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Different Scenarios of Electric Mobility: Current Situation and Possible Future Developments of Fuel Cell Vehicles in Italy

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Abstract: The diffusion of electric vehicles in Italy has started but some complications weight its spread. At present, hybrid technology is the most followed by users, due particularly to socioeconomic factors such as cost of investment and range anxiety. After a deep discussion of the Italian scenario, the aim of the paper is to recognize whether fuel cell technology may be an enabling solution to overcome pollution problems and respect for the environment. The opportunity to use fuel cells to store electric energy is quite fascinating—the charging times will be shortened and heavy passenger transport should be effortless challenged. On the basis of the present history and by investigating the available information, this work reports the current e-mobility state in Italy and forecasts the cities in which a fuel cell charging infrastructure should be more profitable, with the intention of granting a measured outlook on the plausible development of this actual niche market.

Keywords: e-mobility; electric vehicles; battery electric vehicles; socio-technical transition; future of e-mobility

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1. Introduction

In the last twenty years, great attention has been paid 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 [1]. The carbon dioxide emissions from road transportation have increased considerably and in 2013 they were even 50% higher than in 1990 [2].

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 [3].

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) [4]. 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 400 ppm 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 [4].

A change of course is needed but different sociopolitical aspects prevent the development and spread in the communities of sustainable vehicles [5–7]. 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" [8], 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 [9] and also, since a car is a prestige good, of neighbors' opinions [10]. 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 [11–14]. 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 [9], investigates which communities are more ready to accept a complex technology such that of fuel cells.

The paper is divided in the following paragraph. Paragraph 2 refers to the situation of electrification of transport. Paragraph 3 focuses its attention on the sociopolitical aspects in the acceptance of electric vehicles and on the pollution situation in Italy. Paragraph 4 explains the used algorithm to identify cities more ready for new technology. Paragraph 5 refers to the negative aspects that must be considered and overcome. Then, conclusions arrive.

2. Current Scenarios of Electric Mobility

The mobility agenda in Europe [15] 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 [16] show that the use of electric vehicles (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 [17].

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 [18]. 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 [19]. 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 [20]. 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, Figure 1. 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 [21,22].

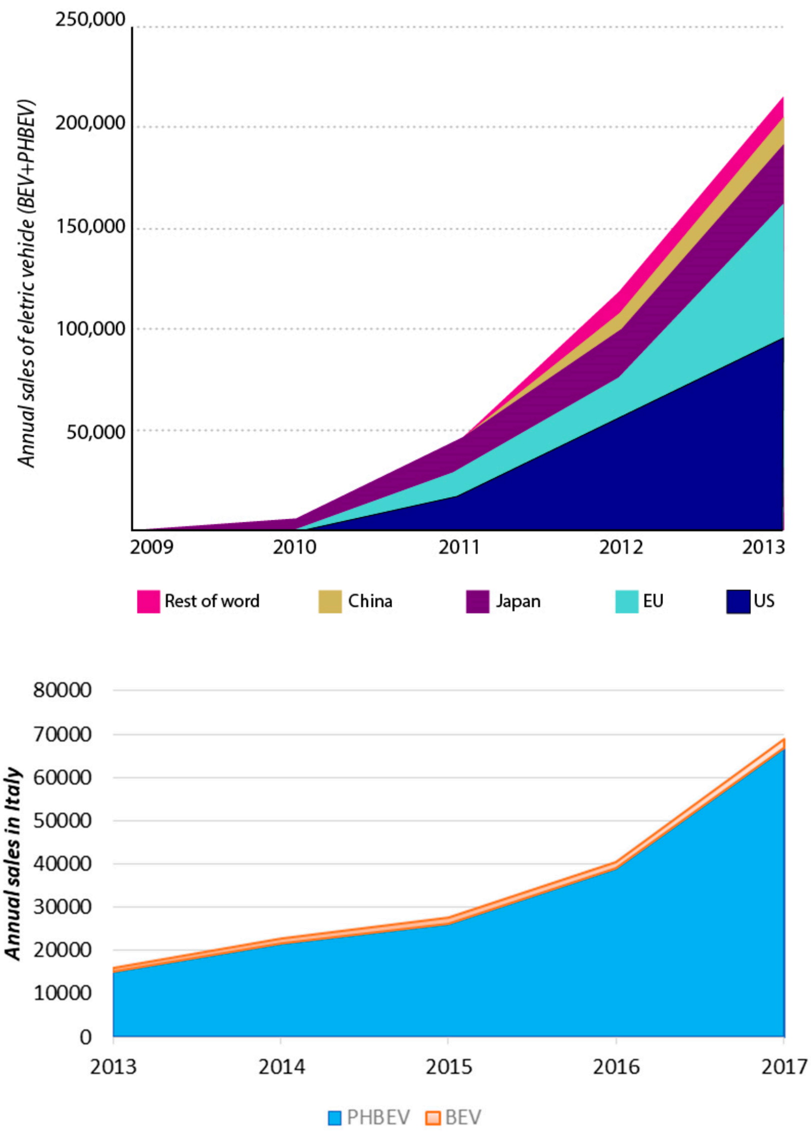

Figure 1. Electric vehicle (EV) sales growth from 2009 to 2013—figure reproduced from Reference [21] and focus on Italian sales [22].

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 2)—high-power direct current DC and alternating current AC charging mode [11].

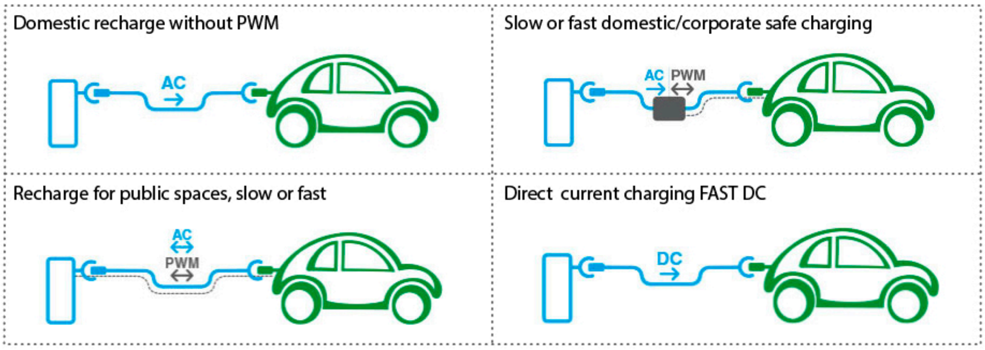

Figure 2. Different ways of electric vehicle charging methods.

Currently the European standard IEC 62,196 [23] 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.

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 3). 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.

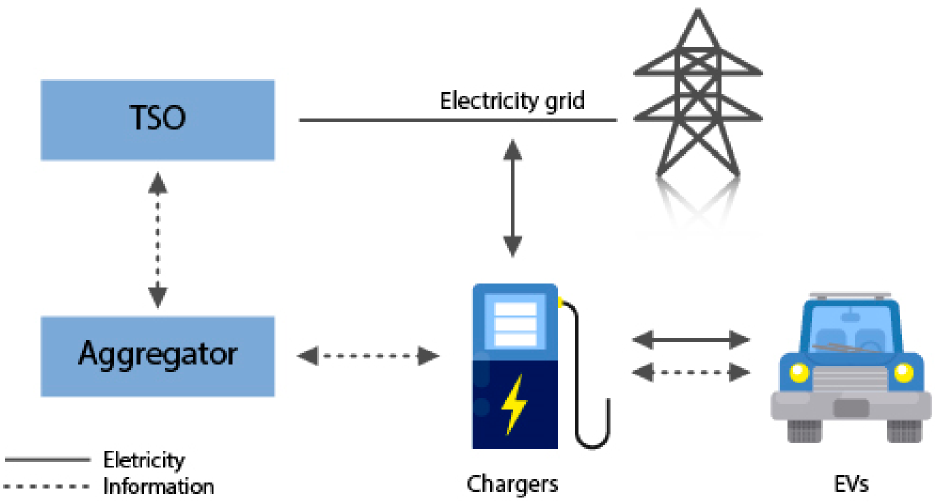

Figure 3. Basic scheme of vehicle-to-grid (V2G).

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 [24]. 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 4).

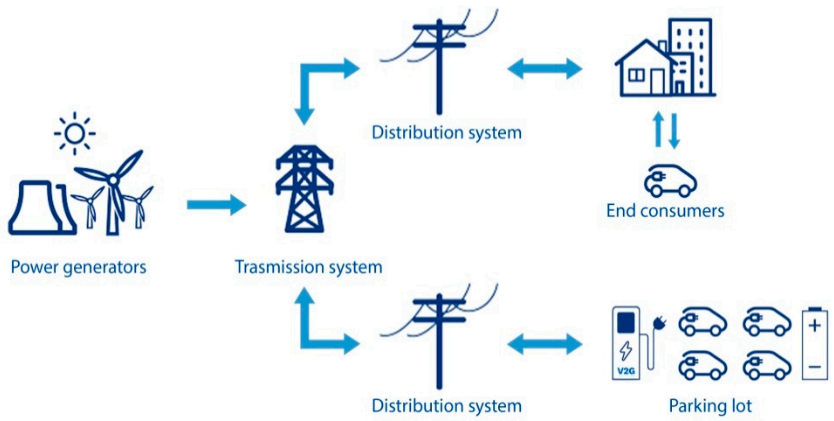

Figure 4. Schematic of the vehicle-to-grid (V2G) concept, it is noted the bidirectionality introduced in the smartgrid.

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 [25].

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 [26]. 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 [27], the feasibility of V2G in the national electricity grid is evaluated (Figure 5). 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.

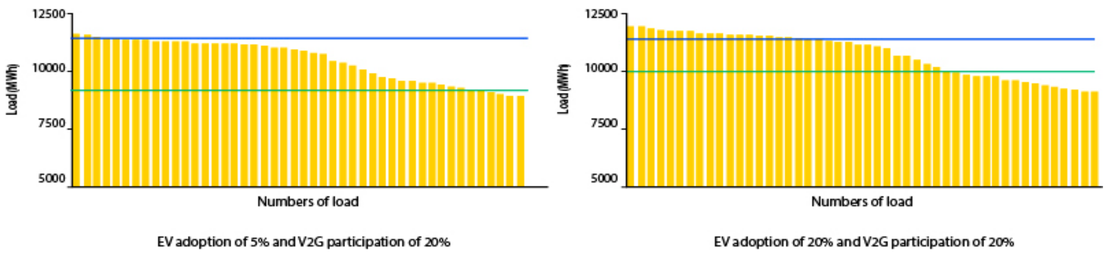

Figure 5. The load leveling amount under different EV acceptance and V2G participation, a quality windows in feeding the grid is given by the two lines—data from Huda et al., 2019 [27].

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 [28]. Along with advances in V2G technology, the implementation of electric vehicle charging stations on electricity distribution nets is facing new challenges (Figure 6). 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.

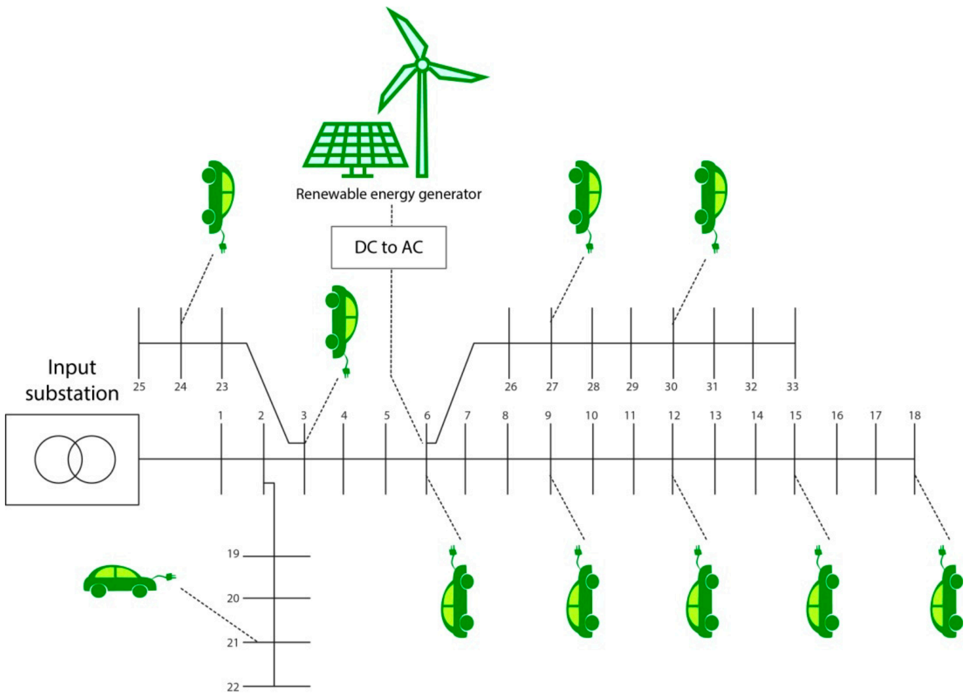

Figure 6. IEEE 33-bus network connecting charging stations and renewable energy system.

Vehicle-to-grid should be used correctly in a domestic energy managing system as a storage element to decrease energy costs [29]. It is also a promising answer to support the diffusion of renewable energy generation; in particular, it could regulate the intermittent service of RES [30]. The key contribution of V2G is to reduce peak demand and provide peak demand through the discharge of electric vehicles (Figure 7). 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 [31]. 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 [32]. The appropriate solution to reduce the cost of battery degradation can be intelligent charging [33].

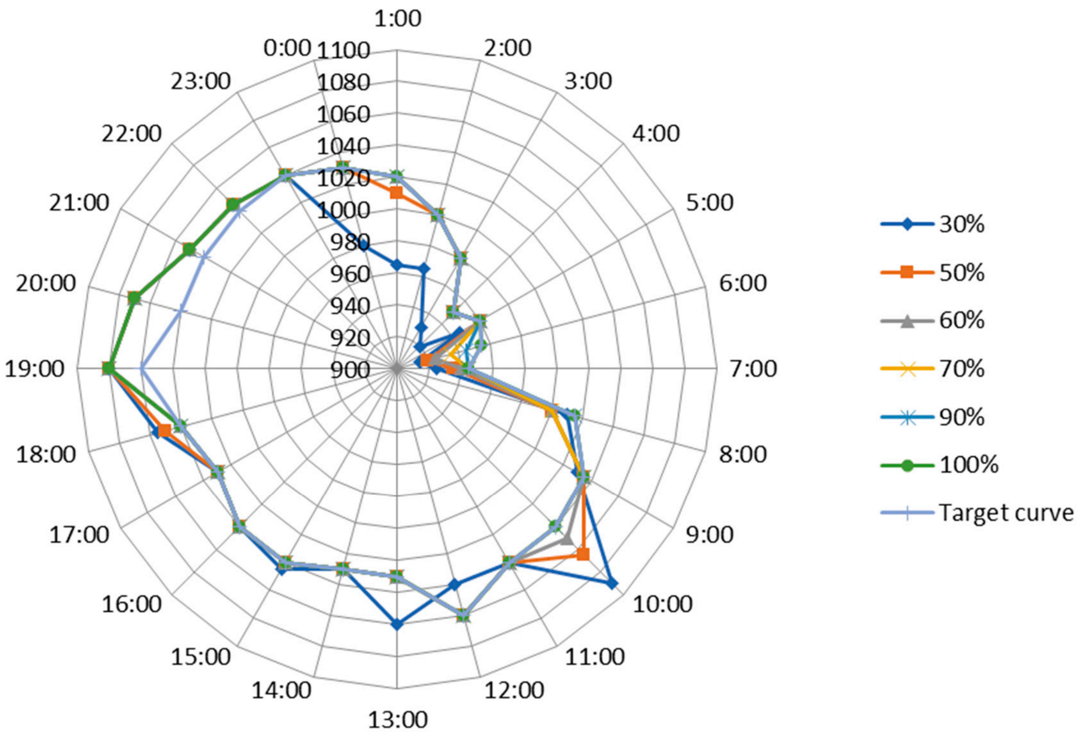

Figure 7. Amount of connected electric vehicles on peak shaving and valley filling, data from Wang and Wang, 2013 [33].

3. Sociopolitical 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 [34] 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 [35].

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 [36]. 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. [37] 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. [38]. 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, that is, ICE, BEV, PHBEV. The study of forecasting models can lead to provide the right political implications for particular countries like Korea [39].

More detailed studies consider various attributes—price, range, acceleration, top speed, pollution, size, luggage space, operating cost and charging station availability [40]. 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 [41], 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 [42]. Authors in Reference [43] 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 [9]. 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.

3.1. 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 [44].

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 ICE fuel vehicles' 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 s it accelerates from 0 to 100 km/h) and the recharge time of the hydrogen tank is assessed in an interval of 3–5 min. 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 [45]. 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 FCEV. 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.

3.2. 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 Reference [46], 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 µg/m^3, PM10 20 µg/m^3) [47], in Figure 8.

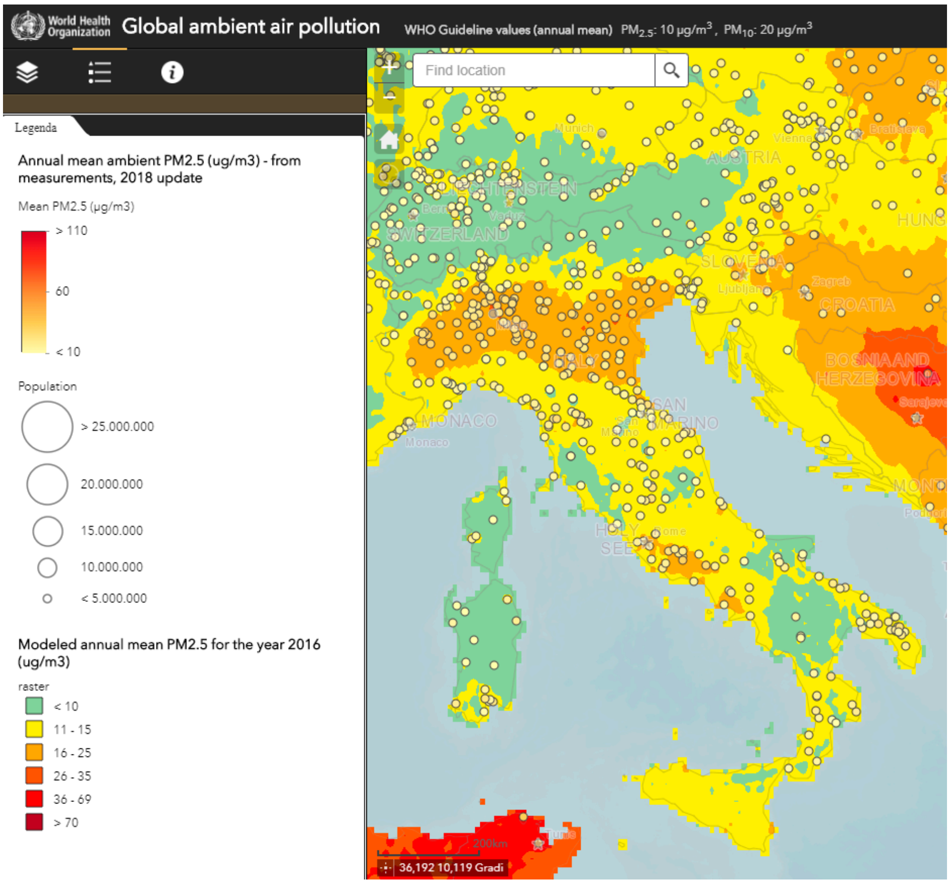

Figure 8. Chart of the PM2.5 distribution among Italy, green areas are under the limitations of 10 µg/m^3, yellow areas in the range of 11–15 µg/m^3, orange areas are in the windows of 16–25 µg/m^3. Air pollution maps are present at http://maps.who.int/airpollution.

By taking into account an additional exhaustive database of WHO for the year of 2016 [48], Figure 9 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.

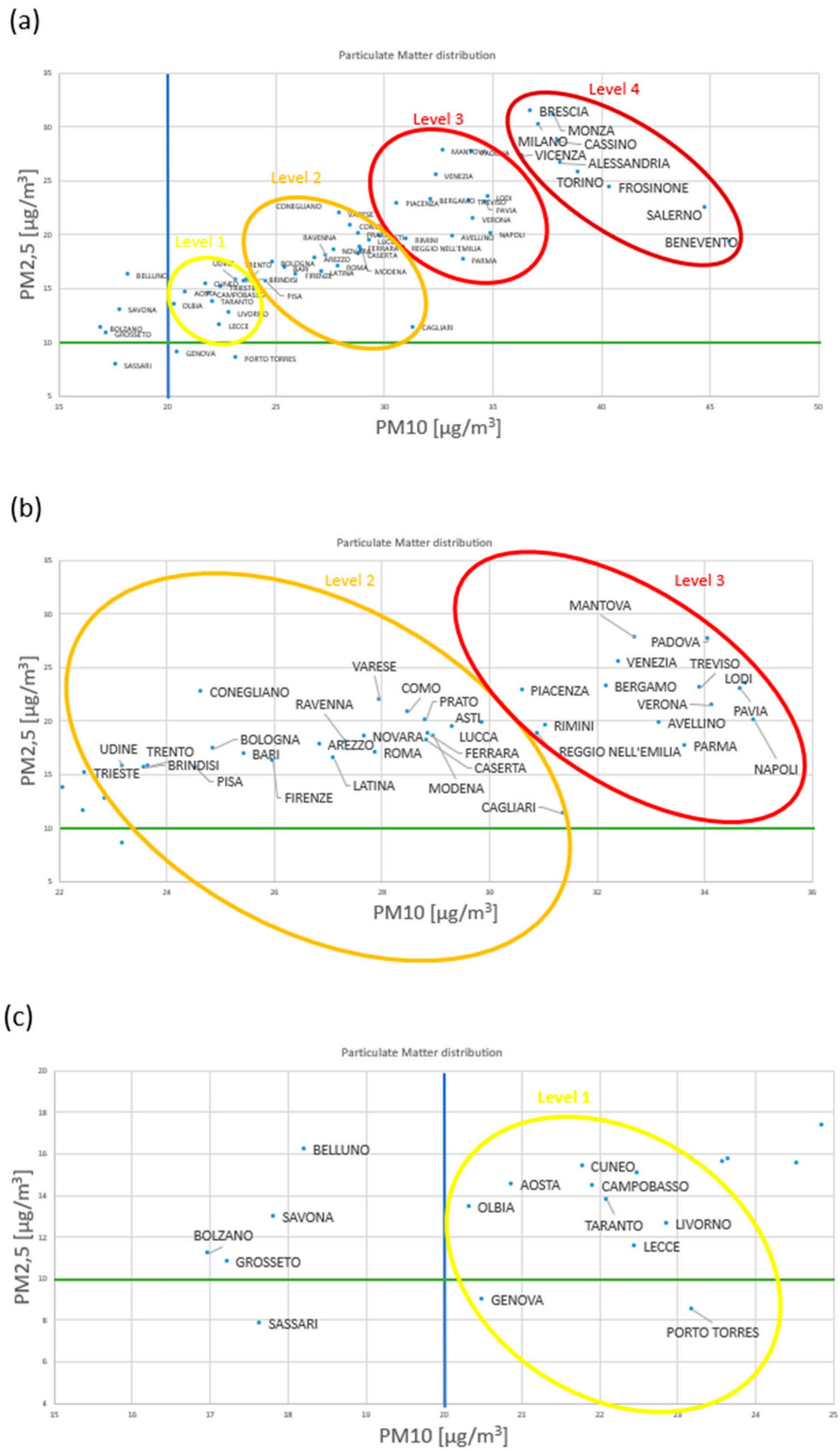

Figure 9. Cluster of particulate matter distribution in Italy. Cities are grouped in four levels (**a**), an enlargement is shown in (**b**,**c**). Green and blue lines dash the limits of WHO. http://www.who.int/phe/health_topics/outdoorair/databases/cities/en/.

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% [49,50].

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 [51]. A contract signed with Ballard [52] 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 eight planned hydrogen charging stations, Figure 10 but few of the planned infrastructures really operate [53]. 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 10. 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.

4. Chart of the Present Scenario

As stated in Section 3, 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 [54]. While SSA is non-parametric and data-driven technique, vector autoregressive model (VAR), can face multiple time series [55] and was successfully used in the dynamic couplings between EV sales and economic indicators [43]. A step forward was presented in Reference [29], 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 Reference [46], 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 the 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, that is, the probable adopters per refilling infrastructure, while in the abscissas the quantity of early adopters per square meter, that is, 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 References [22,53] provided suitable data for the analysis.

The "*priority*" in assessing positive urban markets is shown in Figure 11. Cities were clustered in three grouping levels, that is, 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.

Among 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 also share geographical position—they are in the North of Italy and, above all, in the Lombardy region.

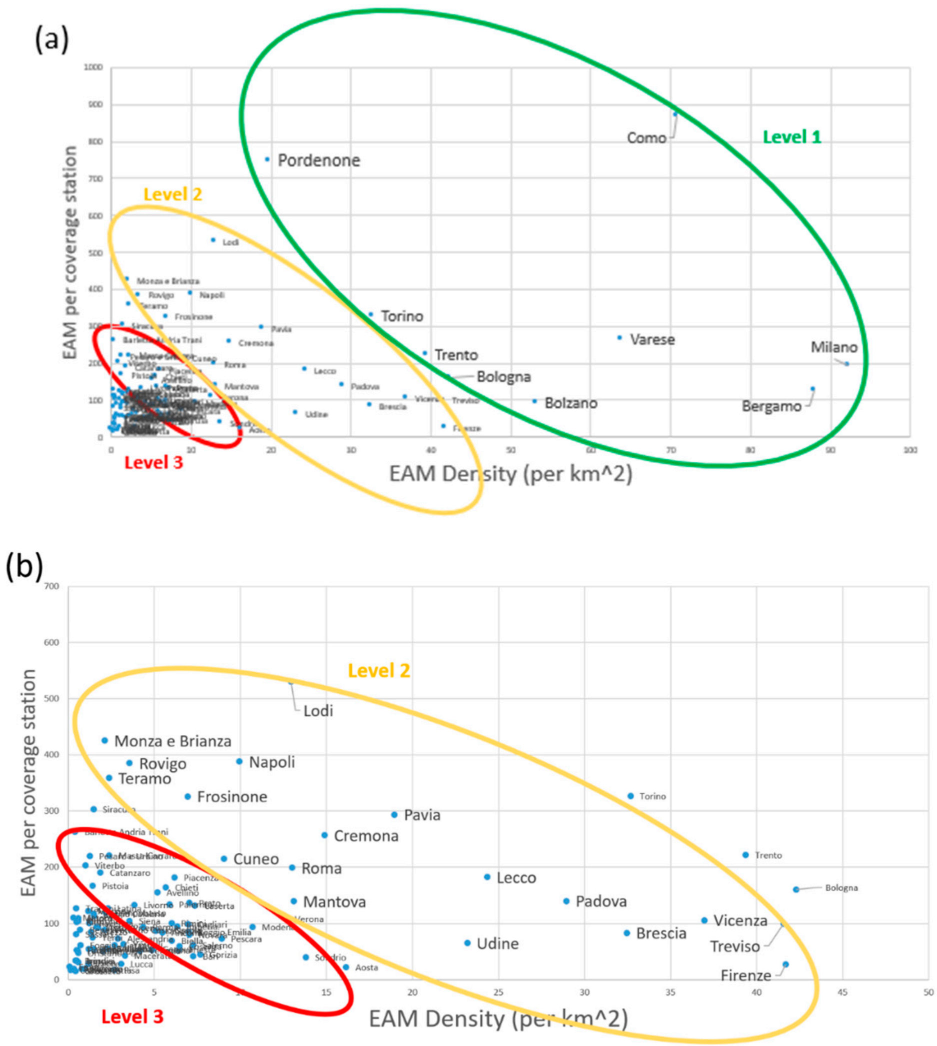

Figure 11. *Cont.*

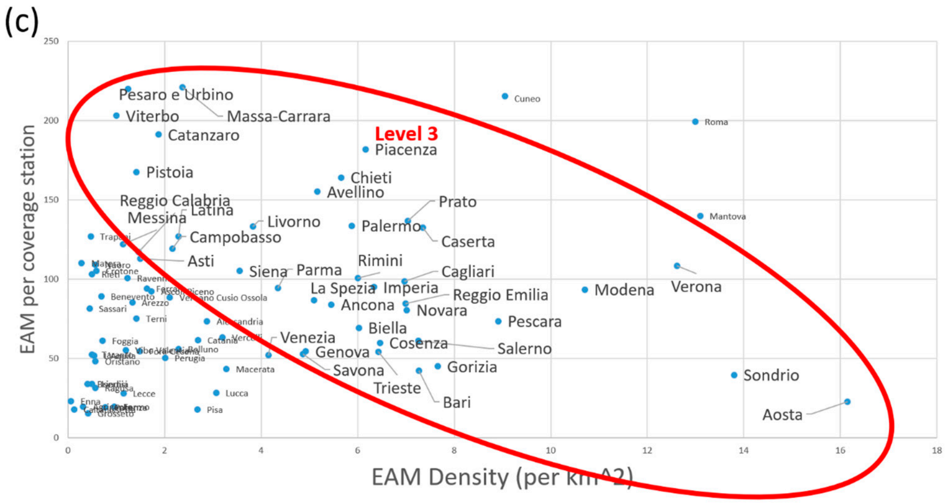

Figure 11. "Early adopters metrics" (**a**), in abscissas the number of early adopters per coverage station, that is, divided by the dimension of cities, in ordinates the amount of early adopter's density weighted by amount of charging infrastructures. (**b**,**c**) an enlargement of (**a**); level 1 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 11 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.

Upcoming Scenarios

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 [46].

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

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

where

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

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

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

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

In Equation (1) 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 (2), 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 (2) to reduce the willingness, it is expressed in (4) which faces the relation "chicken and egg" problem.

Databases present in References [22,53] 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 12. In this analysis only the cities clustered on Level 1 and 2 of Figure 11 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 [56].

Figure 12b 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.

(a)

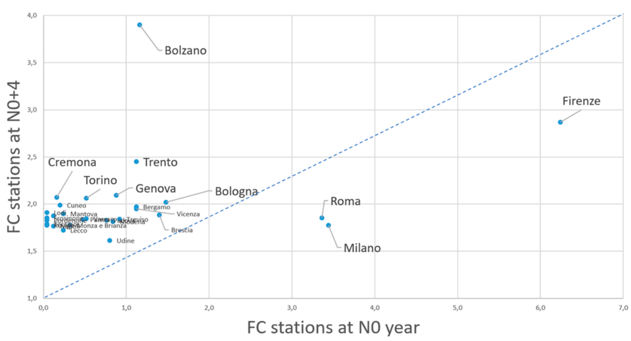

Figure 12. *Cont.*

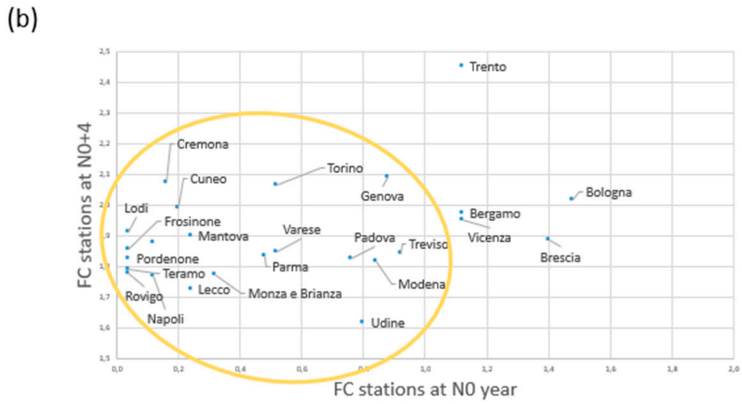

Figure 12. This picture reports the willingness to adopt the FC technology for different cities, Figure (**a**). Among the cities, Bolzano showed the tendency to quadruple the presence in the territory of the FC enabling stations. The considered years are in the windows 2013–2017. Figure (**b**) regroups cities that without having an initial FC enabling station, rapidly increase the number of FC plants.

Substantially Figure 12 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 12 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.

5. 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 [57,58].

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 Reference [59] a fuel cell vehicle requires more energy to drive the same distance, Figure 13.

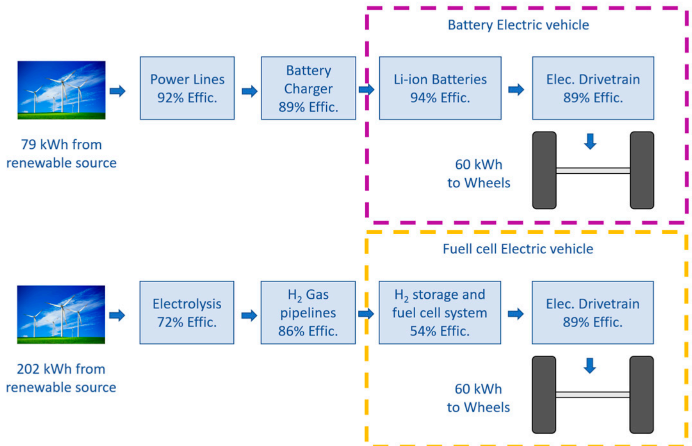

Figure 13. Well-to-wheel energy pathway for battery electric vehicle and fuel cell vehicle. The BEV regeneration capability reduces 60 kWh requirement by 6 kWh, while achieving the same range. For FCEV the pipeline includes losses from compression, expansion, storage and distribution [59].

Such comparison shows the major requirement for a FCEV than BEV in primary energy [59] 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 Reference [59] 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 [60]. 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 Reference [61] reports the cost of an investment in refueling station based on data in Reference [62]; 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 [63]. By considering the more advanced Country in Europe for the adoption of EVs, Norway, similar investment costs are suggested in Reference [64].

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 Reference [65], 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") [66] with the collaboration of the association H2IT [67], a long time missing in Italy. The plan expects FC passenger cars to grow in number from 1000 in 2020 to 27,000 in 2025, 290,000 in 2030 and FC buses to reach 3660 in 2030 from an initial 100 in 2020 and 1100 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 [66].

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.

6. Conclusions

This article aims to study the propensity to adopt ecological and sustainable vehicles in Italy. Specifically, the scenario of FC vehicles was investigated. The objective is to draw which, among the Italian 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.

A reason for urgently adopting vehicles with low emissions can be the city air quality, so the first part of the 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 the study 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 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.

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