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SUSTAINABLE MOBILITY: SIMULATION OF THE ADOPTION OF FUEL CELL ELECTRIC VEHICLES

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GENERAL INTRODUCTION

1.1. Towards a decarbonization of mobility

Today, the demand for transport in Europe is growing significantly and according to estimates by the European Commission, by 2050 passenger transport will grow by more than 50% and freight transport by 80% compared to current levels. Transport currently consumes one third of all final energy in the EU. Most of this energy comes from oil. This means that transport is responsible for a large part of greenhouse gas emissions in the EU and contributes to a large extent to climate change [1]. While other economic sectors, such as power generation and industry, have mostly reduced their emissions since 1990, emissions from transport have increased. Transport is currently responsible for more than a quarter of total greenhouse gas emissions in the EU and no turnaround is expected. This makes the transport sector a major obstacle to achieving the EU's climate protection objectives. Cars, vans, trucks and buses produce over 70% of the greenhouse gas emissions generated by transport. The remainder comes mainly from sea and air transport. Transport also continues to be a significant source of air pollution, especially in cities. Air pollutants, such as particulate matter (PM) and nitrogen dioxide (NO_2), damage human health and the environment. Although air pollution from transport has decreased over the past decade thanks to the introduction of fuel quality standards, EURO vehicle emission standards and the use of cleaner technologies, concentrations of air pollutants are still too high. high. Reducing the negative effects of transport is an important strategic objective of the EU. The main lines of activity are to promote cleaner and more efficient modes of transport, to use more sustainable technologies, fuels and infrastructures and to ensure that transport prices fully reflect the negative impacts on the environment and health. Reducing the negative effects of transport is an important strategic objective of the EU. The main lines of activity are to promote cleaner and more efficient modes of transport, to use more sustainable technologies, fuels and infrastructures and to ensure that transport prices fully reflect the negative impacts on the environment and health. The EU strategy papers focus on the decarbonization of transport. The European Commission's 2018 strategy "A clean planet for all: a long-term strategic European vision for a prosperous, modern, competitive and climate-neutral economy" is intended to chart a transition path towards zero greenhouse gas emissions in the EU by 2050. As regards transport, highlights the need for a systemic approach, notes the importance of switching to low-carbon modes of transport and zero-emission vehicles, stresses the central role of electrification and renewable energy sources and urges operational efficiency improvements. It also requires better urban planning and the implementation of a better public transport service. Similarly, since 2016 the 'European strategy for low-emission mobility' has identified a more efficient transport system, the rapid spread of low-emission fuels and the transition to low- and zero-emission vehicles as priority areas of intervention. In addition, EU legislation directly addresses the impact of transport on the environment and health by setting binding standards. These include emission limits for cars, vans, trucks and buses, specific requirements for transport fuels, noise maps and action plans for noise management for large transport infrastructures, such as airports.

In Italy, the car fleet exceeded 39.5 million vehicles in 2019 (+ 1.4% compared to 2018; + 7.6% in the period 2010-2019) with a further increase in the motorization rate which reached 65.6 vehicles per 100 inhabitants, clearly the highest in the EU27 [2]. To date, the transport system has a significant negative impact on the environment and human health as it largely depends on oil whose consumption not only releases greenhouse gases and environmental pollutants into the atmosphere and contributes to climate change, but to world level makes economies more vulnerable to fluctuations in prices and energy resources. A radical change of perspective is therefore necessary towards a "low carbon" model, which compatibly satisfies the demand for mobility of the population and economic activities (which are predominantly based on private modes of mobility and transport dependent on fossil fuels) and on the other hand, it reduces greenhouse gas emissions. The transition, therefore, operates in the direction of a sustainable mobility system in environmental, social and economic terms by implementing an integrated "policy" approach capable of acting in a coordinated manner on several fronts. Sustainable governance of transport systems, therefore, remains a challenge for policymakers around the world, particularly with regard to reducing CO_2 emissions from transport. Various studies show how smart city solutions can play a crucial role in mitigating transport emissions and achieving reduction targets [3]. Cities and local authorities would play a crucial role in achieving this goal by taking greater consideration of transport, climate and energy policies. It must also be considered the eruption of the pandemic has upset the balance of social life and the economy in every corner of the world, designing a 2020 with an unprecedented and indecipherable face. The mobility behavior of citizens has changed radically in recent months, on the one hand forced by the pincer of restrictions, gradually reshaped, and on the other evolving along new demand trajectories. Economic and employment crisis, reorganization of working methods, domination of online platforms for daily activities, social distancing (and fear of contagion), enhancement of proximity and public space and so on. The consolidated 2020 data of the "Audimob" Observatory [4] on citizen mobility inevitably mark a breaking point in the historical demand series, with heavy negative variations. The volumes of weekday mobility decreased, compared to 2019, by -22.3% in terms of trips and -39.8% in terms of distances covered (passengers * km); holiday mobility recorded an even greater decline in travel (-31.1%) and a homogeneous decline in passengers*km. The mobility rate (weekdays) dropped to 69% (85.3% in 2019), partially offset by the growth in proximity mobility (very short walking distances). n significant reduction also in the average number of trips of the population (from 2.1 to 1.7), the average per capita time perceived for daily mobility (from 50 to 33 minutes) and the average per capita distance traveled each day (from 24 to 15 km). The trends in road traffic for passenger transport in 2020 elaborated by the Technical Mission Structure of the Ministry of Sustainable Infrastructures and Mobility and provided by the major network operators (ANAS - highways) [5] and by some big data providers confirm the negative dynamics described with strong variability over the course of the year: during the period of the first lockdown, flows decreased by up to 80% and then gradually increased from May to August, fully recovering (or even exceeding) the pre-Covid levels at the beginning of the year, and then decreasing from the end of the summer until the end of the year. Profound changes were also recorded in the guidelines for choosing means of transport, confirming a common perception. In fact, 2020 was the year of the deep crisis in public transport, also due to the rules of social distancing and the fear of contagion, which saw the modal share halved (from 10.8% to 5.4%) and lost over 50% of passengers during the year; at the same time, the share of intermodal journeys fell (from 6.5% to 1.7 for motorized ones). Soft mobility is growing strongly thanks in particular to walking, the weight of which has grown from 20.8% in 2019 to 29% in 2020, and the consolidation of bicycles and micro-mobility (from 3.3% to 3.8%). The car has maintained its dominant position in the choice of Italians, reducing the modal share by only 2.5 points (from 62.5% to 59%). Overall, thanks above all to the great thrust of walking, the rate of sustainable mobility (weight of the set of journeys with low-impact solutions: feet, bikes, micro-mobility and public transport) rose in 2020 to 38.2% from 35 % of 2019. Starting from April 2021 there was then a significant recovery in road mobility and in September 2021 the traffic on the ANAS network was only 2% lower than in the same period of 2019 and on the motorway network it was even higher by 3%. As for the economic data of 2021, the trends in road traffic processed by the Technical Mission Structure of MIMS show that starting from December 2020 the flows have grown, reaching about 80% of those in the same period of 2019 in February 2021, and then reduce again until mid-April due to the third wave of spread of the virus. A significant recovery in road mobility was then observed starting from April 2021 and in September 2021 traffic on the ANAS network was only 2% lower than in the same period of 2019 and on the motorway network it was even 3% higher. Audimob's economic (and provisional) data, which include all the demand for mobility, including travel on foot, by bicycle and by public transport, confirm the consistent recovery in demand flows; between September and October the mobility rate reached 77.2% (compared to 67.7% of the 2020 average) and the volume of trips increased by 22% compared to the first quarter of the year, while still remaining a little lower than the pre-Covid regime. Starting from the full deployment of the vaccination campaign (from April onwards), the indicators of an increase in demand experienced a significant acceleration which was confirmed after the summer. Negative signs, on the other hand, on the modal split front. In fact, the first half of 2021 highlights the worrying recovery of the modal share of cars, now at pre-Covid levels, to the detriment of soft mobility (in readjustment after the great growth of 2020). Electric mobility can therefore become a global strategy to drive the decarbonization of transport and mitigate climate change. In addition, there are potentially greater side benefits, such as increased energy security [6], reducing air pollution and improving public health [7], higher cost-effectiveness [8] and stimulation of economic growth.

1.1.1. Characteristics of the transport sector

The private vehicle, to date, still remains the reference vehicle in the transport sector. Many sources are available and all confirm the absolute dominance of the car in satisfying the demand for passenger mobility, with a decline and a clear margin of collective transport. For our country, the main reference is the ISFORT Annual Reports, which provide historical data up to 1999, thus creating a broad profile of the demand for mobility and its characteristics. In the

April 2020 report, 17th Report on mobility in Italy, this description is given: "The car is not a novelty, it tends to monopolize the choices of means of transport for Italians. Overall, about 2 out of 3 trips are carried out by car (mostly as a driver); an incidence that has grown by almost 8 points in the last 15 years and that the economic crisis does not seem to have affected" [9]. From the data processed by "The European House-Ambrosetti" (Figure 1), it is clear that for passenger transport by land, in the EU-27 and in particular in Italy, the presence of personal vehicles is still very strong and those of public transport such as trains and bus are still very low [10].

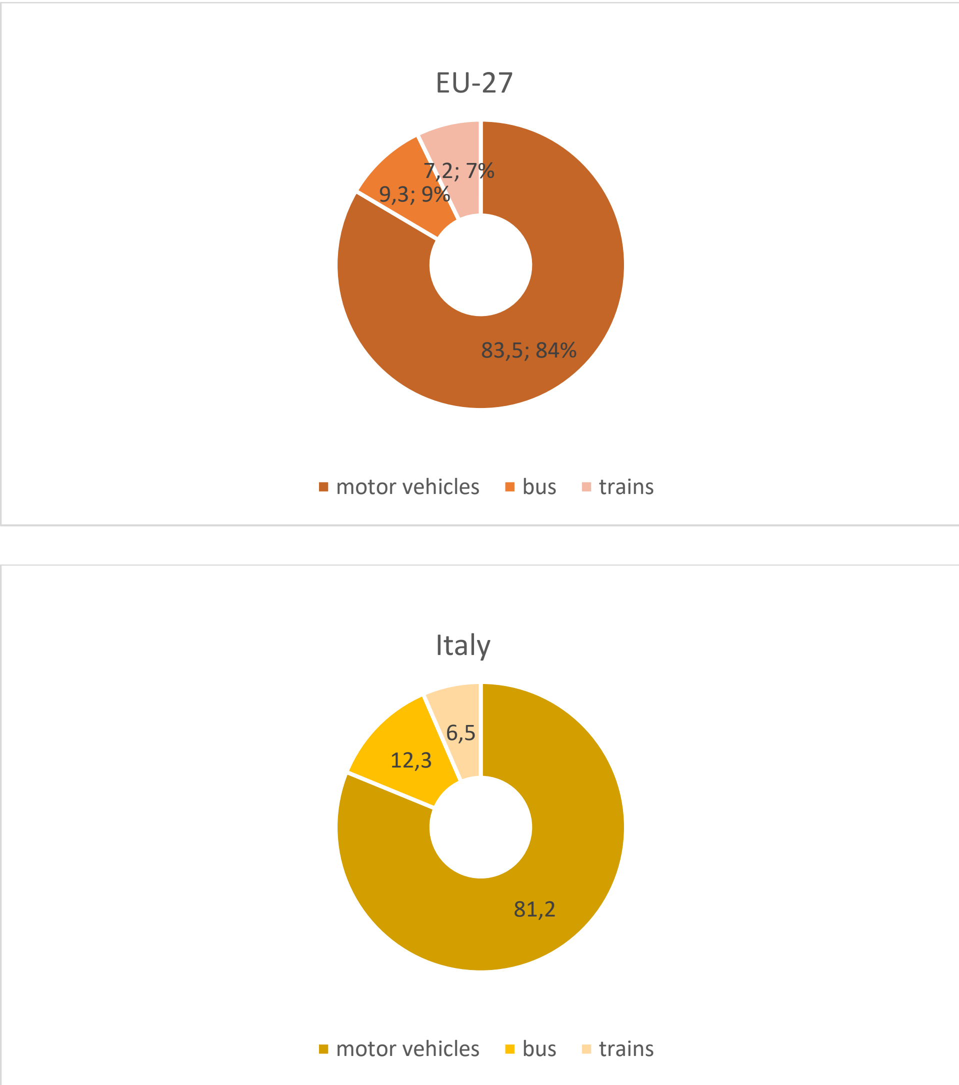


Figure 1. Modal split of passenger transport by land in the European Union and in Italy in 2019 (data source: The European House – Ambrosetti).

In 2019, private mobility continued its growth path, approaching, referring only to cars, to the threshold of 40 million vehicles, 39,545,232 to be exact (Figure 2). Like the stock of cars, the motorization rate is also strengthening, i.e. the ratio between the number of cars and the resident population (including children and the elderly), always reaching in 2019 the value of 65.5 cars per 100 inhabitants (in 2017 it was under 64 points).

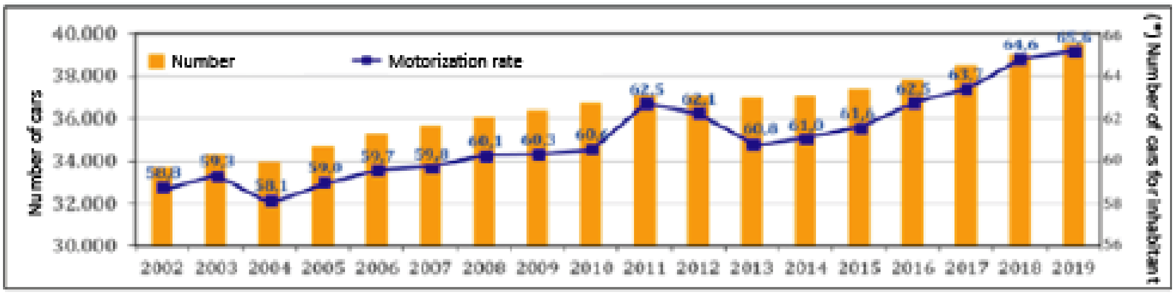


Figure 2. The evolution of the car fleet and motorization rate (data source: ACI, Istat).

A careful analysis of the major Italian cities, that is, those that exceed 250,000 inhabitants, clearly shows how in almost all of them there has been a substantial increase over the years, particularly in the cities of Southern Italy, led by Catania which in 2019 reaches the record value of 73.3 cars per 100 residents (5.4 points more than in 2015) (Table 1). The city of Milan alone is subtracted from the general trend, in fact in 2019 less than one resident out of two owns a car, probably as a result of an important offer of (old and) new forms of sustainable mobility linked to more stringent private traffic limitation policies.

Table 1. Motorization rate in the main Italian cities (data source: ACI).

	2015	2018	2019	Variation 2015-19
Roma	61.3	61.2	62.5	+1,2
Milano	51	50.7	49.5	-1,5
Napoli	54.4	56.5	57.3	+2,9
Torino	61.9	65.3	63.7	+1,8
Palermo	56.7	58.5	59.8	+3,1
Genova	46	46.8	37.2	+1,2
Bologna	51.5	53.3	52.4	+1,9
Firenze	50.7	52.1	53.7	+3,0
Bari	53.9	55.7	56.8	+2,9
Catania	67.9	71.5	73.3	+5,4
Venezia	41.8	42.9	42.6	+0,8
Verona	60.9	65.2	64.3	+3,4

A market therefore in expansion but which in 2020 will be strongly affected by the drop in sales, as is evident from the following graph (Figure 3). A contraction that will likely make its impact felt on the total number of cars in circulation, and hopefully on the quality of the fleet itself thanks to the scrapping incentive policies implemented during the year. The numbers testify to what was stated, in fact in the first part of the year during the months in which the restrictions linked to the containment of the spread of Covid-19 were more significant, from February to July, about 590 thousand new factory cars were sold, which in comparison with the same period of the previous years, this translates into a reduction in sales of just under 50%. The subsequent months of August, September and October 2020, however, showed signs of recovery in part due to bonuses for car scrapping extended also to traditional thermal engines, but with CO_2 emissions not exceeding 110 g/km [11].

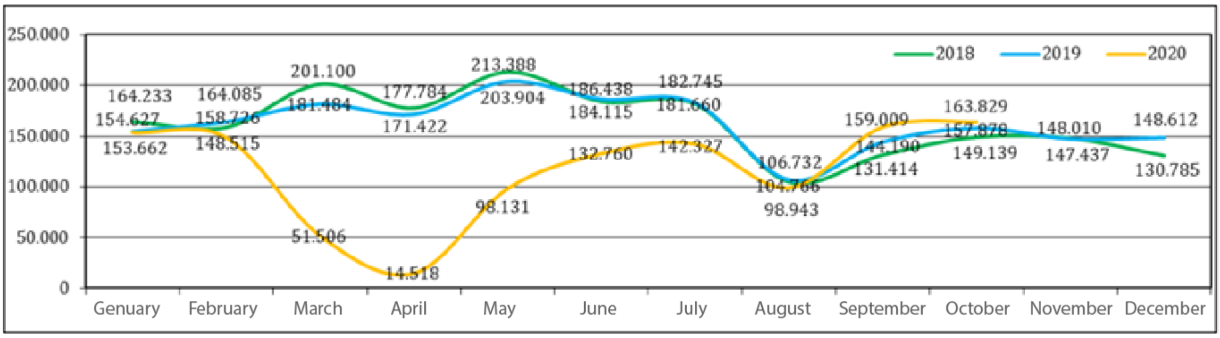


Figure 3. First registrations of new cars per month in Italy (data source: ACI).

Returning to the car fleet as a whole and broadening our gaze to the European context, the numbers reported by Italy place it at the top for motorization rate; only Luxembourg (about 600 thousand inhabitants) is able to do "better", but it is in comparison with the other large European countries that the deep distances emerge: Italy 64.6 cars per 100 inhabitants in 2018, Germany 56.7, Spain 51.3, France and the United Kingdom not even one car for every two citizens (respectively 47.8 and 47.3) (Figures 4-5).

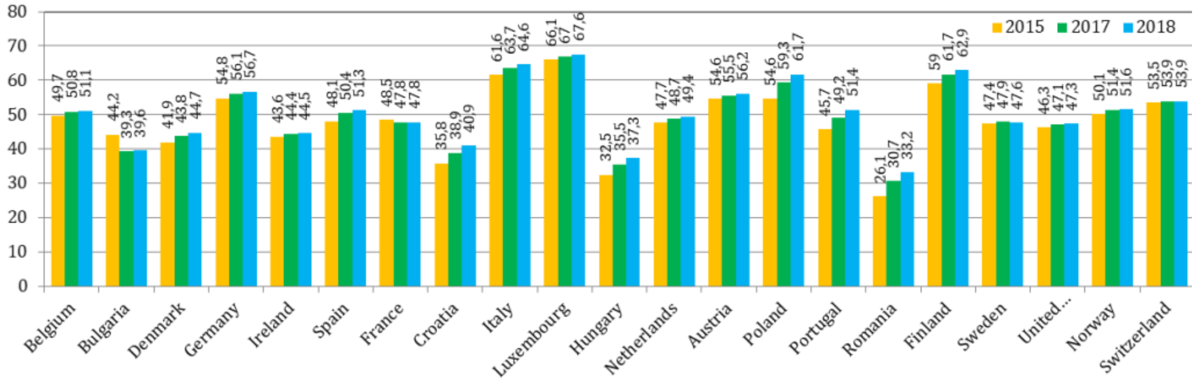


Figure 4. Motorization rate (cars per 100 inhabitants) in the main European countries (data source: Eurostat).

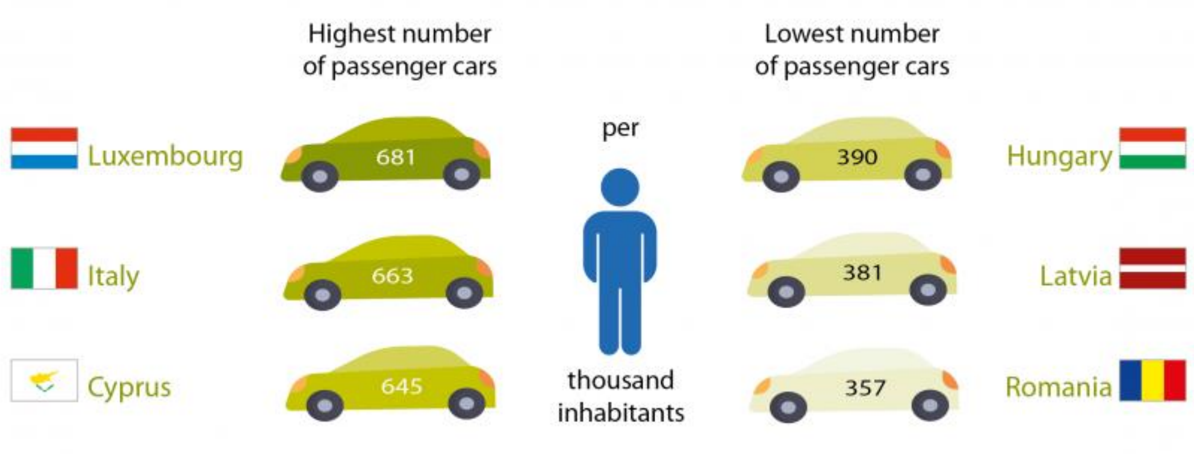


Figure 5. EU Member States with the highest and lowest number of passenger cars per thousand inhabitants, 2019 (data source: Eurostat).

The Italian car fleet does not shine even for environmental quality since in 2019 over 90% of the total is made up of vehicles driven by traditional petrol or diesel fuel engines (Figure 6) [12]. The most ecological cars are struggling to conquer significant market shares, if not 2015, methane, LPG, hybrid or pure electric cars represented 8.3% of the total, in 2019 they reached, as already in other terms anticipated, only 9.8%; moreover, the latter value in turn it consists almost exclusively of LPG cars.

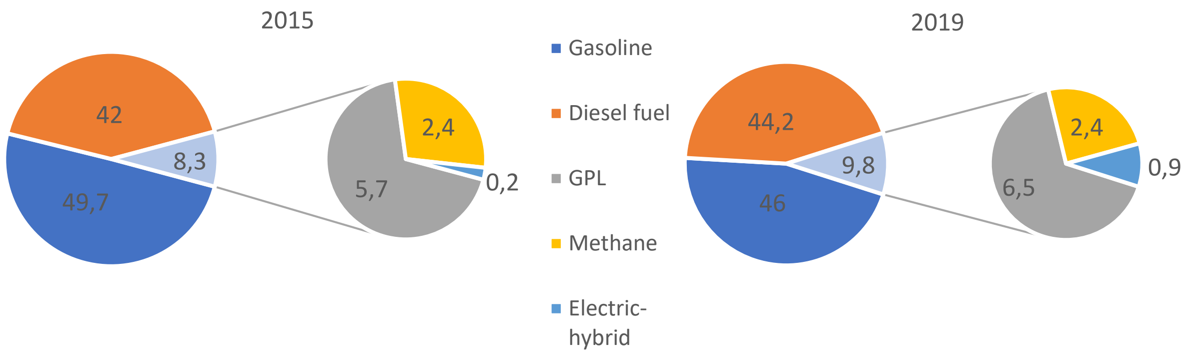


Figure 6. Percentage distribution of the car fleet by type of fuel (data source: ACI).

However, sales of hybrid or fully electric cars in recent years have recorded significant growth rates, effectively multiplying their market shares but still remaining a small niche. Fully electric cars, for example, amounted to just over 18,350 units in 2019.

Motorization rate

This mobility model is therefore strongly supported by the car, where the market maintains consistent growth rates. In our country, motorization levels are known as the highest, not only in Europe, but in the world. In fact, Italy has the highest density of cars, being at the top of the rankings for motorization rates, which compared to the electric market, certainly shows a countertrend, being at the bottom of the rankings for the number of electric vehicles compared to the fleet in circulation [13].

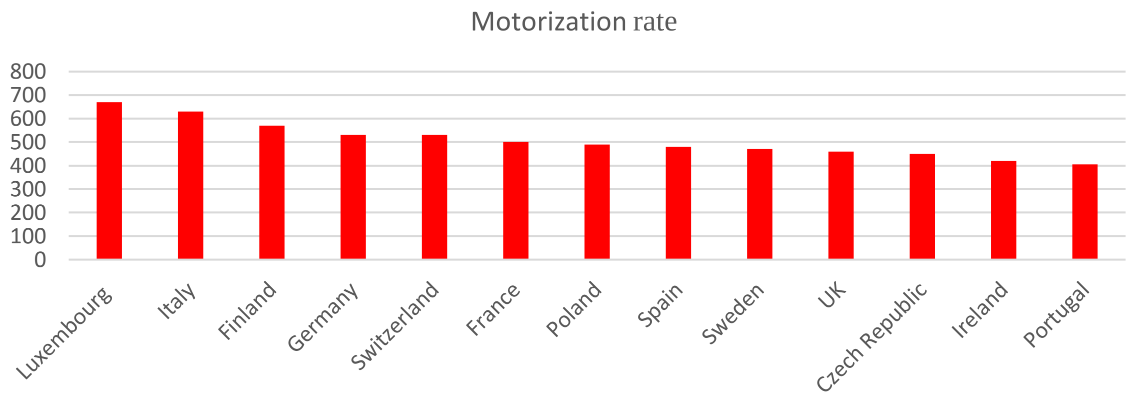


Figure 7. Motorization rate - Comparison between national data and European cities, 2020 (data source: Eurostat).

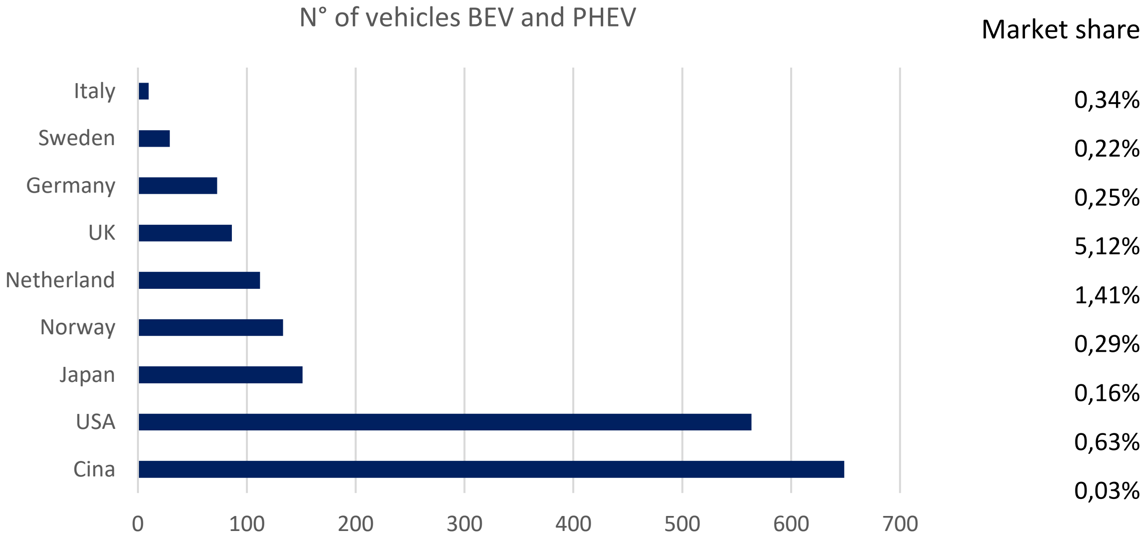
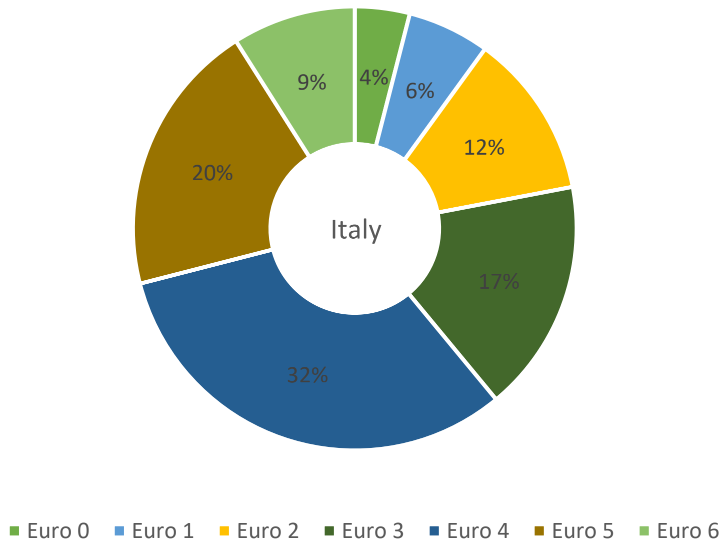


Figure 8. Number of vehicles and market share (BEV and PHEV), 2020 (data source: IEA).

Characteristics of the car fleet in circulation

The national car park is among the most obsolete in Europe (According to estimates made by the ACI (Automobile Club of Italy), the median age in 2020 for petrol cars is 13 years and 9 months, for diesel cars is 9 years and 3 months, for passenger cars overall it is 10 years and 8 months) with a consequent environmental impact higher than the average parameters.



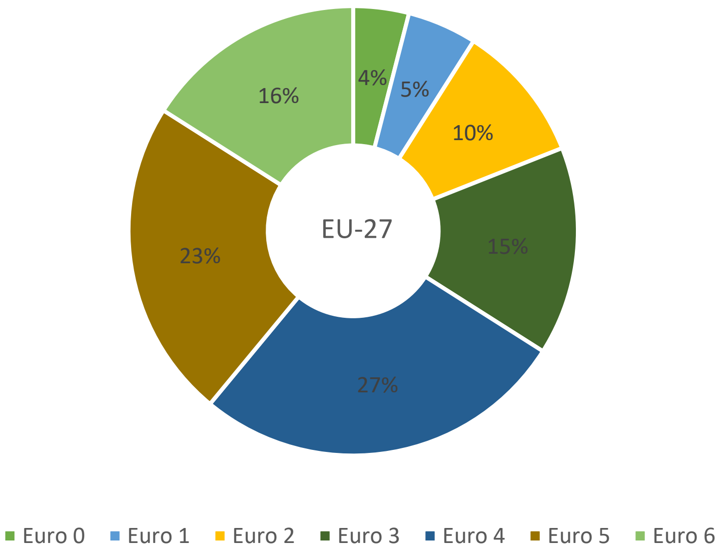


Figure 9. Vehicles by emission category - Italy and EU-27, 2020 (data source: EEA).

The data on registrations also show how our country still lags far behind on the issue of electricity, with a growth of 0.3% per year, while the diesel market is in decline (Table 2) [14]. However, we see a progressive increase in hybrid vehicles, in particular plug-in and extended range. According to the social sciences, these transitions come with intermediate steps, so that people are able to adapt better.

Table 2. Vehicle registration (data source: ANFIA).

	TOTAL 2020	TOTAL 2021	Variation % 21/20
PETROL	522.764	437.060	-16,4
DIESEL	452.156	323.032	-28,6
GAS	125.086	138.252	10,5
- *GPL/LPG*	93.469	106.834	14,3
- *METHAN/CNG*	31.617	31.418	-0,6
IBRID mild-full/Hev	221.931	422.166	90,2
- *IBRID BE/Petrol-Electric*	191.941	365.070	90,2
- *IBRID GE/Diesel-Electric*	29.990	57.096	90,4
RECHEARGEABLE	59.907	137.782	130,0
- *Electric*	32.500	67.274	107,0
- *Plug-in Hybrid*	27.407	70.508	157,3
HYDROGEN	2	10	-
TOTAL	**1.381.846**	**1.458.302**	**5,5**

Energy consumption

From an energy point of view, the impact of the transport sector on overall national energy consumption has a weight of 34.5% (Figure 10) [15]. However, it is true that there has been a significant reduction in energy consumption in the sector in recent years, but it is still lower than the final consumption of the entire economy. If we then consider the percentage of final consumption from petroleum products, the high dependence on fossil fuels is highlighted in particular. Of these, about 83.2%, is entirely absorbed by road transport.

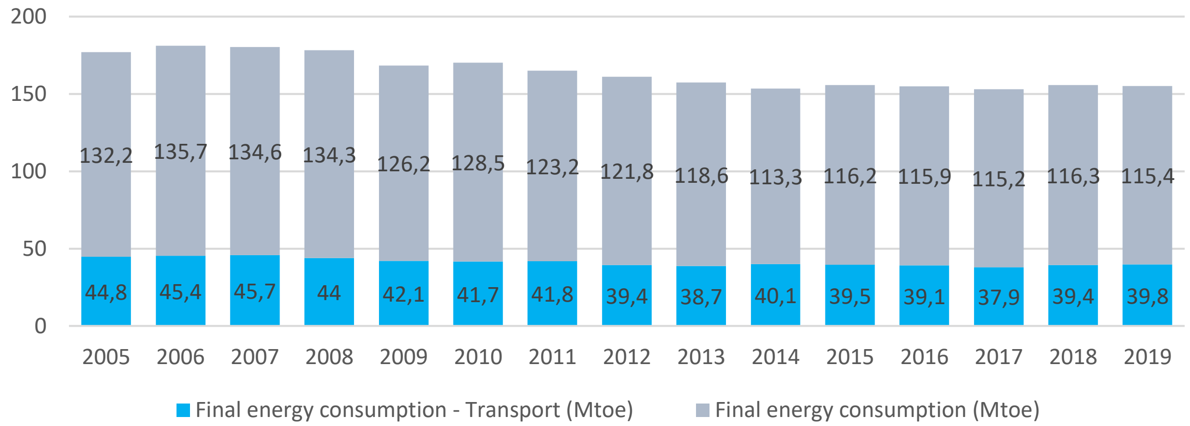


Figure 10. Final energy consumption and share covered by the Transport sector in Italy (Mtoe) (data source: Eurostat).

Figure 11 compares the incidence of the transport sector on overall energy consumption recorded in Italy in 2019 with that of other 4 European countries (the EU-27 average is 34.4%, in line with the Italian figure). In Italy and France, the incidence of transport on overall energy consumption is higher than that recorded in Germany (which, however, records considerably higher total consumption) but lower than France (35.3%), United Kingdom (40%) and especially Spain (44%).

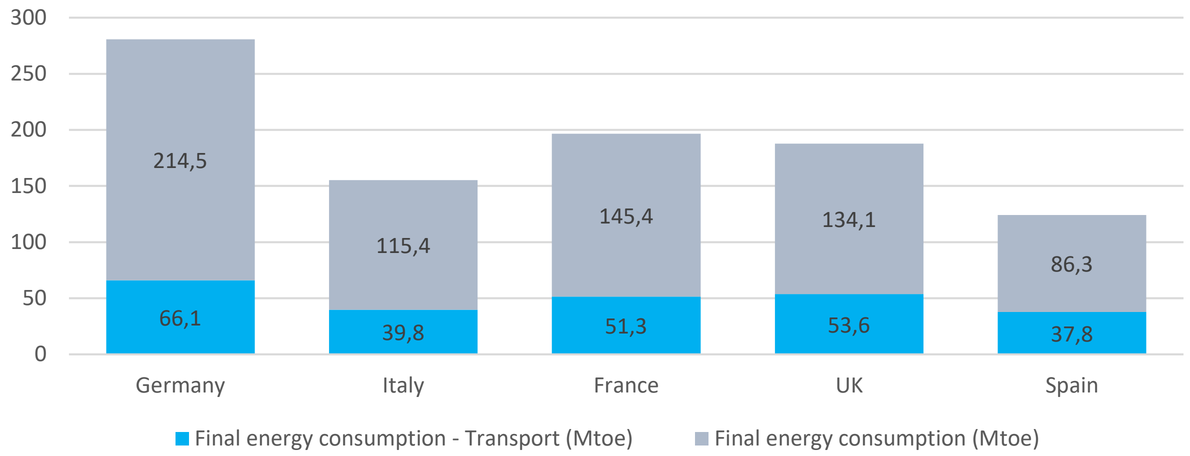


Figure 11. Incidence of final energy consumption in the Transport sector in 2019 - international comparisons (data source: Eurostat).

At this point, electric mobility could really make a strong contribution to the decarbonization process, but many questions still remain open. For example, assuming a strong penetration of electric mobility, compared to the current demand for electricity, one wonders what increase and what impact it will have on the national electricity system. Some answers can be given, for example, by increasing the production of energy from renewable sources or by digitizing the grid in such a way as to reduce dispersions. Therefore, we need to prepare for this change, as the gap between the other countries is already large enough. So electric mobility could make a strong contribution to sustainability. However, it is also necessary to understand the different solutions offered, since electric mobility does not only mean electric car, but above all, it cannot and must not be understood solely as a private vehicle. A true cultural transformation requires a 360 ° view of the latter, where it is possible to make use of public transport, motorcycles, bicycles, etc. For example, car-sharing and electric bike-sharing could be the ideal ways to introduce electric vehicles to more people, promote the spread of E-mobility and reduce the impact that the charging infrastructure could have on cities. The characteristics of some main technologies are presented below.

Types of electric vehicles

Basically, from the outside, the electric car is like a traditional car but the components and operation are completely different, in the sense that they are based more on electronics and less on mechanics. The main components of an electric vehicle are the battery (which affects the cost of the vehicle by about 50%), an electric motor, a motor controller and regenerative brakes. "Hybrid" vehicles comprise all of the same major components as a battery-electric vehicle, as well as having a main or auxiliary combustion engine and associated fuel tank [17]. Currently, major car manufacturers have five main types of electric vehicle technology available, which differ in: Hybrid Electric Vehicles (HEV), Battery Electric Vehicles (BEV), Plug-in Hybrid Vehicles (PHEV), Range Hybrid Vehicles -Extended (REEV) and Hydrogen Fuel Cell Vehicles (FCEV). The wide range of vehicles offers different advantages and disadvantages among the different choice options, including battery capacity, load capacity, technological complexity and refueling availability.

- Conventional vehicles - internal combustion engine

Conventional vehicles use fossil fuels, which are fed into a fuel system and converted into thermal energy by means of combustion. These are the main culprits of sound and air pollution. They are inefficient because only 18-25% of the energy available from the fuel is used for the actual movement of the vehicle [18]. However, they are the most accessible vehicles, because they have developed an important support infrastructure that includes production, repair and refueling facilities.

- Plug-in Hybrid Vehicles (PHEV)

PHEVs are vehicles powered by an electric motor and an internal combustion engine, capable of running together or separately. The substantial difference between these and hybrids (HEVs) is that the on-board battery can be charged from the domestic or public electricity grid and the combustion engine supports the electric one when greater operating power is required, or when the state of charge of the battery is low. In this way, the motorist is no longer worried about running out of charge when traveling long distances. However, batteries may have a lower storage capacity, since the vehicle is not based only on electricity, in fact, this type was designed for short trips to the city or for commuters. The autonomy can vary from 20 to 85 km depending on the size of the batteries. The vehicle in fully electric mode involves zero exhaust emissions, however, relying solely on endogenous mode would result in even higher emissions and consumption than conventional vehicles, since the mass of the vehicle is greater due to the weight of the batteries [19].

- Hybrid Electric Vehicles (HEV)

The hybrid HEV system takes advantage of the presence of two motors inside. The internal combustion engine is supported by the electric, in fact hybridization can be considered a technology added to conventional vehicles with the aim of increasing fuel efficiency, thus reducing pollutant and CO_2 emissions. The battery cannot be recharged from the mains, but is generally charged during regenerative braking or while the vehicle is decelerating, thus recovering the released kinetic energy. They tend to be more expensive than battery electric vehicles (BEVs), as they require higher power-to-energy performance. In any case, the two engines are completely independent and the driver can decide at any time to travel in pure electric mode [20]. There are different types of models ranging from "MicroHEV", able to travel short distances in electric only, up to "Full-HEV", in which electric technology becomes prevalent at low speeds, and the combustion engine only comes into action. when more power is needed.

- Range-Extended Hybrid Vehicles (REEV)

The REEVs are also vehicles that take advantage of the presence of two engines. In this case, the internal combustion engine has no connection with the traction of the wheels, but rather acts as an electricity generator that powers the electric motor, or recharges the battery when it is discharged; the electric motor is therefore solely responsible for powering the vehicle directly. The battery must then be recharged from the mains. An advantage of REEV is that the internal combustion engine can be smaller, so as to sufficiently reduce the weight and consequently also the emissions since the fuel on-board simply serves to replenish the battery level. This also helps to overcome the problem related to the distance that can be traveled, because refueling can also take place in conventional stations [21]. Indicatively, the autonomy varies from 70 to 150 km in electric operation.

- Battery Electric Vehicles (BEV)

BEVs are vehicles that use only the electric motor and are powered by electricity stored in an on-board battery, which can be recharged through the mains. Batteries tend to be very large to maximize energy storage capacity and to allow longer driving intervals; they generally cost more than those used in hybrids, but have the highest efficiency, as they convert about 80% of stored energy into movement. Further advantages also come from the braking system, which uses the regenerative system, thus helping to keep the battery charged. There are no exhaust emissions, this could significantly contribute to improving air quality, while the contribution of renewable sources to recharge the battery will bring greater benefits to the environment in terms of CO_2 emissions [22]. However, there are some disadvantages mostly related to technological and social issues. First of all, is the high cost of the battery, but it is expected that in a few years the price will decrease thanks to the spread of electric vehicles and the technological innovations in progress. Secondly, the long charging times and the scarce diffusion of the charging infrastructures mean that there are still many doubts about switching to a fully electric vehicle.

- Hydrogen Fuel Cell Vehicles (FCEV)

The FCEVs are vehicles that use only the electric motor, but instead of a battery system, the energy for propulsion is provided by a stack of fuel cells that uses hydrogen combined with oxygen in the air. The main benefits are due to shorter refueling times (similar to those of a conventional vehicle), and longer driving intervals compared to BEVs. This technology, however, still has many limitations, mainly due to the absence of a refueling infrastructure and the high costs due to technological complexity [23].

1.2 Analysis of the electric mobility system in Italy

Reducing or eliminating the oil dependency of transport systems has become an important element of energy research activities. In fact, transport represents a strategic and necessary sector of the world economy that directly affects the daily life of all people. In recent decades, the volume of goods and passengers handled around the world has experienced an epochal growth that is expected to continue. In fact, road transport is the most popular means of transporting goods and passengers. According to estimates by the European Commission, by 2050 passenger transport will grow by more than 50% and freight transport by 80% compared to the growth levels of 2013. Unfortunately, the transport sector in Europe is heavily dependent on fossil fuels, which represents a serious challenge for the environment. Oil consumption not only releases greenhouse gases and other pollutants into the atmosphere, contributing negatively to climate change but also makes the European economy more vulnerable to global fluctuations in the prices of energy resources. Lately, technological advances have made it possible to obtain greater returns on new electric vehicles sold. Vehicle performance has also significantly improved in terms of fuel consumption, energy efficiency and pollutant emissions into the environment. These results were due to the introduction of more restrictive measures. In this new market framework for the automotive sector, the energy efficiency of the electric car makes it a potentially important tool for reducing the environmental impacts of private mobility. As the number of vehicles on the road and the distances traveled continue to grow, it becomes necessary to establish a new clean, intelligent and complete mobility system that meets the transport needs of people and guarantees new important services to users. The transfer of some pollutants from the point of the generation where the car circulates to the location of the power plants allows not only a reduction of the subjects exposed to pollution but also a minimization of atmospheric pollutants, provided that the electricity used comes from renewable sources or nuclear plants. This is true if the electricity used to power the car's electric batteries is generated by systems capable of producing less than 700 g of carbon dioxide per kilowatt-hour, as pointed out by the International Energy Agency. In recent years, the development of electric vehicles has become a global consensus in order to cope with the serious energy and environmental problems due to the ever-growing road transport sector. Faced with the challenges of the future development of electric vehicles, Europe has continuously introduced policies that promote the electric vehicle industry [24]. Among the most recent is the 2020 initiative in which the European Commission launched the "European Climate Pact", with the aim of inviting people, communities and organizations to build a greener Europe. The "climate pact" is an integral part of the Grean Deal. Furthermore, the initiatives of private subjects in the development of electric mobility must also be considered. Various initiatives have been undertaken by private entities on the development of electric mobility of which, in this context, the most significant are listed below, in terms of coverage of the national territory. The most important initiative, in the interlocution between the various stakeholders, is the installation plan conducted by Enel which, since November 2017, has been carrying out its corporate plan which will see the installation of approximately seven thousand columns up to 2020 to reach fourteen thousand in 2022 on the national territory. The Plan is currently being developed in collaboration with the Municipalities and Regions concerned, in which Enel envisages an investment program aimed at the construction of dedicated infrastructures, to be created together with any private subjects who wish to participate in the project (this is, in the latter case, of the installation of recharging columns in private areas accessible to the public of small and medium-sized enterprises, commercial establishments, large-scale retail trade, supermarkets, agritourism, hotels, etc.). This is therefore the context in which Enel's project is located, whose strategic objective is to contribute to the creation of a capillary, functional, interoperable and effectively distributed charging network in the area, aimed at improving the attractiveness of places. and, at the same time, respect for the quality of the environment (reduction of harmful emissions and noise pollution) and of society as a whole. The studies conducted show how the government's policy of incentives on the purchase of electric vehicles and the initiatives of private entities can promote the spread of these cars by up to 60%. The percentage increases when production subsidies and infrastructure construction are added. So electric vehicles are poised to transform every aspect of road transport, such as fuel, CO_2 emissions, driving habits and costs. It is expected that in the future electric vehicles may be cheaper and more efficient than petrol ones, but the main question that still remains pending today is how far electrification will go and how this change will impact the energy system and the geo-economy. While electric mobility contributes significantly to the reduction of pollutants such as nitrogen oxides and particulate matter in urban areas and CO_2 during use, it must be borne in mind that the production of electric vehicles itself still involves non-negligible greenhouse gas emissions. Furthermore, the impact of charging electric vehicles on the network must be considered. Previous studies show that in hypothetical scenarios of penetration of electric vehicles of 50% with respect to the total urban car park in metropolitan cities, there is a maximum variation of the peak power of the primary substations of about 37%. impact of V2G technology on the case study of the city of Palermo, the results obtained showed that a low penetration of V2G technology, of 10% and 20% compared to the total planned infrastructures, determine a limited impact on the network. With a penetration of 50%, the most problematic situation would arise in the event that the charging stations are powered by a 400 kVA transformer, while the situation is much more accentuated with a degree of penetration equal to 100%, both in the case of of transformer of 400 kVA and of 630 kVA, resulting more contained in the case of transformer of 1000 kVA. Vehicle to Grid is therefore a new emerging technology born because a large number of electric vehicles can be used as a load and as an energy storage system to support the grid. However, uncoordinated charging of electric vehicles shows the crucial impact on the power system. Therefore, optimal coordination of the V2G system is required and for this there are still obstacles to the adoption of the V2G on a commercial level. [25].

Faced with these doubts and problems, it be continued to study and look for new sustainable mobility solutions. A valid alternative to electric cars can be considered the technology of Fuel Cell Vehicles, in which the batteries are powered by chemical processes deriving from hydrogen and oxygen. Conceptually, but also in terms of driveability, hydrogen cars are slightly more advanced electric cars. The main points in favor, which in particular mark a clear advantage over electric cars, are the range and charging times. The Toyota Mirai has in fact broken through the barrier of 1000 km traveled with a full tank of hydrogen which, for the record, requires the same wait as traditional fuels. In addition to this, it should be noted that the tank does not tend to deteriorate in the face of a long non-use of the car. However, there are disadvantages that still make hydrogen cars unsuitable for market diffusion. Among the most controversial aspects (and partly shared with electric cars) is that related to production. In order to be considered a totally green fuel, it must be obtained from renewable sources such as wind and photovoltaic (or alternatively recovered from methane), yet storing it is not so immediate and above all economical. In the hypothesis of an imbalance between supply and demand, it would therefore be wasted energy with the consequent damage to the environment. A major disadvantage is the very low diffusion of hydrogen distributors in Italy. Compared to about 20,000 electricity columns, there is only one hydrogen distributor in Italy, located in Bolzano; this translates into a reduction if not absence of the number of potential buyers. As for the electricity counterpart, however, there is a development plan that should lead to the creation of a hundred stations by 2025, when the technology may have advanced a further step. Subsequently, following interventions on infrastructures and tax incentives, the weight can be considered broadly comparable to that of electric cars. Where, on the other hand, hydrogen loses significantly compared to electricity, it is in refueling costs. At the aforementioned distributor in South Tyrol a price of 10-15 € per kg is applied, which translates into about 60-80 € for a full tank. The reason lies in the difficult availability of the material and in the absence of an economy of scale at present. Italy has a large number of initiatives to support the introduction of electric vehicles. At the municipal level, some municipalities in Italy have committed to implementing an Action Plan for sustainable energy and climate. From an economic point of view, Italy has a National Fund for Energy Efficiency, which allocates approximately 310 million euros to support sustainable mobility. In addition, a tax policy has been introduced, exempting electric vehicle users from the motor vehicle tax for five years, and new building regulations require new buildings to have a private infrastructure for charging electric vehicles. In addition, the Ministry of Infrastructure and Transport provides substantial funding for local and regional initiatives. To this we must also add that in the country the production of Renewable Energy Sources (RES) has increased in recent years: in 2019, the share of overall gross final consumption covered by RES was equal to 18.2%. This is an increase compared to 2018 (17.8%), as well as higher, for the sixth consecutive year, than the target assigned to Italy by Directive 2009/28 / EC for 2020 (17.0%). Despite these advantages, however, the public sector in Italy has a low awareness of electric vehicles and electric mobility. This is mainly due to the duplication and overlap of skills, as well as to the weak relationships between the public sector, business and research. Another problem is the limited popularity of electric vehicles combined with a high motorization rate in the capital, where we find almost one vehicle per inhabitant. This causes high pollution, noise and congestion. Most of the opportunities for electric mobility have been identified at the political level. At the municipal level, according to the new building regulations, new homes must have infrastructure for charging electric vehicles. In addition, the government has launched the National Strategic Framework for electronic infrastructures for the development of a recharging system in Italy and a Single National Platform to collect information on recharging infrastructures accessible to citizens and operators. The other opportunities are the growing popularity of electric vehicles and the increase in the numbers of electric vehicles in Europe and Italy. While there are more policy opportunities on the one hand, more threats have been identified on the business and technology sector. First, the high purchase price of electric vehicles and their batteries is the main economic risk, which could limit electric vehicles. Other economic problems are the low degree of internalization of the company and a strong dependence on traditional energy sources [26]. A SWOT analysis of Italy is presented in the Table 3.

Table 3. SWOT analysis of electric mobility in Italy.

Strengths	Weaknesses
• National Energy Efficiency Fund supports sustainable mobility	• The weak relationship between enterprises, research, and public
• Taxation policy	• Low awareness in the public sector
• Increasing production of RE	• Lack of a clear National Legislative address strongly geared towards e-mobility
• New buildings with EV-charging infrastructure	• Lack of National and Regional financial instruments for new policies
• Local and regional initiatives funded by the Ministry of Infrastructure and Transport	• Limited competitiveness
• Expansion of electric car-sharing	• High car ownership and congestion

• Innovation is driven by great innovative companies	• Lack of needed funds to implement new infrastructures and technologies • Lack of true electrical corridors and recharge station infrastructure
Opportunities	**Threats**
• Contribution to the Paris Climate Change Agreement • Support of EU Directives • New building regulations help to develop EV-charging networks • National Strategic Framework for e-infrastructures • Three Year Plan for National Electricity Research • An increasing number of EV models on the market • Growing EV popularity	• High costs of EVs as a barrier of broad market penetration • Limited EV-charging infrastructure • Still very low degree of internationalization of enterprises • Strong dependence on traditional energy sources (oil products)

1.4 Crisis due the invasion of Ukraine

In the face of the emerging global energy crisis triggered by Russia's invasion of Ukraine, the IEA's *10-Point Plan to Cut Oil Use* proposes 10 actions that can be taken to reduce oil demand with immediate impact – and provides recommendations for how those actions can help pave the way to putting oil demand onto a more sustainable path in the longer term [27]. Russia's invasion of Ukraine has thrown global commodity markets into turmoil. The global oil market – in which Russia is a major force – is one of the most heavily affected. Russia is the world's third largest oil producer and the largest oil exporter. Significant strains are showing in the global oil market, compounding difficulties in natural gas markets and creating a looming emergency for global energy security. Oil prices have swung violently since the Russian invasion, with the global benchmark nearing the all-time high of USD 150 per barrel at times, putting the still fragile and uneven global economic recovery at risk. The United States and Canada are banning imports of Russian oil while the United Kingdom has announced plans to do so by the end of the year. The IEA's latest Oil Market Report on 16 March identified the potential for a shut-in of 2.5 million barrels a day of Russian oil exports starting from April; but losses could increase should restrictions or public condemnation escalate. A prolonged period of volatility for markets appears likely. More than half of Russia's oil exports go to Europe and around 20% go to China, but the market is global, meaning changes in supply and prices affect everyone. The increases in prices are being felt everywhere. Even if the price of oil on international markets has not so far risen as high as the all-time record reached in 2008, currency exchange rates mean that the price at the pump is at the highest level ever in some countries.

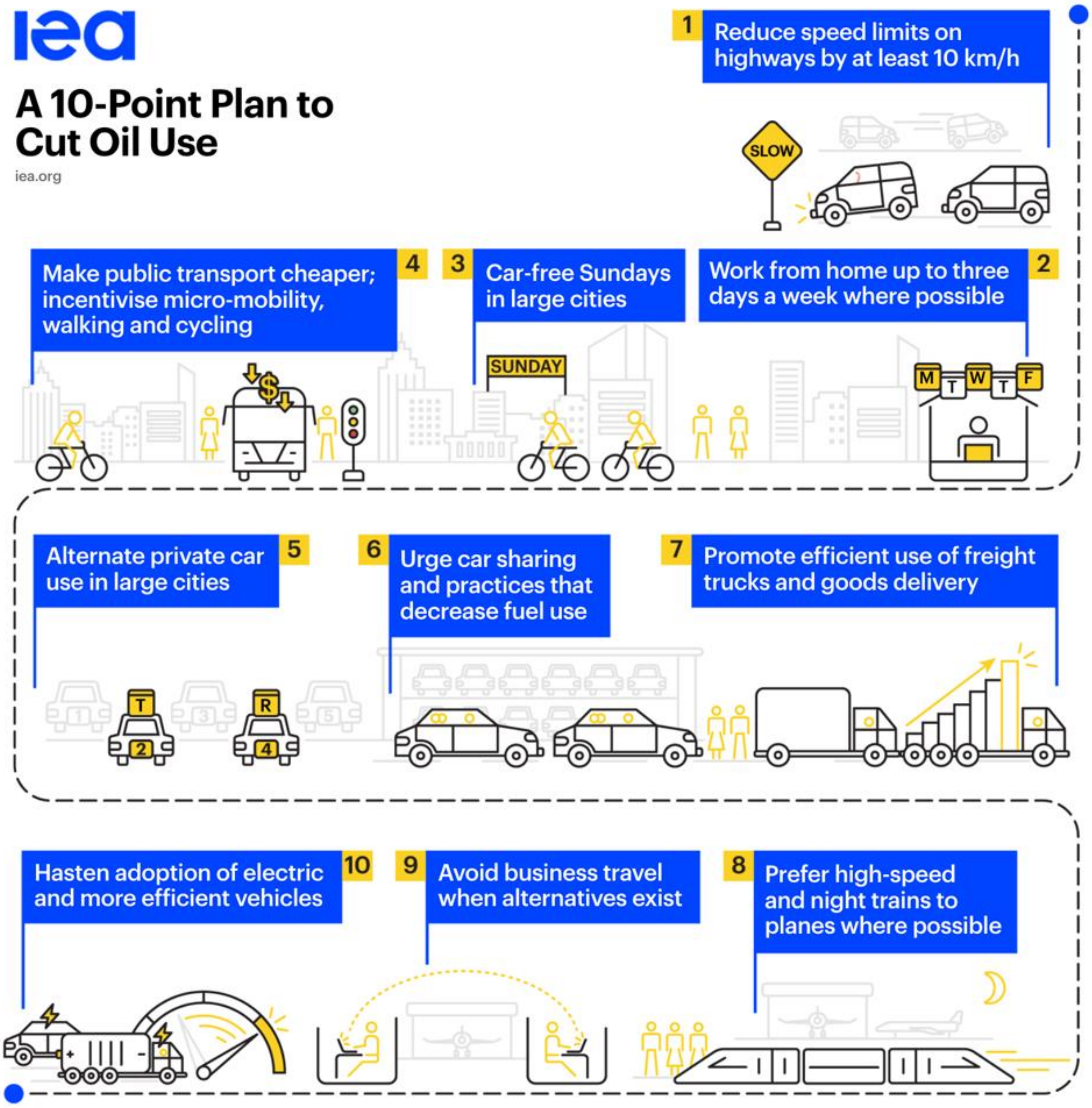


Figure 12. 10 point oil plan (data source: IEA).

On average, monthly spending on oil products for transport and heating in January and February rose by more than USD 40 per household (nearly 35%) in advanced economies, and nearly USD 20 per household (over 55%) in emerging and developing economies compared with last year's levels. With the potential loss of large amounts of Russian supplies looming, there is a real risk that markets tighten further and oil prices escalate significantly in the coming months as the world enters the peak demand season of July and August. The risks are most acute – and already being felt in some cases – in market segments where Russia is a major supplier, such as diesel.

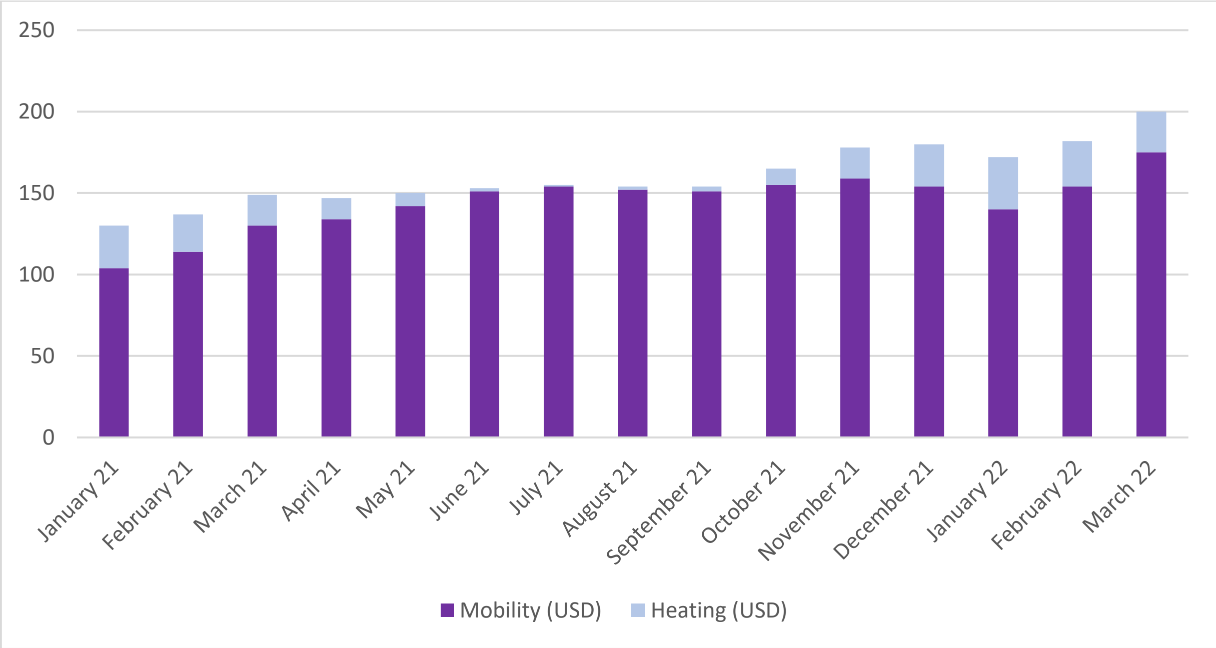


Figure 13. (rivedere le altre figure) Average monthly expenditures by households for oil products in advanced economies, Jan 21 - Mar 22 (data source: IEA).

Several governments are introducing measures to help consumers by reducing prices at the pump. Wherever possible, pricing measures should be designed carefully, prioritizing the poorest parts of the population and those for whom cars are an indispensable part of their economic activity. Governments have a variety of tools that could be used, depending on the country context. For example, where taxes represent a large portion of prices for consumers, a temporary reduction in those levies or VAT can alleviate the extra burden on households. Direct payments are a means to target the poorest parts of the population. Such measures, however, do not address the broader strains affecting the market. One way to do so is to increase supply. Spare capacity is available in some major producers outside Russia, but the disappointing outcome of recent OPEC+ discussions suggests limited willingness to provide immediate relief to the market. IEA member countries, as part of their collective response, unanimously agreed this month to draw on emergency stocks for an initial release of 62.7 million barrels, the largest stock release in IEA history. New oil production projects could increase liquidity in the market in the medium term but would not be able to ease the current strains. The oil industry's stocks typically help balance the market when demand outweighs supply. But even before Russia's invasion, the industry's oil inventories were depleting rapidly. At the end of January, inventories in advanced economies were 335 million barrels below their five-year average and at eight-year lows. Another way to help balance the market and reduce the pain caused by high oil prices is to bring down demand. Following Russia's invasion of Ukraine, the IEA's March Oil Market Report lowered its forecast for global oil demand in 2022 by 950 thousand barrels a day (kb/d) because of the expected impacts of higher prices and weaker GDP growth. But this would still leave the oil market very tight, with upward pressure on prices likely to remain in an uncertain geopolitical environment. Further reductions in demand are possible in the near term, however, through actions by governments and citizens. The world's advanced economies together account for around 45% of global oil demand, and most of them are members of the IEA. Demand restraint (see annex) is one of the emergency response measures that all IEA member countries are required to have ready as a contingency at all times – and that they can use to contribute to an IEA collective action in the event of an emergency. In view of this and the potential emergency the world is facing, the IEA is proposing 10 immediate actions that can be taken in advanced economies to reduce oil demand before the peak demand season. We estimate that the full implementation of these measures in advanced economies alone can cut oil demand by 2.7 million barrels a day within the next four months, relative to current levels.1 The analysis in this report focuses on the potential effect of these measures in advanced economies, but their adoption in more countries would further increase their impact. Ensuring local and regional coordination of their implementation would maximize the impact. Looking further ahead, this report also suggests a path for countries to put oil demand into structural decline in the medium term, building on measures already included in economic recovery packages introduced to deal with the impacts of the Covid-19 pandemic. Adopting the immediate and longer-term recommendations would put the countries on track for a decline in oil demand consistent with what is required to reach net zero emissions by 2050. The majority of oil demand is in transport, so the proposed measures of the 10-Point Plan essentially focus on how we get from A to B. How these measures are implemented is subject to each country's own circumstances – in terms of their energy markets, transport infrastructure, social and political dynamics, and other aspects. The IEA stands ready to support all countries in designing and optimising measures to suit their respective circumstances. Government regulations and mandates have proven to be very effective for successfully implementing these measures in various countries and cities, while public information and awareness campaigns can serve as alternative or complementary measures. Ultimately, however, reducing oil demand does not depend solely on national governments. Several of the measures can be implemented directly by other layers of government – such as state, regional or local – or just voluntarily followed by citizens and companies, enabling them to save money while showing solidarity with the people of Ukraine and reducing greenhouse gas emissions.

1. *Reduce speed limits on highways by at least 10 km/h*
    - A country-by-country and state-by-state analysis shows that a reduction of speed limits on highways by 10 km/h relative to current levels can significantly reduce fuel consumption for cars, light commercial vehicles and trucks.
    - Speed limits on highways vary widely among countries but are typically in the range of 100 km/h to 135 km/h. For example, average speed limits on urban and rural interstate highways in the United States are around 110 km/h. In the European Union, speed limits vary between 100 km/h and 140 km/h – except in Germany, which has no speed limit on some highways.
    - A reduction in speed limits can be implemented by national governments; many countries did so during the 1973 oil crisis, including the United States and several European countries. Today, many countries use temporary speed limit reductions on highways, mostly to reduce congestion and/or air pollution and to improve road safety. They are also frequently adopted within cities to combat local air pollution

Impact: Around 290 kb/d of oil use can be saved in the short term through a speed limit reduction of just 10 km/h on motorways for cars. A further 140 kb/d (predominantly diesel) can be saved if heavy trucks reduce their speed by 10 km/h.

2. *Work from home up to three days a week where possible*
    - Before the pandemic, the use of private vehicles to commute to work in advanced economies was responsible for around 2.7 million barrels of oil use a day. Yet, around one-third of the jobs in advanced economies can be done from home, opening up the possibility of reducing oil demand while maintaining productivity.

- The impact of working from home on oil consumption varies widely by region, depending on the distance of the commute and average fuel consumption of the car. In the United States, the average one-way commute by car is around 18 kilometers, and over three-quarters of car commuters travel alone, according to the US Census Bureau. In Europe, the average one-way car commute is around 15 kilometers. Differences in the fuel economy of vehicles further affect the variations among countries. For example, a new car in the United States consumes around 40% more fuel than one sold in Europe for a trip of the same length.
- There is an additional seasonal element to the impacts of working from home due to the use of air conditioning in cars (see Point 6). As the weather gets warmer, air conditioning systems increase the amount of fuel used by cars. Therefore, working from home tends to save more oil during the summer months.
- During confinement periods triggered by the pandemic, many countries implemented requirements for people to work from home for activities where it is possible. While most of those requirements have been lifted, some governments such as France are encouraging working from home without a minimum weekly quota. The employer has the flexibility to set the terms and conditions while keeping an eye on preventing social isolation. Working from home up to three days per week would cut oil demand and could reduce fuel bills. We estimate that avoiding an average daily commute by car currently saves around USD 2 to USD 3 each time in advanced economies.

Impact: One day of working from home can avoid around 170 kb/d of oil use. Three days of working from home avoids around 500 kb/d in the short term.

3. *Car-free Sundays in cities*
   - Car-free Sundays were introduced in countries such as Switzerland, the Netherlands and West Germany during the 1973 oil crisis. Brussels, Edinburgh, Vancouver, parts of Tokyo and other cities have used them more recently to promote public health, community-oriented spaces and cultural events. More

than 3 000 towns and cities registered for the European Mobility Week in 2021, which included a commitment to a car-free day.

- Car-free Sundays help support the uptake of walking and cycling, which can generate a positive spillover effect throughout the week. This can in turn be supported by fare reductions or the provision of free public transport.
- Banning the use of private cars on Sundays brings a number of additional benefits to public health and well-being, including cleaner air, reduced noise pollution and improved road safety. In warmer climates, reduced traffic can also reduce urban "heat-island" effects. The measure is also relatively straightforward to enforce using spot fines and road closures.

Impact: Avoids around 380 kb/d of oil use in the short term if implemented in large cities every Sunday. If only one Sunday per month, the amount drops to 95 kb/d.

4. *Make the use of public transport cheaper and incentivize micro-mobility, walking and cycling*
   - An effective way to reduce oil demand is to shift travel demand away from private cars to public transport, micro-mobility options, walking or cycling wherever practical.
   - Where public transport exists, a short-term temporary response can be to reduce fares for public buses, metro and light rail. Trial initiatives, including in some US cities, have shown that reduced or free public transport fares result in increased ridership. New Zealand, for instance, is halving public transport fares for the next three months in response to high fuel prices. Public transport systems' available spare capacity during peak travel periods differs by country and city. However, there is typically spare capacity available in off-peak periods that can be used to "spread" the peak if employers simultaneously provide flexibility in working hours.
   - In countries where it is culturally acceptable, cycle lanes and pavement-widening strategies exist or can be made available quickly. And where distances are sufficiently short, encouraging people to walk or cycle can be a complementary measure. In cities with available public transport, this can help

make public transport less crowded and therefore more attractive and accessible. Rolling out programs to incentivize the purchase of electric bikes can also be effective, particularly in cities where journeys involve larger distances. Belgium, France and Italy offer residents an allowance to buy a bicycle, with the amount depending on bicycle type. Boosting shared micro-mobility options such as electric kick scooters or electric bicycles can also help – Lime, Bird or Dott are some examples of app-based providers that already provide this service in major cities.

- Investment in public transport and infrastructure to support walking and cycling has been boosted by sustainable economic recovery packages introduced in response to the Covid crisis. For example, the French government allocated EUR 500 million to an "active mobility fund" to build cycling itineraries, and Italy supports the design and development of cycle highways (EUR 50 million per year for the next three years). New Zealand enacted a nationwide cycle lane investment drive in 2020 of over USD 140 million in direct government spending by 2024. In 2021, Milan repurposed 35 kilometers of road previously used for motor traffic into cycling lanes and aims at achieving 750 kilometers of segregated lanes by 2035. Several cities – such as Paris, London and Brussels – created very low-speed zones (30 km/h) to discourage car use. When the summer months approach, cycling becomes more popular and can be further encouraged.
- Overall, governments in advanced economies are set to spend around USD 2.5 billion in the next two years on cycle lanes and pedestrian walkways, and a further USD 33 billion on urban transport infrastructure as part of economic recovery packages.

Impact: Short-term measures where feasible and culturally acceptable can avoid around 330 kb/d of oil use.

5. *Alternate private car access to roads in large cities*
    - Restricting private cars' use of roads in large cities to those with even number plates on some weekdays and to those with odd-numbered plates on other weekdays is a measure with a long track record of successful implementation.

During the first oil shock, the Italian government substituted car-free Sundays with an odd/even number plate policy. Since the 1980s, such schemes have been deployed in many cities to tackle congestion and air pollution peaks, including Athens, Madrid, Paris, Milan and Mexico City.

- Implementation of restrictions based on number plates typically hinges on the availability of other options to satisfy travel demand. They can pose logistical or fairness concerns, especially as they are most disruptive for less wealthy single-car households. These concerns can be mitigated by the other measures that we propose, such as reducing the price of public transport or promoting carpooling. Exceptions can be made for electric vehicles. The measure's effectiveness in reducing car activity may fall in the longer term if wealthier households buy additional internal-combustion engine cars to circumvent it.
- Households that own multiple cars may be able to circumvent the restrictions, but this effect and others (such as the remaining cars allowed on roads making longer multipurpose trips) are factored into our estimates of the potential reduction in oil demand.

Impact: A reduction of around 210 kb/d of oil in the short term if alternate car access is applied on two days per week in large cities with good public transport options.

6. *Increase car sharing and adopt practices to reduce fuel use*
    - Car users from different households can choose to carpool for non-urban trips, reducing oil demand and saving money at the same time. Governments can provide additional incentives by designating dedicated traffic lanes and parking spots next to public transport hubs and by reducing road tolls on higher occupancy vehicles. Such measures are in force in suburban areas of cities like Madrid and Houston, among others.
    - Non-urban car trips are responsible for over 4 million barrels a day of oil use in advanced economies. Currently, very few of these trips involve the pooling of people from different households, which results in lower levels of car occupancy. The average car occupancy in Japan is 1.3 people per car; in the

United States, it is around 1.5 per car; in Europe, it is between 1.4 and 1.6 per car. Across advanced economies, the average is around 1.5.

- Organising carpooling is more practical today than it was in the past. Several smartphone apps are available, including BlaBlaCar, Liftshare, Scoop, TripBuddy, ecov and GoKid. The carpooling market has grown by over 10% annually in recent years, although the Covid pandemic has reversed this trend since 2020 due to health concerns.
- A higher average car occupancy rate can be interpreted either as an indication that carpooling in certain regions is more viable (e.g. culturally, technically, habitually) or as an indication of lower capacity for additional carpooling. Governments will need to take this into account when deciding upon the measures to take to incentivise carpooling.
- Cars can also be used more fuel efficiently by adopting best practices both in driving and maintenance. For example, regular tyre pressure monitoring can save up to 1.5% of fuel use. In addition, air conditioning in cars typically accounts for 4% to 10% of total fuel consumption in advanced economies, depending on the local climate and comfort preferences. For those car users who can, we therefore propose a temporary 3 °C increase in the temperature setting to give an immediate improvement in fuel economy and cut fuel bills.

Impact: An increase of around 50% in the average car occupancy across advanced economies in 1-in-10 trips and adopting best practices to decrease car fuel use can save around 470 kb/d of oil in the short term.

7. *Promote efficient driving for freight trucks and delivery of goods*
   - Vehicles can be driven to optimize fuel use. The possible measures span a wide range and can include improved vehicle maintenance (such as regular checks of tyre pressure) as well as driving habits. Governments can introduce so-called eco-driving techniques as part of the tuition and examination processes required to receive a driving license and advanced driving certificates, as has been done in France and other countries. Broader public information campaigns can supplement these targeted efforts.

- Companies with vehicle fleets – such as for the delivery of goods – are particularly well placed to provide training and awareness campaigns to promote eco-driving of commercial vehicles, cutting into diesel use in particular, given the structure of their fleets. Additionally, lower demand for very short delivery times can contribute to increasing the overall fuel efficiency of logistics during last-mile delivery. Besides reducing diesel use, eco-driving can also help reduce fuel bills and vehicle maintenance costs.
- Trucks are major consumers of diesel, and so improving the efficiency of their operations can be an important contributor to reducing oil use. Readily accessible measures for the next four months can be in improving logistics: truck companies can optimize vehicle loads and reduce empty travelling. Cooperation between companies and widespread use of digital technologies can help achieve these goals.

Impact: These measures can avoid around 320 kb/d of oil use in the short term.

8. *Using high-speed and night trains instead of planes where possible*
    - Where high-speed rail lines connect major cities at distances under 1 000 km, trains provide a high-quality substitute for short-distance flights. High-speed rail can substantially replace short-haul air travel on routes that offer affordable, reliable and convenient train journeys. The use of night trains can be a means to cross wider distances in particular and spread traffic across different times of the day.
    - Based on existing high-speed rail infrastructure, around 2% of aviation activity in advanced economies could be shifted to high-speed rail, including for leisure as well as business travel. Almost all of this involves flights of less than 800 km.
    - Rail services must be operated and serviced efficiently to get widespread acceptance as an alternative to flights. In that case, high-speed rail can not only reduce oil demand and emissions from short-haul flights – it can also be faster and more comfortable, reliable and affordable. Rail stations are often located in or near city centres, making them more convenient and sustainable than airports.

- In France, the recent Climate and Resilience law requires the cancellation of flights if alternatives exist to reach the destination within two-and-a-half hours. Companies have already started to cut some flights, including between Paris and cities such as Nantes, Lyon and Bordeaux.

Impact: Avoids around 40 kb/d oil use in the short term.

9. *Avoid business air travel where alternative options exist*
    - Given the space requirements in planes, the journeys of passengers in premium classes consume three times more oil than those in economy class. Although not all business travel by plane can be avoided, in many cases the use of virtual meetings can be an effective substitute. A significant reduction of around two out of every five flights taken for business purposes is feasible in the short term, based on the notable changes witnessed during the Covid pandemic.
    - In response to the pandemic, virtual business interactions have become more common. Many companies have invested heavily in enhancing the experience of remote meetings, making this a more effective, acceptable and viable substitute to business flights and direct human engagement. Businesses continued operations – and in some cases thrived – despite having to make this major adjustment.
    - Several major corporations – such as HSBC, Zurich Insurance, Bain & Company and S&P Global – have already announced targets to cut their business travel emissions by as much as 70%. Reducing business travel can play a role in meeting ESG goals and help reduce corporate carbon footprints.
    - Before the outbreak of the pandemic, about one-fifth of passenger trips by plane in advanced economies were for business purposes. Business travel was hit harder than other categories of passenger air travel during the pandemic, dropping to historic lows. High oil prices may disincentivise airlines to operate underutilised routes in response to reduced business travel. But, to maximise the impact, governments can provide flexibility on flight slot allocations so as to minimise the occurrence of ghost flights.

Impact: Avoids 260 kb/d of oil use in the short term.

10. Reinforce the adoption of electric and more efficient vehicles

- By the end of 2021, 8.4 million electric cars were on the roads in advanced economies, building on record sales in Europe in particular. Demand for electric cars continues to be strong, on the back of plummeting costs of batteries in recent years and government support. However, supply chain bottlenecks in semiconductors, vehicle raw materials, and battery materials and manufacturing are putting strains on the market. The impacts are likely to be felt longer term, but facilitating logistical coordination to shore up flows of materials and components is a near-term priority so that disruptions in some parts of the automotive supply chain can be absorbed by less-affected manufacturing capabilities elsewhere in the global market.
- The near-term priority is to ensure successful delivery of car orders to consumers. Where possible, fleet orders may be prioritised, as their impact on moderating oil demand is larger than for households with multiple cars.
- Actions taken now to hasten the adoption of electric vehicles will have a sustained effect in the future. Similarly, new conventional vehicles sold must be fuel-efficient; fuel economy targets as well as taxes that penalise high-emissions vehicles are key for supporting further fuel economy improvements. Enforcing existing regulation and supporting them via awareness campaigns is central to reaping benefits in the near term.

Impact: Avoids more than 100 kb/d of oil use in the short term, building on expected sales of electric and more fuel-efficient cars over the next four months. Sustained action on supply chains and policy support can help secure further savings.

1.5. Objective and contributions of this thesis

Hydrogen plants are recognized worldwide as decarbonizing energy systems, but strategic actions are needed by intensifying the effort on feasibility studies regarding the integration of more hydrogen systems, to favor and accelerate the achievement of break-even points. In this line of thinking, the present work proposes a feasibility assessment in two different European countries. The final decision on whether to make a political transition to hydrogen and the FCEV should ideally be based on a cost-benefit analysis, including financial, environmental and social aspects. Although this topic has been dealt with in previous research from purely technical points of view, in the proposed thesis we wanted to deal with the topic according to a multidisciplinary approach, taking into account both the essentially technical aspects, but also the social and planning strategy aspects, taking into account I also take into account the background possessed. The objective of this thesis is to study the diffusion of fuel cell vehicles through data to better address these choices. The articles proposed in this thesis highlight the shortcomings of studies on existing scenarios. Modelling approaches are adopted to identify the winners and losers of transition policies, to identify the parameters crucial to the success of the transition, to better target initial infrastructure investments and, ultimately, to identify successful policies. The analysis conducted helps to improve existing and future scenarios. The papers analyse the impact of combined fiscal and infrastructure programs large enough to overcome the chicken and egg problem. In fact, the combinations of fiscal and infrastructural policies are the exogenous drivers that oblige the adoption of the FCV. Simulations are applied based on a deterministic algorithm, called "Station Counts", which allows us to estimate the amount of infrastructure to be built in the next few years, in a specific urban area, based on the dynamic records of new electric vehicles purchased in previous years. The SERA (Scenario Assessment and Regionalization Analysis) model provides insights that can guide infrastructure development and transport investment decisions and accelerate the adoption of electric vehicles. The model is calibrated to represent the main characteristics of the Italian and Portuguese electric car market as a potential segment for the introduction of the new technology.

II

REVIEW OF FUEL CELL VEHICLE TECHNOLOGY

2.1. The vision of hydrogen and Fuel Cells Vehicles

In Europe and around the world in recent years, interest in hydrogen has rekindled and is growing rapidly. Hydrogen can be used as a feedstock, fuel, carrier or energy storage and has multiple applications in the industry, transport, electricity and construction sectors. Even more important, however, is the fact that when used it does not emit CO_2 and causes almost no air pollution. It therefore represents a solution for the decarbonization of industrial processes and economic sectors in which the reduction of carbon emissions is as urgent as it is difficult. All of this makes it essential to support the European Union's commitment to achieving climate neutrality by 2050 and global efforts to implement the Paris Agreement, while pursuing the "zero pollution" goal. Yet at the moment hydrogen represents only a small percentage of the world and Union energy mix, and is still largely produced from fossil fuels (in particular natural gas or coal) with processes that release 70-100 million tons. of CO_2 per year in the EU. For it to contribute to climate neutrality, it must take hold on a much larger scale and production must be completely decarbonized. Several indicators suggest that we are close to a turning point: new investment plans are announced every week, often for projects on the order of gigawatts; between November 2019 and March 2020, market analyzes highlighted an increase in investments planned worldwide for electrolysers from 3.2 GW to 8.2 GW by 2030 (of which 57% in Europe) and the companies that joined at the Hydrogen Council went from 13 in 2017 to 81 today. There are many reasons why hydrogen is a key priority of the European Green Deal and of Europe's transition to clean energy. By 2050, electricity should make it possible to decarbonize a large share of the EU's energy consumption, but not all of it. As a vector for the transport and storage of renewable energy, together with batteries, hydrogen is able to fill some of these gaps, ensuring reserves in the event of seasonal variations and connecting production sites to more distant demand centers. The Commission's strategic vision for a climate-neutral Union, published in November 2018, projects the growth of the share of hydrogen in the European energy mix, currently below 2%, to 13-14% by 2050. Furthermore, hydrogen can replace fossil fuels in some carbon-intensive industrial processes, for example in the steel industry or chemicals, reducing greenhouse gas emissions and further strengthening the global competitiveness of these sectors. It can offer alternatives for parts of the transport system where it is not easy to reduce emissions, alongside electrification and other renewable and low-carbon fuels. The progressive diffusion of hydrogen-based solutions can also lead to the reconverting or reuse of parts of the existing natural gas infrastructure and thus avoiding that pipeline are transformed into non-recoverable assets. Hydrogen will be part of the integrated energy system of the future, along with renewable-based electrification and a more efficient and circular use of resources. The large-scale and fast-paced application of clean hydrogen is crucial for the EU to achieve more ambitious climate goals with cost efficiency, reducing greenhouse gas emissions by at least 50-55% by 2030. investments in hydrogen will promote sustainable growth and jobs, both of which are essential for recovery from the COVID-19 crisis. The Commission's recovery plan, which stresses the need to unlock investments in clean technologies and key value chains, points to clean hydrogen as one of the elements to focus on in the energy transition and lists a number of possibilities for support it. Furthermore, Europe is very competitive in clean hydrogen technologies and is in an ideal position to benefit from its emergence as an energy carrier on the world stage. By 2050, cumulative investments in renewable hydrogen in Europe could be quantified between € 180 and 470 billion, while those for low-carbon fossil hydrogen could amount to € 3-18 billion. The emergence of a hydrogen value chain serving numerous industrial sectors and other end-uses, coupled with EU leadership in renewable technologies, could (directly or indirectly) employ one million people. It is estimated that clean hydrogen could meet 24% of the world's energy demand by 2050, with an annual turnover of the order of € 630 billion. On the cost side, however, neither renewable nor low-carbon hydrogen can still compete with hydrogen of fossil origin. To seize all the opportunities that hydrogen offers, the European Union needs a strategic approach. EU industry is rising to the challenge and has come up with an ambitious plan to have 2x40 GW of electrolytic power by 2030. Almost all Member States have included clean hydrogen initiatives in their national energy and climate plans, 26 have joined the hydrogen initiative and 14 of them have included hydrogen in their national strategic infrastructure frameworks for alternative fuels. Some have already adopted or are adopting national strategies. However, the spread of hydrogen in Europe is being held back by significant obstacles that neither the private sector nor the Member States can tackle alone. A critical mass of investments, a favorable regulatory framework, new leading markets, sustained research and innovation focused on cutting-edge technologies and new market solutions, a wide-ranging infrastructure network are needed for the development of hydrogen to pass the tipping point. scale that only the EU and the single market can offer and cooperation with partners in third countries. All public and private actors, at European, national and regional level, must work together along the entire value chain to create a dynamic hydrogen ecosystem in Europe. This Communication, which is geared towards realizing the ambitions of the European Green Deal and building on the new industrial strategy for Europe and the Commission's recovery plan, illustrates how the Union can succeed in making clean hydrogen a solution. feasible to decarbonize several sectors, with the installation in the EU of at least 6GW of renewable hydrogen electrolysers by 2024 and 40GW by 2030. With investment cycles in the clean energy sector lasting around 25 years, now is the time for action. The strategic roadmap provides a concrete framework within which the European Clean Hydrogen Alliance - a collaboration launched today between public authorities, industry and civil society, building on the success of the European Battery Alliance - will set an agenda of investments and a portfolio of tangible projects. The roadmap is complementary to the contextual energy system integration strategy, which describes how current EU energy policy strands, including hydrogen development, will promote a climate-neutral and integrated energy system. on renewable electricity, circularity and renewable and low-carbon fuels. Both strategies contribute to the Sustainable Development Goals and the Paris Agreement goals. Currently, crude oil is still the main fuel source in road transport. The share of petrol and diesel in road fuels is around 70% in the European Union (EU). This reliance on a single fossil fuel creates three main problems: - the combustion of fossil fuels inevitably leads to emissions of carbon dioxide (CO_2) and other greenhouse gases (GHG). CO_2 emissions from road transport are responsible for over 20% of total emissions, exceeding those of the industrial sector [28]. Furthermore, there has been a notable increase in road transport over the past 10 years, mirrored by an increase in emissions, indicating that the problem is indeed escalating (EEA, 2020). Similar data applies to other regions of the world, so road transport contributes significantly to anthropogenic climate change. - The health impacts of local emissions, such as ozone, sulfur dioxide and nitrogen dioxide remain problematic, as advances in fuel efficiency, technologies and cleaner fuels have been at least partially offset by increase in the number and use of vehicles. However, regional differences are considerable, depending on vehicle density, average vehicle age and climatic conditions. - oil is a non-renewable resource and it is estimated that, given current demand, the physical peak of conventional world oil production will be reached in 2067 (Statistical Review of World Energy by British Petroleum 2021) [29], so further increases in prices. Furthermore, most of the estimated remaining reserves are located in the politically unstable region of the Middle East. This implies further uncertainty about oil supplies for net importers like the EU and increases price fluctuations due to speculation. These negative conditions require alternative fuels and vehicle technologies. The goal of this thesis is to use a prediction model based on real data in order to obtain a better understanding of the dynamics of a large-scale transition to an alternative fuel / vehicle system. The focus of this thesis is on hydrogen and fuel cell vehicles (FCV), because this technological combination allows a completely sustainable individual transport and is a valid alternative also to electric vehicles. In fact, hydrogen can be produced from any renewable energy source via electrolysis ("renewable hydrogen") and the conversion of energy into the FCV emits nothing but water vapor. Hydrogen is a widely used industrial gas and the 700 bar high pressure tanks for onboard storage are state of the art. They allow vehicle autonomy of over 800 km. The entire system of fuel cells, tank and electric motor adapts to compact cars, providing them with similar performance to conventional cars. FCVs that run on hydrogen appear to be a "shared vision" of the future individual transport. Stakeholders involved in a potential transition to this technological combination in industrialized countries have already taken steps to do so. Wide-ranging actions are being taken both globally and, in the EU, to implement fuel cell technology. In addition, they are developing the infrastructure of hydrogen refueling stations. Currently the fastest developing country in the world is Japan, while in Europe we find Germany [30]. Interest in clean hydrogen is growing around the world. Several countries are developing ambitious research programs to accompany national hydrogen strategies (eg Australia, Canada, Norway, South Korea and several EU Member States) and there are prospects for the development of the international hydrogen market. The United States and China invest heavily in research and industrial development of the hydrogen sector. Some of the current EU gas suppliers and countries with strong renewable energy potential are looking into the possibilities of exporting renewable electricity or clean hydrogen to the EU. For example, Africa, which has an abundant renewable energy potential and in particular North Africa due to its geographical proximity, is an economically competitive potential supplier of renewable hydrogen for the EU. In this context, the EU should actively promote new opportunities for cooperation in the clean hydrogen sector, in order to contribute to the transition of neighboring countries and regions to clean energy and to foster sustainable growth and development. Taking into account natural resources, physical interconnections and technological development, the countries of the eastern neighborhood, in particular Ukraine, and the countries of the southern neighborhood should be priority partners. Cooperation should range from research and innovation to regulatory policy, direct investment and fair trade in hydrogen without distortion of competition, to hydrogen and its derivatives with associated technologies and services. According to industry estimates, 40 GW of electrolysers could potentially be installed in the eastern and southern neighborhood by 2030 to ensure sustained cross-border trade with the EU. The ambition of supplying the Union with large quantities of renewable hydrogen should be present at the table of cooperation and diplomacy in the energy sector. In this context, the EU should actively promote new opportunities for cooperation in the clean hydrogen sector, in order to contribute to the transition of neighboring countries and regions to clean energy and to foster sustainable growth and development. Taking into account natural resources, physical interconnections and technological development, the countries of the eastern neighborhood, in particular Ukraine, and the countries of the southern neighborhood should be priority partners. Cooperation should range from research and innovation to regulatory policy, direct investment and fair trade in hydrogen without distortion of competition, to hydrogen and its derivatives with associated technologies and services. According to industry estimates, 40 GW of electrolysers could potentially be installed in the eastern and southern neighborhood by 2030 to ensure sustained cross-border trade with the EU. The ambition of supplying the Union with large quantities of renewable hydrogen should be present at the table of cooperation and diplomacy in the energy sector. To support investments in clean hydrogen in the European neighborhood, the Commission will mobilize the financial instruments available, including the Neighborhood Investment Platform, which for many years has financed projects accompanying the transition of partner countries to clean energy. The Commission would also be ready to support new hydrogen-related projects proposed by international financial institutions for possible co-financing through this instrument, for example in the framework for investments in the Western Balkans.

2.1.1 The challenge of transition

That of hydrogen cars and hydrogen-powered vehicles is one of the great trends in the automotive sector, with a technology of the future. If the electric car market is expanding rapidly, however, the hydrogen market is still taking its first steps, hampered by the lack of infrastructure and the huge production costs that discourage players in the supply chain. But now, with the institutional push for progressive large-scale hydrogen production, the situation may change. Hydrogen is one of the cornerstones of the strategy for the green revolution and ecological transition conceived by the governments of various states: in Italy, for example, within a government mission worth 58.33 billion euros, a 3.19 billion hydrogen project. Specifically, 2 billion are planned for the conversion of production companies to electric furnaces, 500 million for the production of hydrogen in industrial areas, 160 million for research, and 530 for the creation of an infrastructure that allows the use of hydrogen in road and rail transport in non-electrifying sections. In addition, an additional 450 million is foreseen to finance technological development [31]. A first step towards FCVs and hydrogen produced from natural gas can be seen as a hedging strategy with immediately reduced dependence on oil (but increased dependence on gas). Once a hydrogen production and distribution infrastructure is created, hydrogen can be produced directly (through reforming/gasification technologies) or indirectly (through electrolysis) from literally any energy source, creating flexibility. These benefits, coupled with the prospect of renewable hydrogen, must outweigh the costs of setting up a hydrogen infrastructure (based on natural gas) in order to justify government action. There is a long list of scenarios and forecast studies on the introduction of FCV with a focus on estimates of the costs of hydrogen production [32]. Estimates for investments in the EU that are sufficient to allow hydrogen to gain significant market share are still high, but in the same order of magnitude as other infrastructure investments that were once thought to be huge and are now in existence. such as building new highways or high-speed Internet. Car manufacturers are still reluctant to make substantial investments in their products, as lack of supply opportunities prevents consumers from buying. On the other hand, oil companies, as the main operators of filling stations, will not set up a hydrogen production / distribution network and hydrogen outlets in their stations without the demand generated by FCV on the road; this is the so-called “chicken and egg” dilemma [33]. The literature on hydrogen infrastructure costs therefore implicitly requires public investment. But such a substantial government effort to build refuelling infrastructure would be unprecedented and unlikely given the budget constraints of public authorities. Aside from these problems, building infrastructure alone may not be enough. In fact, the existence of supply possibilities may not induce consumers to purchase FCVs (currently more expensive). Furthermore, within the car purchase decisions, the environmental impact is only one aspect in addition to another characteristic, such as size, acceleration and also psychological reasons (e.g. status). Therefore, joint fiscal and infrastructure policies are needed to promote the introduction of FCVs. For the hydrogen economy to thrive across Europe, a whole value chain approach is needed. Production from renewable or low-carbon sources, the construction of an infrastructure that delivers hydrogen to final consumers and the promotion of demand must proceed in parallel, giving rise to a virtuous circle of growth in demand and supply. of hydrogen. Lower procurement costs are also required, which implies a reduction in both the costs of clean production and distribution technologies and the price of renewable energy inputs, so as to ensure competitiveness with fossil fuels. In this context, off-grid renewable hydrogen production can be an alternative. The hydrogen economy will also require a large number of raw materials. The supply aspect should therefore be taken into account in the action plan for essential raw materials, in the implementation of the new action plan for the circular economy and in the definition of the EU trade policy, in order to ensure fairness and prevent distortion of trade and investment in these commodities. There is also a need for a life cycle approach to minimize the deleterious effects that the hydrogen sector could have on the climate and the environment. Stimulating the demand and supply of hydrogen will probably require multifaceted support, in line with the vision of this strategy which aims to favour renewable hydrogen. In the transition phase, it will be essential to adequately support low-carbon hydrogen, but this should not result in stranded assets. The revision of the rules on state aid is expected in 2021, also in favour of the environment and energy: it will be an opportunity to develop a global framework that is marked by the success of the European Green Deal and decarbonization - also on the hydrogen front - and at the same time limiting possible distortions of competition and negative repercussions in other Member States. The creation of new lead markets goes hand in hand with the increase in hydrogen production. Gradually two leading markets can be developed, that of industrial applications and that of mobility, to exploit the potential of hydrogen in a cost-effective way for the benefit of a climate-neutral economy. In the industrial field, an immediate application consists in the reduction and replacement of carbon-intensive hydrogen used in refineries, in the production of ammonia and in new forms of methanol production, or in the partial replacement of fossil fuels in the steel industry. At a later stage, hydrogen could form the basis for investments in zero-carbon steelmaking and the introduction of these processes in the EU, as envisaged by the Commission's new industrial strategy. In the transport sector, too, hydrogen is a promising solution for cases where electrification is more problematic. In the first phase, it can be adopted quickly for restricted uses, such as city buses, commercial fleets (for example taxis) or certain sections of the railway network that cannot be electrified. The hydrogen refuelling stations can be easily powered by local or regional electrolysers, but their construction must be preceded by a careful analysis of the needs of the vehicle fleet and the different needs of light and heavy vehicles. The main obstacle to the use of hydrogen in industrial and transportation applications is often the higher cost, also dictated by the additional investments necessary for the dedicated equipment and for storage and refuelling facilities. Add to this the low margins on final industrial products, due to international competition, which amplifies the potential impact of supply chain risks e market uncertainty. Therefore, supportive policies on the demand side will be needed. The Commission will consider several options regarding incentives at EU level, including the possibility of setting minimum quotas or quotas of renewable hydrogen or its derivatives in specific end-use sectors (e.g. in certain industries, such as chemicals, or in applications transport), which should make it possible to increase demand in a targeted way. In such context, the notion of "virtual blend" could be explored.

The development of internal combustion engines (ICEs), particularly those used in passenger cars, is one of the greatest achievements of modern technology [34]. Since Henry Ford perfected mass production of his groundbreaking Model-T 100 years ago [35], The world of transportation has become affordable, forever altering our notions of place, distance and community. The company has built infrastructure systems such as roads, bridges and tunnels to meet many of the mobility needs in everyday life. In the future, along with global development, road transport will expand further and bring greater benefits to our society. There are currently an estimated 1.2 billion vehicles in the world. The forecast is that, in the year 2035, this figure will exceed 2 billion, according to a study conducted by the US analyst firm Ward [36]. The automotive industry is therefore one of the largest economic forces globally, with nearly 10 million employees and a value chain in excess of $ 3 trillion a year, even more than the UK's total GDP which was worth 2.4 trillion. dollars in 2011, according to a report published by the World Bank [37]. Challenges As a result of this colossal industry, the large number of cars in use around the world has caused and will continue to cause a number of great challenges in our society. Greenhouse gases (GHGs) and other emissions from vehicle exhaust pipes not only affect the climate but also humans, particularly particulate emissions due to the increasing number of diesel vehicles on the road [38]. Furthermore, rapid oil depletion, problems with energy security, dependence on foreign sources and population growth challenges posed by even larger cars [39]:

- Greenhouse gas (GHG) emissions: the transport sector contributes around 24.6% to GHG emissions in Europe, as shown in Figure 12, with over two-thirds of road transport (Eurostat). While greenhouse gas emissions from other sectors are generally decreasing, decreasing between 1990 and 2017, those from transport increased over the same period (Figure 13). This increase occurred despite the improvement in vehicle efficiency because the amount of personal and freight transport has increased dramatically. Worldwide, around 11.9% of GHG emissions come from road transport and a total of 5 billion tons per year. Therefore, the reduction of greenhouse gas emissions in the automotive sector has become a national and international priority.

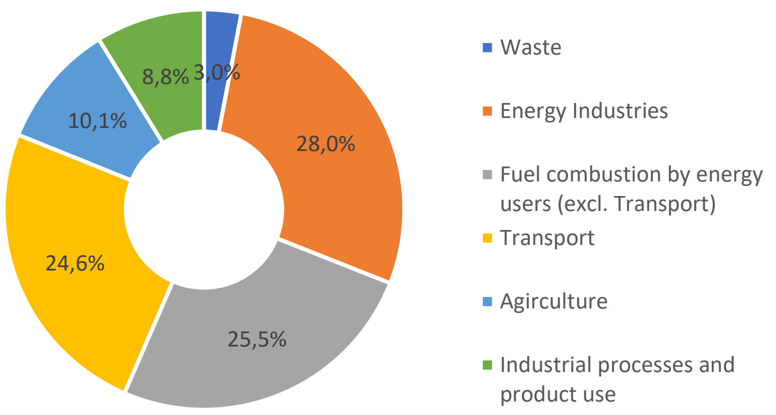


Figure 14. Share of EH greenhouse gas emissions by source, 2019 (data source: Eurostat).

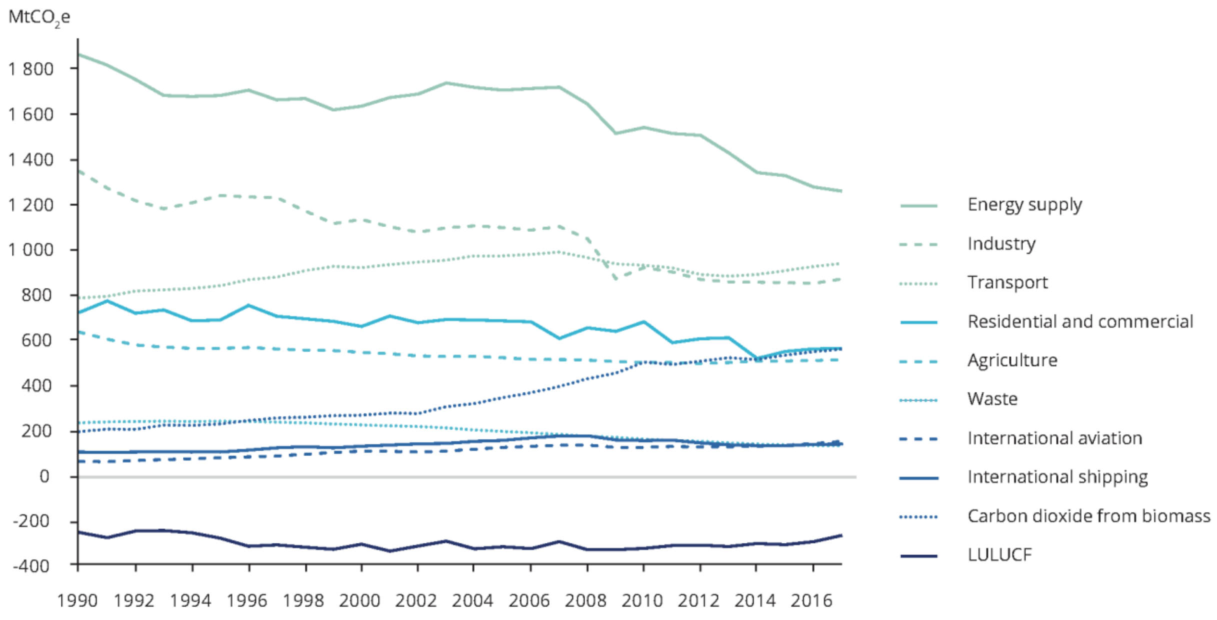


Figure 15. GHG emissions by main sector (data source: EEA).

- Air pollution: vehicle emissions (exhaust pipes) are responsible for several debilitating respiratory conditions, such as asthma [40], As the use of fossil fuels in internal combustion engines produces harmful regulated air pollutants such as CO, SOX, fine particulate matter (PM10), volatile organic compounds (VOC) and oxides of nitrogen (NOX). The growing number of diesel vehicles on European roads will further deteriorate air quality. Furthermore, it is worth noting that by burning the same amount of hydrocarbons, pollutants emitted from vehicles cause more damage when released into an urban area than those upstream of a rural power plant, due to the fact that more people gets hit.

- Oil depletion - The oil depletion theory was first formulated in 1956 by King Hubbert, a Shell geologist, according to whom a spike in crude oil production would occur at the same time as the beginning of the 1950s 70, which would be followed by an inexorable decline [41]. A theory later proved to be incorrect due to the refinement of prospecting and drilling technologies and the achievement of new deposits once considered inaccessible. As a result of the combination of these factors, production peaks have continued to follow one another even in the new millennium. In 2014, data were formulated during the 63rd edition of the Statistical Review of World Energy by British Petroleum, according to which world oil reserves (including LPG and "condensates") will be sufficient until 2067 if their exploitation continues. at the current pace. To date, in the light of some recent discoveries, these predictions are no longer reliable: oil will not run out, in line with what Ahmed Zaki Yamani, the man who headed the oil ministry in Saudi Arabia between 1962 and 1986 said. , but we will consume less and less. If, in fact, oil is today the undisputed queen of energy sources, a welcome solution for its costs, for its flexibility of transport and use, it should also be remembered that the globe is embarking on alternative paths, aimed at coping the threat posed by climate change. The new situation therefore sees the emphasis placed on the need to turn towards new energy models. In which oil will play a much smaller role than in the past.

An energy vector for green and clean mobility: the case of hydrogen

According to the data of the report of BloombergNEF, green gases represent over 25% of the energy mix by 2050. It has been seen how the COVID19 pandemic in 2020 has sharply cut emissions, with fossils slowing down and renewables accelerating (it is considered that wind and solar alone will account for more than half of electricity in 2050). The sharp decline in energy demand due to the Covid-19 pandemic will remove the equivalent of around 2.5 years of emissions from the energy sector between now and 2050. However, there is still a long way to go, as we are witnessing a constant increase in global average temperature which more than double the target set at the Paris conference (Figure 16).

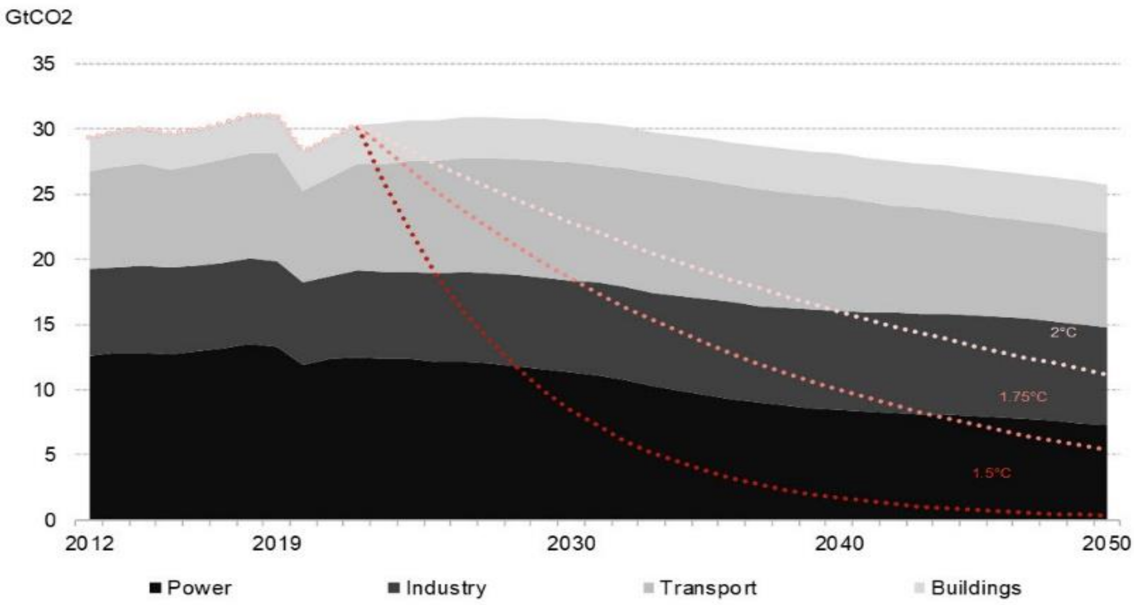


Figure 16. Emissions in the NEO Economic Transition Scenario, by sector and a 1.75°C carbon budget.

According to the BNEF model, the maximum peak of emissions related to the use of fossil fuels was reached in 2019 and then dropped by 10% in 2020 due to the pandemic. According to forecasts, emissions will increase with the economic recovery but without reaching the levels of 2019 and from 2027 they will decrease with an annual rate of 0.7% until 2050. This decrease is due to a huge development of wind and PV, electric vehicles and improved energy efficiency in all sectors. In fact, renewable energy from wind and PV is expected to contribute 56% to global electricity production by mid-century. The same scenario is also expected in China and India, where decreasing coal production will see a 12% drop in global electricity generation [42]. However, despite the energy transition and post-Covid-19 reduction in consumption, a temperature increase of 3.3 degrees Celsius is expected by 2100, according to BNEF, due to emissions from the energy sector. To remain below 2 ° and limit heating to 1.5 ° C, emissions should decrease by 10% per year. According to the New Energy Outlook 2020 scenario, oil demand will peak in 2035 , to then fall by 0.7% on an annual basis until it returns, in 2050, to the levels of 2018. Gas, on the other hand, will be the only fossil fuel to continue to rise until 2050, with an increase of 0.5 % every year. Electric vehicles are expected to reach initial price parity with internal combustion vehicles by 2025. After that, their adoption accelerates, increasingly dampening the growth in crude oil demand. In another scenario, BNEF expects to have 100,000 TWh of clean electricity by 2050 or five times the electricity produced today globally (with a 6-8 times increase in clean electrical power). Two thirds of this energy would go to the direct supply of electricity in the transport, construction and industry sectors, while the remaining third would go to the production of hydrogen. It is therefore estimated that between $ 78 trillion and $ 130 trillion of new investments between now and 2050 are required to realize this scenario based on clean electricity and green hydrogen.

The policies of the European Union and Italy for green mobility

Among the main recent European Union policies promoting sustainable mobility we have the DAFI directive 2014/94 / UE [43]. The DAFI Directive of the European Parliament is of fundamental importance for the development of green cars, because it sets the goal on the creation of infrastructures to assist in the use of alternative fuels to oil. Italy has transposed the rule with Legislative Decree 257 of December 2016 and 2020 is identified as the starting year for the creation of a substantial number of charging points accessible to the public for electricity; moreover, the directive includes hydrogen in the list of alternative fuels for which

Italy undertakes to develop an adequate network of refueling stations by 31 December 2025. This is of fundamental importance, since infrastructures are the turning point that encourages the purchase and circulation of electric vehicles. Therefore, if 2020 is identified as the key year for its development for electricity, for hydrogen it is assumed that it will be 2025 [44]. In Italy in 2015 "Mobilità Idrogen Italia" (MH2IT) was established, an association that brings together the main Italian hydrogen stakeholders, which identifies the future Italian prospects for hydrogen mobility.

Hydrogen in Italy: consumption and costs in 2019 and 2030

Globally, the consumption of H2 estimated by IEA compared to 50 million in 1990 (Figure 15).

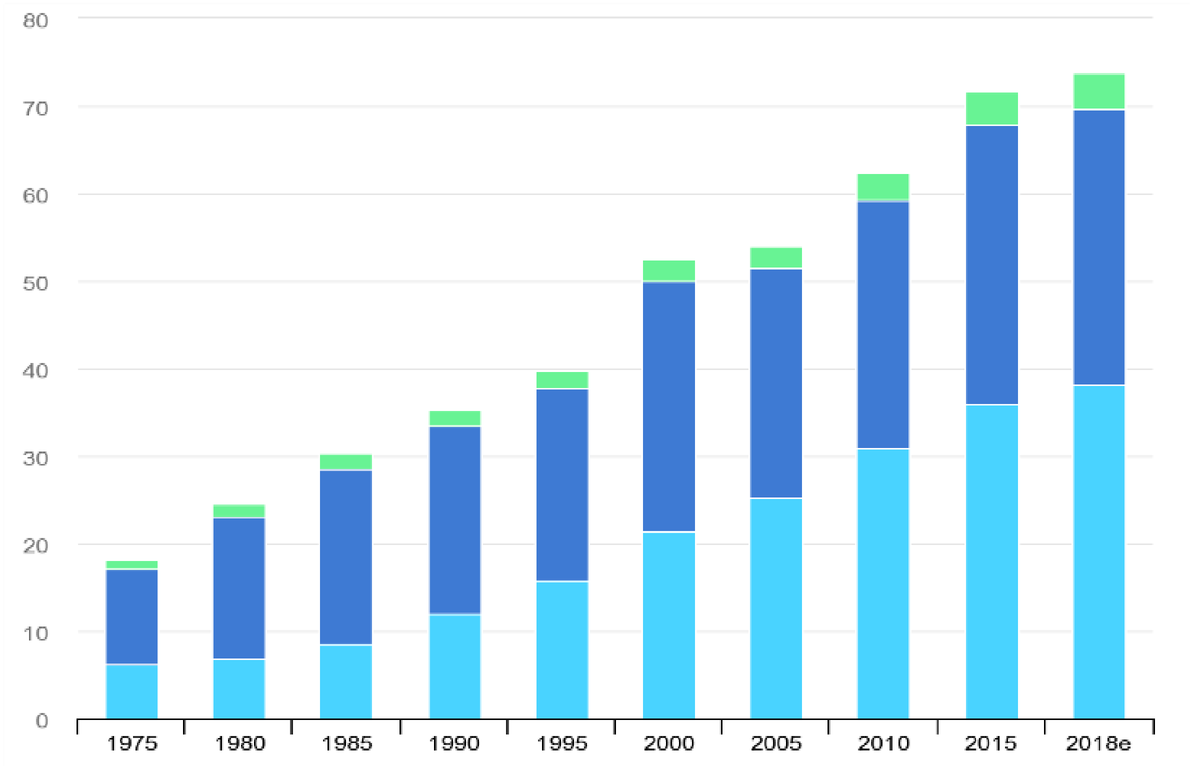


Figure 17. Global demand for pure hydrogen, 1975-2018 (data source: IEA).

As regards Italy, previous studies estimate the consumption of H2 at 2050 [45] in the order of 218 TWh for various uses plus electricity production (G2P) for about 100 TWh (RSE approx. 8% in 2050) (Figure 16).

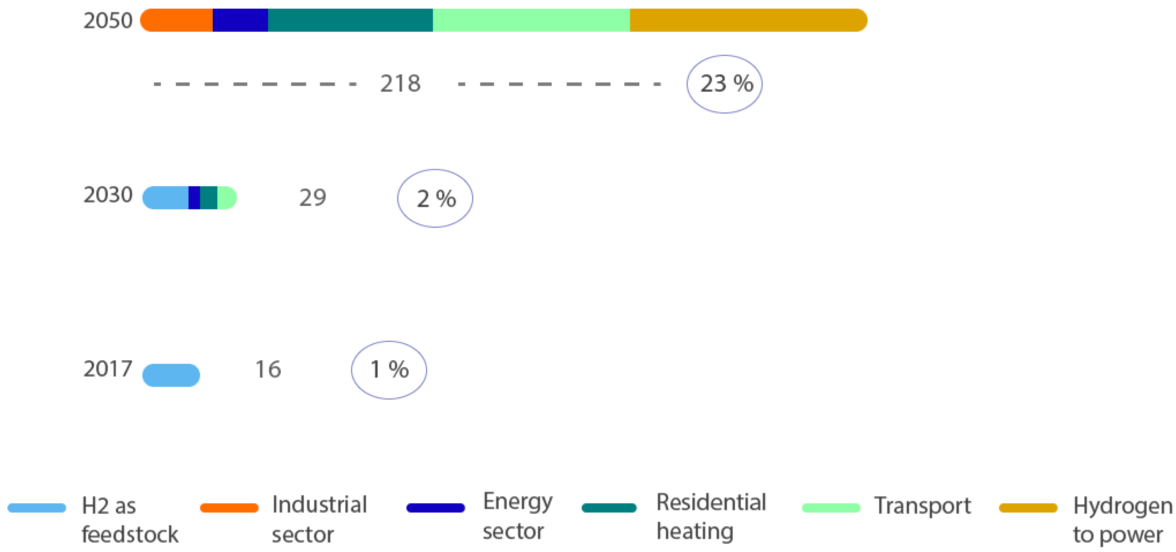


Figure 18. Consumption of H_2 in Italy in TWh up to 2050
(The European House Ambrosetti on a study commissioned by SNAM).

In particular, with reference to the transport sector, MobilitàH2IT provides a scenario that estimates the production of hydrogen by 2025 for light mobility and buses in Italy. There are the following data:

Table 4. Mobility Scenario H2IT, production H2 up to 31/12/2025 for light mobility and buses.

H2 Production		**2020**	**2021**	**2022**	**2023**	**2024**	**2025**
H2 from SMR	%	60.0	56.0	52.0	48.0	44.0	40.0
	t/year	535	1,130	1,804	2,641	3,6	4,664
	Kg/day	1,467	3,096	4,941	7,235	9,864	12,779
	MW	2.4	5.1	8.1	11.8	16.1	20.9
	Consumption (GWh/anno)	23.2	48.8	77.6	113.2	153.7	198.4
H2 from Electrolysis	%	40.0	44.0	48.0	52.0	56.0	60.0
	t/year	357	888	1,665	2,861	4,582	6,997
	Kg/day	987	2,433	4,561	7,838	12,554	19,169
	MW	2.4	5.1	8.1	11.8	16.1	20.9
	Consumption (GWh/anno)	23.2	48.8	77.6	113.2	153.7	198.4
TOTAL	**t/year**	**892**	**2,018**	**3,468**	**5,501**	**8,183**	**11,661**
	Kg/day	**2,445**	**5,529**	**9,503**	**15,072**	**22,418**	**31,948**
	MW	**4.0**	**9.0**	**15.5**	**24.7**	**36.7**	**52.3**

To date, 99% of hydrogen production is black (ie that produced from fossil fuels without any capture of CO_2 emissions), with significant greenhouse gas emissions; in fact, with the Steam Methane Reforming (SMR) process at high temperature, about 9 kg of CO_2 are emitted to produce 1 kg of hydrogen (necessary to move a Fuel Cell car for 130 km. Currently, for Fuel

Cell cars, efficiency on the road is about 1 kg of hydrogen per 100 km traveled, with ranges from about 500 km to 750 km and refueling times of less than 5 minutes. For buses, the daily ranges reach up to 450 km, with consumption efficiencies of around 8-9 kg of H2 / 100 km, refueling times are less than 10 minutes[46].

The cost of black hydrogen at the point of production was estimated by IEA in 2019 globally in the range of 1,25-2,7 $ / kg (from 32 to 69 € / MWh) depending on local gas costs and CO_2 capture. For gray hydrogen, the cost of production depends on the price of methane. Considering the price of European methane before Covid-19 (13 € / MWh), the production cost was about 1 € / kg; with the price of methane after Covid-19 at 25 € / MWh, the cost rises to 1.5 € / kg. For blue hydrogen it is necessary to add the costs for the capture and sequestration of CO_2, which almost double the cost of the plant (estimated to date at about 1,500 € / kW-hydrogen, against 800 € / kW of the plant for gray hydrogen) and decrease efficiency (about 69% versus 75-80% of gray). The calculation of the production cost of green hydrogen is more complex, which depends on the cost of the electrolysers and other system components, the cost of the renewable electricity that feeds them and the load factor (number of hours per year at nominal power equivalent), which impacts the depreciation of the production plant [47]. Still according to estimates provided by IEA, it is expected that by 2030 the plant cost could further reduce to 1,200 € / kW-hydrogen and up to 1,100 in the long term (> 2040).

Prospects for the use of hydrogen in the transport sector

In recent years, the use of green hydrogen for energy purposes is becoming increasingly important in the debate on the decarbonization of the economy; Among others, possible uses in the transport sector, where green hydrogen can be used as a zero-emission fuel for transport, appear promising. The legislative and regulatory context, both at a European and national level, is now certainly geared towards encouraging and speeding up this development dynamic. Within the EU, the European Hydrogen Strategy approved in July 2020 provides for a significant growth of hydrogen in the energy mix, with a target of new installed capacity of electrolysers totaling approximately 40 GW by 2030. In Italy the main regulatory reference consists of Legislative Decree no. 257 of 16/12/2016 "National strategic framework for the development of the alternative fuel market in the transport sector and the construction of the related infrastructures", aimed at encouraging the use of alternative fuels, in particular electricity, natural gas and hydrogen. From a strategic planning perspective, on the other hand, the Integrated National Plan for Energy and Climate (PNIEC), transmitted by the Italian government to the European Commission in January 2020, provides for hydrogen a contribution of around 1% of the RES-Transport target by 2030, through direct use in cars and buses as well as in hydrogen trains, or through the introduction of methane into the network. The preliminary guidelines on the national hydrogen strategy, published at the end of 2020 by the Ministry of Economic Development in line with the PNIEC and the European strategies, identify the hydrogen penetration objectives and the sectors in which this energy vector can become competitive in time. short, identifying the areas of intervention to develop their use. This strategic vision becomes concrete in the recent National Recovery and Resilience Plan (April 2021), which provides for various interventions and financing both for the development of electrolysis plants, for the production and transport of hydrogen, and for the development of stations. refueling station for hydrogen wheeled vehicles and rail transport. In the PNRR Mission called "Green Revolution and Ecological Transition", in particular, the Renewable Energy, Hydrogen, Grid and Sustainable Mobility Component provides a particular focus on more sustainable mobility and on the decarbonization of some industrial segments, including the launch of adoption of hydrogen-based solutions, in full coherence with the guidelines of the European strategy. Looking more in detail at the individual interventions from the PNRR, in the long-haul truck transport sector, the planned intervention has for example the objective of promoting the creation of hydrogen-based refueling stations and implementing projects for testing the lines. hydrogen. The distributors will be suitable for trucks and cars, even operating at pressures of over 700 bar. Through these investments it will be possible to develop around 40 refueling stations, giving priority to strategic areas for heavy road transport such as the areas close to internal terminals and the routes most densely crossed by long-haul trucks. The PNRR also considers the use of hydrogen in passenger rail transport to be strategic, through the conversion project to hydrogen of non-electrified railway lines in regions characterized by high traffic in terms of passengers with a strong use of diesel trains such as Lombardy, Puglia, Sicily, Abruzzo, Calabria, Umbria and Basilicata. As regards the field of research, a specific line of intervention of the Plan provides for the development of four main lines of study: production of green hydrogen; development of technologies for storage and transport of hydrogen and for transformation into other derivatives and green fuels; development of fuel cells; improvement of the resilience of current infrastructures in the event of a greater diffusion of hydrogen.

Looking instead at the initiatives already started, the systems for exploiting hydrogen in transport in Italy are still scarce today. The only active hydrogen distributor (since 2015) and open to the public is located in Bolzano, on the Brenner motorway (the hydrogen made available is produced with renewable electricity generated by hydroelectric plants). Two other distributors are present in Milan and Capo d'Orlando, in the province of Messina; however, these are service stations for hydrogen buses and minibuses, they are not open to the public. On the other hand, there are numerous projects at an advanced stage to encourage the development of hydrogen mobility for both passenger and freight transport, with particular reference to heavy transport and rail transport, where hydrogen trains can replace diesel trains. existing on some routes. Among the most important initiatives under construction in Italy, for example:

- the European project PROMETEO, coordinated by ENEA, aimed at containing the costs of producing green hydrogen by applying high-efficiency technologies that combine electricity obtained from photovoltaic or wind power plants with heat obtained from concentrating solar plants. The project involves the construction in Italy of a 25 kWe electrolyser prototype capable of producing 15 kg of hydrogen per day; It is an Italgas project for the construction of a green hydrogen hub in Sardinia, near Cagliari. The initiative, carried out in collaboration with CRS4 - Research Center of the Technology Park of Sardinia - to create a hydrogen energy community, involves the installation of a renewable energy feed electrolyser with which to produce green hydrogen;
- the Province of Bolzano plans to purchase 12 hydrogen-powered buses to be included in the scheduled service, which will be added to the fuel cell prototypes already in service in Bolzano since 2013;
- FNM and Trenord will promote the use of hydrogen trains in the Sebino and Valcamonica areas, through the H2iseO project, which involves the purchase of new trains that will serve the non-electrified Brescia-Iseo-Edolo line from 2023, replacing the current diesel engine;
- SNAM recently announced the Hydrogen Innovation Center, a center of excellence for hydrogen technologies, which aims to aggregate companies and university research centers to accelerate the development of the sector and contribute to the achievement of national climate objectives and Europeans.

Against the background described above, at the time this Note is drawn up (June 2021) the permanent use of hydrogen-powered vehicles and/or refueling stations remains limited to a few realities, mainly in the north of Italy; from a statistical point of view, therefore, the energy uses of hydrogen in the transport sector in Italy are still scarcely relevant. The numerous projects launched or planned, and the more general regulatory and institutional context, however, allow us to hypothesize significant increases in hydrogen-based technology, and therefore in relative consumption, starting in the next few years. It is important to note, in closing, that today large quantities of hydrogen are used by oil refineries (about 0.5 Mton / year together with the chemical sector). A conversion, even partial, of the production processes of this hydrogen towards the use of electricity from renewable sources would make it possible to use green hydrogen in the production process of fuels, largely used in transport, contributing indirectly to the decarbonization of transport. This possibility is also expressly provided for by Directive 2018/2001, which allows for the accounting of green hydrogen used as an intermediate for the production of fossil fuels for the purpose of achieving the obligations for operators regarding the minimum renewable fee.

2.2. Working principles of Fuel Cells

A Fuel Cell is an electrochemical device capable of directly converting chemical energy into electricity through a constant temperature process in which hydrogen is combined with oxygen to form water. The principle of operation of the fuel cell was discovered in 1839 by the English physicist William Grove [48]. Almost a hundred years later, also in Great Britain, the engineer Francis Th. Bacon further developed Grove's invention, paying particular attention to the morphology of the electrodes and the role of the catalyst in promoting cell processes. In more recent times there have been further technological developments, first in the 1970s, following the space programs that selected fuel cells as the preferred systems for power supply on board important missions, such as the Gemini and Apollo programs and, more recently, in relation to their potential in energy renewal (hydrogen cycle) and eco-sustainable transport (electric vehicles). The operation of a fuel cell is based on the following electrochemical reaction:

$$H_2\,(g) + \tfrac{1}{2}\,O_2\,(g) \rightarrow H_2O$$

which involves the combustion of gaseous hydrogen with gaseous oxygen with the formation of water. Hydrogen is the most used fuel, but alcohols or gasoline can also be used. Since hydrogen is not a natural resource, it must be produced using processes that include water electrolysis, cracking or steam reforming of organic fuels such as natural gas, methanol or hydrocarbons. Among all these synthesis processes, only the electrolysis of water gives rise to pure hydrogen, while from the others mixtures are obtained in which hydrogen is present with other gaseous components, generally undesirable as they can affect the correct functioning of the Fuel Cell [49].

The operating principle of a fuel cell can be described as follows: the fuel, hydrogen, is supplied to the negative electrode where it oxidizes to the H^+ ion (proton) with the release of electrons. The electrons flow into the external circuit and produce electrical work, and then reach the cathode where they reduce oxygen to the OH^- (hydroxyl) ion. The circuit is closed by the transport of ions from one electrode to the other through the electrolyte. Depending on the nature of the electrolyte used (acid or basic), the reactions of the individual electrodes can be written as follows:

In the acid electrolyte:

$$\text{anode: } H_2 \rightarrow 2H^+ + 2\,e^- \tag{1}$$

$$\text{cathode: } \tfrac{1}{2}O_2 + 2H^+ + 2\,e^- \rightarrow H_2O \tag{2}$$

$$\text{total: } H_2 + \tfrac{1}{2}O_2 \rightarrow H_2O \tag{3}$$

and the electrical circuit is closed by the transport of protons that pass through the cell from the anode until they reach the cathode to complete the electrochemical reaction. In the basic electrolyte:

$$\text{anode: } H_2 + 2OH^- \rightarrow 2H_2O + 2\,e^- \tag{4}$$

$$\text{cathode: } \tfrac{1}{2}O_2 + H_2O + 2e^- \rightarrow 2OH^- \tag{5}$$

$$\text{total: } H_2 + \tfrac{1}{2}O_2 \rightarrow H_2O \tag{6}$$

and the electrical circuit is closed by the transport of hydroxyl ions that migrate from the cathode to the anode to complete the electrochemical reaction. In both cases the global electrochemical process leads to the formation of water. In summary, a fuel cell exploits the hydrogen combustion process in order to produce electrical work; therefore this cell can be considered as an electric motor capable of converting the free energy of the electrochemical reaction into electrical energy, with a process similar to that which can take place in a heat engine. However, the great merit of a fuel cell lies in the fact that, unlike what happens in a heat engine, it can convert chemical energy into electrical energy without incurring the limitations imposed by the Carnot cycle. As is known, the maximum efficiency of a heat engine (Carnot efficiency, ε_{Carnot}) depends on the extreme temperature values, according to the relationship:

$$\varepsilon_{Carnot} = \frac{T_1 - T_2}{T_1} \qquad (7)$$

where T_1 is the maximum value of the absolute operating temperature and T_2 the minimum. This equation implies that the efficiency can reach a value equal to 1 (100%) only if T_2 is equal to absolute zero, or if T_1 approximates an infinite value. Under normal conditions, the maximum efficiency does not exceed 40%. The efficiency of a fuel cell, ε_{therm}, on the other hand, is related to the ratio of two thermodynamic quantities, the variation of Gibbs free energy, ΔG, and the variation of enthalpy, ΔH, in the oxidation reaction of the fuel, according to the relation :

$$\varepsilon_{therm} = \Delta G/\Delta H \qquad (8)$$

The relationship between the two thermodynamic quantities, both negative in the water formation reaction, allows to reach double efficiency values compared to those obtainable from the heat engine. Figure 17 shows, in comparison, the trend with varying temperature of the efficiency of a fuel cell, hydrogen and air, and of a heat engine, assuming a value of T_2 equal to 25 ° C. Since ΔG decreases in value absolute as the temperature increases and ΔH remains essentially unchanged, the efficiency of the fuel cell decreases as the temperature increases while the opposite occurs for the thermal engine, up to reaching high temperature values in which the efficiency of the engine at combustion exceeds that of the fuel cell.

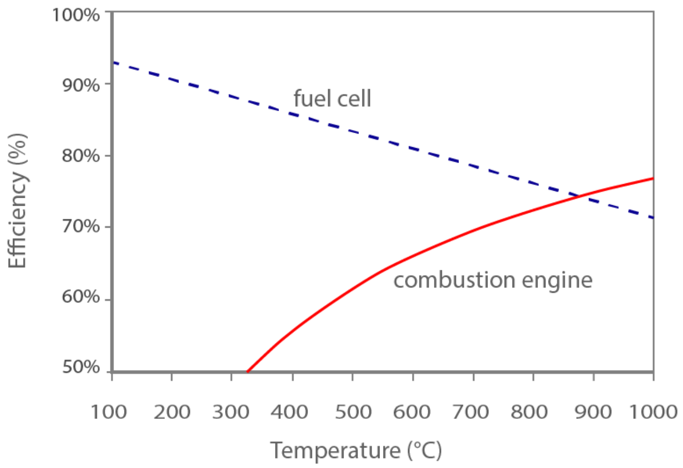


Figure 19. Trend with varying temperature of the efficiency of a fuel cell and of a heat engine.

The electromotive force, f.e.m., or potential E of a fuel cell is expressed by the Nernst equation:

$$E = E_{0} - \frac{RT}{nF} ln \frac{P_{H_20}}{P_{H_20} * P_{O_2}^{1/2}} \qquad (10)$$

where E_0 is defined as the standard cell potential, that is the value that would be obtained if reagents and products were in their standard state. The Nernst equation shows how the value of E increases as the partial pressure of the fuel (eg, hydrogen, PH_2) and air (PO_2) increases and decreases as the temperature increases. The potential E is related to the Gibbs free energy by the relation:

$$\Delta G = -nEF \qquad (11)$$

where n is the number of electrons involved (2 in the reaction of interest) and F is Faraday's constant (96.495 C mol^{-1}). The Gibbs free energy change at 298 K, in the case in which products and reactants are in their standard state (liquid H2O, pure H_2 and O_2 under unit pressures), coincides with the standard free energy change, ΔG0, and is equal to - 237 $kJmol^{-1}$. Therefore, the cell potential, coinciding with the standard potential, E0, is equal, under the aforementioned reaction conditions, to 1,23 V. Figure 19 illustrates a typical trend of the current-voltage curve of a fuel cell.

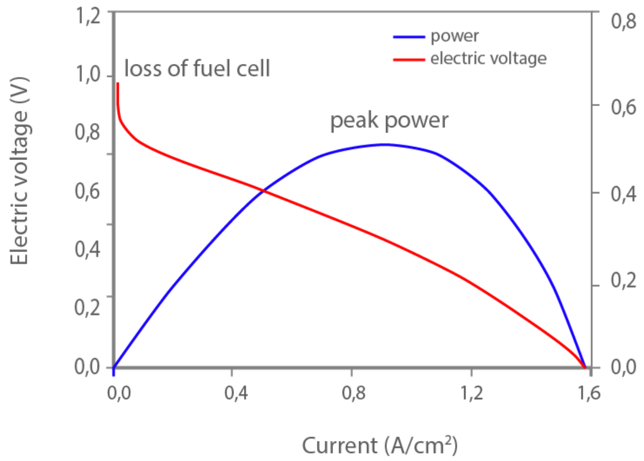


Figure 20. Trend of the current-voltage curve of a fuel cell.

In open circuit conditions the current is zero and the cell voltage is at its maximum value, corresponding to the electromotive force in the particular reaction conditions. When the circuit is closed and the consequent passage of current in the cell, irreversible drops in potential occur which result in a progressive decrease in the cell voltage V according to the relationship:

$$V = E - \eta_{att} - \eta_{ohm} - \eta_{diff} \qquad (12)$$

from which it can be seen how V differs from E for a series of voltage drops indicated respectively with: (a) η_{att} - which identifies the activation overvoltage linked to the anode and cathode processes; (b) ηohm - which identifies the ohmic overvoltage due to the voltage drop iR following the passage of electrons and ions through the electrode and electrolytic materials, respectively, which have finite resistance; (c) η_{diff} - which identifies the diffusion overvoltage due to mass transport limitations. These voltage drops are reflected in different regions in the current-voltage curve of previous Figure: (a) the activation overvoltage, ηatt, appears in the initial low current part; (b) the ohmic drops, η_{ohm}, in the central part at medium current; (c) the mass transport limitations, η_{diff}, in the final high current part. A further voltage drop may occur following the passage of the reagents through the electrolyte and, to a lesser extent, any unwanted electronic conduction through it. These losses, generally negligible, become important in the case of a liquid fuel (methanol) and, in general, in the case of low temperature fuel cells, causing a marked effect of reducing the electromotive force value.

It follows that the efficiency of the cell decreases passing from the ideal conditions, that is to say in an open circuit, to the real ones under load where part of the free energy is dissipated in the form of heat due to the cell resistances. Although the final value of the cell efficiency also depends on factors related to collateral processes of the auxiliary cell components - such as those related to the pumping, heating, cooling and compression of the gaseous reagents - the direct conversion efficiency remains high so as to represent one of the distinctive advantages of fuel cell technology. However, it is always advisable to minimize overvoltage through the appropriate choice of the materials used and the cell geometry. To favor the electrode reactions, for example, and accelerate their kinetics, it is necessary to resort to the use of a catalyst since the electrode processes, such as the oxidation of hydrogen and the reduction of oxygen, proceed through adsorption-desorption phenomena on a solid substrate, on which hydrogen or oxygen release or receive electrons. In the case of hydrogen oxidation, for example, it can be assumed that the process takes place through a sequence of steps, which initially involves the transport of a hydrogen molecule from the gas phase to the solid substrate and its adsorption on the surface; this stage is followed by the electrochemical oxidation of the adsorbed hydrogen and, finally, by the release in the electrolytic phase of the species that have formed. The oxygen reduction process is even more complex, since it involves a number of parallel and consecutive steps, including the formation of hydrogen peroxide as an intermediate product. It can therefore be understood how the speed of the processes at the electrodes is influenced by the nature of the substrate and, in particular, by the hydrogen or oxygen adsorption enthalpy value. It follows that the kinetics of the electrode processes can be accelerated, and therefore the overvoltage reduced, by choosing the most suitable substrate. In other words, the substrate acts as a catalyst for electrode reactions. The most effective catalysts for the hydrogen oxidation process are noble metals - such as platinum, palladium or ruthenium - while for oxygen reduction, in addition to platinum and palladium, they can be used, under high regimes. temperature, nickel and its oxides. The high cost of these catalysts contributes to the overall cost of a fuel cell. However, an effective compromise between cost and efficiency is obtained by designing the structure of the electrodes in such a way that the catalyst - for example, platinum - is in a finely dispersed form on a suitable support, such as, for example, high-grade carbon. surface development. Figure 20 schematically shows an electrode configuration of a fuel cell, highlighting the interphase that occurs between the electrolytic component and the electrode ones (diffusion layer of the reagent gases and electrocatalyst material). It can be seen how the catalyst (e.g., Pt), reduced to nanometric dimensions, can be effectively dispersed on the carbon substrate. With this morphological device, the precious metal load can be reduced to very low levels, i.e. a few milligrams per surface unit, typically of the order of 0.5 mg/cm^2, with significant cost savings for the entire electrode structure.

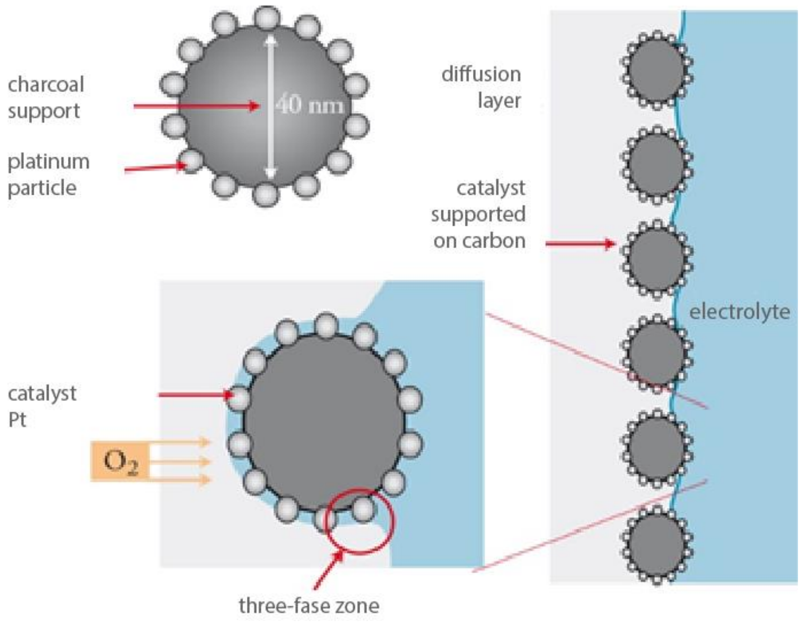


Figure 21. Electrode configuration of a fuel cell.

Furthermore, as the different types of fuel cells operate in a wide temperature range, ranging from 100 ° C up to 1000 ° C, the choice of catalyst can vary, ranging from platinum for low temperature regimes to less expensive compounds. of nickel for high temperature cells. Extremely important, for the proper functioning of a fuel cell, is the prevention of electrode contamination with impurities that could poison the catalyst. This aspect is particularly felt in cells fed by gaseous streams obtained from cracking or reforming processes of chemical compounds, such as alcohol or methane, which provide mixtures containing, in addition to hydrogen, also other gaseous components. Among the harmful substances we must mention the sulfur compounds and, above all, the carbon monoxide which, if present even in traces, can poison the catalyst, rendering its surface sites inactive. Since the strength of the Pt-CO bond is greater than that of the Pt-H bond, carbon monoxide is able to bond tenaciously to platinum, preventing the adsorption of hydrogen and thus leading to the rapid degradation of cell performance. The actual operation of a fuel cell requires the creation of an electrode assembly capable of catalyzing the oxidation and / or reduction process of the gaseous reactants, while ensuring the transport of electrons in the external circuit and of ions through the electrolyte. To take this requirement into account, it is necessary to appropriately design the electrode, so as to ensure the transport of the gaseous reagents in the area where the electrode processes take place, simultaneously favoring the release of the products. The design of this 'three-phase' zone is one of the critical aspects in the operation of a fuel cell, since the gas must come into contact (a) with the solid substrate, to ensure contact with the dispersed catalyst on its surface in so as to favor the development of the electrode reactions and the simultaneous transport of electrons in the external circuit; (b) with the electrolyte, to ensure the transport of ions through the cell. In this regard, the development of porous structures, made of coal or metal (commonly called gas diffusion layers), modeled with a network of channels such as to ensure the efficient distribution of the gas throughout the electrode, was of fundamental importance. and at the same time favor the contact between the components of the three phases. Porous carbon substrates are made using certain plastic additives such as polytetrafluoroethylene, PTFE as binding agents. The external contact is ensured by current collectors consisting of thin metal wires incorporated in the electrode mass. The metal electrodes with a porous structure are prepared by sintering the relative powders. There are two cell configurations: monopolar and bipolar. The monopolar is chosen for the manufacture of modules (stacks) designed to guarantee high currents. In this case, the individual electrodes are connected to each other, along their sides, through the tips (tab) that ensure external contacts. Since an efficient collection of current requires a high electronic conductivity along the entire electrode, porous metal electrodes are preferably used for this configuration. The bipolar configuration is chosen for the development of high potential modules. The electrodes of the individual cells are connected in series; the connection concerns, in fact, the entire surface of a cathode and that of the anode of the next cell. In this case the most suitable materials are those based on porous carbon which, although less conductive, ensure that the current passing through the electrodes can be collected along their entire surface. There are various types of fuel cells, which differ in the operating temperature and the type of electrolyte used. A convenient and commonly accepted classification is based on the nature of the chosen electrolyte. Therefore, six types of fuel cells can be distinguished: (a) Alkaline Fuel Cell or (AFC); (b) Phosphoric Acid Fuel Cell (PAFC); (c) Polymer Electrolyte Membrane Fuel

Cell (PEMFC); (d) Direct Methanol Conversion Cell (DMFC); (e) Molten Carbonate Cell (MCFC); (f) Solid Oxide Fuel Cell (SOFC) (Table 5).

Table 5. Types of fuel cells.

Cell type	Electrolyte	Anodic process	Cathodic process	T °C
alkaline AFC	solution 35-50% KOH	$H_2+2OH \rightarrow 2H_2O+2e^-$	$H_2+2OH \rightarrow 2H_2O+2e^-$	80-100
phosphoric acid PAFC	H_3PO_4 concentrated	$H_2 \rightarrow 2H^++2e$	$^{1/2}O_2+H_2O+2e^- \rightarrow 2OH^-$	200
polymer electrolyte PEMFC	perfluorosulfonic membrane	$H_2 \rightarrow 2H^++2e$	$^{1/2}O_2+2H^++2e^- \rightarrow H_2O$	60-90
direct methanol DMFC	perfluorosulfonic membrane	$CH_3OH+H_2O \rightarrow CO_2+6H^++6e^-$	$^{1/2}O_2+2H^++2e^- \rightarrow H_2O$	80
molten carbonates MCFC	melted mixture $Li_2CO_3Na_2CO_3$	$H_2+CO_3^{2-} \rightarrow H_2O+CO_2+2e^-$	$^{1/2}O_2+CO_2+2e^- \rightarrow CO_3^{2-}$	650
solid oxide	Yttria-stabilized zirconia	$H_2+O^2 \rightarrow H_2O+2e^-$	$^{1/2}O_2+2e^- \rightarrow O^{2-}$	1000

2.3. Hydrogen production and environmental impact

In recent years, hydrogen electrolysis has encountered considerable interest as a potential use option to facilitate the large-scale integration (i.e. the megawatt scale) of intermittent renewable energies. In fact, hydrogen offers a number of advantages as a clean carrier of energy, with numerous applications [50]. It is one of the few potentially emission-free energy sources, but it does not exist in nature and the process by which it is produced must always be considered; based on this it is classified into gray, blue or green hydrogen depending on the production method [51]:

- Gray hydrogen produces atmospheric emissions of carbon dioxide (substantially equal to those of the combustion of natural gas), as it is obtained from fossil fuels through a process of Steam Methane Reforming (SMR) or Autothermal Reforming (ATR) of natural gas, or by means of a hydrocarbon reformation technique (often methane) which involves steam and/or oxygen. Most of the current hydrogen production takes place via steam methane reforming, as it is the most convenient both from the economic point of view of the plant and of control of the chemical reaction. In both cases, a mixture of hydrogen and carbon monoxide (syngas) is produced during the chemical reaction, which then requires the removal of carbon monoxide via the water-gas displacement reaction to produce additional hydrogen and carbon dioxide:

$$CO + H_2O \rightarrow CO_2 + H_2 \qquad (13)$$

SMR

The reforming reaction takes place in two stages:

- Primary reforming

$$CH_4 + H_2O \rightarrow CO + 3\ H_2 \qquad (14)$$

Contains residual methane (CH_4), carbon monoxide (CON), water (H_2O) and hydrogen (H_2);

- Secondary reforming, in which a post-combustion with air is carried out from the gas mixture obtained from (1) from which a higher concentration of CO and H_2 and a lower concentration of residual CH_4 are obtained. The reactions involved are:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O \qquad (15)$$

$$2H_2 + O_2 \rightarrow 2H_2O \qquad (16)$$

$$CH_4 + H_2O \rightarrow CO + 3H_2 \qquad (17)$$

$$CH_4 + CO_2 \rightarrow 2CO + 2H_2 \qquad (18)$$

Primary SMR is an endothermic process that first requires the removal of traces of sulfur compounds from natural gas to avoid catalyst poisoning, then substantial heat input (at temperatures up to 700 ° C) and water in the form of superheated steam . In the second phase, on the other hand, pure oxygen is not used, but air because the reaction is exothermic and too high temperatures would be reached in the presence of pure oxygen.

ATR

The starting reagent is natural gas which is placed in a reactor where it undergoes both partial oxidation with oxygen and a reforming reaction with steam. This occurs at a higher temperature than SMR (up to 1150 ° C). Compared to SMR, ATR is more efficient because the heat obtained in the exothermic oxidation phase is reused by the reformation reaction, but on the other hand requires more oxygen in the initial phase.

$$4CH_4 + O_2 + 2H_2O \rightarrow 10H_2 + 4CO \qquad (19)$$

A mixture of natural gas and steam is partially converted by pressurized combustion under conditions of excess fuel, after the conversion of the hydrocarbons into balanced synthesis gas it is completed in a fixed bed catalytic reactor. The complex of chemical reactions that take place in the ATR reactor is described in the following equations:

Combustion $CH_4+3/2O2 \rightarrow CO+2H_2O$
$-\Delta H°_{298}=519$ kJ/mol

Reforming $CH_4+H_2O \rightarrow CO+3H_2$
$-\Delta H°_{298}=-206$ kJ/mol

Shift $CO+H_2O \rightarrow CO_2+H_2$
$-\Delta H°_{298}=41$ kJ/mol

From the previous equations, it is noted that the primary input source for the production of hydrogen, in both cases, is the incoming water and not fossil fuels [52]. These techniques produce a hydrogen-rich gas mixture that contains hydrocarbons, CO, CO_2, nitrogen and various other traces of contaminants. Therefore it turns out that the purity of gray hydrogen is 87% (coal gasification), 93% (ATR) and 94% (SMR). Previous studies [53] 98% hydrogen purity is required through the pipeline network to end users. So it is clear how hydrogen produced from a carbon capture (CC) ATR or SMR and no further purification would not meet this standard, due to CO and higher methane, carbon dioxide and total hydrocarbon content. However, with pressure swing adsorption purification, which is currently standard industry practice, this standard can be met.

- If during the process for the production of gray hydrogen carbon dioxide, instead of being released into the atmosphere, is captured and injected stably (for example in the same reservoir from which methane is extracted) then we speak of blue hydrogen. Blue hydrogen is characterized by upstream methane emissions and an imperfect downstream CO_2 capture process. In this case the associated carbon dioxide emissions are very low or zero, depending on the percentage of CO_2 coming from the steam reforming process that is captured and stored. Given that the production of gray, green or blue hydrogen from natural gas also causes "fugitive" emissions, ie losses of methane upstream of the production process that cause further emissions, this should also be considered and is currently underestimated. So to level the greenhouse gas emissions produced by blue hydrogen, it is essential to capture the "negative emissions", but this entails an increase in the price;

- Finally, green hydrogen (ie the one with the least greenhouse gas emissions ever) is obtained from water, feeding the electrolysis plants with renewable energy. Therefore green hydrogen is completely decarbonized (for its production no carbon dioxide is released into the atmosphere), while blue is 90%. In electrolysis (single-phase low-temperature process) there are two inputs, namely electricity and water, and two outputs which are high purity hydrogen and oxygen. Proton Exchange Membrane Electrolysers (PEMs) are used which offer decidedly rapid response times. The electrolysis reaction of water can be written as:

$$2H_2O \rightarrow 2H_2 + O_2 \qquad (20)$$

Hydrogen with a purity greater than 99% is thus obtained. When the electrolyzer is powered by renewable energy, it is referred to as renewable hydrogen (green hydrogen). Furthermore, the production of hydrogen could be of two types: 1) on-site, or directly at the hydrogen refueling station (HRS); 2) at the centralized plants, with subsequent transport to the hydrogen refueling station (HRS). At the moment it is difficult to say which of these two is the most advantageous because they both have advantages and disadvantages. If on the one hand, in fact, on-site production reduces transport costs related to distribution and CO_2 emissions related to it, this minimizes economies of scale, making the cost of selling hydrogen higher; exactly the opposite of centralized production.

Role of hydrogen in the energy transition

In an energy system based on RES, hydrogen plays a fundamental role as it is suitable for large-scale storage of electricity; in this case the excess electricity can be transformed into hydrogen which then finds different applications of use. In this case we have different hydrogen technologies which are:

- Power-to-hydrogen: electricity is used in the electrolysis process to divide water from hydrogen. This can be stored and transported in a liquid or gaseous state and can be burned or used in fuel cells to generate heat and electricity. Therefore, hydrogen could play a key role in the seasonal storage of renewable electricity; Added to this is the potential for the decarbonization of other sectors such as the automotive or industrial sectors. Power-to-gas: is the process of converting renewable energy into gaseous energy carriers such as hydrogen or methane. Power-to-gas also uses electrolysis to generate hydrogen from renewables, which is then reacted with carbon dioxide in the presence of bio-catalysts to produce methane. This is then blended into the natural gas network or transformed into synthetic natural gas. Power to feedstock: electricity is transformed into hydrogen which is then used directly as raw material, for example in the refining industry or in the chemical industry.

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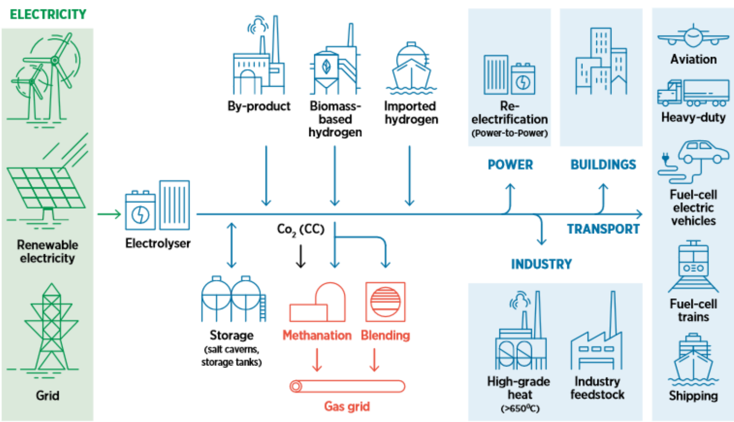


Figure 22. Integration of Variable renewable energy (VRE) into end-uses by means of hydrogen (source IRENA, 2018).

Considering the future forecasts collected in a study conducted by the Italian research center ENEA (Table 6) [54], it appears clear as from 2030 electrical storage will assume more and more importance and from 2030 onwards it will become indispensable. In fact, this study analyzes the relationship between unpredictable RES capacity and electricity consumption in the minimum condition, i.e. at noon on the day of the year with minimum load.

Table 6. Hypothesized scenario of the evolution of electricity consumption and RES production (data source: ENEA).

Energy	2012	2020	2030	2050
Consumption of electricity (TWh/year)	328	367	415	420
Share of renewable (%)	28.4	35.4	52	85
Electricity from predictable renewable sources (TWh)	60.7	79.1	91.5	117
Electricity from unpredictable renewable sources (TWh)	32.3	50.9	124.5	240
Ratio unpredictable production/consumption (%)	9.85	13.86	30.0	57.14
Wind power (GW)	8	12.1	20	25
PV power (GW)	16.6	23.7	70.2	152.3
Maximum ratio unpredictable renewable sources	0.77	0.92	2.12	3.93

In this, hydrogen will certainly play a role of fundamental importance, as its production from water electrolysis is a promising way to compensate for fluctuations in RES, managing to manage variable loads. Its characteristic, as we have seen, is the ability to act at the same time as a source of clean energy (which can have various end uses) and as an energy carrier for storage. In fact, hydrogen can be transported through existing gas pipelines, mixed with natural gas and in future in dedicated pipelines, and can offer a solution for storing energy at a cost ten times lower than batteries (about 20 dollars per megawatt / hour against $ 200 / MWh).
The European Union is betting a lot on hydrogen. For example, in the guide drawn up by the international energy agency, to overcome the crisis of the lack of Russian gas supplies, due to the invasion of Ukraine, in the ten-point plan, the use of efficient electrolysers is already present in point 2, here reported:

2. *Replace Russian supplies with gas from alternative sources*

"Complementing the point above, our analysis indicates that production inside the EU and non-Russian pipeline imports (including from Azerbaijan and Norway) could increase over the next year by up to 10 bcm from 2021. This is based on the assumptions of a higher utilization of import capacity, a less heavy summer maintenance schedule, and production quotas/caps being revised upwards. There is limited potential to scale up biogas and biomethane supply in the short term because of the lead times for new projects. But this promising low-carbon sector offers important medium-term upside for the EU's domestic gas output. The same consideration applies to production of low-carbon hydrogen via electrolysis, which is contingent on new electrolyser projects and new low-carbon generation coming online. Increased output of low-carbon gases is vital to meet the EU's 2030 and 2050 emissions reduction targets"[55].

III

SIMULATION OF THE ADOPTION OF FUEL CELL VEHICLES: THE ITALIAN CASE

3.1 Introduction

In the last twenty years, there was great attention to the problem of climate change and to the decrease of greenhouse gas emissions in the atmosphere. Most of the carbon dioxide, CO_2, emissions in the environment are due to road transportation consuming fossil fuels [56]. The carbon dioxide emissions from road transportation have increased considerably and in 2013 they were even 50% higher than in 1990 [57].

In 2016, global CO_2 emissions due to fuel combustion were about 32 Gt CO_2, substantially similar to 2015 levels. These data show that emissions have more than doubled since the beginning of the 1970s and have increased by around 40% since 2000. Most of these increases are relative to the growth in economic production. Although emissions are relatively stable between 2013 and 2016, the initial International Energy Agency (IEA) investigation exposed that in 2017 emissions increased by about 1.5%, directed by the growing demand of China and India and the European Union [58].

Total energy consumption in 2018 increased by almost double compared to 2010 and CO_2 emissions grew by 1.7% within a year, reaching a new negative record (33 Gt) [59]. According to the study, the demand for all types of fuels has grown, driven by natural gas, which has been the fuel of "first choice"; its demand has in fact increased by almost 45% compared to the total energy market. Fossil fuels follow, with a growth of about 70% for the second consecutive year. The fact is that the final balance sheet is worrying, because due to the higher energy consumption, the IEA warns CO_2 emissions are increasing. The energy production of coal-fired power plants continues to be the main cause of the deterioration, given that it represents 30% of all CO_2, emissions related to energy (10 Gt). In Asian region China and India are the main producers of CO_2 emissions and together with the United States they account for 85% of the net intensification in emissions, while pollution levels in Germany, Japan, Mexico, France and the United Kingdom are decreasing. Overall, the global average annual CO_2 concentration in the atmosphere was more than 400ppm in 2018, up 2.4 ppm from 2017. This is a significant increase over pre-industrial levels, which ranged from 180 to 280 ppm. Despite the growth in coal consumption, the IEA notes, however, that the transition to gas was accelerated in 2018, avoiding the use of nearly 60 million tons of coal and the dispersion in the air of 95 million tons of CO_2. Without this result, the increase in emissions would have been over 15% higher.

A change of course is needed, but different sociopolitical aspects prevent the development and spread in the communities of sustainable vehicles [60-62]. In technical literature different papers deal with the acceptation of new technology cars also using complex correlative algorithms to face “the egg and hen problem” [63], considering incentives for the purchase, the total cost of ownership of electric vehicles, and highlighting the advantages of road use offered by the various municipalities [64] and also, since a car is a prestige good, of neighbors’ opinions [65]. The authors believe that a possible way to solve problems related to the environment could be the use of hydrogen-powered cars, whose charging methods are similar to those of traditional cars, but which require huge investments, especially for charging stations, which should be accurately planned in position and time [66-69]. So, this paper, after having discussed the situation of the electrification of transport and the perception that the population has in different Countries and especially in Italy, investigates which communities are more ready to accept a complex technology such that of fuel cells.

3.2 Current scenario

The mobility agenda in Europe [70] supports the transition to low-emission and zero-emission vehicles with targets to be achieved by 2025. In 2025, in fact, the average CO_2 emissions of new heavy vehicles will have to be 15% lower than the 2019 level and, for 2030 an indicative reduction target of at least 30% is proposed in comparison with 2019.

In the communication "Europe on the move - an agenda for a socially just transition towards clean, competitive and interconnected mobility for all", the Commission presented several legislative initiatives concerning transport on the road. Mobility is the main economic sector in the world, and in Europe there is a continuous growth of transportation activities, so that between 2010 and 2050 passenger transport should increase by about 42%, while freight transport by 60%. It is widely recognized that electric and automated vehicles will be an important part of achieving the goals set in these documents.

Previous studies [71] show that the use of EVs compared to petrol-driven vehicles can save (around 60%) greenhouse gas emissions throughout or in most EU Member States, related to the assessed consumption of EVs. Compared to diesel instead, electric vehicles show an average greenhouse gas savings of about 50% in some EU member states [72].

Even though EVs are not entirely free of environmental influence, due to greenhouse gas (GHG) emissions both during the production process and its end of life, studies on the impact and life cycle of EVs have suggested that these may have greenhouse gas emissions overall lower than conventional internal combustion (ICE) vehicles [73]. However, the process towards the adoption of EVs is still long. Even in the Countries where the embracing of EVs by the users is remarkable, these cannot presently be considered a true opponent of traditional automobiles and buses with internal combustion engines because their diffusion is still marginal. One of the biggest obstacles to the expansion of electric cars is the reloading anxiety of users, as the infrastructure of charging stations is not yet sufficiently widespread and the autonomy of cars is limited. The development of a recharging network is therefore one of the keys to allow the spread of EVs [74]. From 2005 to today, the use of an electric motor for the mobility has exceeded its own first detachment friction, surpassing a critical line, by benefiting from various developments (technical and not) whose influence is growing increasingly importance: high oil prices, carbon constraints and an increase in organized car sharing and integration with other mobility forms, as micro-mobility. The progress of full electric vehicle and hybrid technology is subjected to changes in refueling infrastructure, variations in mobility, vicissitudes in the global automotive market, variations in energy prices, climate policy and improvements in the electricity sector. Particular care is devoted to the collaboration of technical alternatives, such as full electric vehicles, hybrid ones and hydrogen fuel cells vehicles [75]. The EVs sector is constantly growing in almost all parts of the world and the current situation is characterized by several disconnected projects in many countries. An attempt is made to assess the tendency of direct current charging systems to verify the feasibility of a transnational corridor infrastructure that guarantees accessibility to all automobiles. A predictive algorithm for the study of the trend for the electric vehicle was implemented to comprehend the market and infrastructure growth in the coming (Figure 23) [76].

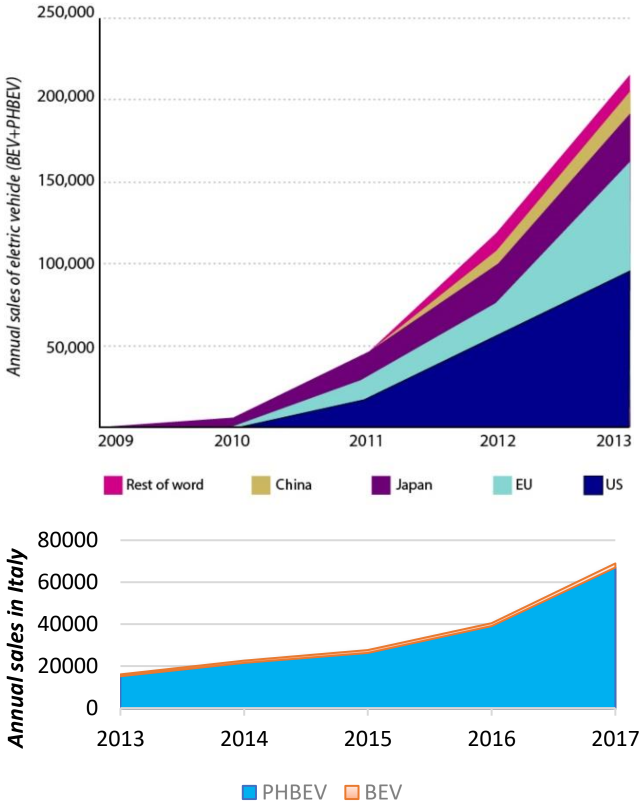


Figure 23. EVs sales growth from 2009 to 2013 - figure reproduced from [76] and focus on Italian sales.

Furthermore, in the near future other obstacles to the implementation of EVs will have to be overcome, such as the standardization of charging and refueling stations. This, with attention to connector types and adopted charging methods, must be addressed immediately. Between the several and diverse standards, guidelines and rules, there are two dual categories of charging method for electric vehicles (Figure 24): high-power direct current DC and alternating current AC charging mode.

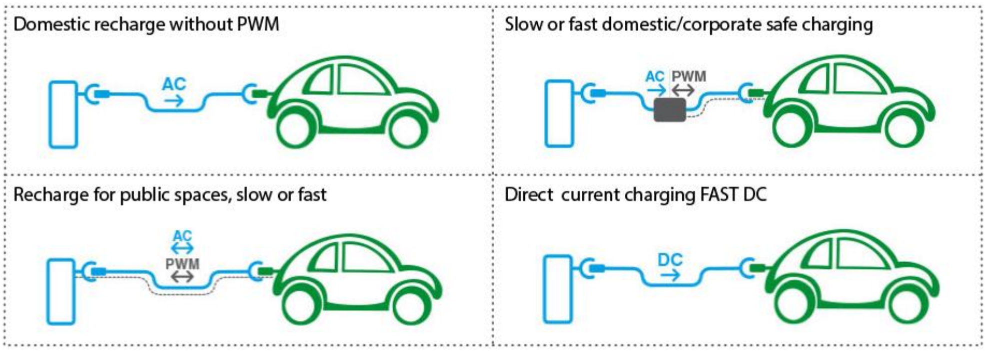


Figure 24. Different ways of electric vehicle charging methods.

Currently the European standard IEC 62196 [77] considers four charging modes based on the speed of charge (slow or fast), the protection systems and the types of connectors. As for the fast-charging DC stations, the Tokyo Electric Power Company (TEPCO) in Japan has developed the quick-charge DC connector, also called CHAdeMO. In 2014, Japan and Europe had the most widespread CHAdeMO charging installations in the world, with 2129 and 1372 rapid loaders each, respectively.

3.2.1 Vehicle to grid paradigm

In addition to studies on the progress and convenience of plug-in hybrid vehicles (PHEV) and batteries (BEV) ones, attention must also be paid to the growing relation and interaction between the developing Smart Grid and the electric vehicles, seen as a resource of energy (Figure 24). Currently, many car manufacturers have invested significant resources in the development and production of new electric vehicle models; however, the development of an efficient recharging network, as the presence in city of different charging columns, but also in the link connections between different cities, is one of the keys to allow the spread of this new way of vehicles. In different Countries a question is arising, could the actual electric grid support the EVs revolution? The vehicle to grid paradigm (V2G) should be a solution.

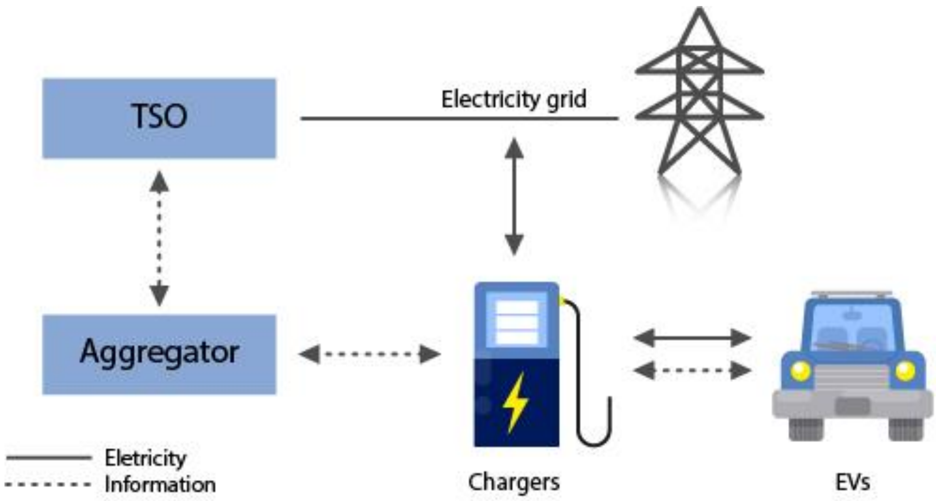


Figure 24. Basic scheme of V2G.

In the energy area, two significant progresses will concern electric mobility, the development of renewable energy technologies (but especially their acceptance by the consumer) and the emergence of smart grid systems, for which the energy flow is bilateral. The irregular availability of most renewable energies requires the storage of electricity, usually made with dedicated batteries. With the assistance of advanced smartgrid-based electricity management systems, batteries can be employed in the storage of electric energy and aid as “rotating energy reserve”, when the peaks of demand occur if the BEVs are inactive. For electric energy providers, electrification of vehicles offers a way to solve peak demand, by offering a support to the stability of the local network, without having to intervene distant production plants, so reducing the weight on the network structure during peak hours [78]. In addition to generating demand and sales, batteries in EV should support utilities in decrease inadequacies and system variations built into today's network. For electric utilities, a synergistic connection among smartgrids and battery vehicles and renewable energy sources is clear. Besides, when BEV are progressively joined into smartgrids, great amounts of data and information will be available to those involved in infrastructure and communication systems, the whole sector of energy will be included. New chances and opportunities for companies operating in the automotive sector will rise, also influencing the competitive places, market shares, business models and strategies of current car manufacturers, the next electric and connected cars can be built by large corporations of the information technology.

The protocol vehicle to grid, V2G, realized together with the other protocols to have a connected car (vehicle to vehicle V2V, vehicle to everything V2X) enables not the spreading of information to improve travel times but the bidirectional flux of energy. This is one of the smarter technologies that allows the feeding of energy to the grid, due to the capability to simplify two-way communication between EV and the electricity grid to spread and obtain energy when the EVs are connected to the network (Figure 25).

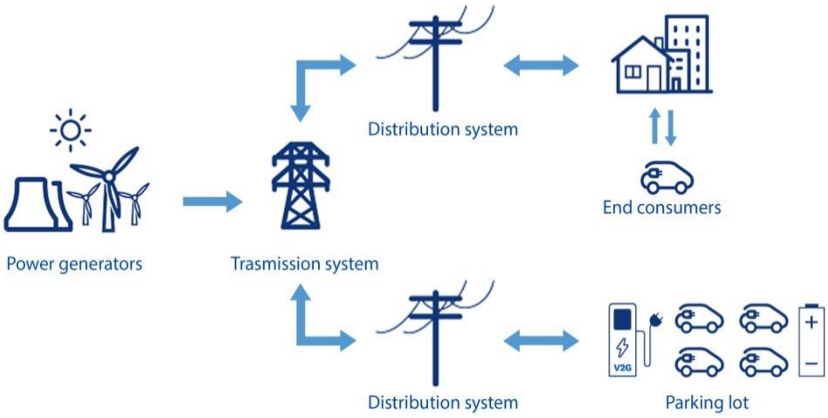


Figure 25. Schematic of the vehicle-to-grid (V2G) concept, it is noted the bidirectionality introduced in the smartgrid.

The enormous number of electric vehicles should be used in different possibilities of auxiliary services, for example frequency balance, voltage regulation, load leveling (downstream filing), peak load leveling, lines congestion mitigation and energy storing [79]. Since the charger is bidirectionally connected to the network, the charger receives (EV charging mode) and supplies (EV discharge mode) electric energy to and from the net, respectively. In fact, not only can the two-way charger participate in V2G, the unidirectional loader is also capable of running the V2G service, which is absorbing electric energy from the network [80]. As a matter of fact, the growing market share of EVs displays a global fear for climate changes. Numerous policies were introduced by the administration to promote the growth and implementation of electric vehicles, such as conventional ICE car purchase limitations in big cities and subsidies for domestic electric vehicles and plug-in hybrid electric vehicles. However, the stress on the electricity net becomes a problematic issue when there is a high diffusion of the EVs recharging request. In a study conducted in Indonesia [81], the feasibility of V2G in the national electricity grid is evaluated (Figure 26). In the Indonesian case, as the network's current capacity to regulate supply and demand is very restricted, the huge EV charge further aggravates the condition due to the lack of energy storage. The auxiliary services of electric vehicles have led to the idea of using electric vehicles to support the network, in particular with the increase in the number of electric vehicles. Load leveling and frequency re-balance have been carefully observed. This study also analyzes the impacts of the adoption of electric vehicles and V2G contribution rates, which are driven by a certain incentive from the transmission service operator (TSO). The outcomes show that the energy received and released by electric vehicles after their recharge and discharge is feasible to provide the Indonesian network if electric vehicles are correctly controlled.

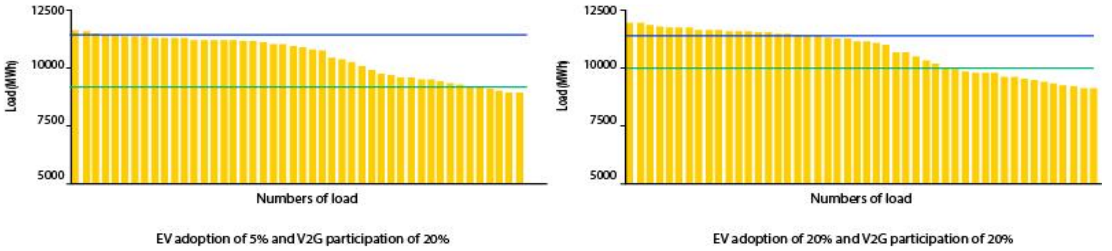


Figure 26. The load levelling amount under different EV acceptance and V2G participation, a quality windows in feeding the grid is given by the two lines, - data from Huda et al., 2019 [81].

It is also known that Renewable Energy Resources (RES) are promising solutions for energy issues and EVs and V2G are the appropriate support systems for RES, to overcome the problem of their intermittent nature [82]. Along with advances in V2G technology, the implementation of electric vehicle charging stations on electricity distribution nets is facing new challenges (Figure 27). As already underlined, the recharging infrastructures with V2G capacity should be columns in the energy management of the network and offer positive effects on the stability of the same net.

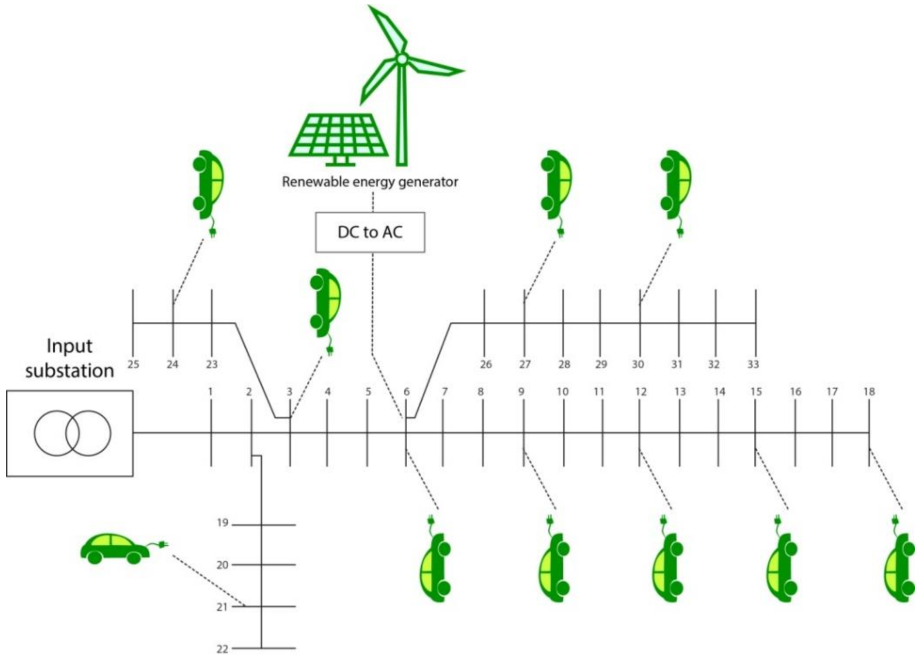


Figure 27. IEEE 33-bus network connecting charging stations and renewable energy system.

Vehicle to grid should be used correctly in a domestic energy managing system as a storage element to decrease energy costs [83]. It is also a promising answer to support the diffusion of renewable energy generation; in particular, it could regulate the intermittent service of RES [84]. The key contribution of V2G is to reduce peak demand and provide peak demand through the discharge of electric vehicles (Figure 28). This procedure provides positive technical, environmental and economic impacts on EVs. Electric vehicles can be considered as local energy reserves, thus not using very distant "rotating" sources, therefore subject to transport losses. Both for shaving the peak and for filling the valley at the same time V2G would be applied [85]. Therefore, it can support the network from different points of view, such as load shifting and congestion managing. Following common strategies, electric vehicles charge the surplus of RES during off-peak periods and send this energy to the grid when renewable energy decreases. It could be effectively treated with V2G technology. As a negative problem, battery degradation, and its perception by users, is one of the problems related to the participation in V2G program and the cost of battery degradation limits undoubtedly the economic advantages, if providers do not support and incentive the participation in the program. Battery degradation is associated with energy emission and is highly sensitive to discharge depth. To make the operation of a battery storage system for V2G systems economically feasible, it is necessary to design an efficient power electronics converter that must be supported by an adequate control strategy [86]. The appropriate solution to reduce the cost of battery degradation can be intelligent charging [87].

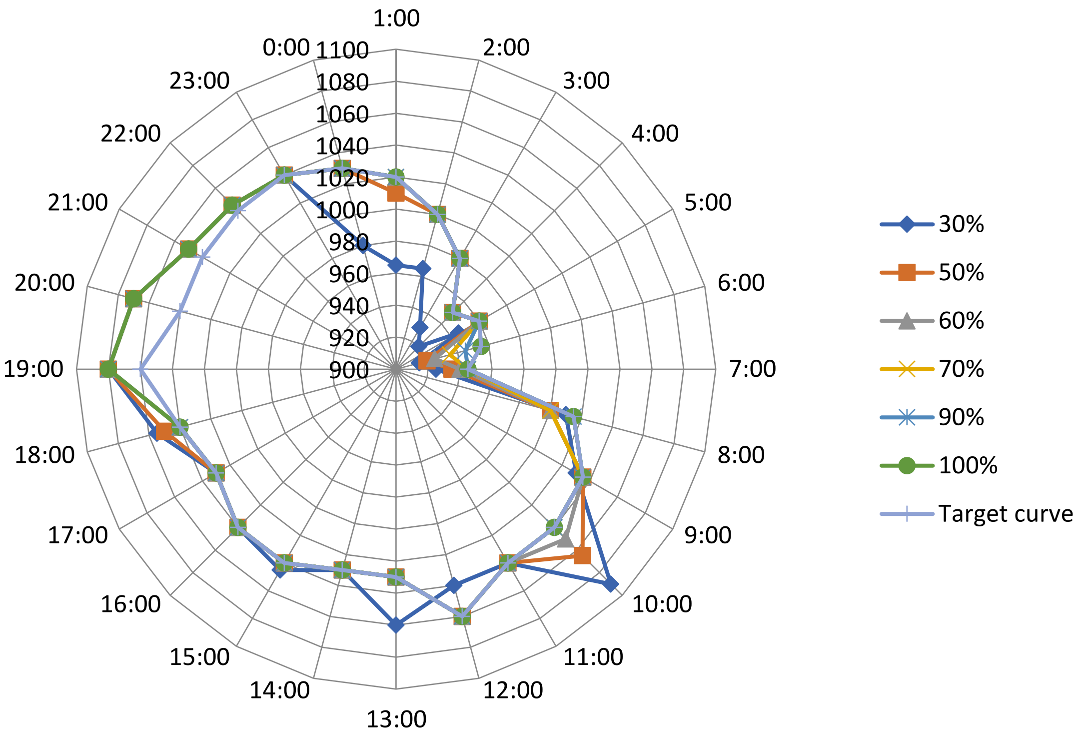


Figure 28. Amount of connected electric vehicles on peak shaving and valley filling, data from Wang and Wang, 2013 [87].

Socio-political aspects and care to the environment

Other aspects to be taken into consideration in the process of transition to sustainable mobility are those related to the sociopolitical context, since the national contextual factors can favor certain emerging technologies. The commitment and public support for the definition of new development paths play a crucial role in the transition to sustainable transport technologies. Socio-technological schemes consist of formations of social and technological elements. Geels [88] has shown that technical and social transitions are the result of co-evolution among various actors and clusters of actors, for example organizations, legislative bodies, economic corporation, natural resources and physical artifacts such transportation structures. Previous research demonstrates how local policy instruments such as subsidies for the purchase, regulation of the use of public car parks and the encouragement of public procurement contribute to the development of this system [89].

A study carried out in several European cities shows how the rate of adoption of electric vehicles is influenced by numerous factors, both locally and nationally. This study presents a qualitative comparative analysis (QCA) of incentive e-mobility policies and supports in 15 European cities in order to identify political configurations at urban and local level that lead to favorable results in the promotion of the consequent adoption of electric vehicles [90]. It emerges how particular configurations are sufficient for favorable results to occur, such as the total cost of ownership of electric vehicles in combination with encouraging the installation of domestic battery chargers or recharging points on private parking lots in addition to the creation of a public recharging network in combination with other factors that discourage the use of conventional cars. The results of this study, even if mostly empirical, confirm that the adoption of successful electric vehicles is connected to a systemic political approach that encourages electric vehicles by simultaneously discouraging conventional cars, using both fiscal and specific local policy measures. This means that isolated measures are unlikely to work. This analysis has similarities with other recent results. For example, Wang et al. [91] employed correlation analysis approach and multiple linear regression analysis in order to discover the relationship between incentive policies and other socioeconomic factors with the adoption of electric vehicles in 30 countries considering the year 2015. Such study states that the positive and statistically significant factors are the practicability of the road (access to bus lanes), the density of tariffs (the number of battery chargers correct for the population), the price of fuel, while direct incentive and subsidies are not the only reason for the enormous difference in the absorption of electric vehicles among different countries. Comparable results have been found by Yong and Park [92]. The current results highlight that the social-technological transitions have complex nature and particularly they depend on the location. A starting point for the current study can be learned, within the same country, where the incentive policy is the same, different behaviors can be diversified in cities with the same number of inhabitants, but dissimilar infrastructure conditions.

Authors tend to prefer empirical studies, discrete choice models using stated preference data are frequently adopted in previous studies, conducted on consumer preferences, by considering a small group of items such the type of fuel vehicle, i.e. ICE, BEV, PHBEV. The study of forecasting models can lead to provide the right political implications for particular countries like Korea [93]. More detailed studies consider various attributes: price, range, acceleration, top speed, pollution, size, luggage space, operating cost, and charging station availability [94]. These parameters can differ enormously from country to country, due to objective aspects such as geography, climate and wealth, but also subjective as the goodness of the incentives applied, awareness campaign and driving styles. Again empirically-based choice models have been used in a study based on the impressions of different Canadian citizens [95], to learn the choice models in a community. The behavior is influenced by incentives and disincentives as carbon taxes, gasoline vehicle deterrents, and single occupancy vehicle discouragements. The analysis has shown different levels of technological change. The study of persuasive techniques on a socio-cultural environment is interesting. Other items, to predict the sale of EVs, were studied with the vector regression; the prediction of sales in automotive markets employs economic parameters: gross domestic product, consumer price index (CPI), interest rate, unemployment rate, and gas prices with automobile sales [96]. Authors in [97] after providing an interesting review on prediction markets in different countries, offer a discussion on short-term and long-term forecasting. Incentive policies are investigated, the subsidy-based and the tax-based policies. The former embraces purchase, charging as well as maintenance subsidies. The latter is demonstrated in tax on vehicle purchase, circulation and electricity cost. Authors show the effects of policy in the vehicle fleet in China.

Substantially the major impediments encountered by new vehicles users are restricted to two fields: one economic and other technical. With an economy of scale, the economic bottleneck can be reduced. The costs of EVs are constantly decreasing and also those of the charging stations. From a technical point of view, the most important parameters in catching EV customer preferences are the number of kilometers the vehicles can travel between recharging and the number of stations that have the capability to recharge the vehicles. Fuel cell vehicles should be the right solution of the problem.

3.2.2. Fuel cell: forecasts for the development of hydrogen technology for the reduction of air pollution

In this scenario of transition towards sustainable mobility linked to the use of electric vehicles, Fuel Cell EV (FCEV) technology is introduced, where the battery in the vehicle is recharged by hydrogen stored in a special tank. The advantage of this system is that it has zero emissions, since the only waste product is water vapor. However, pollution is not completely eliminated because of the way the hydrogen is produced. The latter does not exist naturally in its natural state and to produce it is necessary to consume more energy to produce it. Therefore, the overall environmental impact of hydrogen mobility depends on the energy source used to produce it. There are in fact several methods to produce of hydrogen: the methane reforming of natural gas vapor, the biomass gasification, electrolysis and hydrogen derivation from existing industrial plants. Production can be located on-site or in central production units [98].

The use of different technologies, such as fuel cells, aims to overcome the problems related to charging anxiety, since the FCEV have a greater autonomy and a shorter recharge time. Fuel cell vehicles are more appropriate for long-term units, since their autonomy is much longer than PHEV or BEV, but require special charging infrastructure. Their diffusion will depend critically on the costs of fossil fuel (oil), the progress of ICEV fuel effluents and the CO_2 regulations. The first hydrogen car with Full Cell System zero emission technology is the Toyota Mirai. This vehicle can travel a distance of 500 km (in 10 seconds it accelerates from 0 to 100 km / h) and the recharge time of the hydrogen tank is assessed in an interval of 3 - 5 minutes. In commercial catalogues, beyond the Mirai, Honda Clarity and Hyundai Tucson, are present with comparable presentations.

In Europe, Germany is the country that has so far invested the most in hydrogen cars and filling stations. The most served areas (disclosed by Fleet Europe) are those of Frankfurt, Stuttgart and Munich. The situation in Scandinavia is different, even though Denmark is a positive exception, with refueling stations for hydrogen cars located throughout the country. Sweden, on the other hand, is "hydrogen free", while France has no widely distributed stations (they are mainly in the north), as well as the UK, and the situation in Spain is similar to that of our country. In Italy there are only, for cars and buses, three functioning filling stations, among which the Centro Alto Adige of Bolzano stands out, which is the connection point between our country and the rest of Europe.

Forecasts indicate 2025 as the year in which Fuel-Cell and traditional electric will reach a substantial break-even [99]. In a study conducted by Harrison et al. an analysis of the European electro-mobility market was presented, with the aim of obtaining information on what could inhibit the success of market penetration of electric vehicles. The results of this study provided a forecast of the market diffusion of PHEV, BEV and FCEV. The authors hypothesize the evolution of BEV sales quotas between 2015 and 2050 in different scenarios. Based on the observations made, the BEV and the PHEV show a similar market penetration even if more successful for the PHEV until 2030, a period in which the technologies should become mature and the objectives have been achieved, leaving room for the less mature FCV. The latter shows a slightly quick sales growth between 2025 and 2045, which growths further from 2045 when the new targets will be visible to the manufacturer.

Focus on Italian air pollution and hydrogen stations

It is well known that e-mobility therefore is a significant technology that has a core purpose: decrease the direct emissions of exhaust pipes and improve the air quality in the metropolises. Different are the means employed in several Countries: some Asian States are fronting the fast diffusion of vehicles and are developing the construction own EVs, contemplating all the segments from micro-mobility such bicycle, electric scooters to heavy bus, but old European Countries face the problematic issue of the conversion from a traditional use of long range internal combustion engine, for which they hold the largest number of patents, to electric motor fresh technology, and this necessitates very high standards for EVs to be compared with actual long range mobility.

As specified in [100], in 2015, sellers in California introduced in their showrooms the first commercially available FCEV. Recharging stations, devoted to sustenance private clients in refilling, correspondingly arrived at the identical time, significantly circumventing the problematic of the "*chicken and the egg",* a philosophical dilemma establishing in this case a paradox without charging station no one buys an EV and without EVs no one constructs a recharge station. In Italy, the scenario is dissimilar from Californian one; until now few refilling infrastructures are dedicated to experimental FC bus and the participation of private users or customers is not active.

The use of reduced exhaust pipe emission vehicles and better battery vehicles can give high benefits and help for Italy since pollution of air surpasses the limit levels recommended by the World Health Organization (WHO) (particulate matter PM2.5 10 $\mu g/m^3$, PM10 20 $\mu g/m^3$) (Figure 29) [101].

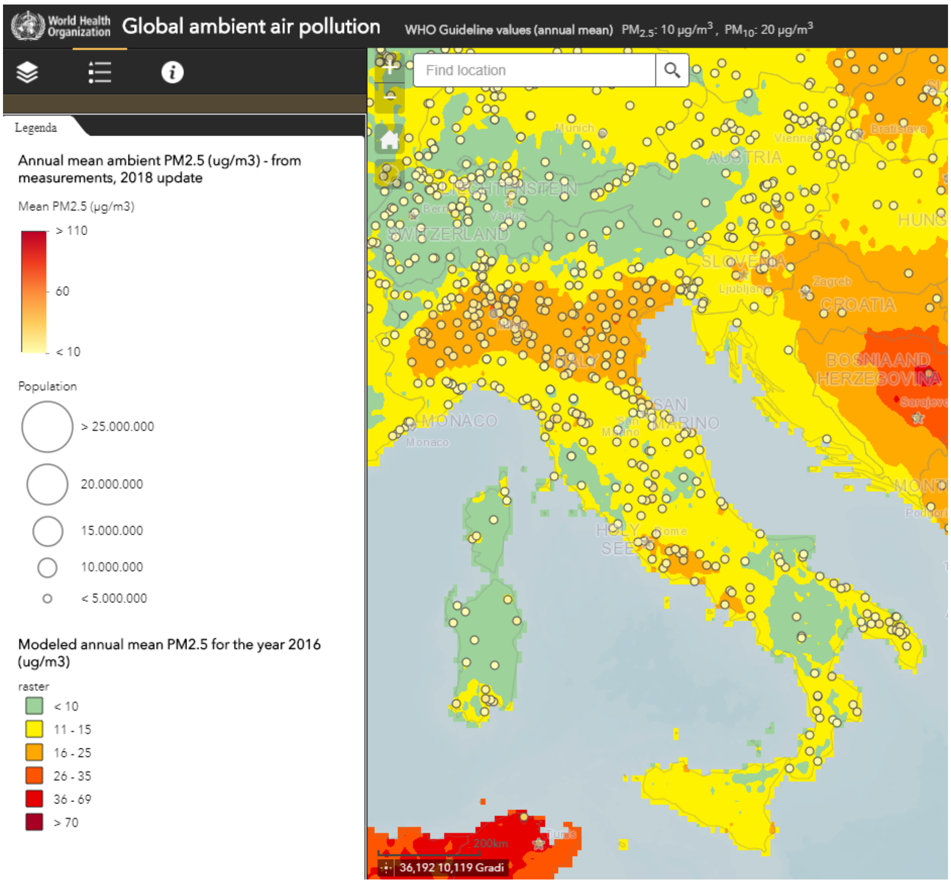
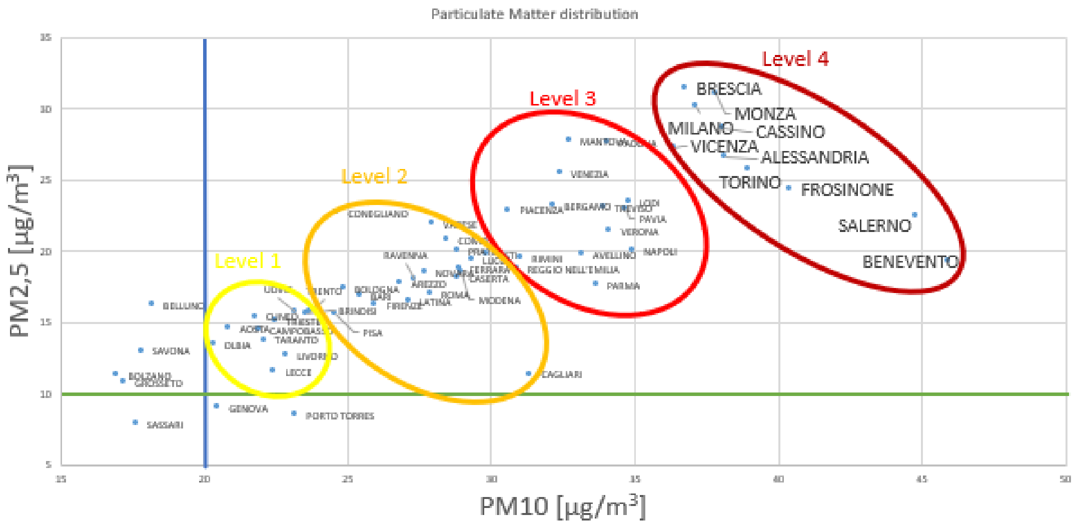


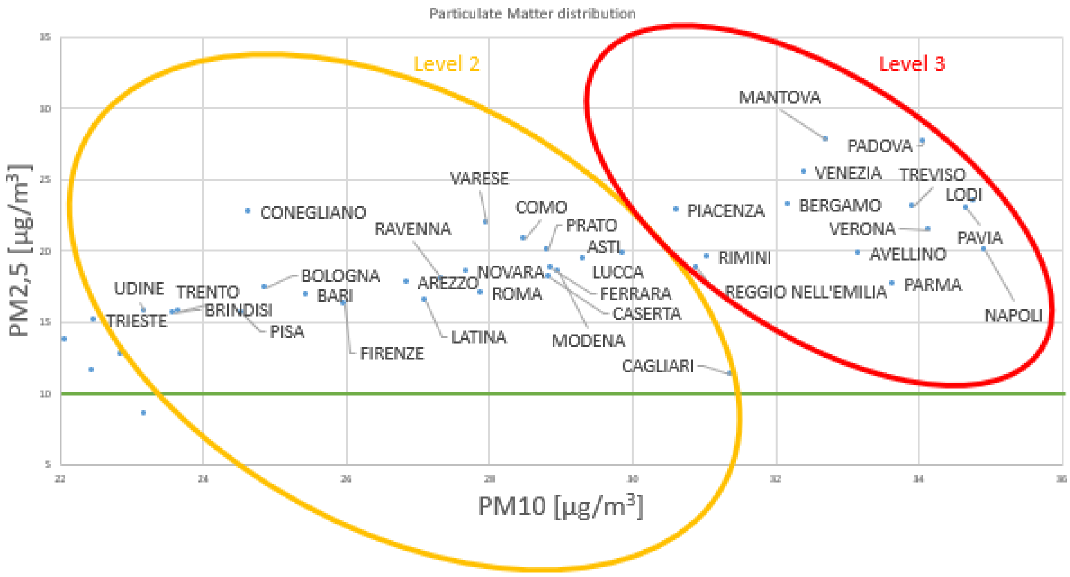
Figure 29. Chart of the PM2.5 distribution among Italy, green areas are under the limitations of 10 µg/m^3, yellow areas in the range of 11- 15 µg/m^3, orange areas are in the windows of 16-25 µg/m^3. Air pollution maps are present at http://maps.who.int/airpollution.

By taking into account an additional exhaustive database of WHO for the year of 2016 [102], Figure 30 refers the limits of PM2.5 and PM10 for different Italian Cities. Different cities overcome the limits suggested by WHO, a possible clustering in the exceeding the levels, takes four set levels, so recognizing cities on which an urgent action is required to improve air quality.

(a)


Particulate Matter distribution
PM2,5 [µg/m³]
PM10 [µg/m³]
Level 1
Level 2
Level 3
Level 4
BRESCIA
MONZA
MILANO
CASSINO
VICENZA
ALESSANDRIA
TORINO
FROSINONE
SALERNO
BENEVENTO

(b)


Particulate Matter distribution
PM2,5 [µg/m³]
PM10 [µg/m³]
Level 2
Level 3
MANTOVA
PADOVA
VENEZIA
TREVISO
VARESE
LODI
PIACENZA
BERGAMO
CONEGLIANO
COMO
RAVENNA
PRATO
VERONA
PAVIA
ASTI
RIMINI
AVELLINO
LUCCA
NOVARA
BOLOGNA
UDINE
AREZZO
PARMA
REGGIO NELL'EMILIA
FERRARA
TRENTO
BARI
ROMA
CASERTA
BRINDISI
NAPOLI
TRIESTE
PISA
LATINA
MODENA
FIRENZE
CAGLIARI

(c)

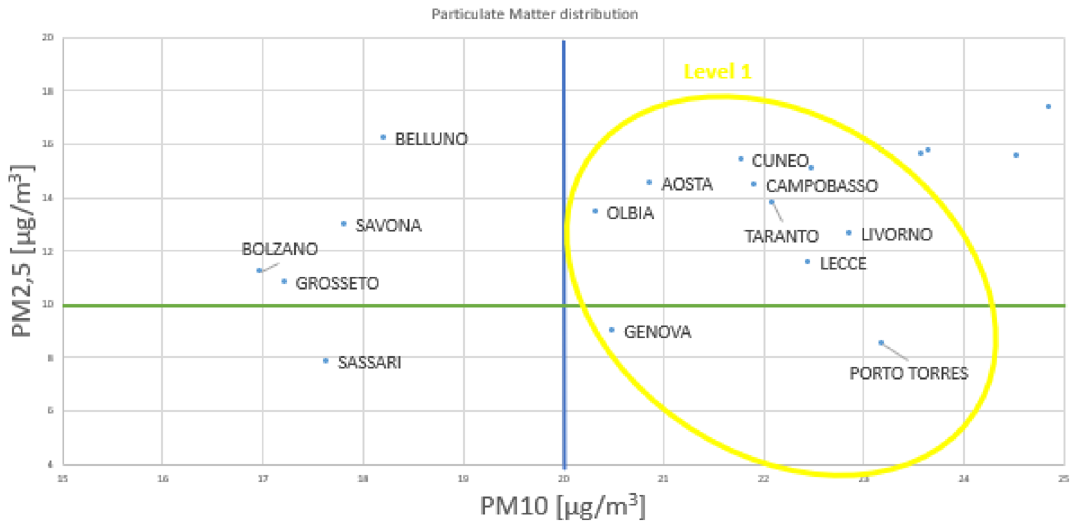


Figure 30. Cluster of particulate matter distribution in Italy. Cities are grouped in four levels (a), an enlargement is shown in (b) and (c). Green and blue lines dash the limits of WHO. http://www.who.int/phe/health_topics/outdoorair/databases/cities/en/.

A method to contrast the rising occurrence of particulate matter, is the use of hydrogen to fill of energy the vehicles, but the derivation of hydrogen gains principal importance: if it is obtained from deposit of natural gas, or if as the fuel are employed hydrocarbons, emissions of particulate matter should be reduced by 50% compared to conventional use of ICEs; once the hydrogen is gained by using renewables or nuclear sources, productions should be reduced by 90% [103, 104].

In the old Continent, at the present time, the diffusion of such vehicles is very limited. To investigate the growth of FCEVs attention should be dedicated to the buses. In Europe the few hydrogen charging stations were realized for experimental plans, then for support private customers. Buses employing Ballard FCs technology run in London and about 61 buses are operating in all Europe. Due to the experimental achievement of FC buses in Europe, China, where the car problem grows due to dependence on a Western model, it has developed the largest hydrogen cell bus (HFCB) project in the world, with 300 buses operating or being expected to operate in Foshan [105]. A contract signed with Ballard [106] realized a novel assembly line, in Yunfu. Units with 90 kW of FC power components, started from July 2017 to achieve to the premeditated 300 buses. The cost of single bus is around $600.000, employment of 7.05 kg of hydrogen is considered for a range of 100 km.

The Italian region at present claims over 8 planned hydrogen charging stations, Figure 31, but few of the planned infrastructures really operate [107]. Bolzano, Carpi, Milan, Pontedera, Trento, Verona, Rome and Capo d'Orlando are the cities involved in different projects that realized a recharge station. This number is very limited to really favor the growth of FCEVs. In order to discuss a similar delay in supporting of this enabling technology, the tardive measures adopted by the Government may be indicated. A technical issue forbade the diffusion of FCEV until March 2017; before such date FCEVs could only use as refueling systems only ones that not exceed the threshold of 350 bar, while the modern and much evolved generation of hydrogen vehicles, employs 700 bar tanks, like the Toyota Mirai.

Figure 31. Chart of the Italian hydrogen charging stations (in green the distributors in operation, in red those inactive) https://www.mobilitah2.it/distributori.

With Legislative Decree 257 of 16 December 2016, entered into force on March 2017, FC supply infrastructures embraced the pressure of 700 bar. In such a way, Italy incorporated the European directive 94 of 22 October 2014, on the deployment alternative fuel infrastructures (DAFI), so launching a clean fuel strategy.

At present, among the FC infrastructures set in Italy, only the plant in the H2 Alto Adige technological center of Bolzano reaches 700 bars. So, it can be highlighted that the network of infrastructures is lacking in Italy, but it is required in order to guarantee a satisfactory coverage and to expand the sales of the FCEV themselves. Also, the population should be pushed to understand and adopt this new sustainable technology which release only water from the exhaust pipe.

The policy of the competent ministry is to undertake a path to build a suitable supply network through the whole national region by 2025.

The objective of next sections is to offer an outline of the Italian inclination to the adoption of consolidated PHEV and BEV, and to extrapolate the feasibility of FC refilling infrastructures in Italy, by employing models, that try to point-out the necessities for the construction of hydrogen refueling stations. By considering the following key features such the knowledge of the current scenario of EV charging infrastructures, EVs adoptions during years, cities dimensions and density, mean personal income in the cities, a map of cities ready to adopt the FC technology can be drafted and also the trend to increase the amount of charging infrastructure year by year can be obtained.

3.3 The model: scenario hypothesis

As stated in the previous section, different forecasting method can be chosen. The models available to deal with the prediction of the development of EV adoption are substantially based on empirical reproductions. Singular spectrum analysis (SSA), which was developed to model univariate time series, in its application with financial and economic data has shown acceptable results [98]. While SSA is non-parametric and data-driven technique, vector autoregressive model (VAR), can face multiple time series [108], and was successfully used in the dynamic couplings between EV sales and economic indicators [97]. A step forward was presented in [83], in which, in addition to the forecasting model based on the algorithm of random-coefficient logic model, the impact on the power grid is projected. Key-features are in limiting access to charging stations, limiting maximum driving distance, and in introducing a high vehicle price negatively to influence the consumer choice of electric vehicles on the automobile market. The adoption of FCEVs is still in its infancy, so in order to create a robust prediction in this study it has been preferred to use an algorithm that does not have multiple parameters. On the other hand, as specified in the previous paragraphs, the main bottleneck that blocks the adoption of EVs is represented by the technical aspects as the distance to travel and the availability of charging stations.

By following a metric traced in [100], in this paper the SERA (Scenario Evaluation, Regionalization and Analysis) model is used. By referring to the same terminology, an early adopter's metric (EAM) is followed. This is an analysis in which EV adoption is used to predict FCEV one. The metric is able to define and outline areas where there can be the development of *early adopters* (literally "*first users*", like seeds) of FCEVs, by taking into account socioeconomic factors, also dependent on the wealth of the city, such as population density, having consequences in the historical sales of electric and hybrid cars, and varying on geographical region, town by town.

In Italy, different population densities characterize metropolitan areas. As a consequence, the amount of refueling infrastructures essential to guarantee the access of "*early adopters*" to a reliable support network, differs also in the same city, more in the high-density part of the city, less in the other one. But not only, if an amount of stations is required, it is based on the quantity of EVs existing in a territorial part of the city and on the geographical extension itself, just to ensure consistent covering. Again, by using the same terminology adopted in SERA model, first charging infrastructures are called *enabling stations*.

In order to explain the SERA model, two Italian cities, Brescia and Parma, can be taken as an example. The two cities share the same number of inhabitants, Parma, due to the dimension of the city, has a density of inhabitants nearly four times lower than Brescia, so a major quantity of infrastructures is needed.

By using the "*Urban Market Sequencing*" model, an analysis of the propensity for innovation of the inhabitants is made, in order to find the importance of urban markets, for the FC infrastructures.

By using a Cartesian coordinates system, the number of early adopters for enabling stations was indicated on the vertical axis, i.e. the probable adopters per refilling infrastructure, while in the abscissas the quantity of early adopters per square meter, i.e. the density of early users, was specified. The number of users is therefore related to the difficulties in using the charging stations, whether they are few in number, or distant from each other. These limitations have to be understood as how early adopters tackled problems such low urban density and low number of charging infrastructures. Thus, the efficiency of placing a limited quantity of infrastructures coping the concentration of early adopters of a specific urban market, can be evaluated.

The databases present in [107, 109] provided suitable data for the analysis.

The "*priority*" in assessing positive urban markets is shown in Figure 32. Cities were clustered in three grouping levels, i.e. Level 1, on the top right, Level 2 in the middle, Level 3 on the bottom left. Level 1 cities were grouped since these cities provide a higher presence of early adopters, against ballasting factors such as the limited number of charging infrastructures or city extension. An excellent option is to finance and construct charging infrastructures in these cities, due to the great quantity of sales of electric and hybrid cars.

Amongst the “greenest” cities, for which the development of environmental sustainability is straightforwardly realizable, there are Como, Pordenone, Trento, Turin, Varese, Milan, Bergamo and Bologna. These cities share also the geographical position, they are in the North of Italy and, above all, in the Lombardy Region.

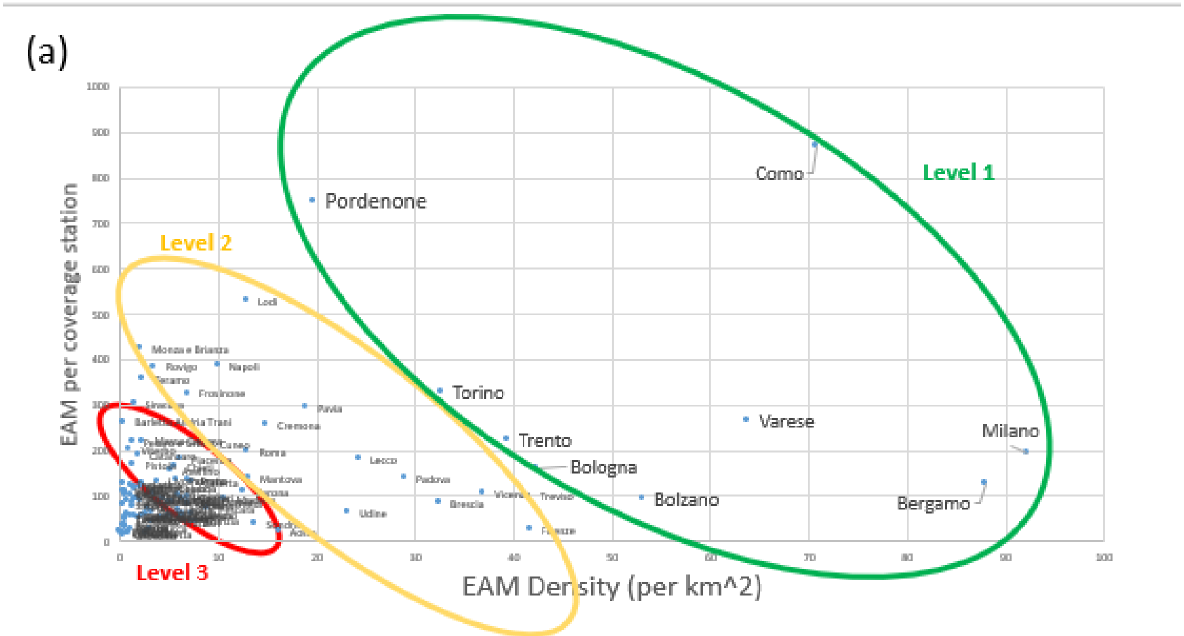


Figure 32. "Early adopters metrics" (a), in abscissas the number of early adopters per coverage station, i.e. divided by the dimension of cities, in ordinates the amount of early adopter's density weighted by amount of charging infrastructures. (b) and (c) an enlargement of (a); level 1 represents the cities that are more ready to adopt the Fuel Cell technology; level 2 represents the cities that are behind in the adoption of ecological vehicles; level 3 shows the cities in which there is the presence of obstacles (economic or infrastructure) that limits so much the adoption of ecological vehicles.

In Figure 32 Level 2 shows the cities that soon, but not immediately, can embrace the electric revolution. These cities suffer from structural or economic deficiencies, which have ballasted the acceptance of the new model of vehicle. Level 3 represents that set of cities in which some impediments inhibit the development and spread of electric vehicles.

The incentive policies must therefore be extended from a national level, common throughout the Italy, keeping an eye on the local characteristics that will make it difficult to adopt and embrace a new vehicle technology, if they are not resolved first. For example, the reduction in the cost of purchasing an electric vehicle, a global incentive, can attract a larger proportion of potential users in the richer regions; on the contrary a policy of access to limited traffic areas, preferential lanes and free parking spaces can be more attractive locally, even in the less wealthy areas.

3.4 Results

The chosen SERA model is not limited to a static analysis but it also predicts the upcoming scenarios. SERA uses a method of space-time placing of the infrastructures; a deterministic algorithm, called *"Station Counts"*, allows the estimation of the quantity of infrastructures to be realized in next years, in a precise urban zone, based on the dynamic recordings of new EVs bought in the previous years. The method applies a forward finite difference scheme, refining with a time domain study, the unknown relationship between the presence of charging stations and the use of electric vehicles.

Basing on this scheme and by taking into account the data associated to the EV sales and the amount of charging infrastructures already present, the algorithm enables the prediction of the increase in the number of infrastructures from the initial ones, city by city.

The initial point of the analysis is based on a hypothetical value, so as defined in section 3.2; such hypothesis is used to resolve the *chicken and the egg* problem.

Thus, by considering a spending capacity to realize the hydrogen stations equal to that already spent to realize the charging infrastructures, the initial number N_0 of starting hypothetical FC infrastructures is 1/25 of the number of electric recharging plants existing in the Italian regions in 2016.

By taking $D(t)$ the recordings of EV sales in year t, $D(t+1)$ the recordings in year $t+1$ and $N(t)$ the number of recharging plants realized in the year t. An empirical parameter α adopts the rate of 2.5, while the *Qave_max (t)* takes the rate of 8000 [100].

By following a forward difference scheme, the amount of plants after one year is:

$$N(t+1) = N(t) + \beta\, W(t+1), \qquad (21)$$

where

$$W(t+1) = \frac{D(t+1) - D(t)}{Q_{ave}(t)}, \qquad (22)$$

$$N(t=0) = N_0, \qquad (23)$$

$$Q_{ave} = \frac{D(t)}{N(t)}, \qquad (24)$$

$$\beta = \alpha^{\left(\frac{Q_{ave}(t)}{Q_{ave\_max}(t)} - 1\right)}. \qquad (25)$$

In equation (21) the number of EVs depends on the number of EVs the previous year, increased by a factor β multiplied for the so called *"willingness"* of the citizen to assume a new ecological lifestyle and buy an EV.

The willingness $W^{*}(t+1)$ in (22), obtained with a dynamic function, is a time dependent function, realized with the forward finite difference scheme employing the number of bought EVs taking into account two different years.

A weighing factor is used in (23) to reduce the willingness, it is expressed in (24) which faces the relation "chicken and egg" problem.

Databases present in [107, 109] are taken into account and particularly to enforce the forward finite difference the recording of years 2014-2017 were employed.

The attitude of various cities to increase the number of FC plants, seen as enabling stations, are plotted in Figure 33. In this analysis only the cities clustered on Level 1 and 2 of Figure 32 have been considered.

Abscissas represents the amount of starting FC stations (also not integer number), given by the number of electric recharging infrastructures divided by a factor of 25, about equal to the cost ratio between the FC station and the electric charging station.

A different behavior is immediately evidenced: some cities start with a considerable number of plants, others with a fractional number.

The ordinate axis hosts the progression of the number of enabling stations, year after year. Such number is amplified as a consequence of novel recordings of vehicles.

Milan and Rome, very big cities, start with a large number of hydrogen infrastructures, but fail in double up the amount of enabling stations. Florence keeps quite the hypothetical initial number; Bolzano almost quadruples the starting number [110].

Figure 33 (b) clusters a group of cities that increase the limited initial number of enabling stations, but currently do not have structures whose cost can be compared to that of the first FC enabling station.

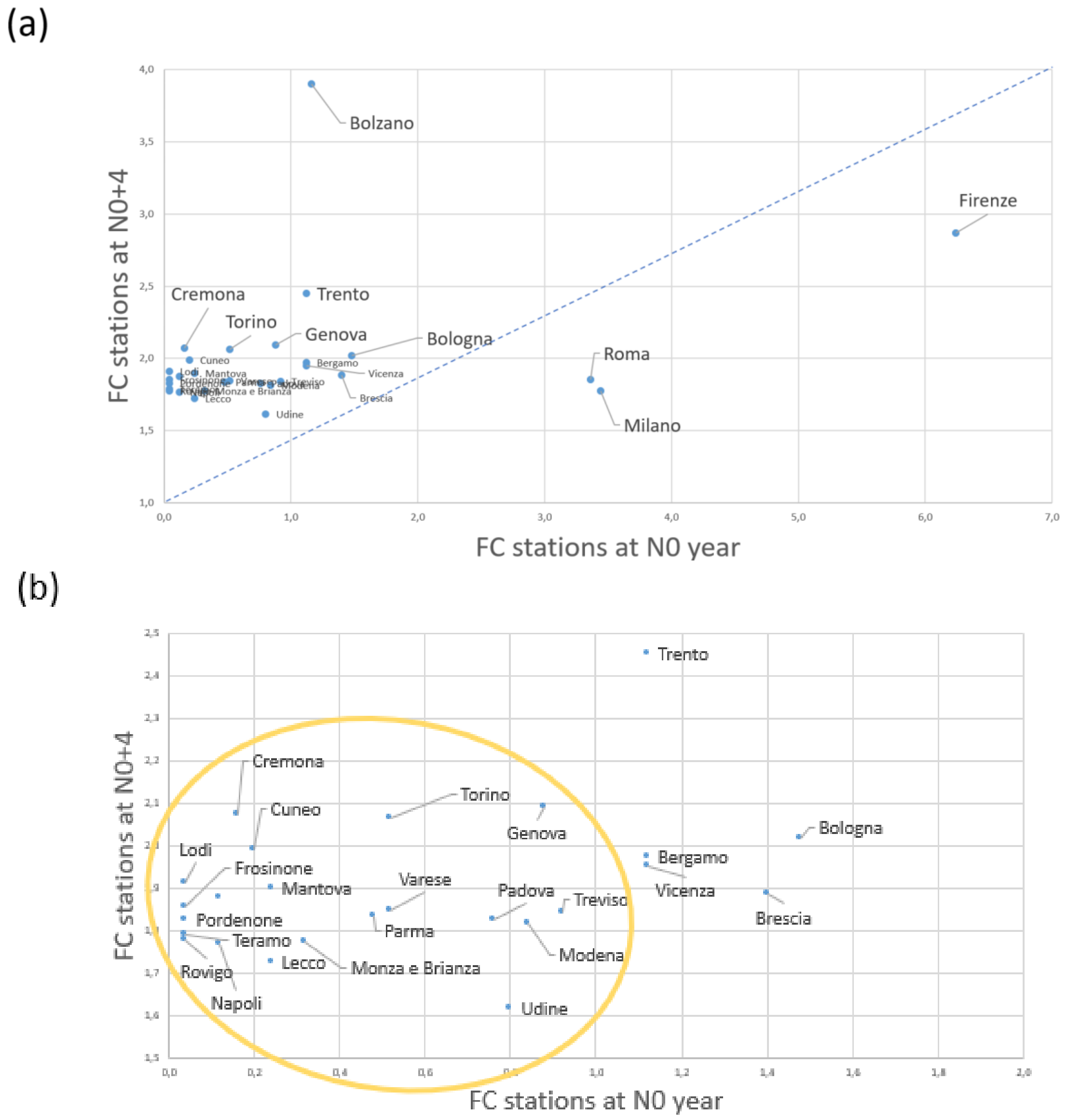


Figure 33. This picture reports the willingness to adopt the FC technology for different cities. Among the cities, Bolzano showed the tendency to quadruple the presence in the territory of the FC enabling stations. The considered years are in the windows 2013-2017. Figure (b) regroups cities that without having an initial FC enabling station, rapidly increase the number of FC plants.

Substantially Figure 33 can be broken down into two halves: the left upper part shows a tendency to increase the number of enabling stations, while the lower right part tends to preserve the initial number.

Although Figure 33 has been obtained by considering data from past years, the goodness of the choice of a dynamic approach has highlighted the trend of adoption of the new technology. The adoption trend reflects the smart mentality of the population, but also the easiness with which modern charging stations can be used; cities with the same number of inhabitants, but with different population density or with equal extension but different average income, showed very different behaviors.

Drawbacks in development

The development of a hydrogen economy is not new. This theme pervades scientific and less scientific circles, and in the collective imagination it represents the future [111, 112].

There are certainly pitfalls that slow down its development.

Let's start with the comparison between a battery and fuel cell vehicles. We consider the same distance to travel on vehicles similar in mass and performance. The differential will be due to how the powertrain gets energy. As reported in [113] a fuel cell vehicle requires more energy to drive the same distance (Figure 34).

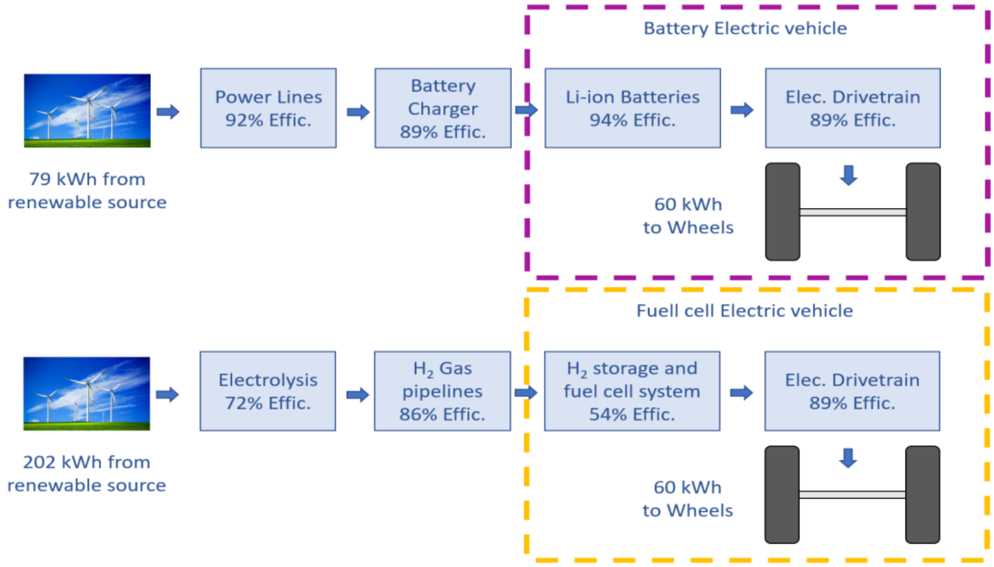


Figure 34. Well-to-wheel energy pathway for battery electric vehicle and fuel cell vehicle. The BEV regeneration capability reduces 60 kWh requirement by 6 kWh, while achieving the same range. For FCEV the pipeline includes losses from compression, expansion, storage and distribution [112].

Such comparison shows the major requirement for a FCEV than BEV in primary energy [113], but also advises that the production and transport chain has a low yield and if no renewable energies are used, a great amount greenhouse gas emission is created, which may be close to those generated by the employment of ICE. Again in [113] a comparison can be made for the cost of the vehicle. The cost is divided by items, such lion battery, fuel-cell, storage tank, drivetrain. In 2004 the hypnotized total investment costs are $ 19.951 for BEV and $ 29.157 for FCEV.

A recent study actualizes the costs by considering the same parameters (fuel cell stack, batteries, drivetrain) and reports the following costs: ICE $ 13.784, BEV $ 37.838, FCEV $ 90.090 [114]. At the present moment the Mirai has a cost of $ 58,500, included among those previously hypothesized.

The cost of a charging station is the biggest obstacle for the diffusion of FCEV. Mayer at al. in [115] reports the cost of an investment in refueling station based on data in [116]; a Liquid H_2 pump requires an investment costs of $ 650,000 for 2015, $ 650,000 for 2020, and $ 250,000 for 2050. A recent review suggests a window of costs for the investment, currently it ranges between € 0.8 and € 2.1 million and it is expected to drop to €0.6 to €1.6 million by 2023 [117]. By considering the more advanced Country in Europe for the adoption of EVs, Norway, similar investment costs are suggested in [118].

Another obstacle to the development of such vehicles is the risk of accidents due to the strong explosiveness of hydrogen. For example, EuroTunnel does not allow "vehicles powered by any flammable gasses", including hydrogen, to use the link between the UK and France. However this problem is to be considered also in all battery-powered vehicles, since as explained in [119], in case of short circuit, the thermal runaway produces the same explosive hydrogen.

In 2016 the Ministry of Economic Development (MISE) adopted the National Plan for Hydrogen Refueling Infrastructure (“Piano Nazionale di Sviluppo – Mobilità Idrogeno Italia”) [120] with the collaboration of the association H2IT [121], a long time missing in Italy. The plan expects FC passenger cars to grow in number from 1,000 in 2020 to 27,000 in 2025, 290,000 in 2030, and FC buses to reach 3,660 in 2030 from an initial 100 in 2020 and 1,100 in

2025. Such goals should be matched by the deployment of 440 strategically placed FC charging stations by 2030, starting from an initial 20 in 2020 and about 200 in 2025.

These factors certainly influence the development of fuel cell technologies in recharging station investment, but as has been discussed in the previous sections, some cities are advanced and smart enough to be able to face and overcome these problems.

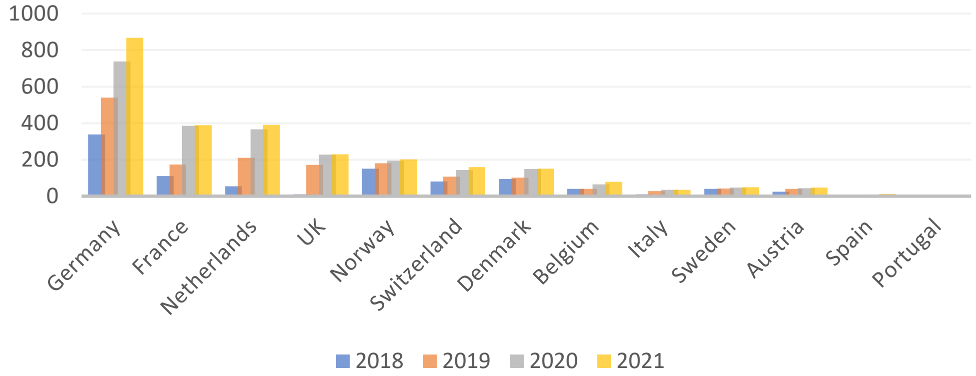
IV

SIMULATION OF THE ADOPTION OF FUEL CELL VEHICLES: THE PORTUGUESE CASE

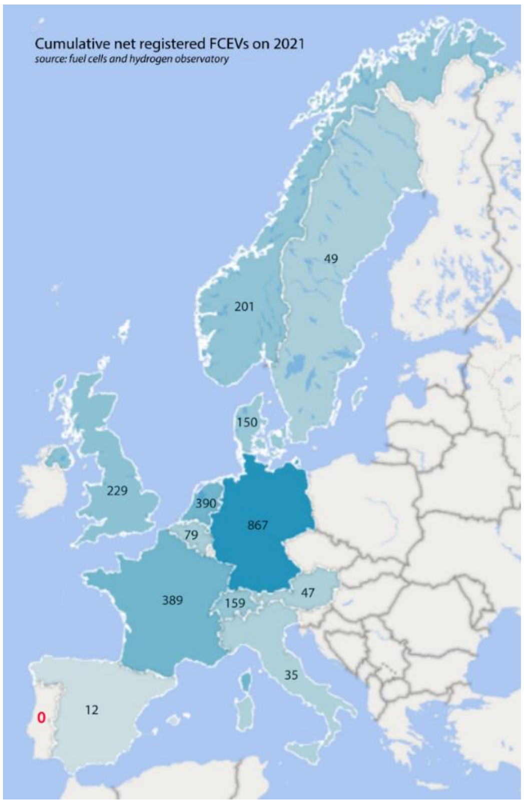
4.1 Introduction

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 [122], 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 [123]. 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 or plug-in hybrid EVs, 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, 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 [124]. As can be seen from Figure 35 (a, b) Fuel Cell Vehicle data in Portugal show that as yet, no private FCEVs have been sold over the years [125].



(**a**)



(**b**)

Figure 35. (**a**, **b**) Cumulative Net registration FCEVs in Europe (data source: fchobservatory) [125].

McNichol et al. [126] 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. [127] 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. [128] 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 36).

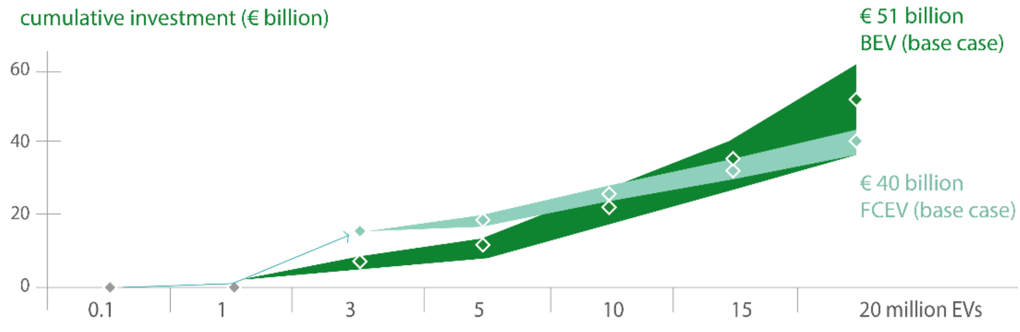


Figure 36. Comparison of the investment for the charging/supply infrastructures BEV and FCEV [128].

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 37).

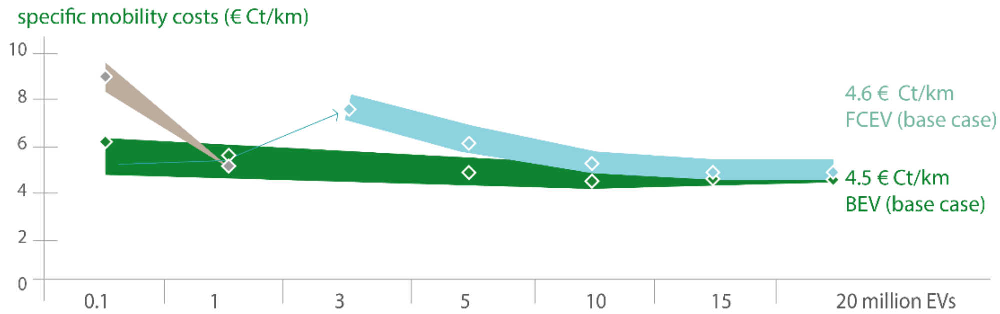


Figure 37. Comparison of specific mobility costs [7].

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 [129]. 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. [130] 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. [131] 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. [132] 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. [133] 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 [134]. However, most of these studies, such as Bass and Gompertz [135], among others, have not used diffusion models to predict the spread of electric vehicles. Martino et al. [136] 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. [137] 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. [138] 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. [139] 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.

4.1.1 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 [140]. 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 [141]. 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.

4.2 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 [142] indicate that the Netherlands, Norway and the UK are currently best prepared for the transition to Evs (Table 7). 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 7. LeasePlan's EV Readiness Index 2020—max. score is 40 points (Source: Leaseplan) [142].

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%.

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 [143]. 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 [142] (Tables 8 and 9).

Table 8. EV market maturity in 2019 (Source: Leaseplan) [142].

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 9. Charging infrastructure maturity in 2019 (Source: Leaseplan) [142].

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 38 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 [144] (Figure 39). 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 [145].

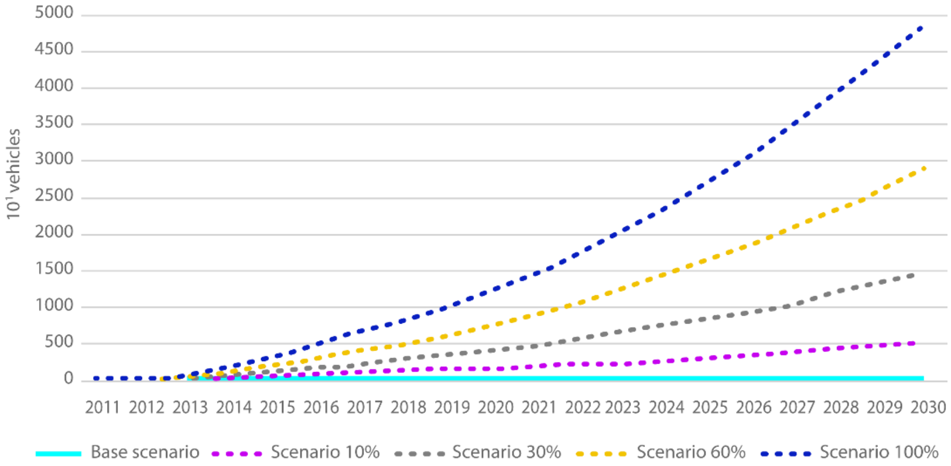


Figure 38. Prediction of the fleet of BEVs, HEVs and PHEVs.

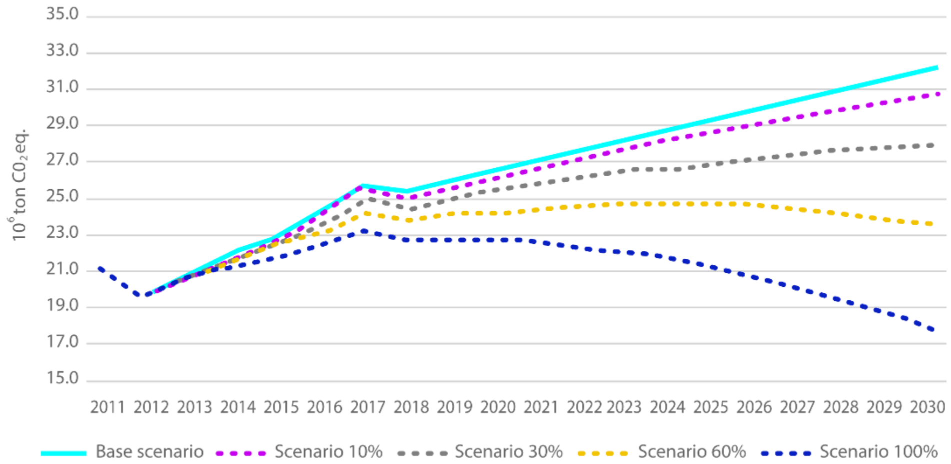


Figure 39. Evaluation of GHG emissions in the scenarios.

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%) [146] (Figure 40).

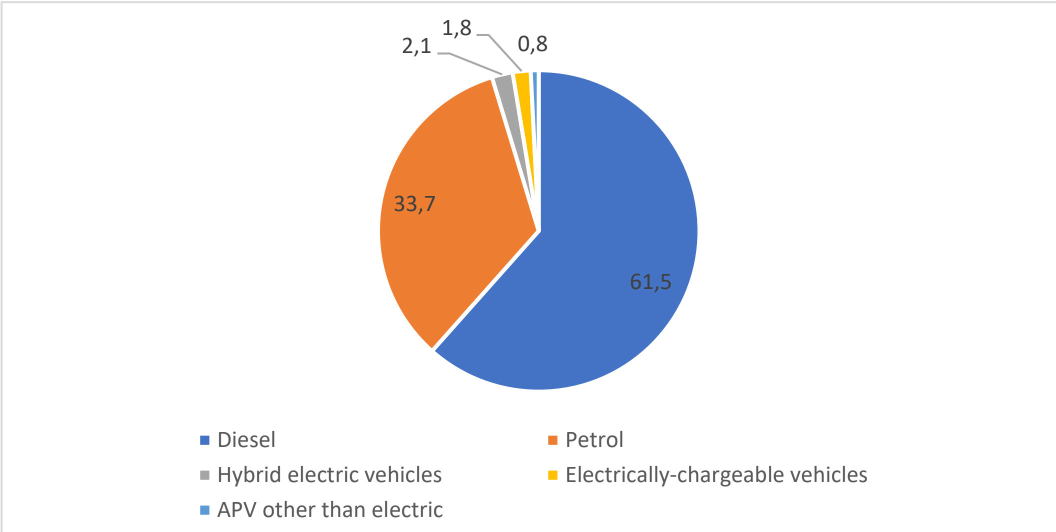


Figure 40. New passenger cars in Portugal by fuel type, 2017, from the European Automobile Manufacturers' Association (ACEA).

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 10). 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% [147] (Table 11).

Table 10. Sales ranking of light passenger electric vehicles in Portugal [146].

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 11. The twelve most registered brands in Portugal, first 8 months of 2020 [146].

Position	Brand	2020	2019	Varation %
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 [148] (Figure 41).

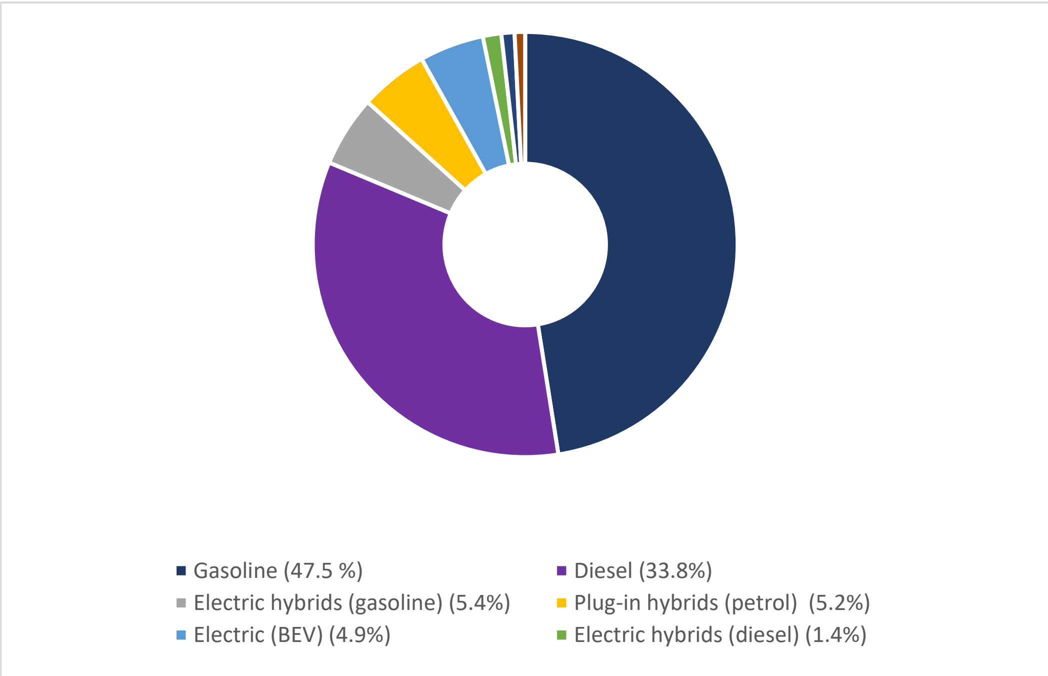


Figure 41. Vehicle market by type of energy in Portugal, 2020 (Source: ACAP Statistics) [148].

To get an idea of the distribution of EV in the Portuguese territory, in Figure 42 the distribution of the number of light electric vehicles is represented according to the registration location of the respective vehicles, up to June 2018 [149]. 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.

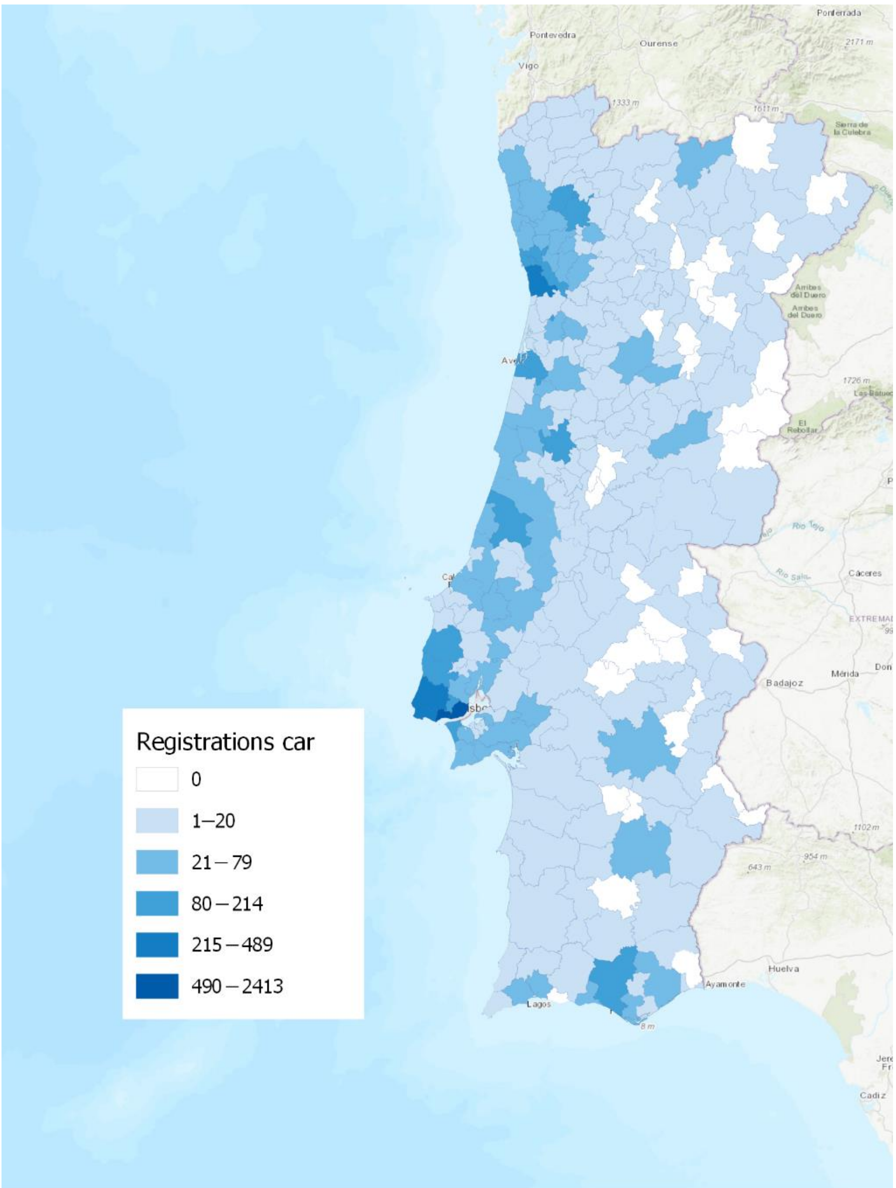


Figure 42. BEVs registered until June 2018 in Portugal (Map elaborated with QGIS).

Electric Recharging Points in the Area

Based on data provided by the European Alternative Fuels Observatory [150], 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 43).

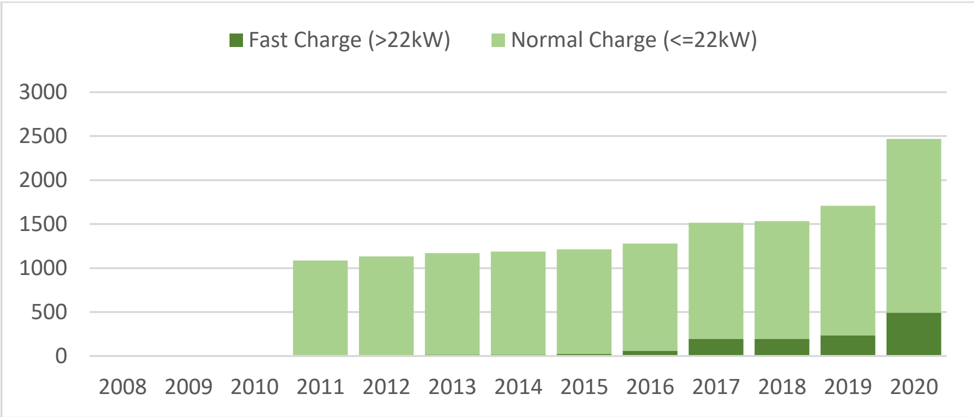


Figure 43. Total number of Normal and Fast public Charging points (2020) [150].

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) [151]. 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 [152]. 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.

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. 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. [153] 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 [154]. 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 12 [155]. 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 [156]. Thus, this stands as a valid alternative for future sustainable mobility.

Table 12. 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 [157]. 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 [158].

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

- FCEVs take a short H_2 refill time due to high-pressure refueling;

- FCEVs have a high-level air purification system to keep dust or particulate matter out of the fuel cell;

- FCEVs have longer mileage for one time refueling than ICEVs and BEVs;

- 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 [159]. 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 [160]. 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 $0.045 \times 100 = 4.5$ €. 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 [161]. 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 [162].

4.3 Materials and Methods: Description of the SERA Model

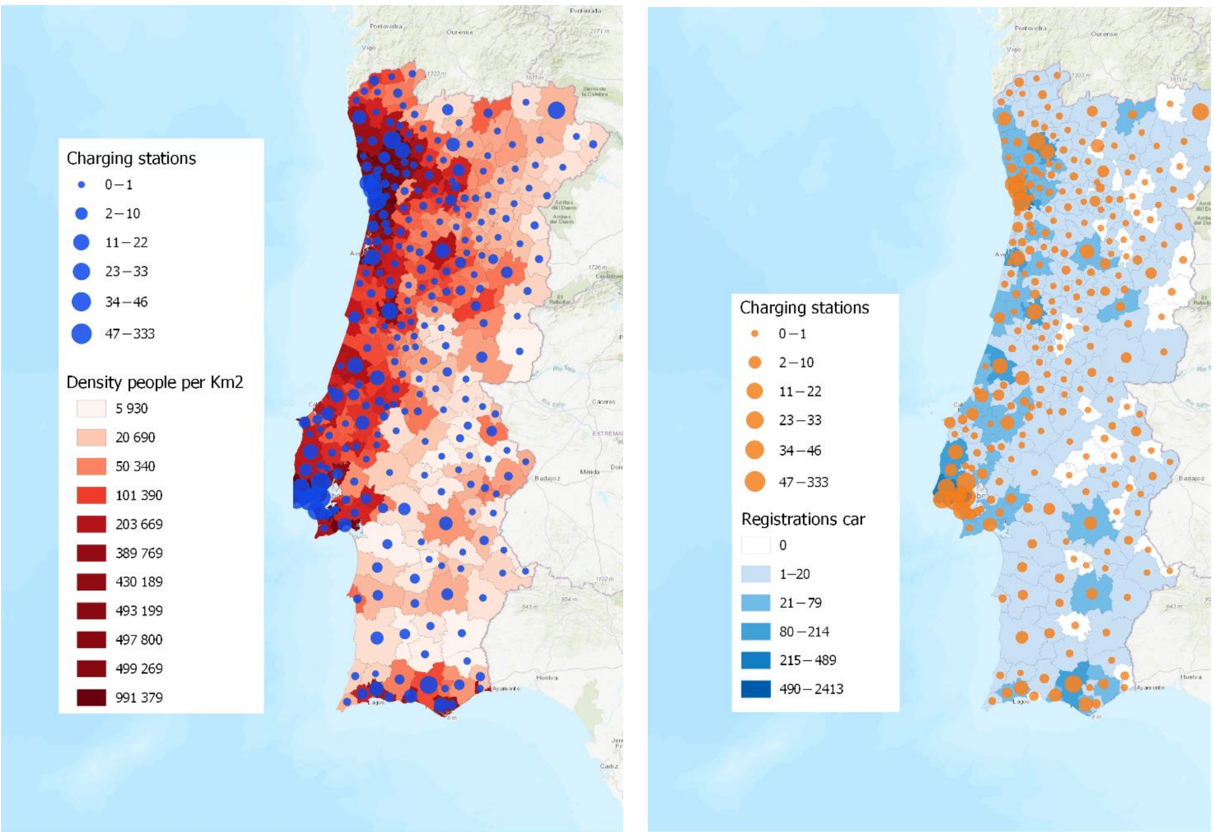
The SERA (Scenario Evaluation and Regionalization Analysis) model of the National Renewable Energy Laboratory occupies a unique and important niche in the temporal and geospatial analysis of the construction of hydrogen infrastructure for production and delivery. The model evaluates the quantity, size 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. [163], 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 [145, 146], data on the existing charging infrastructure or public to private charging stations throughout the country by Municipality and District [164, 165] 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) [166].

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 44 a, b).



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

Figure 44. (**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 45–47) and predictive Cartesian graphs on the development of Fuel cells in Portugal, starting from the Early Adopters of the EVs (Figures 48 and 49).

4.4 Results

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 45, the number of “early adopters” per square meter is found that is the density of the first users, while in Figure 46, 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 47.

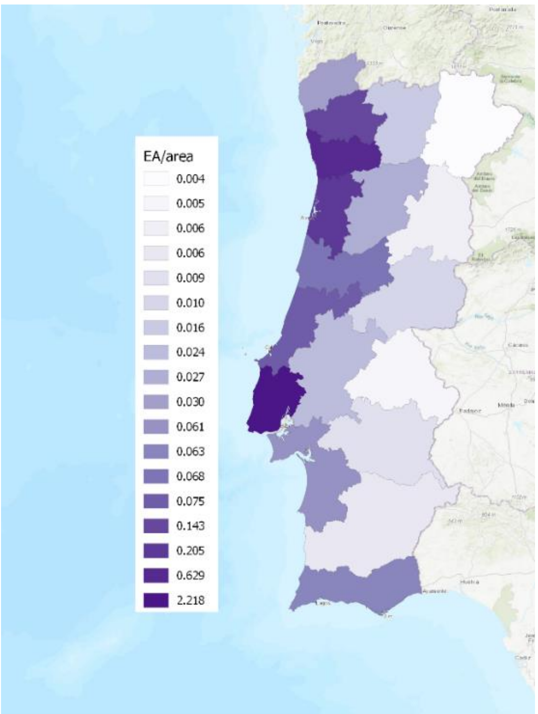


Figure 45. EAM per density (km^2) (map elaborated with QGIS).

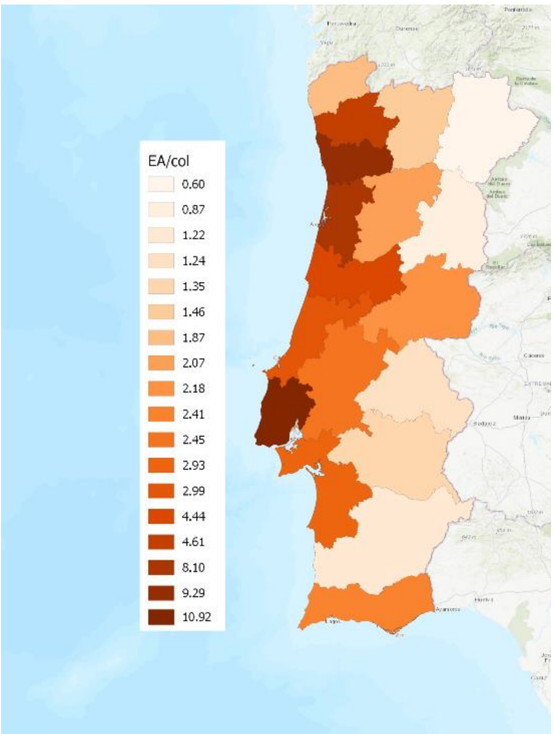


Figure 46. EAM per coverage station (map elaborated with QGIS).

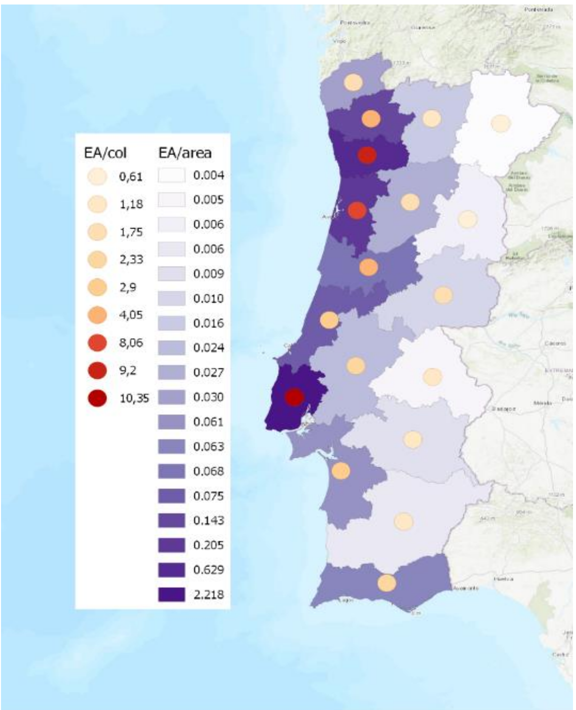


Figure 47. EAM identifies the levels of propensity in the use of new technology vehicles, which are considered constraining factors, such as the limited number of recharging infrastructures (map elaborated with QGIS).

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 48). 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.

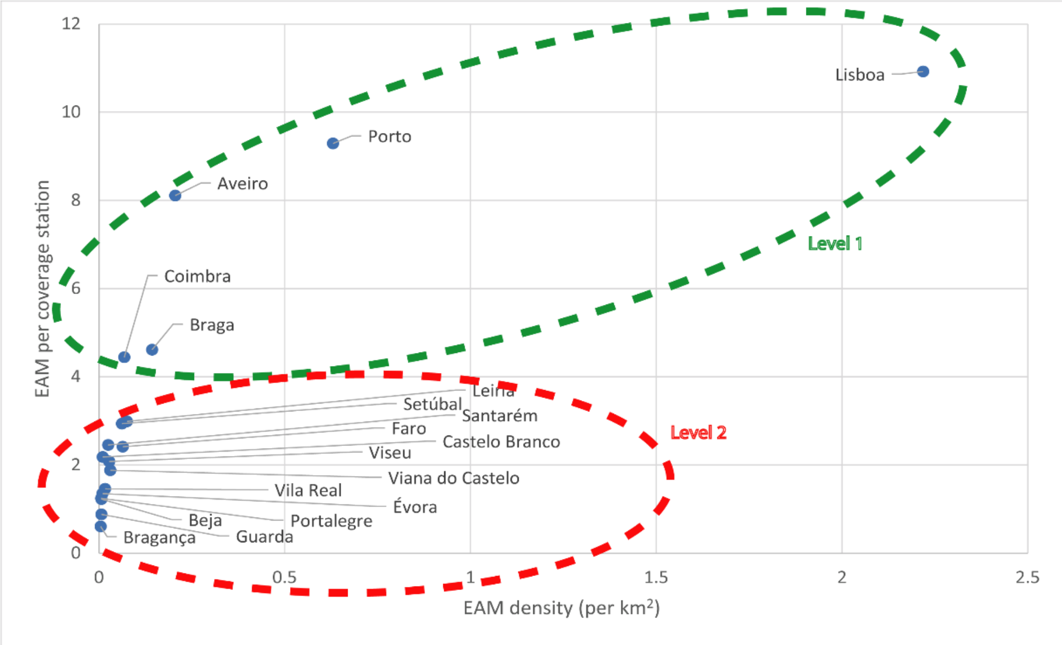


Figure 48. Districts with greater propensity according to the SERA model.

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 49).

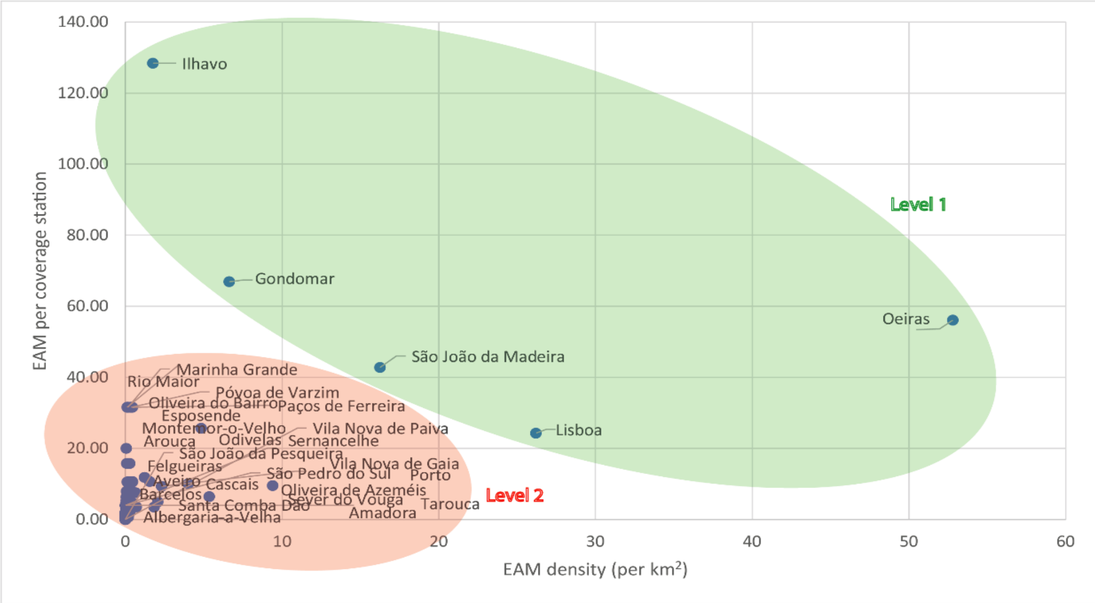


Figure 49. Cities with greater propensity according to the SERA model.

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). By reporting again the equations presented in 3.4, 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 [167]; following a term difference scheme, the number of implants after one year is:

$$N(t + 1) = N(t) + \beta\, W(t + 1), \qquad (26)$$

$$W(t + 1) = \frac{D(t+1) - D(t)}{Q_{ave}(t)}, \qquad (17)$$

$$N(t = 0) = N_0, \qquad (28)$$

$$Q_{ave} = \frac{D(t)}{N(t)}, \tag{29}$$

$$\beta = \alpha^{\left(\frac{Q_{ave}(t)}{Q_{ave\_max}(t)} - 1\right)}. \tag{30}$$

where the following conclusions can be drawn:

- In Equation (26), 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 (27), the will *W*(*t* + 1) in (27), 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 (28), the factor *Qave_max*(*t*) is equivalent to 8000;
- In Equation (29), a weighting factor, which is also used in Equation (27), is used to reduce the will and addresses the problem of the "chicken and egg" relationship.

The databases in [168] 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 50 shows the different behaviors.

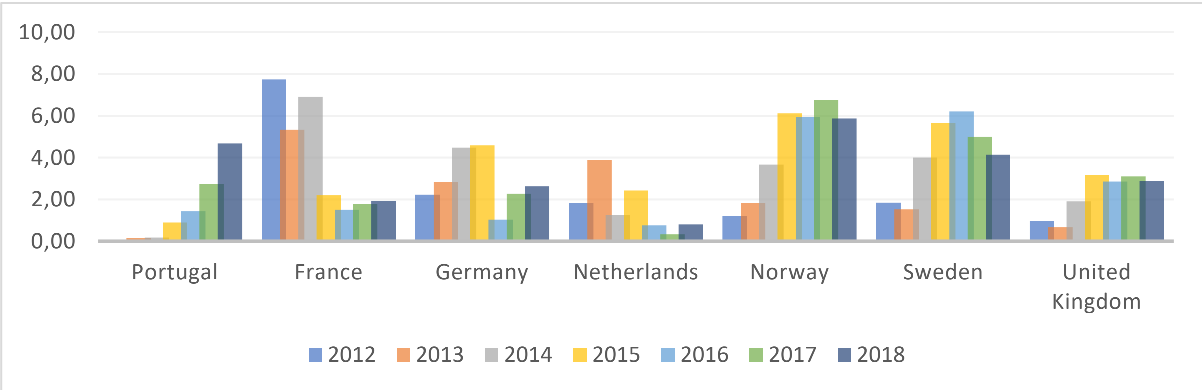


Figure 50. Ratios of new registrations and active charging stations.

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 [169], 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 50.

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 [170].

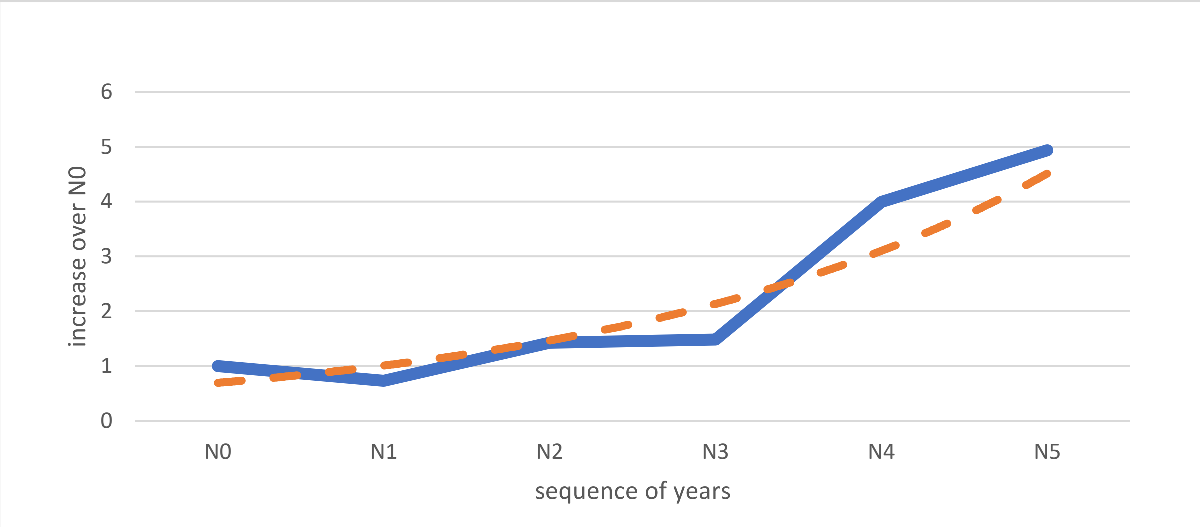


Figure 51. Ability to increase FC charging stations in Portugal, numerical evaluation (blue) and trend (orange).

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 [171].

IV

CONCLUSIONS AND PERSPECTIVES

The theme of sustainable mobility is a subject of study and research. Their advantages in terms of reducing global air pollution emissions compared to traditional systems are well demonstrated by their application. Literature research shows that it has become increasingly important to establish new modes of road transport compared to conventional internal combustion engines and to understand the dynamics of city penetration of certain technologies over others, as well as their acceptance by users. Many studies have been conducted on production systems, on the environmental impact or on the mechanics of these technologies, but few have focused on the psychological and social aspects that lead to change in this sense.

The purpose of this work was to develop a method to study the propensity to adopt ecological and sustainable vehicles in Italy and in Portugal, replicable in other countries. Specifically, the scenario of FC vehicles was investigated. The objective was to draw which, among the Italian and Portuguese cities, are motivated and organized to adopt the new FC technology which requiring similar investment for the total cost of the ownership of the vehicle (FCEV and BEV have similar prices), but most expensive costs in the infrastructures of refueling stations.

It follows that a reason for urgently adopting vehicles with low emissions can be the city air quality, so the first part of the Italian study shows which cities need a rapid intervention to reduce the particulate matters PM10 and PM2.5 mainly due to the use of internal combustion engines. Several cities in the Lombardy region should carry out severe interventions to lower pollution levels. Second part of Italian case highlights, by the *"early adopters metric"* method, the propensity for innovation in the use of electric vehicles among Italian cities. Again, Lombardy region, between the twenty Italian ones, should be the most motivated to follow the FC technology. The third part of the analysis starts from the observation that there are no appreciable FC refueling stations on the Italian territory. So, the study highlights what is the response capacity of the cities in increasing their infrastructure investments, which are the cities able to successfully convert initial investments in this technology in a continuous development over the years. To predict the development in the number of refueling infrastructures over the years, the *"willingness"* to accept a novel electric vehicle technology is evaluated by enforcing a mathematical approach. Once supposed the existence of a FC infrastructure (or a part of it), the growing of it is calculated by means of a dynamic scheme. Year by year the model correlates the effects of a new quantity of recharging plants in the city influencing in following year the EV sales and an increased quantity of EVs that requires new charging stations. This *"willingness"* thus represents the development trend of the recharging stations. The final part of the Italian analysis shows that the cities requiring an immediate action to reduce particulate matter, are not among those most likely to increase investments in recharging stations. Bolzano is the city with the highest tendency to increase the number of FC enabling stations.

The same methodology was replicated for the study in Portugal, to provide forecasts on the purchasing trend and use of Fuel cell (FC) vehicles in Portugal, based on historical EV deployment in this country. The 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 study, 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.

References

1. European Environment Agency. Available on: https://www.eea.europa.eu/it/themes/air.
2. ISFORT – Higher Institute of Training and Research for Transport. Available on: https://www.isfort.it/wp-content/uploads/2021/11/211130_RapportoMobilita2021.pdf.
3. Zawieska, J., & Pieriegud, J. (2018). Smart city as a tool for sustainable mobility and transport decarbonization. Transport Policy, 63, 39-50.
4. Audimob – ISFORT. Available on: https://www.isfort.it/ricerca/audimob/.
5. Traffic Observatory Archive | Anas S.p.A. Available on: https://www.stradeanas.it/it/le-strade/osservatorio-del-traffico/archivio-osservatorio-del-traffico.
6. Skerlos, S. J., & Winebrake, J. J. (2010). Targeting plug-in hybrid electric vehicle policies to increase social benefits. Energy Policy, 38 (2), 705-708.
7. Gai, Y., Minet, L., Posen, ID, Smargiassi, A., Tétreault, LF, & Hatzopoulou , M. (2020). Health and climate benefits of electric vehicle deployment in the greater Toronto and Hamilton area. Environmental pollution, 265, 114983.
8. Peterson, S. B., & Michalek, J. J. (2013). Cost-effectiveness of plug-in hybrid electric vehicle battery capacity and charging infrastructure investment for reducing US gasoline consumption. Energy policy, 52, 429-438.
9. 16th Report on the mobility of Italians "Audimob". Available on: https://www.isfort.it/progetti/16-rapporto-sulla-mobilita-degli-italiani-audimob/.
10. The European House - Ambrosetti. Available on: https://www.ambrosetti.eu/lo-scenario-di-oggi-e-di-domani-per-le-strategie-competitive-2019/.
11. Statistical analysis on the trends of the car market in Italy. Available on: https://www.aci.it/fileadmin/documenti/studi_e_ricerche/auto-trend/2021/Auto-trend1221.pdf.
12. ACI Studies and research – Data and statistics. Available on: https://www.aci.it/fileadmin/documenti/studi_e_ricerche/dati_statistiche/autoritratto2019/Nota_metodologica_e_considerazioni_2019.pdf.
13. International Energy Agency: IEA. Available on: https://www.iea.org/reports/global-ev-outlook-2020.
14. Italian registrations – ANFIA. Available on: https://www.anfia.it/it/dati-statistici/immatricolazioni-italia.

15. Energy in the Transport sector – GSE. Available on: https://www.gse.it/documenti_site/Documenti%20GSE/Rapporti%20statistici/Energia%20nel%20settore%20Trasporti%202005-2020.pdf.
16. The European Environmente Agency (EEA). (2016). EEA Signals 2016. Toward clean and smart mobility. Copenhagen: Publications Office of the European Union.
17. Rajper, S. Z., & Albrecht, J. (2020). Prospects of electric vehicles in the developing countries: a literature review. Sustainability, 12(5), 1906.
18. Reitz, R. D., Ogawa, H., Payri, R., Fansler, T., Kokjohn, S., Moriyoshi, Y., ... & Zhao, H. (2020). IJER editorial: the future of the internal combustion engine. International Journal of Engine Research, 21(1), 3-10.
19. Yang, C., Zha, M., Wang, W., Liu, K., & Xiang, C. (2020). Efficient energy management strategy for hybrid electric vehicles/plug-in hybrid electric vehicles: review and recent advances under intelligent transportation system. IET Intelligent Transport Systems, 14(7), 702-711.
20. Singh, K. V., Bansal, H. O., & Singh, D. (2019). A comprehensive review on hybrid electric vehicles: architectures and components. Journal of Modern Transportation, 27(2), 77-107.
21. Xiao, B., Ruan, J., Yang, W., Walker, P. D., & Zhang, N. (2021). A review of pivotal energy management strategies for extended range electric vehicles. Renewable and Sustainable Energy Reviews, 149, 111194.
22. Suarez, C., & Martinez, W. (2019, September). Fast and ultra-fast charging for battery electric vehicles–a review. In 2019 IEEE Energy Conversion Congress and Exposition (ECCE) (pp. 569-575). IEEE.
23. Singla, M. K., Nijhawan, P., & Oberoi, A. S. (2021). Hydrogen fuel and fuel cell technology for cleaner future: a review. Environmental Science and Pollution Research, 28(13), 15607-15626.
24. Santos, G., & Davies, H. (2020). Incentives for quick penetration of electric vehicles in five European countries: Perceptions from experts and stakeholders. Transportation Research Part A: Policy and Practice, 137, 326-342.
25. Shariff, S. M., Iqbal, D., Alam, M. S., & Ahmad, F. (2019, October). A state of the art review of electric vehicle to grid (V2G) Technology. In IOP Conference Series: Materials Science and Engineering (Vol. 561, No. 1, p. 012103). IOP Publishing.

26. Petrauskiene, K., Dvarioniene, J., Kaveckis, G., Kliaugaite, D., Chenadec, J., Hehn, L., ... & Erman, M. (2020). Situation analysis of policies for electric mobility development: Experience from five european regions. Sustainability, 12(7), 2935.
27. IEA-10 REPORTS PLAN. Available on: https://www.iea.org/reports/a-10-point-plan-to-cut-oil-use?utm_source=SendGrid&utm_medium=Email&utm_campaign=IEA+newsletters.
28. European Commission – Make Transport Greener. Available on: https://ec.europa.eu/commission/presscorner/api/files/attachment/869687/Transport_Factsheet_EN.pdf.pdf.
29. Statistical Review of World Energy by British Petroleum 2021. Available on: https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2021-full-report.pdf.
30. Gis, W., & Merkisz, J. (2019). The development status of electric (BEV) and hydrogen (FCEV) passenger cars park in the world and new research possibilities of these cars in real traffic conditions. Combustion Engines, 58.
31. Ministry of Ecological Transition. Available on: https://www.mite.gov.it/pagina/missione-2-m2-rivolution-verde-e-transizione-ecologica.
32. Morrison, G., Stevens, J., & Joseck, F. (2018). economic competitiveness of light-duty battery electric and fuel cell electric vehicles. Transportation Research Part C: Emerging Technologies, 87, 183-196.
33. Tanç, B., Arat, H. T., Baltacıoğlu, E., & Aydın, K. (2019). Overview of the next quarter century vision of hydrogen fuel cell electric vehicles. International Journal of Hydrogen Energy, 44(20), 10120-10128.
34. Song, C. H., & Aaldering, L. J. (2019). Strategic intentions to the diffusion of electric mobility paradigm: The case of internal combustion engine vehicle. Journal of Cleaner Production, 230, 898-909.
35. Tomac, N., Radonja, R., & Bonato, J. (2019). Analysis of Henry Ford's contribution to production and management. Pomorstvo, 33 (1), 33-45.
36. Wards Intelligence. Available on: https://wardsintelligence.informa.com/datacenter.
37. World Bank Database, GDP of United Kingdom Report 2011. Available from: http://data.worldbank.org/country/united-kingdom.

38. Santiago, JL, Rivas, E. , Gamarra, AR, Vivanco, MG, Buccolieri, R., Martilli, A., ... & Martín, F. (2021). Estimates of population exposure to atmospheric pollution and health-related externalities in a real city: The impact of spatial resolution on the accuracy of results. Science of The Total Environment, 152062.
39. Norouzi, N., Fani, M., & Ziarani, ZK (2020) . The fall of oil Age: A scenario planning approach over the last peak oil of human history by 2040. Journal of Petroleum Science and Engineering, 188, 106827.
40. Smyth, T., & Georas, S. N. (2021). Effects of ozone and particulate matter on airway epithelial barrier structure and function: a review of in vitro and in vivo studies. Inhalation toxicology, 33 (5), 177-192.
41. Bardi, U. (2009). Peak oil: The four stages of a new idea. Energy, 34 (3), 323-326.
42. Pan, X., Wang, L., Dai, J., Zhang, Q. , Peng, T., & Chen, W. (2020) Analysis of China's oil and gas consumption under different scenarios toward 2050: An integrated modeling. Energy, 195, 116991.
43. European Commission (EC) Directive 2014/94 / EU of the European parliament and of the council of 22 October 2014 on the deployment of alternative fuels infrastructure (2014).
44. Ala, G., Di Filippo, G., Viola, F., Giglia, G., Imburgia, A., Romano, P., ... & Miceli, R. (2020). Different scenarios of electric mobility: Current situation and possible future developments of fuel cell vehicles in Italy. Sustainability, 12 (2) , 564.
45. SNAM - H2 Italy 2050 a hydrogen value chain for growth and decarbonization: a study by The European House - Ambrosetti in collaboration with Snam. Available on. https://www.snam.it/en/Media/news_events/2020/H2_Italy_2050_Snam_Ambrosetti.html.
46. Fuel cell for heavy-duty transportation; a compelling value proposition. Available on: https://static1.squarespace.com/static/5b02e08a506fbe726e4dbbd2/t/5d1ac7a3768fab00013e22f9/1562036135768/Ballard+Ohio+Fuel+Cell+Symposium+2019-+2019-06-27.pdf.
47. Nikolaidis, P., & Poullikkas, A. (2017). A comparative overview of hydrogen production processes. Renewable and sustainable energy reviews, 67, 597-611.
48. Aja, EA, Thomas, S., Aina, O., Inuwa, ID, Saka, B., & Mohammed, YS (2019, December). A Fuel Cell technology approach to generate electricity using air-conditioner water. In 2019 15th International Conference on Electronics, Computer and Computation (ICECCO) (pp. 1-5). IEEE.

49. Kumar, S. S., & Himabindu, V. (2019). Hydrogen production by PEM water electrolysis – A review. Materials Science for Energy Technologies, 2 (3), 442-454.
50. Ball, M., & Weeda, M. (2015). The hydrogen economy – vision or reality ?. International Journal of Hydrogen Energy, 40 (25), 7903-7919.
51. Newborough, M., & Cooley, G. (2020). Developments in the global hydrogen market: The spectrum of hydrogen colors. Fuel Cells Bulletin , 2020 (11), 16-22.
52. Luo, M., Yi, Y., Wang, S., Wang, Z., Du, M., Pan, J., & Wang, Q. (2018). Review of hydrogen production using chemical-looping technology. Renewable and Sustainable Energy Reviews, 81, 3186-3214.
53. Hy4Heat Work Package 2: Hydrogen purity. Report to BEIS. Available on: https://static1.squarespace.com/static/5b8eae345cfd799896a803f4/t/5e58ebfc9df53f4eb31f7cf8/1582885917781/WP2+Report+final.pdf show that for distribution) (2019).
54. Renewable sources and electricity grid in Italy. Basic considerations and evolution scenarios of renewable electricity sources in Italy, ENEA (2020).
55. IEA- A 10 POINT PLAN TO REDUCE THE EUROPEAN UNION’S RELIANCE ON RUSSIAN NATURAL GAS. Available on: https://www.iea.org/reports/a-10-point-plan-to-reduce-the-european-unions-reliance-on-russian-natural-gas.
56. IEA. CO2 Emissions from fuel combustion, 2018 highlights. Available on https://webstore.iea.org/co2-emissions-from-fuel-combustion-2018-highlights (accessed on 11 July 2019).
57. IEA. CO2 Emissions from fuel combustion. Paris: IEA report 2013: p. 566. Available on www.iea.com (accessed on 11 July 2019).
58. IEA. CO2 Emissions Statistics, 2017. Available on https: // www. iea.org/statistics/co2emissions (accessed on 11 July 2019).
59. IEA. Global Energy & CO2 Status Of the International Energy Agency, 2018. Available on https://www.iea.org/geco/ (accessed on 11 July 2019).
60. Huétink, F. J., van der Vooren, A. A., & Alkemade, F. (2010). Initial infrastructure development strategies for the transition to sustainable mobility. Technological Forecasting and Social Change, 77(8), 1270-1281. https://doi.org/10.1016/j.techfore.2010.03.012

61. Al-Alawi, B. M., & Bradley, T. H. (2013). Review of hybrid, plug-in hybrid, and electric vehicle market modeling Studies. Renewable and Sustainable Energy Reviews, 21, 190–203.
62. Zagorskas, J.; Burinskienė, M. Challenges Caused by Increased Use of E-Powered Personal Mobility Vehicles in European Cities. Sustainability 2020, 12, 273..
63. Till Gnann, Patrick Plötz & Martin Wietschel, How to address the chicken-egg-problem of electric vehicles? Introducing an interaction market diffusion model for EVs and charging infrastructure, Conference: Eceee Summer Study 2015, At: Hyères, France June 2015
64. Fabio Viola, Michela Longo, On the strategies for the diffusion of EVs: Comparison between Norway and Italy, International Journal of Renewable Energy Research, January 2017, 7(3):1376-1382
65. Schwoon, M. Simulating the adoption of fuel cell vehicles. Journal of Evolutionary Economics, 16 (4): 435–472, October 2006.https://doi.org/10.1007/s00191-006-0026-4
66. Rosario Miceli, Fabio Viola, Designing a Sustainable University Recharge Area for Electric Vehicles: Technical and Economic Analysis, Energies 10(10):1604, October 2017, DOI: 10.3390/en10101604
67. Chen, T. D., Kockelman, K. M., & Khan, M. (2013). The electric vehicle charging station location problem: a parkingbased assignment method for Seattle. In Transportation, Research Board 92nd Annual Meeting (Vol. 340, pp. 13–1254).
68. Ge, S., Feng, L. and Liu, H. (2011) The Planning of Electric Vehicle Charging Station Based on Grid Partition Method. IEEE Electrical and Control Engineering Conference, Yichang, China
69. Melaina, M. W. Initiating hydrogen infrastructures: preliminary analysis of a sufficient number of initial hydrogen stations in the US. International Journal of Hydrogen Energy, 28 (7): 743–755, July 2003
70. EUROPEAN COMMISSION, Press Release Database, 2018. Available on https://europa.eu/rapid/press-release_IP-18-3708_it.htm (accessed on 11 July 2019).
71. Harrison, G.; Vilchez, J. J. G.; Thiel, C. Industry strategies for the promotion of E-mobility under alternative policy and economic scenarios. European Transport Research Review 2018, 10(2), 19.

72. Moro, A.; Lonza, L. Electricity carbon intensity in European Member States: Impacts on GHG emissions of electric vehicles. Transportation Research Part D: Transport and Environment 2018, 64, 5-14.
73. Union of Concerned Scientists, 2018. Available on https://www.ucsusa.org/clean-vehicles/electric-vehicles/ life-cycle-ev- emissions (accessed on 11 July 2019).
74. Fox, G. H. Electric vehicle charging stations: Are we prepared?. IEEE Industry Applications Magazine 2013, 19(4), 32-38.
75. Dijk, M.; Orsato, R. J.; Kemp, R. The emergence of an electric mobility trajectory. Energy Policy 2013, 52, 135-145.
76. Brenna, M.; Foiadelli, F.; Longo, M.; Zaninelli, D. E-Mobility forecast for the transnational e-corridor planning. IEEE Transactions on Intelligent Transportation Systems 2015, 17(3), 680-689.
77. General Requirements, Eur. Std. IEC 62196-1, 2014. Available on https://webstore.iec.ch/publication/6582 (accessed on 11 July 2019).
78. Aziz, M.; Oda, T.; Ito, M. Battery-assisted charging system for simultaneous charging of electric vehicles. Energy 2016, 100, 82-90.
79. Luo, X.; Xia, S.; Chan, K. W. A decentralized charging control strategy for plug-in electric vehicles to mitigate wind farm intermittency and enhance frequency regulation. Journal of power sources, 248 2014, 604-614.
80. Mehrjerdi, H.; Rakhshani, E. Vehicle-to-grid technology for cost reduction and uncertainty management integrated with solar power. Journal of Cleaner Production 2019, 229, 463-469.
81. Huda, M.; Aziz, M.; Tokimatsu, K. The future of electric vehicles to grid integration in Indonesia. Energy Procedia 2019, 158, 4592-4597.
82. Mehrjerdi, H. Optimal correlation of non-renewable and renewable generating systems for producing hydrogen and methane by power to gas process. International Journal of Hydrogen Energy 2019, 44(18), 9210-9219.
83. Wu, X.; Hu, X.; Moura, S.; Yin, X.; Pickert, V. Stochastic control of smart home energy management with plug-in electric vehicle battery energy storage and photovoltaic array. Journal of Power Sources 2016, 333, 203-212.

84. Dallinger, D.; Wietschel, M. Grid integration of intermittent renewable energy sources using price-responsive plug-in electric vehicles. Renewable and Sustainable Energy Reviews 2012, 16(5), 3370-3382.
85. Wang, Z.; Wang, S. Grid power peak shaving and valley filling using vehicle-to-grid systems. IEEE Transactions on power delivery 2013, 28(3), 1822-1829.
86. Garcés Quílez, M.; Abdel-Monem, M.; El Baghdadi, M.; Yang, Y.; Van Mierlo, J.; Hegazy, O. Modelling, analysis and performance evaluation of power conversion unit in g2v/v2g application—A review. Energies 2018, 11(5), 1082.
87. Ahmadian, A.; Sedghi, M.; Mohammadi-ivatloo, B.; Elkamel, A.; Golkar, M. A.; Fowler, M. Cost-benefit analysis of V2G implementation in distribution networks considering PEVs battery degradation. IEEE Transactions on Sustainable Energy 2017, 9(2), 961-970.
88. Geels, F. W. The dynamics of transitions in socio-technical systems: a multi-level analysis of the transition pathway from horse-drawn carriages to automobiles (1860–1930). Technology analysis & strategic management 2005, 17(4), 445-476.
89. Egnér, F.; Trosvik, L. Electric vehicle adoption in Sweden and the impact of local policy instruments. Energy policy 2018, 121, 584-596.
90. Held, T.; Gerrits, L. On the road to electrification–A qualitative comparative analysis of urban e-mobility policies in 15 European cities. Transport Policy 2019.
91. Wang, N.; Tang, L.; Pan, H. A global comparison and assessment of incentive policy on electric vehicle promotion. Sustainable Cities and Society 2019, 44, 597-603.
92. Yong, T.; Park, C. A qualitative comparative analysis on factors affecting the deployment of electric vehicles. Energy Procedia 2017, 128, 497-503.
93. Shim, D.; Kim, S.W.; Altmann, J.; Yoon, Y.T.; Kim, J.G. Key Features of Electric Vehicle Diffusion and Its Impact on the Korean Power Market. Sustainability 2018, 10, 1941.
94. Brownstone, D.; Train, K. Forecasting new product penetration with flexible substitution patterns. J. Econom. 1998, 89, 109–129.
95. Bruhl B, Hulsmann M, Borscheid D, Friedrich CM, Reith D, editors. A Sales Forecast Model for the German Automobile Market Based on Time Series Analysis and Data Mining Methods. Industrial Conference on Advances in Data Mining Applications and Theoretical Aspects; 2009.

96. Horne, M.; Jaccard, M.; Tiedemann, K. Improving behavioral realism in hybrid energy-economy models using discrete choice studies of personal transportation decisions. Energy Econ. 2005, 27, 59–77.
97. Zhang Y, Zhong M, Geng N, Jiang Y, (2017) Forecasting electric vehicles sales with univariate and multivariate time series models: The case of China. PLoS ONE 12(5): e0176729. https://doi.org/10.1371/journal.pone.0176729
98. Stiller, C.; Bünger, U.; Møller-Holst, S.; Svensson, A. M.; Espegren, K. A.; Nowak, M. Pathways to a hydrogen fuel infrastructure in Norway. International journal of hydrogen energy 2010, 35(7), 2597-2601.
99. Tlili, O.; Mansilla, C.; Frimat, D.; & Perez, Y. Hydrogen market penetration feasibility assessment: Mobility and natural gas markets in the US, Europe, China and Japan. International Journal of Hydrogen Energy 2019, 44(31), 16048-16068.
100. Muratori, M.; Bush, B.; Hunter, C.; Melaina, M.W. Modeling Hydrogen Refueling Infrastructure to Support Passenger Vehicles. Energies 2018, 11, 1171.
101. WHO. Interactive Air Pollution Maps. Geneva, Switzerland ⟨http://maps.who.int/airpollution/⟩ 2016.
102. WHO. Global Urban Ambient Air Pollution Database ⟨http://www.who.int/phe/health_topics/outdoorair/databases/cities/en/⟩ 2016.
103. U.S. Department of Energy, Office of energy efficiency and renewable energy, hydrogen and fuel cell program record 13005: well-to-wheels greenhouse gas emissions and petroleum use for mid-size light-duty vehicles ⟨http://go.usa.gov/xW8CH⟩ May 2013.
104. Michaela Kendall, Fuel cell development for New Energy Vehicles (NEVs) and clean air in China, Progress in Natural Science: Materials International, Volume 28, Issue 2, 2018, Pages 113-120.
105. Kevin Kendall, Michaela Kendall, Bo Liang, Zhixiang Liu, Hydrogen vehicles in China: Replacing the Western Model, International Journal of Hydrogen Energy, Volume 42, Issue 51, 2017.
106. Ballard Power System, Majsmarken 1, DK-9500 Hobro, https://www.ballard.com/.
107. Hydrogen Analysis Resource Center, https://h2tools.org/hyarc.
108. Golyandina N, Nekrutkin V, Zhigljavsky A, editors. Analysis of Time Series Structure. SSA and Related Techniques, Chapman & Hall/CRC, Boca Raton; 2010.

109. Unione Nazionale Rappresentanti Autoveicoli Esteri, http://www.unrae.it/ UNRAE, https://www.colonnineelettriche.it/.
110. Viola, F.; Zaninelli, D.; Ala, G.; Schettino, G.; Castiglia, V.; Miceli, R.; Forecasting the diffusion of hydrogen EV refuelling infrastructures in Italy, 14th International Conference on Ecological Vehicles and Renewable Energies, EVER 2019, art. no. 8813602.
111. Jeremy Rifkin, The Hydrogen Economy: The Creation of the Worldwide Energy Web and the Redistribution of Power on Earth – August 25, 2003
112. Harry Turtledove, Worldwar, 1994, USA, Del Rey ISBN 0-345-38241-2
113. Stephen Eaves, James Eaves, A cost comparison of fuel-cell and battery electric vehicles, Journal of Power Sources, Volume 130, Issues 1–2, 2004, Pages 208-212, ISSN 0378-7753, https://doi.org/10.1016/j.jpowsour.2003.12.016.
114. Ayfer Veziroglu, Rosario Macario, Fuel cell vehicles: State of the art with economic and environmental concerns, International Journal of Hydrogen Energy, Volume 36, Issue 1, 2011, Pages 25-43, ISSN 0360-3199, https://doi.org/10.1016/j.ijhydene.2010.08.145.
115. Thomas Mayer, Malte Semmel, Martin Alberto Guerrero Morales, Karla Maria Schmidt, Artur Bauer, Joerg Wind, Techno-economic evaluation of hydrogen refueling stations with liquid or gaseous stored hydrogen, International Journal of Hydrogen Energy, Volume 44, Issue 47, 2019, Pages 25809-25833, ISSN 0360-3199, https://doi.org/10.1016/j.ijhydene.2019.08.051.
116. U. S. Department of Energy, Fuel cell technologies office multi-year research, development, and demonstration plan. 3.2 Hydrogen Delivery (2015)
117. D. Apostolou, G. Xydis, A literature review on hydrogen refuelling stations and infrastructure. Current status and future prospects, Renewable and Sustainable Energy Reviews, Volume 113, 2019, 109292, ISSN 1364-0321, https://doi.org/10.1016/j.rser.2019.109292.
118. Øystein Ulleberg, Ragnhild Hancke, Techno-economic calculations of small-scale hydrogen supply systems for zero emission transport in Norway, International Journal of Hydrogen Energy, Volume 45, Issue 2, 2020, Pages 1201-1211, ISSN 0360-3199, https://doi.org/10.1016/j.ijhydene.2019.05.170.
119. Gregory Barnett, Vehicle Battery Fires, Why They Happen and How They Happen, Warrendale, Pennsylvania, 2017 SAE International eISBN: 978-0-7680-8359-0

120. IEA, Hybrid and electric vehicle, Italy - Policies and Legislation. Available on: http://www.ieahev.org/by-country/italy-policy-and-legislation/.
121. PNMI. Available on: https://www.h2it.it/wp-content/uploads/2019/12/Piano-Nazionale_Mobilita-Idrogeno_integrale_2019_FINALE.pdf.
122. Skjærseth, J.B. Towards a European Green Deal: The evolution of EU climate and energy policy mixes. Int. Environ. Agreem. Politi Law Econ. 2021, 21, 25–41. https://doi.org/10.1007/s10784-021-09529-4.
123. European Environment Agency. Available online: https://www.eea.europa.eu/soer/2020 (accessed on 25 February 2021).
124. Muthukumar, M.; Rengarajan, N.; Velliyangiri, B.; Omprakas, M.A.; Rohit, C.B.; Raja, U.K. The development of Fuel Cell electric vehicles–A review. Mater. Today: Proc. 2021, 45, 1181–1187.
125. Fuel Cells and Hydrogen Observatory. Available online: https://www.fchobservatory.eu/observatory/technology-and-market/net-number-of-fcevsse%20vedi%20bisogna%20selezionare%20in%20europa%20la%20tipologia%20veicoli%20M1 (accessed on 21 October 2021).
126. McNichol, B.D.; Rand, D.A.J.; Williams, K.R. Fuel Cells for road transportation purposes—yes or no? J. Power Sources 2001, 100, 47–59.
127. Offer, G.; Howey, D.; Contestabile, M.; Clague, R.; Brandon, N. Comparative analysis of battery electric, hydrogen fuel cell and hybrid vehicles in a future sustainable road transport system. Energy Policy 2010, 38, 24–29. https://doi.org/10.1016/j.enpol.2009.08.040.
128. Robinius, M.; Linßen, J.F.; Grube, T.; Reuß, M.; Stenzel, P.; Syranidis, K.; Kuckertz, P.; Stolten, D. Comparative Analysis of In-frastructures: Hydrogen Fueling and Electric Charging of Vehicles; Forschungszentrum Jülich GmbH, Zentralbibliothek, Verlag, Jülich, Germany 2018.
129. Kverndokk, S.; Figenbaum, E.; Hovi, J. Would my driving pattern change if my neighbor were to buy an emission-free car? Resour. Energy Econ. 2020, 60, 101153. https://doi.org/10.1016/j.reseneeco.2020.101153.

130. Noel, L.; de Rubens, G.Z.; Sovacool, B.K. Optimizing innovation, carbon and health in transport: Assessing socially optimal electric mobility and vehicle-to-grid pathways in Denmark. Energy 2018, 153, 628–637. https://doi.org/10.1016/j.energy.2018.04.076.
131. Kumar, R.R.; Alok, K. Adoption of electric vehicle: A literature review and prospects for sustainability. J. Clean. Prod. 2020, 253, 119911. https://doi.org/10.1016/j.jclepro.2019.119911.
132. Nunes, P.; Pinheiro, F.; Brito, M.C. The effects of environmental transport policies on the environment, economy and em-ployment in Portugal. J. Clean. Prod. 2019, 213, 428–439. https://doi.org/10.1016/j.jclepro.2018.12.166.
133. Yong, T.; Park, C. A qualitative comparative analysis on factors affecting the deployment of electric vehicles. Energy Procedia 2017, 128, 497–503. https://doi.org/10.1016/j.egypro.2017.09.066.
134. Jochem, P.; Vilchez, J.J.G.; Ensslen, A.; Schäuble, J.; Fichtner, W. Methods for forecasting the market penetration of electric drivetrains in the passenger car market. Transp. Rev. 2018, 38, 322–348. https://doi.org/10.1080/01441647.2017.1326538.
135. Sood, A.; James, G.M.; Tellis, G.J.; Zhu, J. Predicting the Path of Technological Innovation: SAW vs. Moore, Bass, Gompertz, and Kryder. Mark. Sci. 2012, 31, 964–979. https://doi.org/10.1287/mksc.1120.0739.
136. Martino, J.P. A comparison of two composite measures of technology. Technol. Forecast. Soc. Chang. 1993, 44, 147–159. https://doi.org/10.1016/0040-1625(93)90024-2.
137. Yazdanie, M.; Noembrini, F.; Dossetto, L.; Boulouchos, K. A comparative analysis of well-to-wheel primary energy demand and greenhouse gas emissions for the operation of alternative and conventional vehicles in Switzerland, considering various energy carrier production pathways. J. Power Sources 2014, 249, 333–348. https://doi.org/10.1016/j.jpowsour.2013.10.043.
138. Wang, C.; Zhou, S.; Hong, X.; Qiu, T.; Wang, S. A comprehensive comparison of fuel options for fuel cell vehicles in China. Fuel Process. Technol. 2005, 86, 831–845. https://doi.org/10.1016/j.fuproc.2004.08.007.
139. Elgowainy, A.; Han, J.; Ward, J.; Joseck, F.; Gohlke, D.; Lindauer, A.; Ramsden, T.; Biddy, M.J.; Alexander, M.; Barnhart, S.; et al. Current and Future United States Light-

Duty Vehicle Pathways: Cradle-to-Grave Lifecycle Greenhouse Gas Emissions and Economic Assessment. Environ. Sci. Technol. 2018, 52(4), 2392–2399.
140. Rogers, E.M. Diffusion of Innovations; Simon and Schuster, New York, USA, 2010.
141. Zhang, L.; Meng, D.; Chen, G. BEV / HEV / FCEV Architectures; Noise, Vibration and Harshness of Electric and Hybrid Vehicles SAE 2020, 13-24.
142. Leaseplan. E.V Readiness 2020. Available online: https://www.leaseplan.com/en-ix/global-fleet-insights/ev-readiness-index-2020/ (accessed on 20 February 2021).
143. Alexander, D.; Gartner, J. Electric Vehicles in Europe; Amsterdam Roundtables Foundation and McKinsey & Company The Netherlands, 2012; Volume 60.
144. Minucci, A.S.; Ferreira, Â.P.; Fernandes, P.O. Impact of the Increase in Electric Vehicles on Energy Consumption and GHG Emissions in Portugal. In International Conference on Computational Science and Its Applications; Springer: Cham, Swiss, 2020; pp. 521–537.
145. Estatisticas–Autoinforma 2020. Available online: https://www.autoinforma.pt/pt/estatisticas (accessed on 23 February 2021).
146. ACEA Statistics, 2018. Available online: https://www.acea.be/statistics/article/trends-in-fuel-type-of-new-cars-between-2016-and-2017-by-country (accessed on 23 February 2021).
147. Fleetmagazine 2020. Available online: https://fleetmagazine.pt/2020/09/22/matriculas-bev/ (accessed on 25 February 2021).
148. ACAP Statistics 2020. Available online: https://acap.pt/pt/estatisticas (accessed on 25 February 2021).
149. Ala, G.; Colak, I.; Di Filippo, G.; Miceli, R.; Romano, P.; Schettino, G.; Silva, C.; Valtchev, S.; Viola, F. Forecasts on the devel-opment of Hydrogen Refuelling Infrastructures in Portugal. In Proceedings of the 2021 9th International Conference on Smart Grid (icSmartGrid), Setubal, Portugal, 29 June–1 July 2021.
150. Country Detail Electricity|EAFO 2020. Available online: https//www.eafo.eu/countries/portugal /1749/infrastructure/electricity (accessed on 20 February 2021).

151. Ec.europa.eu 2020. Available online: https://ec.europa.eu/energy/sites/default/files/documents/ptneeap2017en.pdf (accessed on 20 February 2021).
152. Magueta, D.; Madaleno, M.; Dias, M.F.; Meireles, M. New cars and emissions: Effects of policies, macroeconomic impacts and cities characteristics in Portugal. J. Clean. Prod. 2018, 181, 178–191. https://doi.org/10.1016/j.jclepro.2017.11.243.
153. Mebarki, B.; Allaoua, B.; Draoui, B.; Belatrache, D. Study of the energy performance of a PEM fuel cell vehicle. Int. J. Renew. Energy Res. (IJRER) 2017, 7, 1395–1402.
154. Wahib, A.; Samir, G.; Hatem, A.; Abdelkader, M. Energy Management Strategy of a Fuel Cell Electric Vehicle: Design and Implementation. Int. J. Renew. Energy Res. (IJRER) 2019, 9, 1154–1164.
155. Liu, F.; Zhao, F.; Liu, Z.; Hao, H. The impact of fuel cell vehicle deployment on road transport greenhouse gas emissions: The China case. Int. J. Hydrog. Energy 2018, 43, 22604–22621. https://doi.org/10.1016/j.ijhydene.2018.10.088.
156. Martinez-Burgos, W.J.; Candeo, E.D.S.; Medeiros, A.B.P.; de Carvalho, J.C.; Tanobe, V.O.D.A.; Soccol, C.R.; Sydney, E.B. Hydrogen: Current advances and patented technologies of its renewable production. J. Clean. Prod. 2021, 286, 124970. https://doi.org/10.1016/j.jclepro.2020.124970.
157. Partidário, P.; Aguiar, R.; Martins, P.; Rangel, C.M.; Cabrita, I. The hydrogen roadmap in the Portuguese energy sys-tem—Developing the P2G case. Int. J. Hydrog. Energy 2020, 45, 25646–25657. https://doi.org/10.1016/j.ijhydene.2019.10.132.
158. Working_Paper_-_National_Hydrogen_Strategies_-_September_2021. Available online: www.worldenergy.org/assets/downloads/ (accessed on 12 October 2021).
159. Staffell, I.; Scamman, D.; Abad, A.V.; Balcombe, P.; Dodds, P.E.; Ekins, P.; Shah, N.; Ward, R.K.The role of hydrogen and fuel cells in the global energy system. Energy Environ. Sci. 2019, 12, 463–491.
160. Samsatli, S.; Samsatli, N.J. A multi-objective MILP model for the design and operation of future integrated multi-vector energy networks capturing detailed spatio-temporal dependencies. Appl. Energy 2018, 220, 893–920.

161. Eu Strategy Recovery. Available online: https://ec.europa.eu/info/strategy/recovery-plan-europe/recovery-coronavirus-success-stories/environment-and-climate/hydrogen-drive- eus-green-recovery_it (accessed on 12 October 2021).
162. IEA. Available online: https://www.iea.org/fuels-and-technologies/hydrogen) (accessed on 12 October 2021).
163. Bush, B.W.; Muratori, M.; Hunter, C.; Zuboy, J.; Melaina, M.W. Scenario Evaluation and Regionalization Analysis (SERA) Model: Demand Side and Refueling Infrastructure Buildout; National Renewable Energy Lab. (NREL): Golden, CO, USA,2019.
164. Electromaps Borderless Charging 2021. Available online: https://www.electromaps.com/it/punti-di-ricarica/portugal (accessed on 25 February 2021).
165. MOBI.E 2021. Available online: https://www.mobie.pt/ (accessed on 25 February 2021).
166. INE—Instituto Nacional de Estadistica. Available online https://www.ine.es/en/censos2011_datos/cen11_datos_inicio_en.htm (accessed on 20 February 2021).
167. Muratori, M.; Bush, B.; Hunter, C.; Melaina, M.W. Modeling Hydrogen Refueling Infrastructure to Support Passenger Vehicles. Energies 2018, 11, 1171. https://doi.org/10.3390/en11051171.
168. IEA. Global EV Outlook 2019. Available online: https://www.iea.org/reports/global-ev-outlook-2019 (accessed on 25 February 2021).
169. Ala, G.; Di Filippo, G.; Viola, F.; Giglia, G.; Imburgia, A.; Romano, P.; Castiglia, V.; Pellitteri, F.; Schettino, G.; Miceli, R. Different Scenarios of Electric Mobility: Current Situation and Possible Future Developments of Fuel Cell Vehicles in Italy. Sustainability 2020, 12, 564. https://doi.org/10.3390/su12020564.
170. Turoń, K.; Kubik, A.; Chen, F. When, What and How to Teach about Electric Mobility? An Innovative Teaching Concept for All Stages of Education: Lessons from Poland. Energies 2021, 14, 6440. https://doi.org/10.3390/en14196440.
171. Viola, F. Electric Vehicles and Psychology. Sustainability 2021, 13, 719. https://doi.org/10.3390/su13020719.