Electric Mobility Charging Network– Environmental Impacts and Challenges

Portuguese Case

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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

1 Introduction

The increasing development of humankind and technology has been responsible for a growth in environmental pollution, namely atmospheric. The European Union's members have agreed on planning to decrease the carbonic emissions in 80% to 95% by 2050, using the values from 2005 as a baseline. Portuguese Environment Agency (APA) has created and presented in December 2018 the guidelines to the evolution of the Portuguese economy until 2050 with the objective to decrease emissions of Greenhouse Gases (GHG), "Roteiro para a Neutralidade Carbónica 2050" [1].

The transport sector is one of the economic sectors that consumes the most energy, with high pollution rate since most of the sector's consumption is based on fossil fuels. In [2], it is shown that the transports sector is the only that has not decreased its emissions since 1990's values, registering a significant increase by 30% in 2005, showing that changing this will be challenging for the governments.

This thesis presents a study on the electrification of the light passenger vehicle, specifically in Portugal. The replacement of the traditional Internal Combustion Engine Vehicle (ICEV) by the Electric Vehicle (EV) has great potential of decreasing the carbonic weight of the Portuguese economy. The Portuguese public charging infrastructure is analysed and studied together with the users with the help of a survey conducted by the author. The ambition of this survey is to get the electric driver's perspective which should be one of the most important judgment for the service provider. The charging structure will also be compared with other countries' with different levels of maturity.

2 Literature review

The International Energy Agency (IEA) found that in 2016 transportation emissions almost doubled from the values of 1990 and 74% of those emissions are explained by road transportation [3]. In Portugal there is a high dependency on oil for energy which represented, in 2016, almost 112% of the total final consumption of the whole country [4].

To electrify the transport sector, it is key that the electric energy is properly developed and keeps developing as EV penetration rises since the electric demand is expected to grow. The EV emissions are only going to be low as long as the electricity generation and distribution is responsible for low enough emissions to make the whole consumption chain less emitting than the thermal vehicle's. Several studies are conducted to understand the differences and impacts of the energy sector on the emissions of transport sector [5–7]. In [8] the authors study the mass adoption of EV in Portugal, concluding that for such an electric grid, the emissions would lower.
Changing the transportation sector is impetuous to mitigate the environmental effects of global economies. For the last years, manufacturers have found in the EV the best way to decrease and ultimately eliminate thermic vehicles. This is understandable due to a much higher energetic efficiency on the electric motor than on an internal combustion engine.

The Portuguese charging infrastructure is compared in this thesis with the one from the oldest and most developed market in the world, the Norwegian. In [9], Mersky analyses the performance of Norway's incentives on EV market penetration, concluding that at a regional level, the best incentive is a quality charging structure. A similar study concludes that a good and functional structure is key for building up consumer trust [10].

3 Methodology

The preparation for the work done in this thesis started with the analysis of the evolution of the Portuguese public charging infrastructure and market of EV. 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.

4 Case Study of Portugal

4.1 Survey

The survey conducted in this thesis is divided three main parts: a demographic identification of the respondent to identify if the early buyer is demographically defined as it is in many countries, a section about the charging habits of the EV owner and a final section asking about the respondent's perception on the public charging infrastructure.

From the demographic section, it has been concluded that the Portuguese EV owner is not uniform in the population, and its characteristics show similarities with the Norwegian owners, as can be seen in table 1

For this first comparison, the results from NEVA's surveys of 2018 and 2014 were used because the 2018's did not have results on income which were found on [11] and compared with the Portuguese results. The similarities in each market's consumers suggest that, even though the evolution stages are different in these

countries, Portuguese evolution is in its own way, following Norwegian steps. The main difference in respondent profile was the income which could be explained by the difference in average income and cost of living in each country.

Table 1 - Demographic comparison of the Portuguese and Norwegian 2018 and 2014 results

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

The sectorization of EV buyers by education and age can be explained by the higher income and life stability comparing with younger and less educated people. Higher education might lead to higher conscientization for environmental issues and willingness to pay for technologies that might decrease pollution. Incomes are levelled through OCDE values (source: https://data.oecd.org/natincome/net-national-income.htm)

In the second section, the charging habits are analysed. Just like the Norwegian case, in which only 11% of respondents drive more than 100km/day, the Portuguese average is around 60km/day [12], for which most recent models allow multiple day's use without charging.

It has been found that 80% of Portuguese users charges domestically at least every 3 days, with almost 50% charging their vehicles at home daily. Concerning the public charging structure, 49% of respondents claim to use a public charging station at least once a week. 81% claim to charge in different public stations and the main reasons are: 1) different daily routes, 2) already occupied stations by other EVs and non-EVs and 33% justify it with 3) faulty equipment.

On the last section of the survey the respondents were asked "What is your opinion on the performance of the charging structure?". A simulated 4 point Likert scale ({Very Good, Good, Poor, Very Poor}) with more specification was proposed. The results were quite pessimistic with zero answers on "Very Good" equivalent. Only 13% answered the equivalent of "Good" while 38% and 45% answered "Poor" and "Very Poor" respectively.

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.

4.2 Carbon Assessment

The European Council has announced in 2011 [13] 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.

Even though the emissions from EVs are considered null during their usage phase, this is only correct if a tank-to-wheel model is considered. This type of model is quite incomplete, and so a well-to-wheel should be considered to account all emissions from electricity production. An even more complete study would require a life cycle assessment in which emissions from production and disposal phase would be accounted. The production phase is not accounted due to a low relative variance in emissions when comparing with the two other phases, namely the usage phase which is by far the most emitting in vehicles [14,15]. The disposal is yet very undeveloped with great potential to improvements in a near future when large amount of batteries have to be disposed and recycled [16–18]. For these reasons, only usage phase is considered in this assessment.

The RNC 2050 proposes three different scenarios of economic development from which the best and worst have been used in this carbon assessment. The first scenario "Business as Usual" in which the adaptation level is very low and economic evolution exists only due to the need of replacing outdated and defective technologies instead of the search to innovate. The second scenario "Sustainable Development" represents the best-case scenario proposing all the best changes to a sustainable economy reaching the wanted results to prevent major climate changes. In table 2 the proposed changes by the RNC 2050 are presented for the energetic and transport sector which will be used for the "Sustainable Development" scenario.

The "Business as Usual" scenario will consider the energy sector stagnated with no evolution on the specific emissions from electric production and the EV share is considered to be a third of the high adoptive scenario, reaching only 33.3% in 2050.

Two different predictions on fleet evolution have been considered for both scenarios: a linear trendline with a global decrease on growth and a quadratic trendline with a final growth on fleet size. These represent very different approaches in fleet evolution, while the linear represents a more sustainable development, the quadratic represents a more conservative evolution with an increase of fleet by half a million vehicles from 2016 to 2050.

Table 2 - RNC 2050 goals for the transport and energy sectors (Source: RNC 2050) *linearized result

Year	2020	2030	2040	2050
Electrification of private passenger vehicles	1%	33.3%	66.6%*	100%
GHG Reduction on Electric Generation	-38%	-83%/-84%	-93%/-94%	-98%

The results from these scenarios show improvement in emissions from 2005. Reminding that the goal for carbon emission reduction is in the range of 80%-95% by 2050, it is clear that the "Business as Usual" scenario does not fulfil the proposed goal, while the "Sustainable Development" scenario has not only reached but went further than the European goals. The final emissions on this scenario are neglectable when comparing with 2005's emissions but shall not be neglected in the future plans in which the goal shall be total neutralization of carbon emissions from the Portuguese economy.

Using these two scenarios, a sensitivity analysis was with purpose to find out if there were any dominant parameters and which were. For the "Business as Usual" scenario five parameters were changed with realistic rates: ICE emissions, EV efficiency, electricity emissions, fleet size and EV adoption rate. Even though some parameters are slightly stronger than others, none was dominant enough to change the emissions to reach the desired reduction. In the "Sustainable Development", only two parameters were tweaked in a sensitivity analysis: EV adoption rate and electricity specific emissions. For this scenario, a lower EV adoption does increase greatly the emissions which is understandable since this change represented a considerable introduction of ICEVs in the fleet. The reduction from 2005's emissions is only 90% in this case. The change in electricity specific emissions did not create a significant alteration in results.

To fulfil the charging needs of the EV fleet growth proposed in the RNC 2050, the public charging infrastructure has to keep pace and develop as well satisfy the needs of an increasing EV fleet. 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. Considering previous results and fleet evolution, a prediction on the evolution of the public charging infrastructure is made. Two different rates of EV per charging station are considered, the first based on Portuguese values, the other based on Norwegian values. Both are compared due to their significant difference of around 70% confirming that in a more mature system, the user's reliance on public charging decreases. The Portuguese and Norwegian ratio of EV per regular charger are respectively 5.6 and 18 while the fast charging stations have only been predicted for the Portuguese ratio of around 47.

Using the "Sustainable Development" scenario, the light passenger fleet of Portugal reaches 3.9 million vehicles in 2050, with a 100% share of EV, pointing to almost 700,000 and 215,000 regular chargers using the

Portuguese and Norwegian ratios respectively. The prediction for quick chargers using Portuguese ratio is more than 80,000. All these results are only suggestive, since it is not known yet how the public charging infrastructure will evolve due to its infant stage. It is expected that the amount of EV per public charger increase in the future, but such value might fluctuate with changes in incentives for public and domestic charging. The same goes for quick chargers since their main objective is to cover highways and long/fast roads and once these are covered, the need to further expand quick charging infrastructure might be less urgent.

5 Economic Assessment

The economics of EV ownership are very important to convince the vehicle buyer to choose an EV instead of an ICEV. EVs are still initially more expensive than the thermal equivalent but government and local incentives might decrease that gap significantly. The main advantage of the EV is the variable costs with much lower cost per km due to a much higher efficiency on electric motors but also lower prices of electricity when compared with gasoline and diesel. In table 5 some countries' cost of electric energy are presented as well as the cost of charging a 40kWh battery pack. Considering an average consumption of 16.3 kWh/100km, the German and British costs of driving an EV are only 5.7€/100km and 3.5€/100km, which even for one of the most expensive countries in the world for electricity, is much cheaper than an average ICEV.

Analyzing closely the Portuguese case, two comparable vehicles (an ICEV and an electric) from the same manufacturer are compared: Renault's Clio and Zoe. The Clio has been the best seller for some years and the Zoe has been one of the best sellers in the electric market.

Although these vehicles are comparable, they can have up to 40% difference in price (the Zoe being more expensive), which might help push away new consumers from choosing an EV.

For 15,000km yearly driven, the payback period of the ZOE has been calculated for different modalities of purchasing: private and company ownership but also buying and leasing the battery. The payback periods in years are 12 and 8 years for private and company owners with purchasing the battery. The battery rental is not economically better for these conditions. For higher distances driven, the feasibility improves just like the payback periods that can decrease to 3 or 4 years for companies and 6 years for privates with a yearly distance driven of 27500km even with battery leasing.

The Li-ion battery packs' performance should hold, if no abusive use occurred, for over 1000 charging cycles which is much more than the payback periods presented, leaving room to longer periods of use or second life operation.

Table 3 - Cost of Electricity and home charging a 40kWh battery pack in several countries

Country	Price of Energy (€/kWh)	Total Home Charging Cost for a 40kWh battery pack

Norway	0.127 €	5.976 €
Germany	0.295 €	13.882 €
United Kingdom	0.184 €	8.659 €
France	0.175 €	8.235 €
Netherlands	0.171 €	8.047 €
Portugal (day price)	0.200 €	9.412 €
Portugal (day price)	0.100 €	4.706 €

6 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.

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