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Electric Mobility in Portugal: Current Situation and Forecasts for Fuel Cell Vehicles

Guido Ala [1], Ilhami Colak [2], Gabriella Di Filippo [1], Rosario Miceli [1], Pietro Romano [1], Carla Silva [3], Stanimir Valtchev [4] and Fabio Viola [1,*]

[1] Department of Engineering, University of Palermo, 90128 Palermo, Italy; guido.ala@unipa.it (G.A.); gabriella.difilippo@unipa.it (G.D.F.); rosario.miceli@unipa.it (R.M.); pietro.romano@unipa.it (P.R.)
[2] Department of Electrical and Electronics Engineering, Nisantasi University, 34406 Istanbul, Turkey; ilhcol@gmail.com
[3] Instituto Dom Luiz (IDL), Faculdade de Ciências, Universidade de Lisboa, Campo Grande, 1250-096 Lisboa, Portugal; camsilva@fc.ul.pt
[4] Department of Electrical Engineering, Faculty of Science and Technology, CTS UNINOVA, University Nova of Lisbon, 2829-516 Caparica, Portugal; ssv@fct.unl.pt
* Correspondence: fabio.viola@unipa.it

Abstract: In recent years, the growing concern for air quality has led to the development of sustainable vehicles to replace conventional internal combustion engine (ICE) vehicles. Currently, the most widespread technology in Europe and Portugal is that of Battery Electric Vehicles (BEV) or plug-in HEV (PHEV) electric cars, but hydrogen-based transport has also shown significant growth in the commercialization of Fuel Cell Electric Vehicles (FCEV) and in the development of new infrastructural schemes. In the current panorama of EV, particular attention should be paid to hydrogen technology, i.e., FCEVs, which is potentially a valid alternative to BEVs and can also be hybrid (FCHEV) and plug-in hybrid (FCPHEV). Several sources cited show a positive trend of hydrogen in the transport sector, identifying a growing trend in the expansion of hydrogen infrastructure, although at this time, it is still at an early stage of development. At the moment, the cost of building the infrastructure is still high, but on the basis of medium/long-term scenarios it is clear that investments in hydrogen refueling stations will be profitable if the number of Fuel Cell vehicles increases. Conversely, the Fuel Cell vehicle market is hampered if there is no adequate infrastructure for hydrogen development. The opportunity to use Fuel Cells to store electrical energy is quite fascinating and bypasses some obstacles encountered with BEVs. The advantages are clear, since the charging times are reduced, compared to charging from an electric charging post, and the long-distance voyage is made easier, as the autonomy is much larger, i.e., the psycho-sociological anxiety is avoided. Therefore, the first part of the paper provides an overview of the current state of electric mobility in Portugal and the strategies adopted by the country. This is necessary to have a clear vision of how a new technology is accepted by the population and develops on the territory, that is the propensity of citizens to technological change. Subsequently, using current data on EV development and comparing information from recent years, this work aims to investigate the future prospects of FCEVs in Portugal by adopting a dynamic model called SERA (Scenario Evaluation and Regionalization Analysis), with which it is possible to identify the Portuguese districts and cities where an FC charging infrastructure is expected to be most beneficial. From the results obtained, the districts of Lisbon, Porto and Aveiro seem to be the most interested in adopting FC technology. This analysis aims to ensure a measured view of the credible development of this market segment.

Keywords: electric mobility; fuel cell vehicles; plug-in hybrid; hydrogen; socio-technical transition; forecasting for FCEV; predictive model

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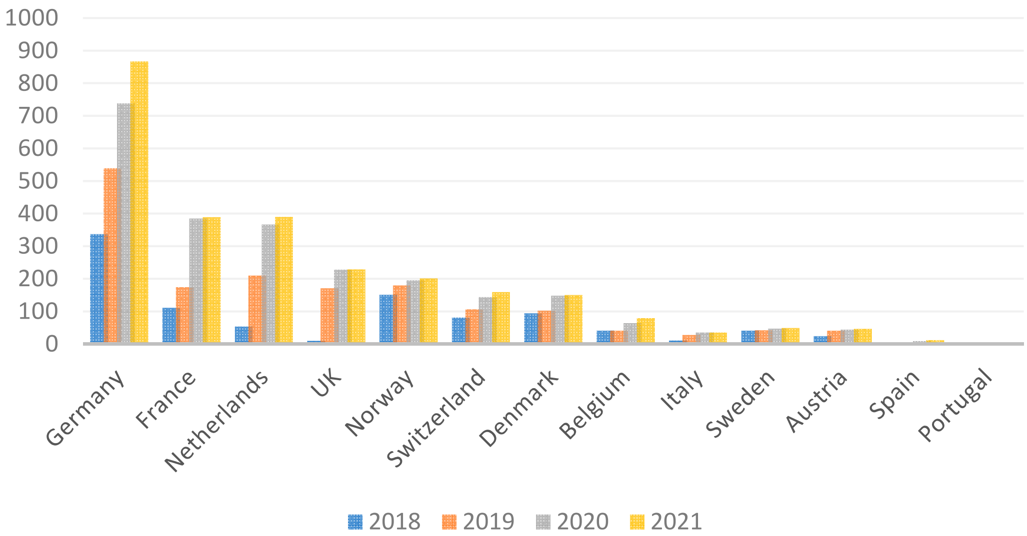
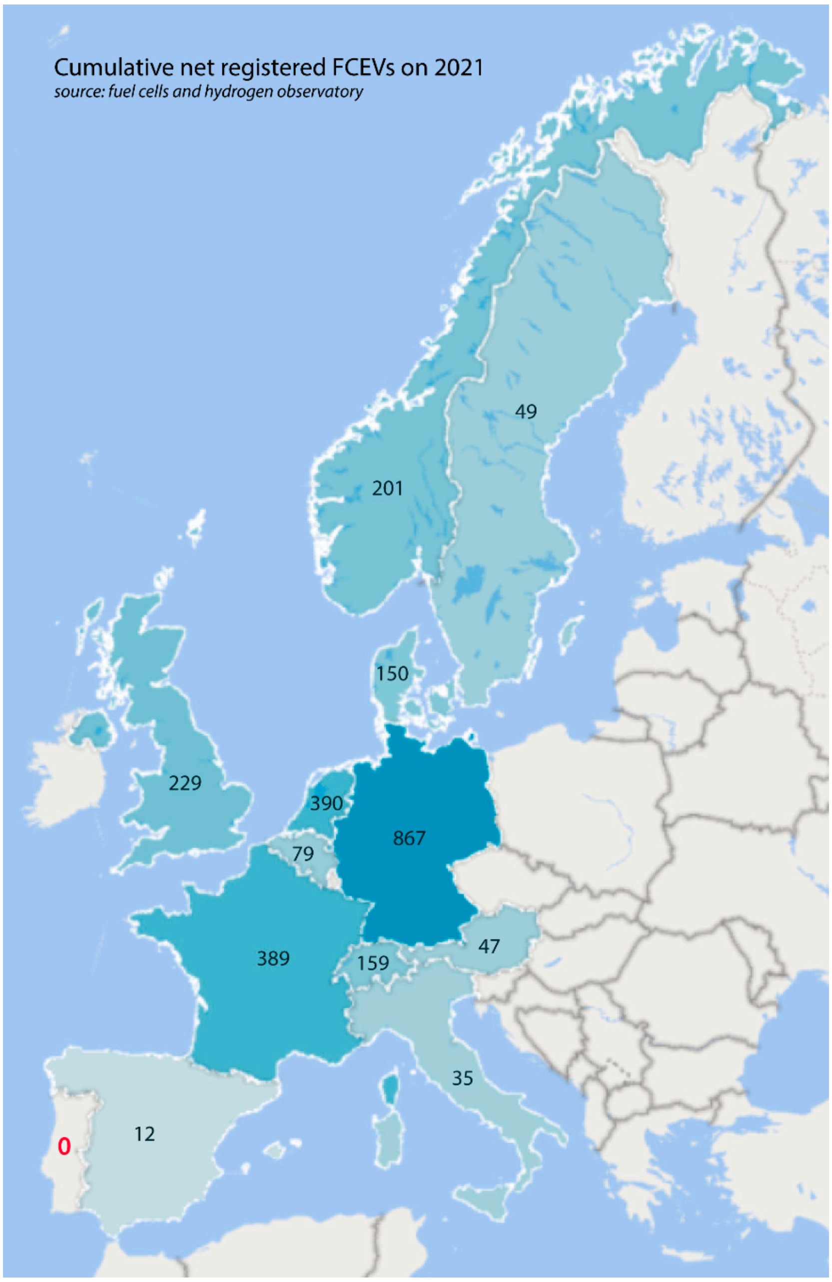
1. Introduction

Growing concerns about environmental issues have led to the evaluation of alternative solutions to the current mobility situation. In fact, in the last two decades, energy and the environment have become increasingly important in Europe, with a steadily increasing demand and consumption of energy. With the launch of the European Green Deal [1], the European Commission has decided to reach the decarbonization goal by 2050. Currently, the transport sector alone accounts for almost one-third of the EU's CO_2 emissions [2]. Thus, sustainable mobility can play an important role in the decarbonization of the mobility in Europe, which is why it is receiving great attention in the old continent. In recent years, the spread of sustainable vehicles has been strongly driven by the governments of many countries as an alternative to the use of traditional internal combustion engine (ICE) vehicles. Currently, the most widely accepted and used sustainable transport technology is based on battery electric vehicles (BEV) or plug-in hybrid EVs (PHEV), which use the energy stored in an on-board battery pack to provide an electric motor for propulsion. There are policies in place at the global and in particular at the European level to allow this transition; economic, technological and industrial developments have certainly favored the EV market in recent years, with great expectations of future expansion. Currently, however, there are still obstacles to overcome, such as prices that are still too high, and some technical aspects, such as the charging infrastructure; this still makes the attractiveness of the EV market lower than conventional ones. One of the most promising alternative options to support BEV mobilities in parallel may be the introduction of Fuel Cell Vehicles (FCEV), which were marketed by Toyota as early as 2014. There is still a technology gap in the success of FCEV due to the problem in hydrogen management, high cost of battery and Fuel Cell components, water management, etc. It turns out that the use of Fuel Cell has a much higher energy density than other types of energy storage devices. The energy density of the Fuel Cell is higher than that of other energy storage devices, and therefore, it can be used for long-term applications. In this way, the so-called "reload anxiety" that conditions people to purchase BEVs is overcome [3]. As can be seen from Figure 1a,b, Fuel Cell Vehicle data in Portugal show that as yet, no private FCEVs have been sold over the years [4].



(**a**)

Figure 1. *Cont.*



(**b**)

Figure 1. (**a**,**b**) Cumulative Net registration FCEVs in Europe (data source: fchobservatory) [4].

McNichol et al. [5] compared the advantages and disadvantages of Fuel Cell vehicles. repurchased to vehicles with IC engine, battery-powered vehicles and hybrid vehicles. Their study found that the Fuel Cell using hydrogen or methanol is the best solution for transportation applications.

Offer et al. [6] conducted a comparative study on hydrogen Fuel Cell plug-in Hybrid Electric Vehicles (FCHEV), Battery Electric Vehicles (BEV), hydrogen FCEV and IC engines for the current circumstances and for 2030. A comprehensive sensitivity analysis shows that in 2030, the FCEVs achieve cost parity with life gasoline vehicles. In the 2030 scenario, the life cycle costs of the FCEV's powertrain range from $7360 to $22,580, while those for BEVs range from $6460 to $11,420 and FCHEVs from $4310 to $12,540.

At the moment, it is still unclear how the hydrogen infrastructure will develop, and as regards the greater market penetration, the studies found in the literature have proved insufficient to provide such data or contain non-transparent data. The scenario analysis conducted by Robinius et al. [7] show that, for low levels of market penetration of a few hundred thousand vehicles, the infrastructure construction costs are substantially the same for both technological paths. It turns out that hydrogen is more expensive during the transition period to electricity-based generation by electrolysis and geological storage, both of which are required to access renewable hydrogen from excess electricity. In the scenario it appears that if vehicle penetration increases to 20 million vehicles in the baseline scenario, a battery charging infrastructure would cost around 51 billion euros, making it more expensive than the 40 billion euros of hydrogen infrastructure (Figure 2).

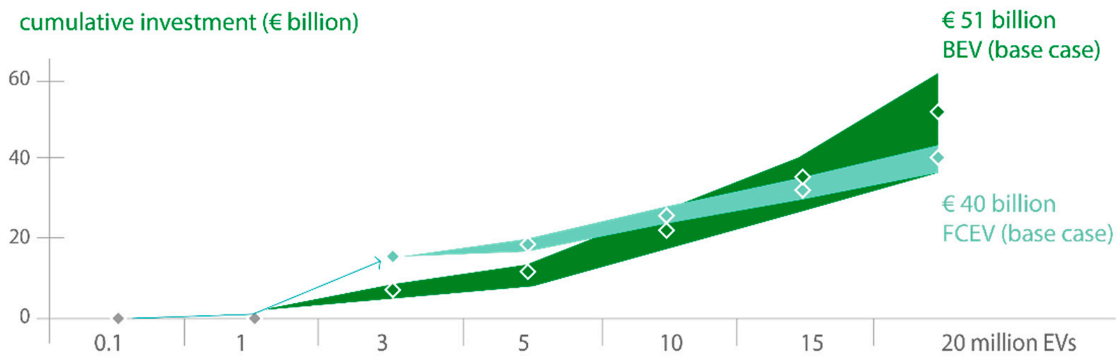


Figure 2. Comparison of the investment for the charging/supply infrastructures BEV and FCEV [7].

The authors use data on investments in electric vehicle charging and hydrogen refueling infrastructure to estimate the specific cost of mobility in terms of fuel economy. All energy costs and the annualized cost of the infrastructure are considered, leaving out margins and taxes, commissions and the cost of the vehicle. The results show that in the case of very small vehicle fleets, i.e., 0.1 million cars, BEV fuel costs are significantly lower than FCEVs but mobility costs become comparable when the number of vehicles exceeds 10 million (Figure 3).

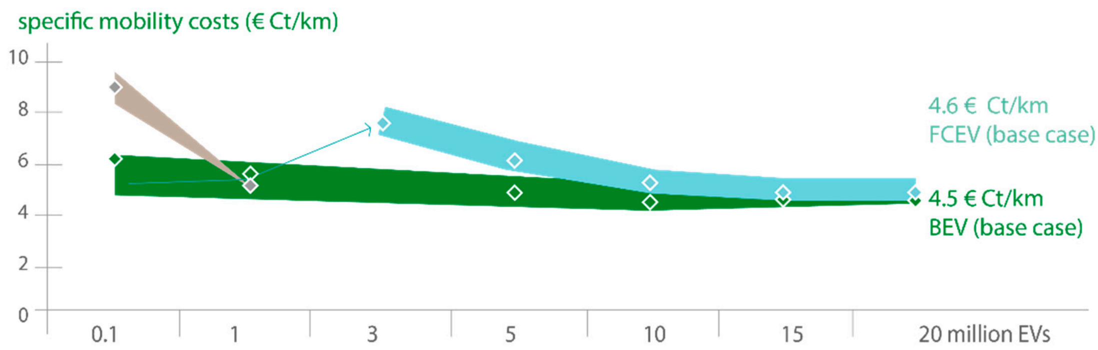


Figure 3. Comparison of specific mobility costs [7].

Thus, when there are more cars on the market, investments in the infrastructure of hydrogen refueling currently show better results. However, there are advantages for a scenario with high market penetration, i.e., 15 and 20 million vehicles. Furthermore, the hydrogen infrastructure shows some obvious advantages thanks to the use of its market infrastructure, which is comparable to today's conventional system. An important aspect to take into consideration is related to the policies adopted by countries to encourage the use of sustainable vehicles in favor of users [8]. At the moment, the data available on Fuel Cells do not allow us to fully study this technology, as it is still under development and little commercialized. Therefore, in this introductory part we concentrated on the study of real data regarding Electric Vehicles, to understand which policies would be useful to implement in the future, which includes policies on Fuel Cells.

There are several studies in the literature that address this issue. For example, in Denmark, Noel et al. [9] examined the social costs and benefits of potential deployment configurations of EVs, and reported that differences in the cost of capital of the vehicle, the absence of the availability to pay for EVs and discount rates for users are still obstacles to the spread of EVs in the country. Kumar et al. [10] used a nomological network to demonstrate the structure of EV adoption. This way, it was possible to have a clear overview of the adoption of EVs through a visual representation as concept maps. From this study, it emerged that the possible future actions for the adoption of EVs include the application of adequate regional and national policies, the improvement of the functionality of the network, financial incentives, the optimization of charging infrastructures, convenience policies, improved performance, reduced range anxiety, improved information sharing, availability of electric vehicle models at dealerships and improved environmental awareness. As for Portugal, Nunes et al. [11] estimated the impacts of promoting transport policies in favor of the environment based on the market and control on mobility, the environment and the economy. In addition, different series of policies up to 2050 are hypothesized through a "what-if" policy analysis, using the ASTRA-EC model. Yong et al. [12] used the fuzzy-set qualitative benchmarking methodology, fsQCA (Fuzzy Sets Qualitative Comparative Analysis), to compare the factors that influence the adoption of electric vehicles and to draw political implications to promote the uptake of electric vehicles. It determines the most effective policies in order to promote the spread of EV, taking into account the circumstances of the countries concerned. In this current scenario, it is interesting to observe what the growth trends of this technology have been in the various countries so far. There are studies in the literature that mainly use disaggregated or aggregated sales volumes or modeled sales data to make future predictions [13]. However, most of these studies, such as Bass and Gompertz [14], among others, have not used diffusion models to predict the spread of electric vehicles. Martino et al. [15] ranked four main models of technological forecasting, which can be applied in the automotive context. Similarly, it is possible to use these forecasting models to predict the spread of other technologies, such as Fuel Cell technology (FCEV). Some studies have been conducted in the literature on the rapid expansion of Fuel Cell Vehicles (FCEV) and on the production of hydrogen. Yazdanie et al. [16] compared the energy demand and greenhouse gas (GHG) emissions for the operation of conventional and alternative vehicles, including light commercial vehicles, in Switzerland. In this research, nine hydrogen production processes were analyzed. Wang et al. [17] conducted a study on the energy, environmental and economic impacts of FCEV from a life cycle perspective (LCA) to conduct a comprehensive study of the energy, environmental and economic impacts of FCEV from well to wheel. In addition, many studies have compared the energy consumption or greenhouse gas emissions of FCVs with those of other types of vehicles. Elgowainy et al. [18] carried out cradle-to-grave light vehicle life cycle research, which included both fuel and vehicle cycles, GHG and costing in the United States, including FCEVs.

The objective of this contribution is to propose a tool to analyze the potential strategies to be adopted for a transition to new forms of mobility and predict the future growth and penetration of hydrogen vehicles in the automotive market in the coming years in a specific country. The proposed tool is used for an application in the state of Portugal. In this country, there are currently no hydrogen plants, but there are plans to develop two industrial clusters for the production, distribution, export and use of green hydrogen in Portugal, one in Sines and one in the north of Portugal. With no real current data available on the hydrogen car market, we used real data on EVs to study users' propensity for technological change and what are the key factors influencing the transition. A predictive model called Scenario Evaluation and Regionalization Analysis (SERA) was used and real data on Electric Vehicle sales and charging infrastructure were used. The structure of the document is as follows: the second section deals with the current situation of electric mobility in Portugal; the main measures adopted by the country to promote the transition to a new form of more sustainable mobility are described, as well as data on the evolution of EVs and charging infrastructure over the last ten years. The third section pays attention to hydrogen technology, describing the reasons why it can be considered an appreciable alternative to EVs and the future horizons envisaged by Portugal. The fourth section describes the materials and methods adopted to use the model. The sixth section shows the results obtained, while explaining the algorithm used to identify the cities that appear most ready for the new technology in the immediate future. Finally, we draw up some conclusions. The importance of this study relies on the green hydrogen economy takeover and the benchmark projecting of several scenarios in 2050 forecasting up to 39% contribution of hydrogen technology in taxi and large car segments (with PHEV and BEV making up the remaining 61%). It will be of importance for municipalities and planners to know how to start the deployment of hydrogen supply infrastructure in the case of passenger car Fuel Cell adopters. The key framework in Portugal is the green-hydrogen industrial cluster in Sines resulting from the coal power plant deactivation.

2. The Early Adopters and the Diffusion of Innovations

In order to understand who will be the "early adopters" of FCEV, this research is based on Everett Rogers' Innovation Diffusion Model, a theory that illustrates how innovation is adopted and disseminated among members of society, through different channels, over time. The theory in question focuses on the speed with which different individuals, within a social system, adopt an innovation. The different users are, thus, divided into categories (innovators, early adopters, early and late majority and laggards), illustrated in the well-known Rogers curve [19]. No new technology other than existing solutions will be successfully brought to the market without first being purchased by these early consumers. According to the theory of diffusion of innovations, these users are highly educated, high-income consumers who have a positive attitude towards change. The most recent research on the adoption of alternative fuel vehicles has reported the same trend. Much of the literature studies and real data available concern BEVs and PHEVs, being the technologies currently most widespread on the market. Several research studies on the differences between BEVs and FCEVs show that Fuel Cell Vehicles have significant advantages, such as attracting range anxiety consumers or those who cannot charge a vehicle from home, making this technology attractive to consumers [20]. Assuming that the first BEV users can be attracted to a more advantageous technology and guide the adoption of FCEV, the research aims to make a forecast of adoption of the FCEV technology. The research uses data on the market introduction of BEV technology to understand the market entry of FCV. Then, after an initial survey on the BEV market in Europe with a focus on Portugal, the researchers investigated who are the first users of these technologies and what has been the spread in the last decade, believing these data to be reliable to make a forecast of the adoption of FCEV technology. This research is used to guide FCEV market entry.

3. Current Scenario of the Electric Mobility in Europe with a Focus on Portugal

The penetration rate of electric vehicles is different in every European country. Recent conclusions from the Leaseplan EV Readiness Index 2020 [21] indicate that the Netherlands, Norway and the UK are currently best prepared for the transition to EVs (Table 1). This research, focused on the level of preparedness of 22 European countries in view of the revolution introduced by electric vehicles, is based on several factors: registrations of electric vehicles, maturity of the infrastructure for the use of electric vehicles and government incentives. According to the data provided, it can be seen how all the countries considered by the study have in all cases shown an increase in performance compared to the previous year. Across Europe, the registrations of EVs have increased by an average of 60%.

Table 1. LeasePlan's EV Readiness Index 2020—max. score is 40 points (Source: Leaseplan) [21].

Country	Total Scoring	EV Maturity	Charging Maturity	Government Incentives	Lease Plan Orders
Netherlands	34	11	8	7	8
Norway	34	12	9	6	7
UK	30	7	7	10	6
Ireland	29	8	5	9	7
Sweden	28	19	5	8	5
Austria	27	8	4	10	5
Luxembourg	26	9	6	5	6
Finland	24	8	6	6	4
Germany	24	8	5	7	4
Belgium	23	8	5	5	5
Portugal	23	7	4	7	5
Denmark	22	8	5	4	5
France	22	5	5	7	5
Hungary	22	5	4	8	5
Switzerland	21	9	6	2	4
Spain	20	5	5	6	4
Italy	17	5	5	4	3
Czech Republic	16	4	5	4	3
Greece	15	3	2	8	2
Romania	12	4	3	2	3
Poland	11	3	2	5	1
Slovakia	11	3	4	3	1

The most mature electric vehicle markets are the Netherlands (nr. 1) and Norway (nr. 2), and thanks to the progress in EV registrations and the growing availability of charging infrastructure, government incentives are steadying. The biggest improvements in the availability of electric vehicles have been achieved by Ireland (up to 6 places) and the UK (up to 5 places) thanks to a more extensive charging infrastructure, a higher number of electric vehicle sales and greater incentives from the government. The number of public charging stations across Europe increased by 73%.

3.1. Portuguese Car Market

Portugal is one of the European countries that has invested most in the creation of incentives for the development of EVs, conceiving purchase subsidies, ensuring benefits for the users of these vehicles, proceeding with the development of infrastructures and creating local incentives [22]. Looking at Leaseplan data on the maturity of the market and the charging infrastructure that take into account various factors such as population, registrations etc., it is clear that Portugal is still far from the indices of countries such as Norway, Sweden and the Netherlands, which have the three highest indices, but despite this, looking at the total European context, it is positioned in a medium range with respect to all the countries taken into consideration [21] (Tables 2 and 3).

Table 2. EV market maturity in 2019 (Source: Leaseplan) [21].

Country	Charging Locations per Inhabits (×1000) 2019	Scoring Charging Points per Population	Stations per EV Registered 2019	Scoring Charge Station per EV
Austria	0.47	2	0.48	1
Belgium	0.51	3	0.46	1
Czech Republic	0.06	1	0.74	2
Denmark	0.46	2	0.40	1
Finland	0.17	2	0.18	1
France	0.44	2	0.70	2
Germany	0.39	2	0.44	1
Greece	0.00	0	0.15	1
Hungary	0.07	1	0.33	1
Ireland	0.21	2	0.25	1
Italy	0.07	1	0.37	1
Luxembourg	1.55	4	0.62	2
Netherlands	2.53	5	1.15	2
Norway	2.33	5	0.20	1
Poland	0.02	0	0.44	1
Portugal	0.28	2	0.33	1
Romania	0.02	0	0.38	1
Slovakia	0.10	1	1.95	2
Spain	0.17	2	0.64	2
Sweden	0.49	2	0.18	1
Switzerland	0.67	3	0.51	2
United Kingdom	0.37	2	0.51	2

Table 3. Charging infrastructure maturity in 2019 (Source: Leaseplan) [21].

Country	EV per Inhabitant (×1000)	Scoring EV per Population	EV Market Share % 2019	Scoring EV Market Share
Austria	0.98	4	3.35	2
Belgium	1.10	4	2.88	2
Czech Republic	0.08	1	0.43	1
Denmark	1.15	4	3.85	2
Finland	0.93	4	5.84	3
France	0.63	2	2.57	1
Germany	0.90	4	2.72	2
Greece	0.03	1	0.37	1
Hungary	0.21	2	1.78	1
Ireland	0.86	4	3.71	2
Italy	0.19	2	0.80	1
Luxembourg	2.50	5	3.56	2
Netherlands	2.21	5	11.52	4
Norway	11.62	5	55.64	5
Poland	0.05	1	0.47	1
Portugal	0.85	3	5.00	2
Romania	0.05	1	0.81	1
Slovakia	0.05	1	0.35	1
Spain	0.27	2	1.29	1
Sweden	2.72	5	11.22	4
Switzerland	1.31	4	4.96	3
United Kingdom	0.72	3	2.58	2

Already in 2009, as part of the electric mobility program in Portugal, an electric mobility network (MOBI-E) was set up. According to the available data, Figure 4 shows that in the country, the electric mobility market has evolved especially in the last 5 years, with an estimated growth of up to 170,000 vehicles by 2030; based on these estimates, the electric car fleet could be large enough to significantly reduce GHG emissions [23]

(Figure 5). Lisbon is the national territory with the highest concentration of EVs, as it concentrates 23% of registrations of light electric vehicles until June 2018 and 33% of the charging stations installed in the country [24].

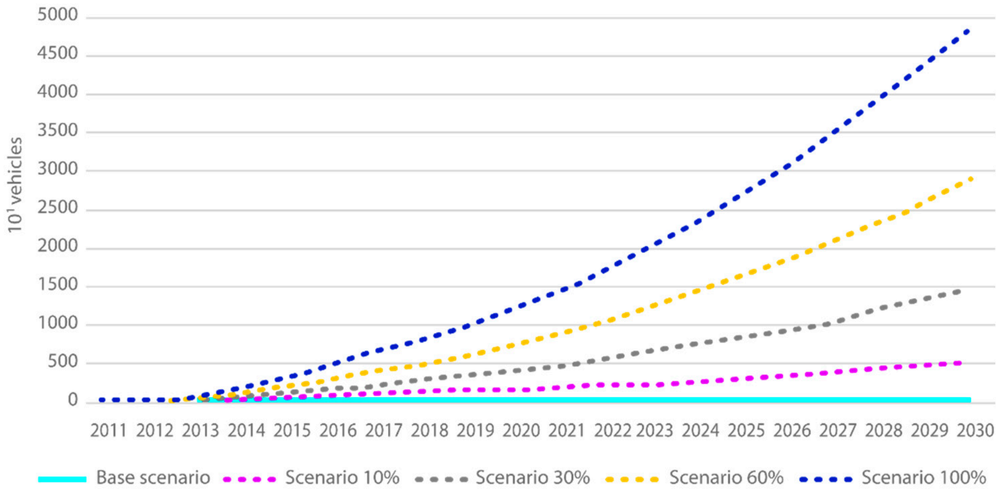


Figure 4. Prediction of the fleet of BEVs, HEVs and PHEVs.

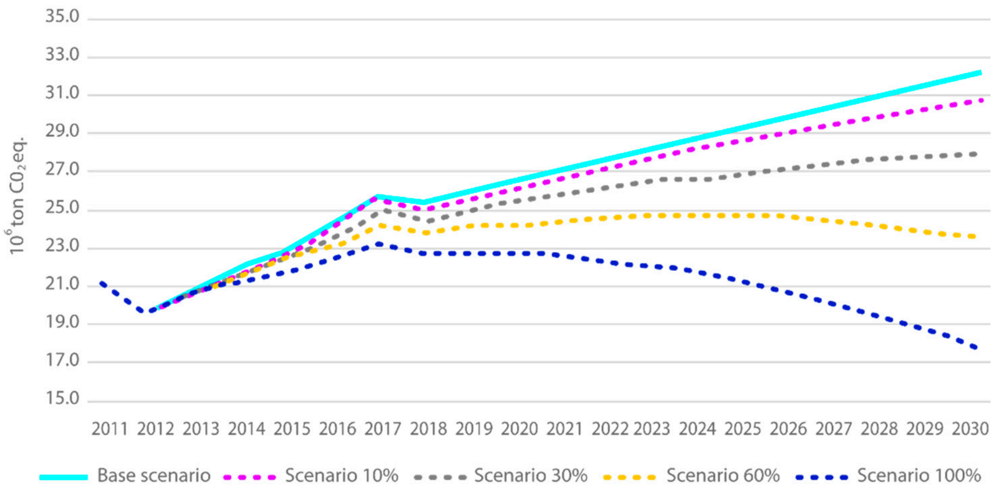


Figure 5. Evaluation of GHG emissions in the scenarios.

Between 2016 and 2017, there was a decline in the share of the diesel market across Europe, which decreased from 49.9% to 44.8% of total passenger car registrations in the EU-15 compared to previous years. Nevertheless, this decline was offset by an increase in sales of petrol cars. Petrol vehicles were the best-selling in the EU-15 in 2018, almost half of the total number of passenger cars. In total, 5.8% of the automotive market in 2017 was represented by alternative propulsion vehicles (APV), while only 1.8% was for electric recharging vehicles (PEV-Plug-in vehicles). During the year the share of diesel sales decreased in almost of Western European countries, especially in Luxembourg and Greece, where there was a loss of more than 10%. The market share of diesel cars, on the other hand, remained stable in Italy and Denmark, with reductions of around 1%. Ireland remains the country with the highest percentage (65.2%), followed by Portugal (61.5%) and Italy (56.3%) [25] (Figure 6).

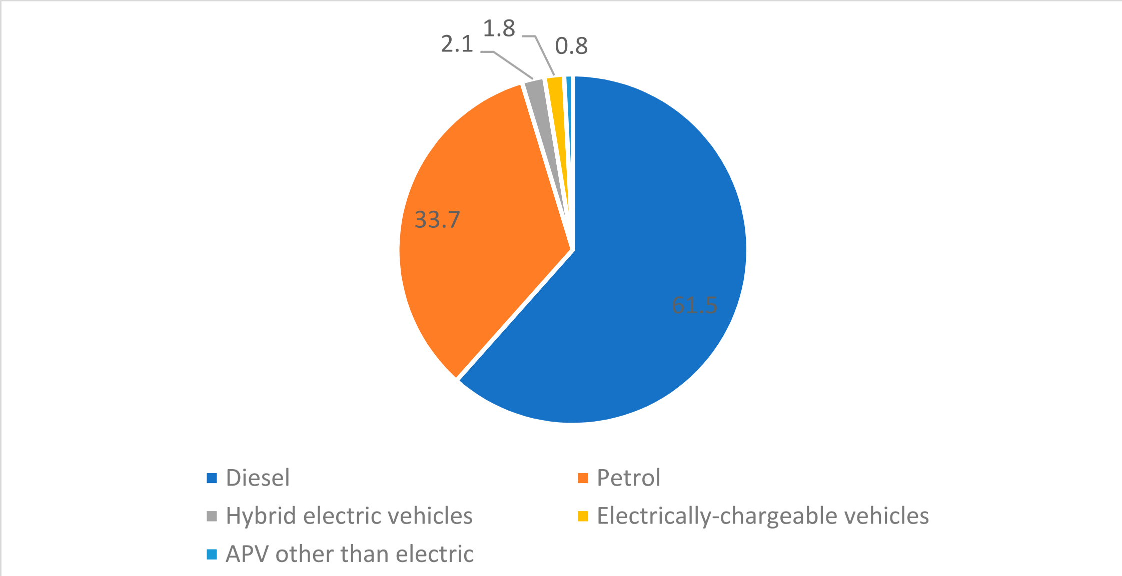


Figure 6. New passenger cars in Portugal by fuel type, 2017, from the European Automobile Manufacturers' Association (ACEA).

As for 2020, in Portugal, there is a small change of course as BEVs account for 5% of car registrations across the country (compared to 1.8 in 2018). Tesla Model 3 was the most registered electric car in the first eight months (Table 4). National car registrations fell by only 0.1% in August. Data from the ACAP (Associação Automóvel de Portugal) reveal a growing in the number of registrations of light vehicles in the country, which in July recorded a drop of 17.8%. Between January and August, the national light vehicle market recorded a decline of 42.0% [26] (Table 5).

Table 4. Sales ranking of light passenger electric vehicles in Portugal [25].

Position	Brand	Model
1	Tesla	Model 3
2	Renault	ZOE
3	Nissan	LEAF
4	Peugeot	208
5	Hyundai	Kauai
6	smart	Fortwo
7	Jaguar	i-PACE
8	BMW	i3
9	MINI	Cooper SE

Table 5. The twelve most registered brands in Portugal, first 8 months of 2020 [25].

Position	Brand	2020	2019	Variation %
1	Renault	11.437	21.263	−46.20%
2	Peugeot	10.162	16.843	−39.70%
3	Mercedes-Benz	9.066	11.383	−20.40%
4	BMW	6.344	9.409	−32.60%
5	Citroën	5.387	10.702	−49.70%
6	Nissan	4.99	7.271	−31.40%
7	SEAT	4.491	7.871	−42.90%
8	Volkswagen	4.263	7.524	−43.30%
9	Toyota	4.232	6.805	−37.80%
10	Ford	4.106	6.424	−36.10%
11	Fiat	3.952	10.728	−63.20%
12	Hyundai	3.468	4.34	−20.10%

Currently, 100% electric vehicles (BEVs) already represent almost 5% of new national car registrations (4.9%). In 2020, there was an increase in registrations of electric vehicles, reaching registrations of hybrid cars (which in the first months of the year represented 5.4% of total car registrations). Petrol remains dominant, with 47.5% of registrations, followed by diesel with 33.8% of registrations. In August, BEVs accounted for 3.5% of new car registrations in Portugal; 48.2% of new passenger cars registered in the eighth month of the year were petrol-powered units. Diesel is in second place, with 33.9% of new registrations. The podium is, therefore, completed by electrified plug-in hybrid solutions (petrol), with 6.0% of new national car registrations [27] (Figure 7).

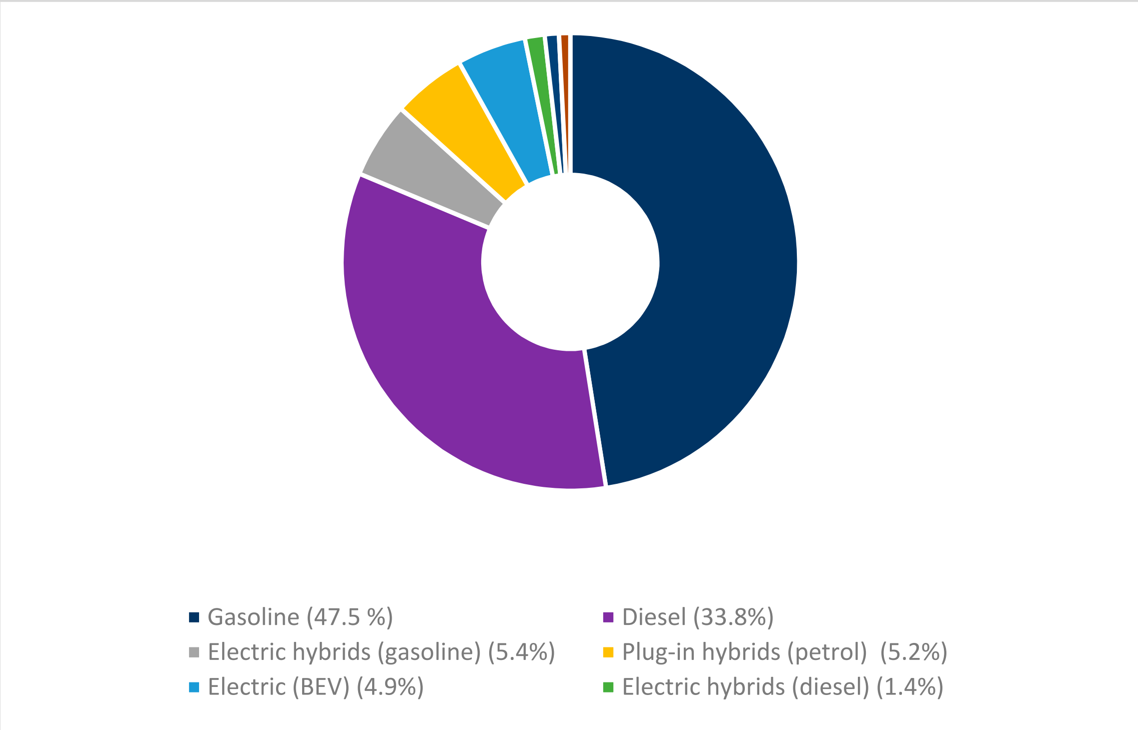


Figure 7. Vehicle market by type of energy in Portugal, 2020 (Source: ACAP Statistics) [27].

To get an idea of the distribution of EV in the Portuguese territory, in Figure 8 the distribution of the number of light electric vehicles (BEVs) is represented according to the registration location of the respective vehicles, up to June 2018 [28]. In total, 9975 BEVs were registered, most of them registered in Lisbon (24%) and Oeiras (14%). There is clearly a greater number of BEVs recorded on the coast of the Portuguese territory (except in the municipalities of the Alentejo Litoral) with some municipalities in more continental regions, namely Viseu, Mangualde, Covilhã, Évora, Beja and Chaves, although together, they represent only 2% of the total number of registered BEVs. Considering the segmentation of the territory of the Portuguese territory based on the percentage of registered BEVs, it appears that 50% of the vehicles are registered in Lisbon, Oeiras, Cascais (5%), Sintra (3%), Porto (3%) and Vila Nova de Gaia (2%). In other words, 50% of BEVs are recorded in only around 1% of the total area of the Portuguese territory.

3.2. Electric Recharging Points in the Area

Based on data provided by the European Alternative Fuels Observatory [29], an evolution of the installation of public charging points in the Portuguese territory can be seen, from 2011 to 2020. As regards the Normal Charge stations (<=22 kW), a rather uniform trend is noted until 2016, which sees between 1100 and 1300 charging points installed, then a slight increase for the following three years to reach 2020, with an increase notable that almost doubled. On the other hand, the numbers of Fast Charge stations (>22 kW) are lower (Figure 9).

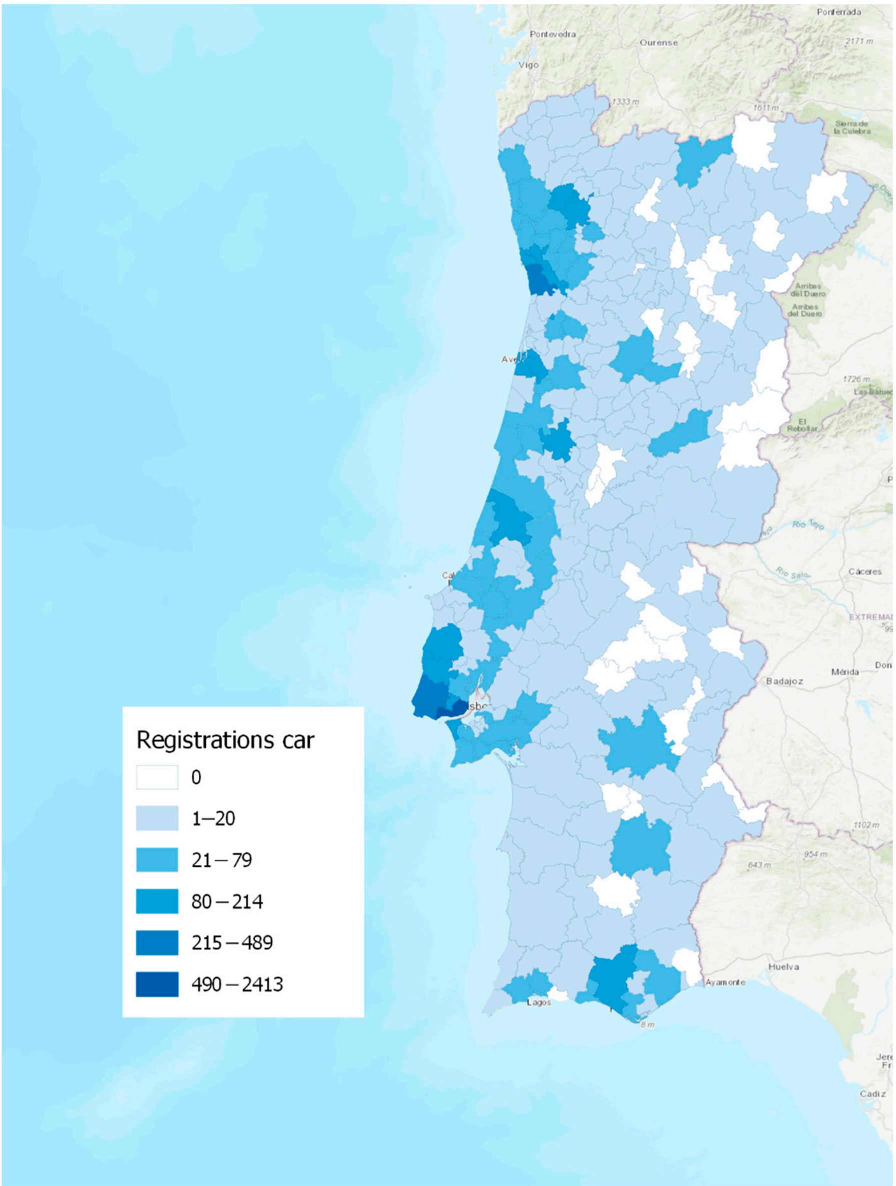


Figure 8. BEVs registered until June 2018 in Portugal (Map elaborated with QGIS).

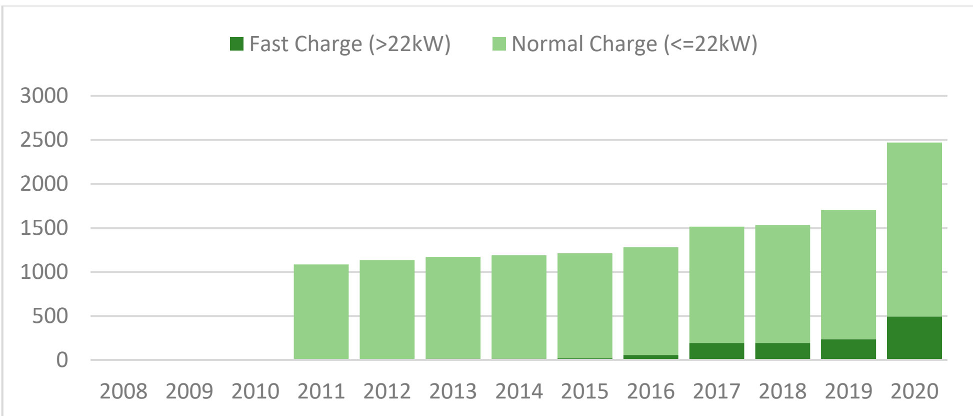


Figure 9. Total number of Normal and Fast public Charging points (2020) [29].

3.3. EV Policies and Plans in Portugal

To reduce emissions caused by the transport sector, the Portuguese government has introduced regulations aimed at energy efficiency, which are part of the third updated National Action Plan for Energy Efficiency (NEEAP, 2017–2020), drafted according to communication from the European Commission pursuant to Article 24 (2) and Annex XIV of the Energy Efficiency Directive (EED, 2012/27/EU) [30]. Regarding EVs, several green taxes have been introduced to promote the market introduction of low-carbon EVs and HVs. These, in fact, have a tax differentiation that translates into exemption from total road tax (Imposto Único de Circulação, i.e., IUC), under the environmental component, and exemption from vehicle tax (Imposto sobre Veículos or ISV), while hybrid vehicles pay only 25% of the registration tax; these are currently the main policy instruments influencing the price of new cars in Portugal. Furthermore, the document introduces the Eco-car program, which also incorporates MOBI.E, the electric vehicles program, which provides the upgrading of existing charging infrastructures for EV [31]. Between 2000 and 2010, to promote the substitution of old vehicles with new ones, the Portuguese government released an automobile scrapping program. Subsequently, this program was replaced in 2014 by the incentive of the scrapping program for end-of-life vehicles (Incentivo ao abate de veículos em fim de vida—VFV) through Law 82-D/2014, also called "The Green Taxation Reform". The main difference between these two programs is that the latter only covered so-called environmentally friendly cars. The idea was to remove from circulation the vehicles over 10 years old and reward the consumers who buy less polluting cars. More recently, Legislative Decree 42-A/2016 included an incentive of €2250 for the purchase of low-emission vehicles (EV). That incentive was financed by the Environmental Fund. That fund applied the incentive for EV purchase, without the need to return a vehicle older than ten years, and this was valid throughout the year 2017. Portugal currently adopts a variable incentive scheme depending on the buyer: if it is a private individual, the bonus for the purchase of an electric car is €3000. In the case of company purchases, it goes down to €2000 for cars and €3000 for battery-powered vans. In addition, a reduced VAT is applied on the purchase and an exemption from the ownership tax is also offered.

4. Fuel Cell: Forecasts for the Development of Hydrogen in Portugal

In the transition process towards more sustainable mobility, we cannot fail to consider hydrogen technology (FCEV). Furthermore, the advantage of using Fuel Cell technologies is to surmount the aspects relative to charging anxiety (which is one of the major obstacles to the social/psychological acceptance of users), because the FCEV have a major autonomy and a lower charging time. Hydrogen vehicles use hydrogen as a fuel. These vehicles convert the chemical energy of hydrogen into mechanical energy, which can be done in the following ways: the use of HICEVs (Hydrogen Internal Combustion Engine Vehicle), then burning it in an internal combustion engine; the use of FCEVs (Fuel Cell Electric Vehicle), then causing it to react with oxygen in a Fuel Cell, producing electricity. The most popular are the FCEVs, and Proton Exchange Membrane Fuel Cell (PEMFC) performance studies show excellent results, making this vehicle a good candidate to replace the conventional engine. Mebarki et al. [32] affirmed that the fuel cell hybrid vehicle is a valid alternative to replace the conventional vehicle, comprising about twice the performance compared to an urban cycle with a petrol engine. Other studies focused on minimizing the hydrogen consumption of a Proton Exchange Membrane (PEM) fuel cell [33]. To achieve this, the system is controlled by an energy management strategy (EMS), in order to minimize the transitions in the Fuel cell's energy demand and thus improve its life. The results of the simulation conducted by the researchers demonstrate an increase of 40% in the consumption of hydrogen through the energy recovered from the braking phases. Furthermore, compared to other propulsion vehicles, FCVs have unique strengths and weaknesses, as shown in Table 6 [34]. Importantly, unlike electricity generation, hydrogen production can provide a solution to the waste of renewable energy as it is suitable for large-scale electricity storage [35]. Thus, this stands as a valid alternative for future sustainable mobility.

Table 6. The strengths and weaknesses of FCV/hydrogen expansion.

Strengths of FCV	Weaknesses of FCV
Copious resources and sustainable procurement	Low energy content per volume unit
Production from renewable energy	High costs
High energy density	Absence of enabling technologies: hydrogen production, storage, distribution, etc.
Zero harmful emissions during use (emits only water vapor)	Lack of infrastructure
Short charging time (5 min)	The production of hydrogen that does not use renewable sources causes pollution
Good autonomy	

Thanks to the many benefits of hydrogen, in recent years, numerous car manufacturers have begun to include Fuel cell passenger vehicles, and some countries around the world have promoted various pilot projects with Fuel cell city buses. Toyota was among the first car manufacturers to produce a Fuel Cell car, the Mirai, which is currently being mass-produced in Japan and the United States. However, in Portugal, unlike other countries of the European Union, hydrogen is not yet present on the territory, but the Portuguese government is moving in this direction. In 2020, 37 renewable hydrogen (green hydrogen) projects were presented as a recovery strategy from the economic effects of the coronavirus pandemic; among these was a plant near the port of Sines. These are currently under evaluation and provide for a total investment of approximately 9 billion euro [36]. Portugal aims to launch the green hydrogen production project on an industrial scale as soon as possible. The Sines Project, also called "Green Flamingo", was developed, which is a 3.5 billion euro industrial scale project for the production of green hydrogen involving the main Portuguese energy stakeholders, such as GALP, EDP and REN. The choice fell on Sines for its strategic advantages: it contains a well-equipped deep-sea port, it has one of the lowest solar energy prices in the world and there is public land available to install the hydrogen industrial complex and a modern natural gas supply network. The goal is to reduce greenhouse gas emissions by 55% and a 47% share of renewable energy in gross final energy consumption. The hydrogen generated in Sines will initially be consumed in the national market, mainly using the natural gas distribution network. As production capacity increases, a significant portion of production is expected to be exported using the deep-sea port of Sines. It is estimated to reach 2 to 2.5 GW of installed capacity to produce hydrogen in the next decade, to have between 10% and 15% of hydrogen injected into the natural gas grid and to build 50 to 100 hydrogen refueling stations. These objectives amount to an investment of around 7–9 billion euro [37].

As already mentioned, FCEVs have some advantages over internal combustion engine vehicles (ICEVs) and battery electric vehicles (BEVs), as shown below:

1. FCEVs take a short H_2 refill time due to high-pressure refueling;
2. FCEVs have a high-level air purification system to keep dust or particulate matter out of the fuel cell;
3. FCEVs have longer mileage for one time refueling than ICEVs and BEVs;
4. FCEVs can accelerate entry into H_2 companies.

The disadvantages for FCEVs are that the H_2 filling station construction fee is still high and that the H_2 supply chain is not fixed [38]. However, FCEVs have received more attention than before in many countries, and recent research has focused on the H_2 supply chain including production, storage, transportation and distribution to prepare H_2 society and achieve an optimized H_2 supply chain in economic and environmental terms. It was concluded that if the demand for FCEVs increases enough, H_2 is considered as a more suitable energy source [39]. As found in the literature or from the data provided by the manufacturers of EV, if for recharging we use the current of various sources supplied by the 220 V network, the cost can be conservatively estimated at 0.25 €/kWh. Thus, the cost per km of an EV is about $0.18 \times 0.25 = 0.045$ €/km, or just 4.5 cent/km traveled.

For a journey of 100 km, such as that usually used to compare consumption, the cost is 0.045 × 100 = 4.5 €. As for FCEV, to date, the price of a full tank of hydrogen per car is comparable to that of a diesel vehicle: to travel 100 km, a fuel cell vehicle consumes about 1 kg of hydrogen. Hydrogen is currently 10 €/kg, and therefore, for a distance of 100 km there is a cost of 10 cent/km. However, when you consider that hydrogen in the supply chain allows for the use of otherwise unusable renewable electricity through on-site electrolysis, the lower efficiency of the hydrogen path is offset by lower excess electricity costs. It can be concluded that electric recharging and hydrogen refueling are key to achieving low-carbon, clean and renewable energy-based transport concepts. A smart and complementary combination of electric charging and hydrogen refueling infrastructure can combine the strengths of both and can avoid unsustainable solutions with low system relevance or efficiency. Leveraging low-range rewards, such as overnight charging of BEVs for short-distance travel and addressing the challenges of long-distance and heavy transportation with FCEVs and hydrogen refueling, can be beneficial in terms of system solutions. Both infrastructures require a small amount of investment compared to other infrastructures. While the electric charging infrastructure allows for greater efficiency, the implementation of the hydrogen infrastructure allows for further large-scale applications. The European "hydrogen" plan provides for a large-scale use of "green" hydrogen by 2030 with final costs, thanks to the reduction in the costs of electrolyzers, the costs of renewable energy and the increase in energy conversion efficiency, lowered up to 2–3 €/kg. In this case, the scenario looks completely different. It will no longer be difficult to find a refueling station and the cost per 100 km will drop to €3/100 km, which is a competitive cost with Superchargers. This is the path that Europe has already taken and the European Commission itself foresees a market share of 16% for the FCEVs by 2050 [40]. However, some sector studies predict by 2030 a few million FCEVs circulating on the road in Europe alone. Hydrogen Europe, a stakeholder representing the European industry in the sector, expects over 4 million hydrogen vehicles on European roads by 2030 [41].

5. Materials and Methods: Description of the SERA Model

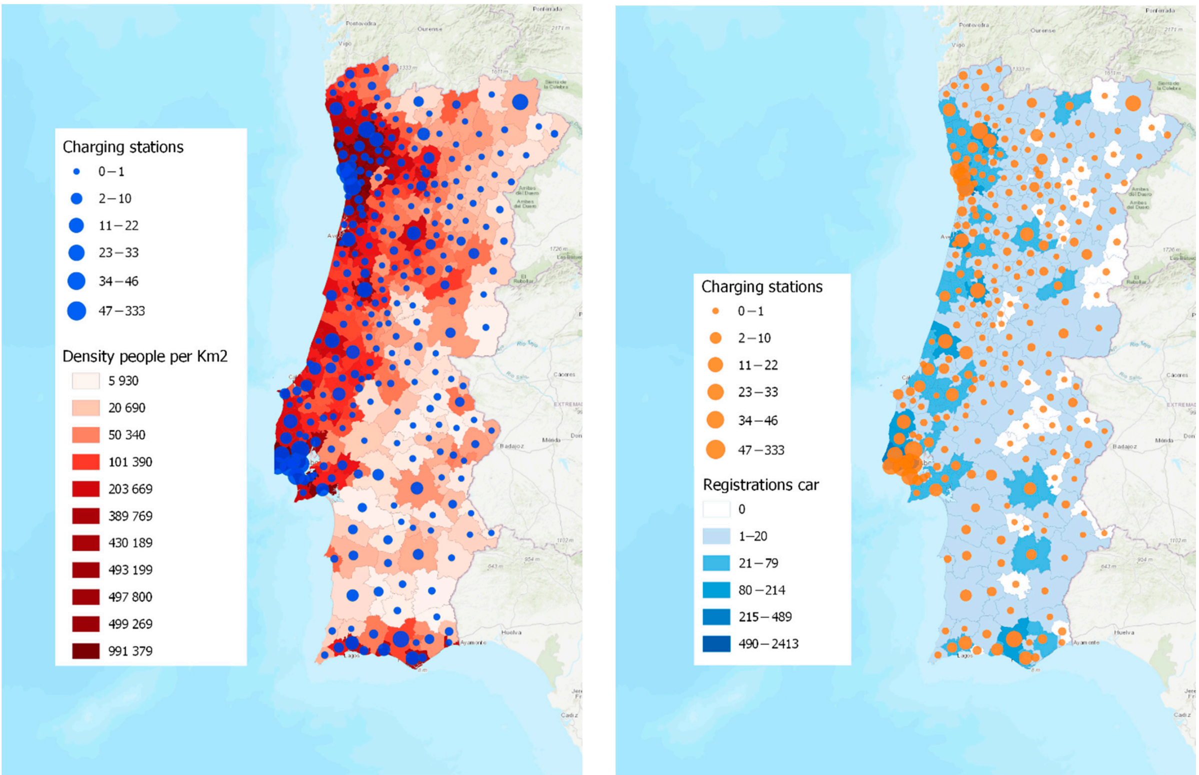
The SERA (Scenario Evaluation and Regionalization Analysis) model of the National Renewable Energy Laboratory occupies a unique and important niche in the temporal and geospatial analysis of the construction of hydrogen infrastructure for production and delivery. The model evaluates the quantity, size and position of hydrogen refueling stations that meet the fuel demand from FCEVs and hydrogen supply requirements to meet that demand in terms of production facilities of hydrogen and distribution infrastructure. SERA simulates the evolution of hydrogen refueling infrastructure, providing useful information to reduce the financial risks related with infrastructure investment choices and helping to rush FCEV adoption. Using a metric defined by Bush et al. [42], this document illustrates the use of the model to simulate the distribution scenarios of hydrogen refueling stations in the Portuguese territory.

The research was developed according to the following phases:

Phase 1: Review of the literature, which is used to set the context of electric mobility in Europe with reference to Portugal, in particular on the regulations and policies adopted by the country. In fact, as is known from the literature, these are a key tool for any innovation process. In this document, this step is located in Section 2.

Phase 2: Collection of quantitative data for the preparation of the forecast model. These include the most recent EV registration data in Portugal [24,25], data on the existing charging infrastructure or public to private charging stations throughout the country by Municipality and District [43,44] and demographic data (population density) and geographical data (extension in km^2) of the main municipalities (the two autonomous regions of the Azores and Madeira are excluded from the study) [45].

Phase 3: Creation of a database with the data collected for the creation of georeferenced maps in QGIS, in order to have an overall overview of the geographical location of the information, as well as the connections between the various data levels (e.g., the ratio of population density/registrations) (Figure 10a,b).



(**a**) (**b**)

Figure 10. (**a**) Charging stations/Density of people per km^2. (**b**) Charging stations/Registration car (map elaborated with QGIS).

Phase 4: Using the SERA model for the creation of GIS maps (Figures 11–13) and predictive Cartesian graphs on the development of Fuel cells in Portugal, starting from the Early Adopters of the EVs (Figures 14 and 15).

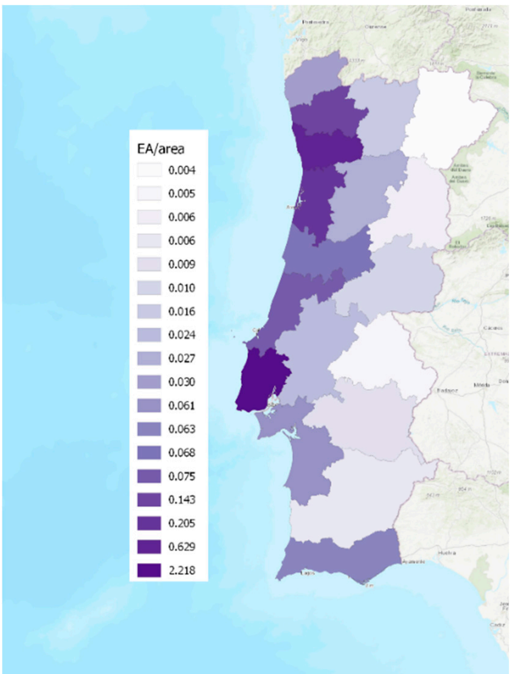


Figure 11. EAM per density (km^2) (map elaborated with QGIS).

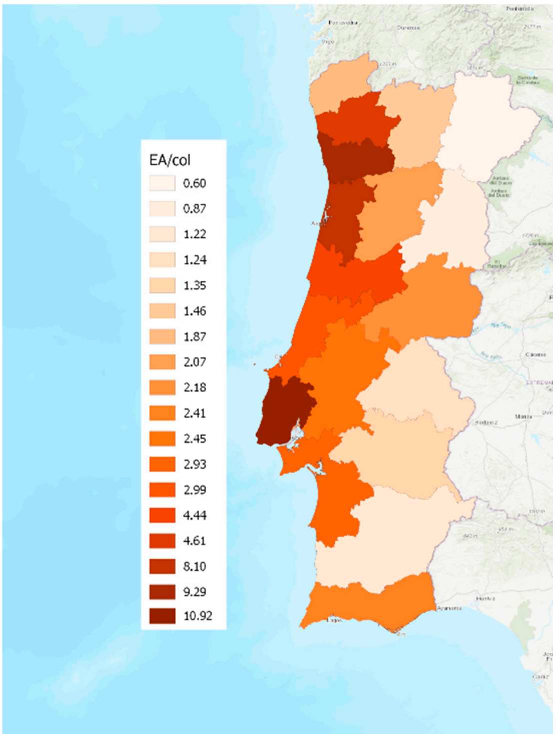


Figure 12. EAM per coverage station (map elaborated with QGIS).

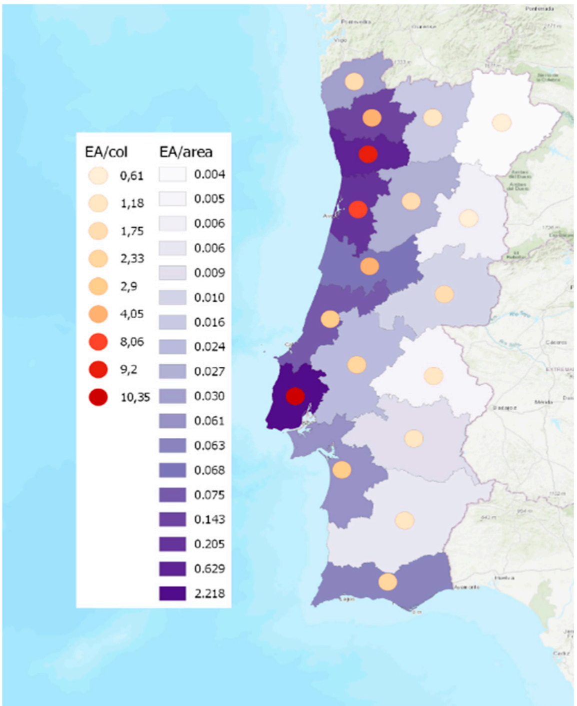


Figure 13. EAM identifies the levels of propensity in the use of new technology vehicles, which are considered constraining factors, such as the limited number of recharging infrastructures (map elaborated with QGIS).

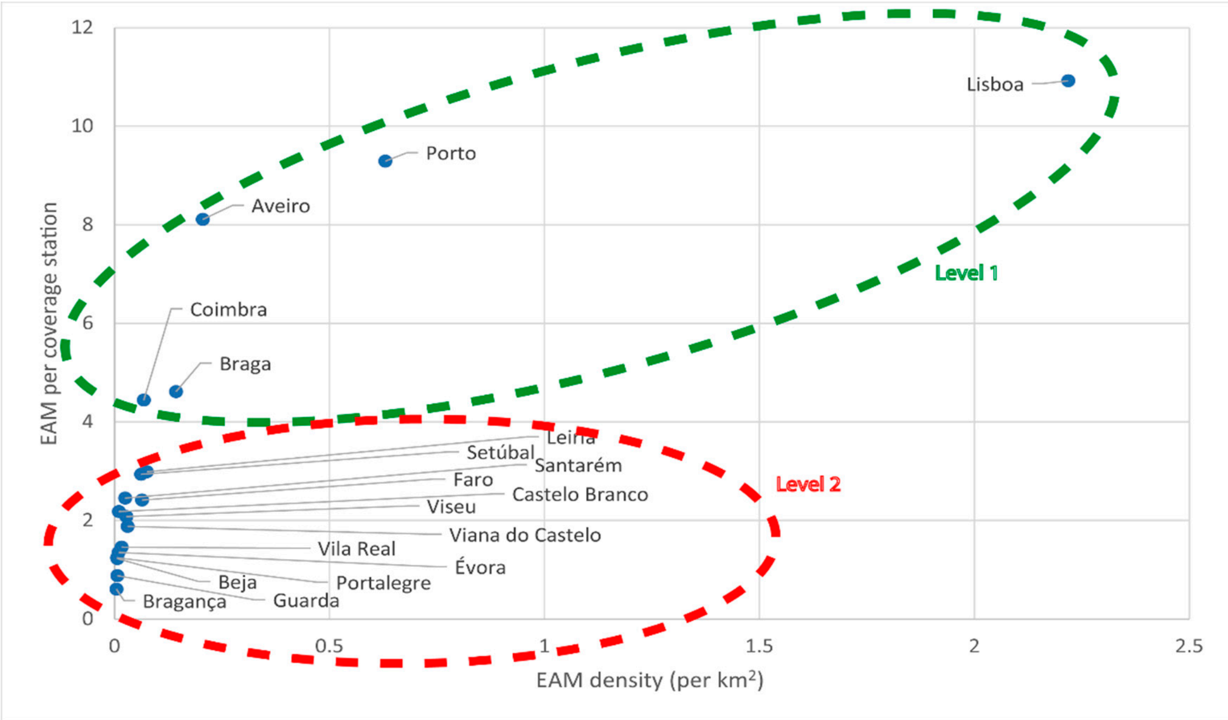


Figure 14. Districts with greater propensity according to the SERA model.

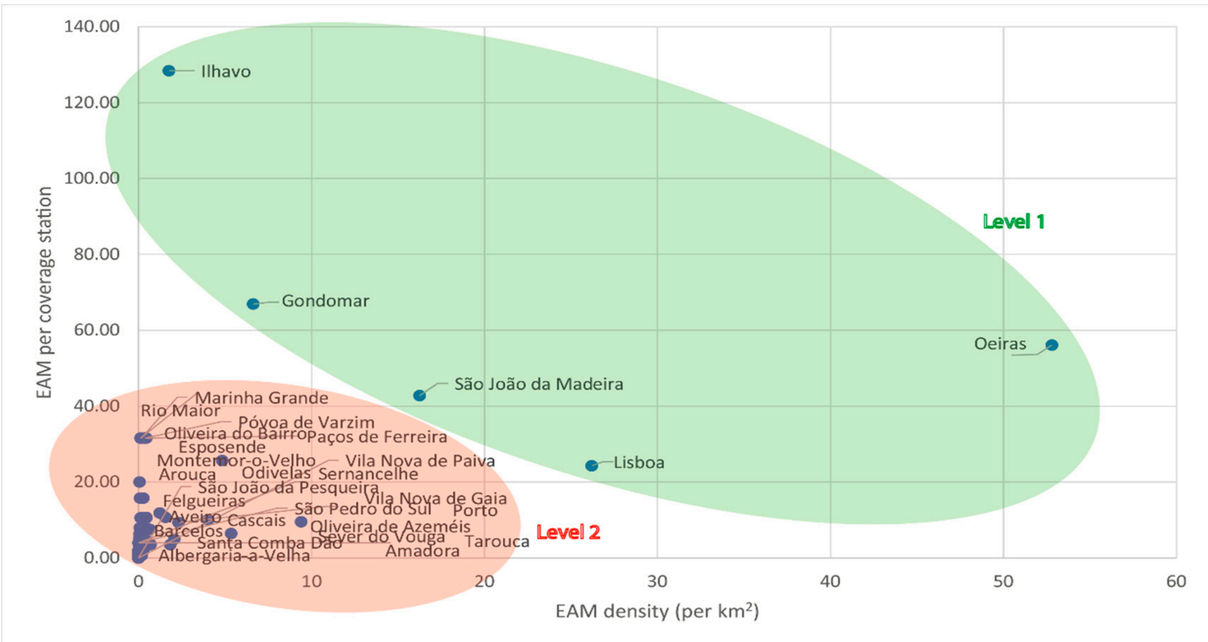


Figure 15. Cities with greater propensity according to the SERA model.

6. Results and Discussion

The model input data are those relating to the EV Early Adopters (EAM) metrics (i.e., those who first use the charging infrastructure). Therefore, through the data on EVs, it is possible to make an assessment and forecast of the adoption of FCEVs. The metric can define the areas in which the first users of FCEVs develop, considering socio-economic aspects, such as the wealth of the city or the density of the population. As defined by the SERA model, we call the first developing infrastructures "enabling stations". The propensity of users to purchase FCEVs is studied through the "Urban Market Sequencing" model. The results concerning the 18 Portuguese districts on a GIS map are reported first. In Figure 11, the number of "early adopters" per square meter is found that is the density of the first users, while in Figure 12, the number of "early adopters" needed to enable the stations can be seen. By superimposing the layers containing the information with the help of GIS, the districts can be found in which the major users of the charging infrastructure will be present; a positive trend is observed in the cities of the coastal strip, with a greater propensity for the districts of Lisbon, Porto and Aveiro. Furthermore, it is also observed in the districts of Lisbon, Porto, Aveiro and Braga that the number of EAMs is higher than the existing infrastructure permits, and therefore, those could be districts in which to invest in this sense. The "priority" in assessing positive urban markets is depicted in Figure 13.

In the same way, the data on a system of Cartesian axes can be reported in which the ordinate axis the amount of "early adopters" needed to enable the stations is found, while the abscissa axis shows the number of "early adopters" per square meter, or the density of first users (Figure 14). Thus, the number of users and the eventuality of being able to use the charging stations are directly connected. This translates into restrictions in districts where there is a low urban density and a limited number of recharging infrastructures. In this way, the efficiency of the positioning of a limited quantity of charging stations necessary to face up with the entry of enabling users in a specific urban market is evaluated.

Two different levels with two colors to group the districts are used in the graph. Those inside level 1 have a greater presence of users, but are disadvantaged due to a limited number of charging infrastructures or the extension of the city. This means that in these regions, there is a strong propensity of the inhabitants to adopt new technologies, and therefore, it could be a convenient choice to invest in charging infrastructures. Making the same reasoning on the individual cities, it appears that Ílhavo and São João da Madeira (in the Aveiro district), Oeiras (in the Lisbon district) and Gondomar (in the Porto district) appear to be the cities with a greater number of Early Adopters, but an insufficient number of charging stations and high population density (Figure 15).

7. Scenarios in the Immediate Future and Limits of the Model

The SERA model, in addition to providing an analysis described in the previous paragraph, is also able to determine upcoming scenarios. In fact, it uses a deterministic algorithm called "Station Counts", which allows to evaluate the charging infrastructure necessary to supply a specific urban area, based on the dynamic records of new EV purchased in previous years (positioning method space-time). The method employs a forward finite difference scheme, and therefore, it allows to predict the growth in the amount of infrastructure from the initial ones, city by city (using the data associated with the sales of electric vehicles and the amount of charging infrastructure already present). Taking $D(t)$, i.e., the sales records of electric vehicles in year t, $D(t + 1)$, i.e., the records in year $t + 1$, and $N(t)$, i.e., the number of charging systems built in year t; an empirical parameter α adopts the rate of 2.5, while $Qave\_max(t)$ assumes the rate of 8000 [46]; following a term difference scheme, the number of implants after one year is:

$$N(t+1) = N(t) + \beta\, W(t+1), \tag{1}$$

$$W(t+1) = \frac{D(t+1) - D(t)}{Q_{ave}(t)}, \tag{2}$$

$$N(t=0) = N_0, \tag{3}$$

$$Q_{ave} = \frac{D(t)}{N(t)}, \tag{4}$$

$$\beta = \alpha^{\left(\frac{Qave(t)}{Qave\_max(t)} - 1 \right)}. \tag{5}$$

where the following conclusions can be drawn:

- In Equation (1), the number of electric vehicles from the previous year increased by a factor β multiplied by the citizen's so-called "willingness" to take on a new ecological lifestyle and purchase an electric vehicle;
- In Equation (2), the will $W(t+1)$ in (2), obtained with a dynamic function, is a time-dependent function, created with the forward finite difference scheme that uses the number of EVs acquired by taking into account two different years;
- In Equation (3), the factor $Qave\_max(t)$ is equivalent to 8000;
- In Equation (4), a weighting factor, which is also used in Equation (2), is used to reduce the will and addresses the problem of the "chicken and egg" relationship.

The databases in [47] concerning the history of registrations and charging stations in European countries are taken into consideration, and in particular, to apply the forward finite differences, the registration of the years 2011–2018 was used. European countries find themselves in different situations between "early adopters" and "following majority". To differentiate this situation, it is possible to introduce a relationship between registrations and charging stations present each year. The behavior of Portugal, France, Germany, Norway, Sweden, the United Kingdom and the Netherlands is considered. Figure 16 shows the different behaviors.

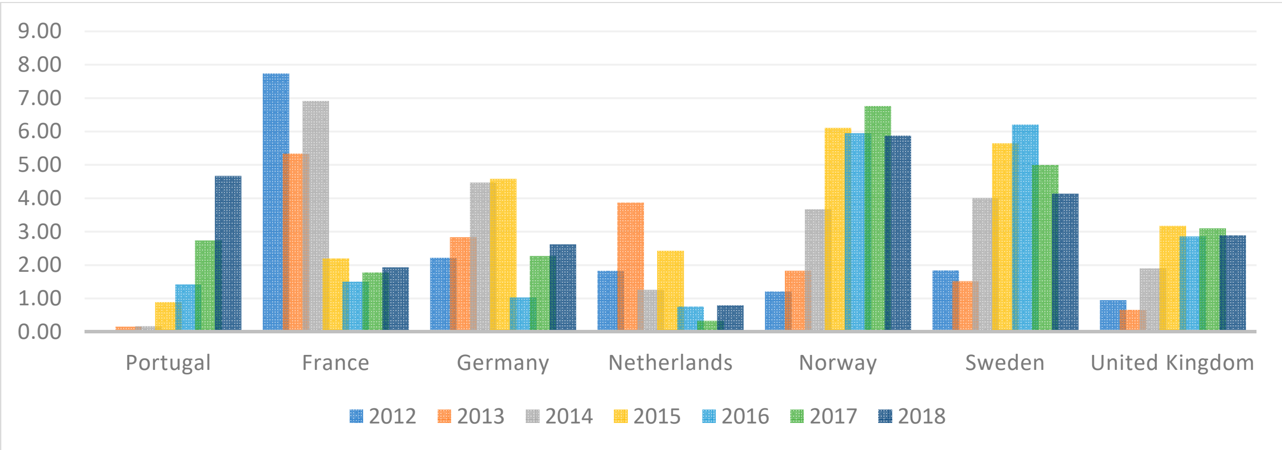


Figure 16. Ratios of new registrations and active charging stations.

Portugal's behavior is constantly growing (only Norway has a similar behavior), so it is possible to imagine how the nation might react to the inclusion of FCEVs. In [48], there is an application of the SERA model that takes into account the so-called "will" of the citizen to take on a new lifestyle and purchase an EV. Portugal's inclination to increase the number of FC stations is shown in Figure 17.

Initially, the number of enabling FCs is considered weighed on the basis of the number of electric charging stations present. If a number of FC charging stations equal to the electric one divided by a factor of 25 are inserted in a year zero, this number can be increased in a sequence of subsequent years based on the reaction to innovation. By inserting the data from Portugal in the SERA model, it is possible to see that in five years, the FC charging stations will increase by a factor between 4 and 5. In Figure 17, the trend in blue represents the discrete values obtained by the SERA model, while orange represents the trend line. These predictions have been made from the inclinations of electric vehicle users [49].

In conclusion, it can be said that the implementation of new mobility solutions based on sustainable vehicles, such as electric, hybrid or hydrogen cars in urban transport systems, can bring several benefits for society, from environmental and economic benefits to improving the quality of life. However, people may be discouraged from using new transport technologies due to a lack of knowledge. Therefore, an aspect to be taken into consideration and which is still not receiving much attention, concerns education that supports sustainable mobility, which can lead to social barriers due to a lack of knowledge [50].

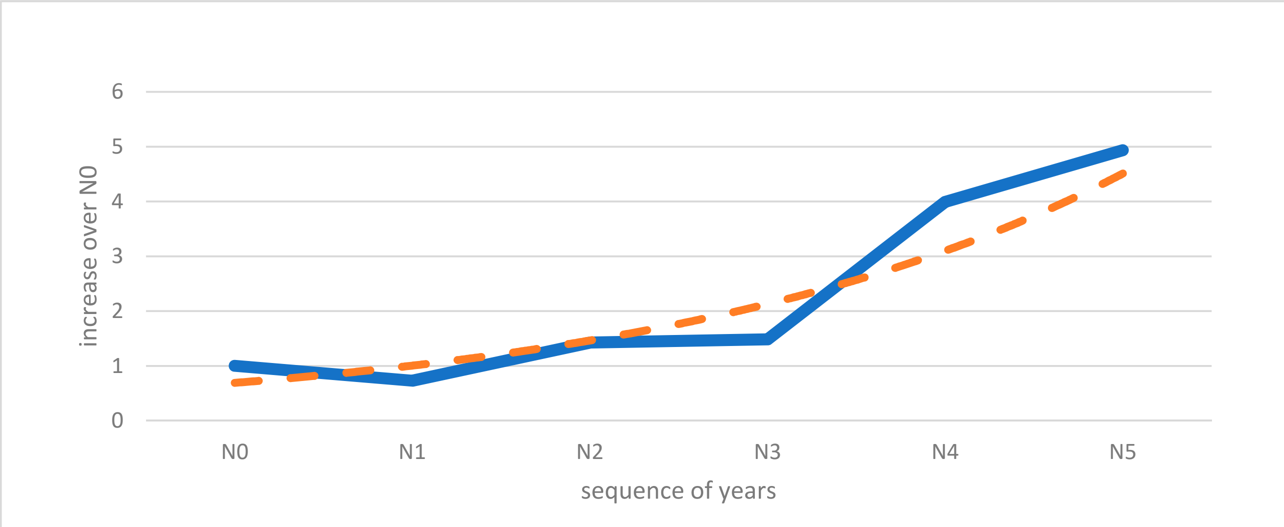


Figure 17. Ability to increase FC charging stations in Portugal, numerical evaluation (blue) and trend (orange).

8. Conclusions

In this document, a study was presented to provide forecasts on the purchasing trend and use of Fuel cell (FC) vehicles in Portugal, based on historical EV deployment in this country. Our analysis shows which districts and municipalities are most ready to adopt this technology. As is found in the literature, it can be said that if the investment for the private purchase of FC vehicles is comparable to that of the electric cars, the same cannot be said about the initial investment in the infrastructure of service stations, nor for the plants to produce the hydrogen. It is presently known that the political and incentive actions that each country adopts to induce the transition process towards sustainability are key elements that must be considered, in addition to the most recent data on the high levels of global CO_2 emissions relating to the road transport sector. Portugal is also moving in this direction, and from the results obtained, the districts of Lisbon, Porto and Aveiro appear to be the most interested to adopt the FC technology. Starting from the assumption that there are no FC refueling stations yet in Portugal, and with the additional problem of the continuing crisis due to the COVID-19 pandemic, the government has set up strategies for an economic recovery. Conforming to that recovery, the intention is to construct hydrogen stations in the Portuguese territory. Those stations response capacity will correspond to the infrastructural investments of the cities mentioned above. The considered regions are highlighted in this article, which will be useful for a correct planning of the initial investments in this technology. Moreover, the Sines reconversion project resulting in the deployment of the coal power plant in green hydrogen production via renewables and electrolysis will play a role on boosting the hydrogen economy in Portugal. A mathematical approach is applied and once the existence of an FC infrastructure is assumed, its growth is calculated using a dynamic scheme. The model used correlates the effects caused by a growth in the charging infrastructure, which also results in an increase in EV sales in the following year and which, therefore, inevitably requires the installation of new charging stations starting from year to year. Thus, these data show the inclination for the development of charging stations and can be translated into a general trend towards innovation starting with Early Adopters, which in this study is applied to Fuel Cell technology. Possible future developments of this study may be related to the spatial planning of hydrogen charging stations. One could think of selecting the cities that were the most ready to adopt the hydrogen technology and identifying the areas on the urban territory in which to place any centralized or on-site hydrogen stations, in order to find the most economically advantageous solutions. Furthermore, this model can be applied to other countries, covering different realities in North America, Latin America, Japan, China, etc.; it is necessary to research further to make a comparison between different countries and the policies they adopt.

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Data Availability Statement: The data that support the findings of this study are available in Estatisticas–Autoinforma, ACAP Statistics 2020, Electromaps Borderless Charging 2021, MOBI.E 2021, reference number [25,27,43,44]. These data were derived from the following resources available in the public domain: https://www.autoinforma.pt/pt/estatisticas (accessed on 30 September 2021), https://acap.pt/pt/estatisticas (accessed on 30 September 2021), https://www.electromaps.com/it/punti-di-ricarica/portugal (accessed on 30 September 2021), https://www.mobie.pt/ (accessed on 30 September 2021).

Conflicts of Interest: The authors declare no conflict of interest.

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