power plants in the carbon assessment conducted in this thesis would be interesting to reach a better global emissions perspective. A complete life assessment on renewable sources of electricity would complete and strengthen some conclusions about the energy and transportation sector.

7.2.2. Calculations of battery charging cycles cost for economic assessment on reselling energy to the grid

The utilization of the electric vehicle's battery pack to support the electrical grid is an increasingly discussed subject. The fluctuations on daily electricity demand can be to some degree evened out with the coordinated usage of EVs by charging during valleys and supporting the grid during peak hours.

Discharging the EV's battery for grid support would require some incentive for the owner which could be either just the difference in price of electricity between valleys and peak hours of demand, or some other incentive could exist. The incentive for the owner is needed not only to create will to help the electric grid, but also to pay the battery charging cycle. As current batteries have limited lifetimes, every charging cycle has a cost. By calculating the cost of a charging cycle, the incentives for the EV owner could be studied and feasibility checked.

The integration on a Peer-to-Peer community represents a good testing platform for such behaviour with easier understanding if tested incentives are effective.

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ANNEX A.1 – Survey Presentation

The presented survey is as presented to the respondents, meaning that is in Portuguese.

Hábitos de utilização de Veículos Elétricos

<u>Secção 1 - Apresentação</u>

Este questionário é conduzido por Afonso Domingues, aluno do Instituto Superior Técnico que está a desenvolver um estudo científico que poderá ser utilizado na sua dissertação de mestrado em Engenharia e Gestão de Energia. Tem o objectivo de recolher informação sobre a população portuguesa que utiliza veículos elétricos (Battery Electric Vehicle) e plug-in híbridos (Plugin Hybrid Electric Vehicle). Veículos híbridos sem opção de plug-in não farão parte do estudo. Pede-se assim que apenas pessoas que possuam veículos elétricos ou híbridos com opção de plug-in respondam a este questionário.

A resposta a este questionário é anonima.

<u>Secção 2 – Perfil Demográfico</u>

Nesta secção vamos traçar o perfil do respondente com perguntas sobre o mesmo.

Sublinha-se que a resposta ao questionário é anónima, e a identidade de quem responde será mantida secreta.

1. Género:

Feminino	Masculino	Outra opção…

2. Faixa Etária:

18-30	31-40	41-50	51-60	61-70	71-80	81-90	Acima de 91

3. Nível de Escolaridade

1º Ciclo (Antiga instrução primária)	2º Ciclo (Antigo Preparatório)
3º Ciclo (Antigo 3º, 4º e 5º Liceal)	Secundário (Antigo 6º, 7º de liceu e ano propedêutico)
Pós-Secundário (Especialização tecnológica, nivel IV)	Licenciatura
Mestrado	Doutoramento

4. Rendimento anual familiar

Menos de 10.000€	Entre 10.001€-20.000€	Entre 20.001€-30.000€
Entre 30.001€-40.000€	Entre 40.001€-50.000€	Entre 50.001€-60.000€
Entre 60.001€-70.000€	Entre 70.001€-80.000€	Entre 80.001€-90.000€
Entre 90.001€-100.000€	Mais de 100.000€	

5. Tipo de Proprietário (Fiscal)

Particular	Empresarial

<u>Secção 3 - Identificação do VE (Veículo Elétrico)</u>

6. Qual o seu veículo? (No caso de ser proprietário de mais de um, escolha a opção outros, e descreva)

Zoe 22kWh	Zoe 40kWh	Renault Twizy	Leaf 24kWh	Leaf 30kWh	Leaf 40kWh
Citroen c-Zero	Smart	Bmw i3	Bmw i8	Hyundai Ionic	Jaguar I-pace
Kia Soul	Mercedes classe B	Mistsubishi MIEV	Nissan E-NV2000	Peugeot iON	Tesla Model S
Tesla Model X	VW eGolf	VW eUP	Híbridos com opção de Plug-In	Híbrido sem opção de Plug-In	Outra opção…

7. Quantos km tem o seu EV?

Menos de 10.000km	Entre 10.001km-20.000km	Entre 20.001km-40.000km
Entre 40.001km-60.000km	Entre 60.001km-80.000km	Entre 80.001km-100.000km
Entre 100.001km-120.000km	Mais de 120.000km	

8. A bateria instalada no seu VE foi comprada ou é alugada?

Comprada	Alugada

<u>Secção 4 - Carregamento doméstico do VE</u>

9. Tem Posto de Carregamento Doméstico?

Sim	Não

Resposta “Sim”, seguir para secção 5. Resposta “Não”, seguir para secção 6.

Secção 5 - Adquiri Posto de Carregamento Doméstico

10. Qual a potência do seu posto de carregamento doméstico?

3.7kW	7.4kW	11kW	22kW	Outra opção…

11. Com que frequência o utiliza?

Diariamente	De 2 em 2 dias	De 3 em 3 dias
Semanalmente	Mensalmente	Raramente
Outra opção…		

12. Está contente com o seu posto de carregamento doméstico?

Sim	Não

Seguir para secção 7 independentemente da resposta.

Secção 6 - Não adquiri Posto de Carregamento Doméstico

13. Considerou a instalação de um posto de carregamento doméstico quando adquiriu o seu EV?

Sim	Não

14. Porque não o fez?

Consigo carregar sempre fora de casa	Consigo carregar com tomada doméstica
Não me foi aconselhado pelo vendedor de VE/Não me lembrei	Foi-me desaconselhado por utilizadores
Preço elevado	Necessidade de alteração do tarifário elétrico em casa
Não existência de garagem	Vivo num condomínio e não foi aprovada a instalação do posto
Outra opção…	

Secção 7 - Carregamento público do VE

15. Carrega o seu VE fora de casa?

Diariamente	De 2 em 2 dias	De 3 em 3 dias
Semanalmente	Mensalmente	Raramente
Não	Outra opção…	

16. Prefere carregar em Posto de Carregamento Rápido (PCR) ou num posto normal?

PCR	Posto de Carregamento Lento

17. Costuma utilizar sempre o mesmo posto?

Sim	Não

Resposta “Sim”, seguir para secção 9. Resposta “Não”, seguir para secção 8.

<u>Secção 8 - Não costumo utilizar sempre o mesmo posto</u>

18. Porquê?

Não estaciono todos os dias no mesmo sítio	Ocupação do posto por outros EV	Ocupação dos lugares por veículos não-elétricos
Avarias no posto de carregamento que uso	Outra opção…	

<u>Secção 9 - Carregamento público do VE</u>

19. A UVE (Associação de Utilizadores de VE) anunciou que os carregamentos passarão a ser pagos entre 5 a 10€/100km. Sabendo isto, acha que o carregamento rápido ainda faz sentido?

Sim, sempre	Sim, mas apenas em longo curso
Não, enquanto o carregamento lento continuar gratuito	Não

20. Como vê o serviço de carregamento rápido?

Como um complemento do carregamento lento	Como um serviço premium

21. Qual é a sua opinião sobre o funcionamento da rede de carregamento publica?

Funciona bem, apesar de ocasionais problemas explicados pela novidade da estrutura
Funciona razoavelmente bem. A maioria da rede funciona bem apesar de haver problemas crónicos com certos postos
Não funciona muito bem, tem muitos postos de carregamento com problemas
Não funciona bem, tem demasiados problemas nos postos funcionais e/ou postos permanentemente não funcionais
Outra opção…

22. A MOBI.E (regulador de mercado) anunciou no passado carregamentos gratuitos até meados de 2017, que ainda não cessaram (ainda não passaram a ser pagos). Como vê este anúncio?

Normal, era sabido que eventualmente teríamos de começar a pagar a energia utilizada
Ansioso, penso que quando o carregamento começar a ser pago os problemas da rede de carregamento diminuirão e será uma prova de maturidade do desenvolvimento do VE em Portugal
Injustiçado, quando comprei o EV não tinha conhecimento destas informações
Outra opção…

23. Estaria interessado em poder utilizar o seu VE para dar apoio à rede elétrica, vendendo energia em horas de pico a preços mais altos do que a comprou?

Sim	Não	Talvez

24. Abre-se aqui um espaço para pequenos comentários, críticas e sugestões para a rede de abastecimento pública

Resposta Aberta

ANNEX A.2 – Survey Answers

The answers from the survey in Annex A.I are hereby presented. The number of respondents to each question is presented in the question. In questions 14 and 18 the respondent is allowed to choose more than one choice, meaning that *n* might not be the sum of the choices selected.

1. Género (n=64)

Masculino	58
Feminino	6
Outro	-

2. Faixa etária (n=64)

18-30	2
31-40	22
41-50	28
51-60	5
61-70	5
71-80	2

3. Nível de Escolaridade - Ultimo frequentado ou presentemente frequentado (n=64)

1º Ciclo (Antiga Instrução primária)	1
Secundário (Antigo 6º, 7º de liceu e ano propedêutico)	6
Pós-Secundário (Especialização tecnológica, nivel IV)	9
Licenciatura	31
Mestrado	9
Doutoramento	8

4. Rendimento anual familiar

Menos de 10.000€	2
Entre 10.001€-20.000€	9
Entre 20.001€-30.000€"	15
Entre 30.001€-40.000€"	12
Entre 40.001€-50.000€"	14
Entre 50.001€-60.000€"	4
Entre 60.001€-70.000€"	3
Entre 80.001€-90.000€"	3
Mais de 100.000€	2

5. Tipo de Proprietário do Veículo (fiscal) (n=64)

Particular	51
Empresarial	13

6. Qual o seu veículo? (No caso de ser proprietário de mais de um, escolha a opção outros, e descreva) (n=64)

Zoe 40kWh	4	Hyundai Ionic	4
Leaf 24kWh	15	Peugeot iON	3
Leaf 30kWh	8	Tesla Model S	4
Leaf 40kWh	12	Tesla Model X	1
Citroen c-Zero	2	VW eGolf	1
Smart	1	VW eUP	1
Bmw i3	1	Híbridos com opção de Plug-In	7

7. Quantos km tem o seu VE? (n=64)

Menos de 10.000km	11
Entre 10.001km-20.000km	7
Entre 20.001km-40.000km	14
Entre 40.001km-60.000km	17
Entre 60.001km-80.000km	5
Entre 80.001km-100.000km	7
Entre 100.001km-120.000km	1

Mais de 120.000km	2

8. A bateria instalada no seu VE foi comprada ou é alugada? (n=64)

Comprada	59
Alugada	5

9.

Sim	44
Não	20

10. Qual a potência do seu posto de carregamento doméstico? (n=44)

3.7kW	22
7.4kW	14
11kW	3
22kW	2
Outras respostas	3

11. Com que frequência o utiliza? (n=44)

Diariamente	20
De 2 em 2 dias	6
De 3 em 3 dias	9
Semanalmente	7
Raramente	2

12. Está contente com o seu posto de carregamento doméstico? (n=44)

Sim	43
Não	1

13. Considerou a instalação de um posto de carregamento doméstico quando adquiriu o seu EV? (n=64)

Sim	6
Não	14

14. Porque não o fez? (n=20)

Consigo carregar sempre fora de casa	4
Consigo carregar com tomada doméstica	16
Preço Elevado	7
Não existência de garagem	2
Outras respostas	1

15. Carrega o seu VE fora de casa? (n=64)

Diariamente	10
De 2 em 2 dias	4
De 3 em 3 dias	5
Semanalmente	12
Mensalmente	7
Raramente	24
Não	1
Outras respostas	1

16. Prefere carregar em Posto de Carregamento Rápido (PCR) ou num posto normal? (n=64)

PCR	25
Posto de carregamento Lento	39

17. Costuma utilizar sempre o mesmo posto? (n=64)

Sim	12
Não	52

18. Porquê? (n=52)

Não estaciono todos os dias no mesmo sítio	26
Ocupação do posto por outros EV	18
Ocupação dos lugares por veículos não-elétricos	14
Avarias no posto de carregamento que uso	17
Outras Respostas	12

19. A UVE (Associação de Utilizadores de VE) anunciou que os carregamentos passarão a ser pagos entre 5 a 10€/100km. Sabendo isto, acha que o carregamento rápido ainda faz sentido? (n=64)

Sim, sempre	8
Sim, mas apenas em longo curso	51
Não, enquanto o carregamento lento continuar gratuito	1
Não	4

20. Como vê o serviço de carregamento rápido? (n=64)

Como um complemento do carregamento lento	46
Como um serviço premium	18

21. Qual é a sua opinião sobre o funcionamento da rede de carregamento publica? (n=64)

Funciona bem, apesar de ocasionais problemas explicados pela novidade da estrutura	0
Funciona razoavelmente bem. A maioria da rede funciona bem apesar de haver problemas crónicos com certos postos	8
Não funciona muito bem, tem muitos postos de carregamento com problemas	24
Não funciona bem, tem demasiados problemas nos postos funcionais e/ou postos permanentemente não funcionais	29
Outras respostas	3

22. A MOBI.E (regulador de mercado) anunciou no passado carregamentos gratuitos até meados de 2017, que ainda não cessaram (ainda não passaram a ser pagos). Como vê este anúncio? (n=64)

Normal, era sabido que eventualmente teríamos de começar a pagar a energia utilizada	34
Ansioso, penso que quando o carregamento começar a ser pago os problemas da rede de carregamento diminuirão e será uma prova de maturidade do desenvolvimento do VE em Portugal	26
Injustiçado, quando comprei o EV não tinha conhecimento destas informações	2
Outras respostas	2

23. Estaria interessado em poder utilizar o seu VE para dar apoio à rede elétrica, vendendo energia em horas de pico a preços mais altos do que a comprou? (n=64)

Sim	30
Não	12
Talvez	22