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Routing Optimization Software for Electric Vehicles Applied to Charging Stations

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Ai miei genitori, alla mia famiglia, alla mia ragazza Giulia
che mi hanno sempre sostenuto durante questo percorso

ABSTRACT

The aim of this work is to develop a software that identifies the charging possibilities present along the route by simulating a trip with an electric vehicle in order to evaluate the planning of the charging stations in an area and identify any critical issues.

The first part of the work focuses on the concept of green mobility and the importance that electric vehicles will have in the future, but also on the difficulties they are encountering in their diffusion, in which their limited range plays a fundamental role. This introduces the importance of a good planning of charging stations, necessary to make the transition from internal combustion vehicles to electric vehicles as comfortable as possible for drivers.

The types of charging infrastructures present at international level, the charging modes and the types of connectors are then addressed, also considering their regulatory aspect.

The second part of the work deals with the current situation in Italy regarding public charging infrastructures. The territorial distribution, the powers used and the operators present in the territory are analyzed basing on a mapping carried out in collaboration with Motus-E. After this general overview, the focus shifts on a brief description of the Lombardy region.

The third part presents the developed software in detail by exposing all the functionalities, the data used and the way it has been processed, the information requested, and the results provided. All the equations entered, and any approximations present are explained, as well as the various scenarios that the program allows are shown.

The last part shows the use of the software. Some simulations have been made considering different input data and scenarios in order to expose the functionality and the possibilities that the program offers, but above all to analyze some areas in Lombardy and identify any critical issues in the presence of charging stations.

Summary

CHAPTER 1: The current Situation of EVs

Nowadays, in the field of mobility, there is much talk about the concept of "Smart Mobility" and the related explosion of the electric vehicle market. The latter, despite the great and evident benefits they can bring, are experiencing some difficulties in mass diffusion. In this chapter we will analyze the concepts of Smart Mobility, the current situation of the electric vehicle market at an international level and the importance that charging structures have in the diffusion of the latter.

1.1 Overview

Considering the growing popularity of Electric Vehicles (EVs), Charging Station Placement has become a topic of great interest.

This popularity comes from the great advantages that EVs have if compared to traditional inner-combustion vehicles; in fact, they use electrical energy to power the vehicle, which has a lower cost than fossil fuels. Furthermore, fossil fuels are limited resources, while electricity can be easily converted from other forms of energies and generated from renewable sources of energy, which makes EVs more environment-friendly.

The consumption of fossil fuels by vehicles has caused serious problems of air pollution, especially in big cities, and switching to electric vehicles would help reducing this problem. This is the main reason why society has made a great effort in researching and developing EVs during the past years.

Despite all these advantages, Electric Vehicles are encountering some difficulties in spreading in the car market and being accepted by the majority of drivers. That is mainly due to what is called “Range anxiety”. Range anxiety is the fear that a vehicle might have insufficient range to reach its final destination. As a matter of fact, EVs have limited battery capacity and mileage (usually from 200 to 400 km, although this numbers are likely to grow thanks to research projects aimed at developing batteries with greater capacity) and need frequent recharging, resulting in a big time consumption (it can take hours to completely recharge the battery of an Electric Vehicle); on the

contrary, inner-combustion vehicles have greater autonomy and refueling only takes a few minutes [1]. Moreover, each EV possessor should charge his car at home, but not every citizen possesses their own garage.
As a consequence, supporting facilities are a vital element for promoting EVs. Electric vehicle charging stations in particular are an essential need for EV drivers: their distribution and size represent vital points in the accessibility and convenience of EVs [2].
One would think that it would be enough to increase the number of charging stations on the territory to solve the problem, but it would be an expensive and not efficient solution.
There are many elements to consider while constructing charging stations, for instance geographical limitations, economic budgets, and, most importantly, the interaction between the charging stations and the EV drivers.
Charging stations are chosen by EV drivers considering their serviceability and position [3].
Firstly, the serviceability of a charging station can be affected by the queues: because of the long time required by the charging process (which, even if shorter than at home, can still take many minutes), queues in charging stations can generate a long waiting time for drivers and ultimately influence the adoption of EVs [4].
Secondly, the position of the charging station is another important issue. Drivers would prefer charging stations located along their path, but if too long a deviation is needed to reach the charging station, the driver could choose not to use that particular station. In return, this would impact on the service quality of the charging station and on the performance of the whole charging system. The placement of charging stations is a key research topic in the field of EVs: it is important to make sure that whether drivers need to charge their cars, this can be done in the easiest, fastest and most comfortable way possible [5].
Furthermore, the construction of charging stations must be accurately planned, as it is irreversible and requires high expenses. However, the distribution of the population in a certain area may change in the future and that could influence the demand from EV owners, making this another aspect that must be taken into consideration [6].
There is great need of methods that can affect EV drivers' behavior, starting from a

dinamic pricing scheme, which is a costless and easily implementable solution [7].
Dynamic pricing schemes can be seen as a flexible complement to charging station placement as they adapt to variances between peak and non-peak time and changes of travel demand.
Due to all these aspect, the Electrical Vehicles market is in continuous and fast evolution and therefore some agreements are needed in order to regulate it.

1.2 The Smart Mobility Concept

The "Smart Mobility" concept, although there is no precise definition of it, indicates the evolution of the world of mobility towards a more "sustainable" model, from an environmental point of view (ie reducing the environmental impact associated with transport), by the economic one (i.e. reducing the cost associated with transport) and the social one (i.e. improving the quality of life of people).
Electrification, Sharing mobility and autonomous driving are the main trends that are redesigning the world of mobility towards this concept.
The term "electrification" means the transition from a traditional power supply (typically diesel or gasoline) to an electric one.
The issue of electrification is involving different types of vehicles: primarily cars but also heavy transport, public transport and other solutions, such as bicycles, scooters, etc.
It is also worth noting that there are other forms of power that are emerging as an alternative to traditional ones and to electric propulsion and always considered among the sustainable forms of energy, for example methane or hydrogen, the diffusion of which requires a significant change both at the vehicle level, both in the energy carrier's supply infrastructure.
In addition, it should be noted that traditional engines, in addition to seeing a progressive improvement in environmental performance, are the subject of initiatives aimed at increasing their level of sustainability, for example by exploiting CO_2 capture systems on board the vehicle.
The second trend, that of sharing, arises from the fact that statistically a vehicle owned by a person remains unused on average for 90-95% of the time during its useful life, and is used only for the rest of the time [8].

Starting from this concept, two possible solutions are outlined: One involves increasing the use of a vehicle through the so-called X-sharing, which is nothing more than sharing the vehicle between different users; the second involves the use of a vehicle when it is stationary (with particular reference to electric vehicles) through Vehicle - Grid Integration (VGI) technology, that is, the possibility of the vehicle to exchange energy bi-directionally with the electrical system [9].

At the moment, the theme of sharing is involving different types of vehicles:

as regards X-sharing, the types of vehicles involved range from cars to bicycles to scooters, while it is not used for heavy and public transport.

As regards the VGI, the types of vehicles involved mainly refer to passenger cars and light commercial vehicles. However, there are studies on the possibility of implementing it also on heavy vehicles, and in particular on buses [10].

It should also be emphasized that car sharing is not strictly linked to electric mobility, in the sense that the sharing of a vehicle can take place regardless of the form of power used.

Conversely, the VGI can only be implemented on electric vehicles, and especially on "plug-in" ones, since a connection with the electricity grid infrastructure is required.

Finally, the theme of autonomous driving refers to the use of sensors, radar, GPS, cameras, data analytics software and artificial intelligence in order to perceive the surrounding environment and thus automate the driving process, which therefore does not require the human intervention.

Currently a classification is in force created by the SAE (Society of Automotive Engineers), which offers 5 different levels of vehicle automation, in addition to level 0, which corresponds to the absence of automation. The Characteristics of each level of automation is expressed in Figure 1.1.

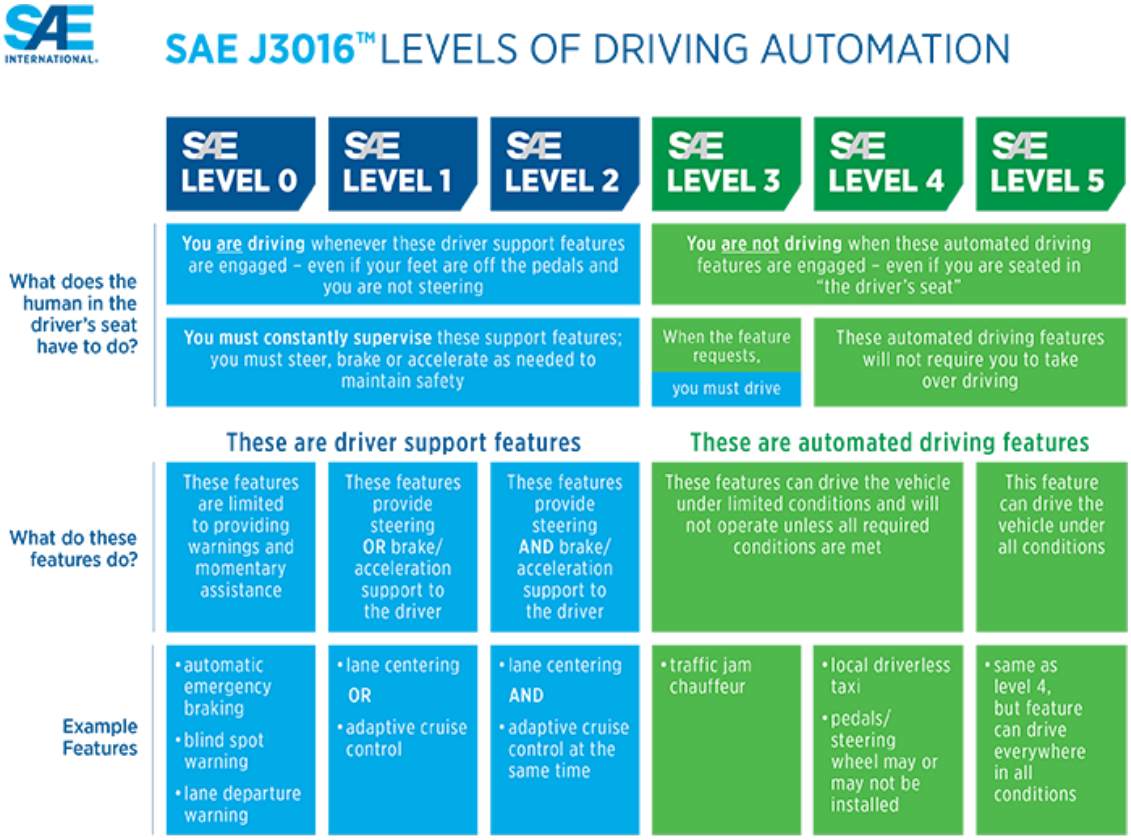

Figure 1.1. Levels of automation for vehicles (Source: sae.org)

At the moment, the topic of autonomous driving is mainly concerning cars. There are also plans for the implementation of autonomous driving technology for other vehicles. As an example, the case of the Swiss town of Zug is reported, where a pilot project of self-driving shuttles is active, whose first road tests were started in March 2018 [11].

Autonomous driving is mainly linked to electric mobility. This is supported by the fact that the majority of car manufacturers that are moving to develop autonomous driving see it combined with an electric motor, or the more hybrid, due to the fact that the two technologies are easily integrated.

1.3 Electric Vehicles Types

Electric vehicles are classified into three groups: Hybrid Electric Vehicles (HEVs), Plug In Hybrid Electric Vehicles (PHEVs) and Battery Electric Vehicles (BEVs), which are represented in Figure 1.2.

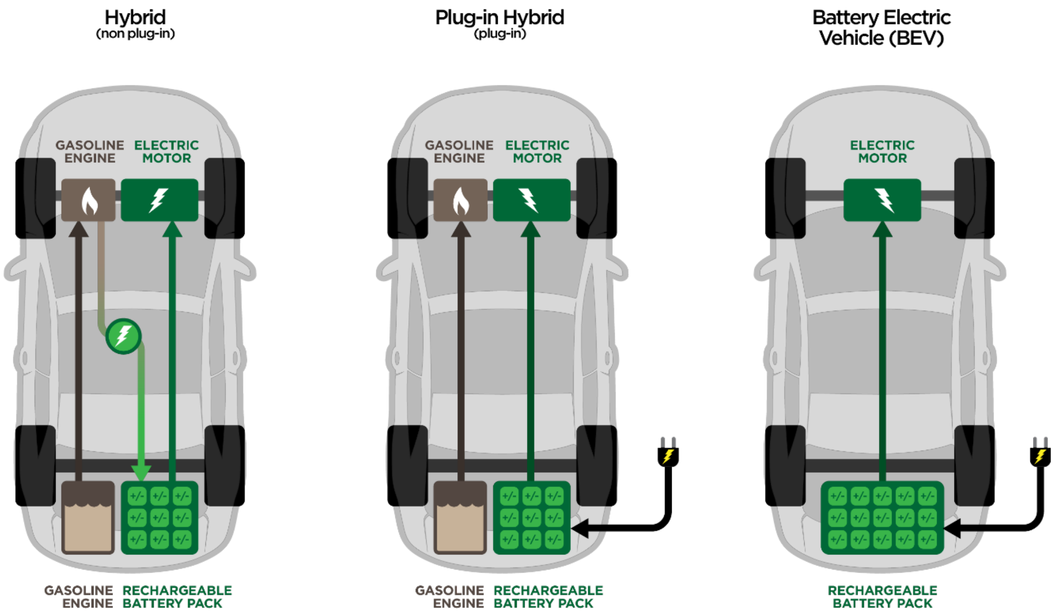

Figure 1.2. Types of electric vehicles (Source: nspower.ca)

HEVs, are vehicles in which the electric motor and internal combustion engine cooperate with traction. In this type of vehicle, the batteries cannot be recharged from the mains and all the energy used to power the electric motor is directly produced on board the vehicle with the usual conventional fuels.

PHEVs are vehicles in which the electric motor and internal combustion engine cooperate with traction exactly like normal HEVs, however, they are also equipped with high voltage batteries which can also be recharged from the mains. This type of vehicles, being able to use energy not directly produced on board the vehicle, are those that have a lower environmental impact.

There are also other HEV category hybrid vehicles without external recharging (commercially known as "Micro hybrid" and "Mild hybrid"), in which the electric motor, if present, is used to support traction (helps propulsion). It is not possible to drive exclusively in electric mode with these vehicles.

Finally, the BEVs are vehicles powered entirely by electricity coming from a battery, however the classification is not so easy, in fact there are other sub-categories of electric vehicles, such as the EREV one [12].

The acronym EREV stands for Extended-Range Electric Vehicle, it is a type of vehicle that moves mainly using electric traction and that, if necessary, can be recharged in the traditional way (from the network), or by exploiting an internal combustion engine on board. This engine has the advantage of operating at constant speed at the point of greatest efficiency and least consumption. In fact, it must not provide traction for the vehicle and consequently must not make starts, overcome climbs or obstacles thus saving substantial doses of fuel and therefore being optimized in design only for the refilling task.

1.4 Strategies to Spread the Electric Vehicles Market

Car buying can be influenced by many factors, both emotional and rational, just as it happens for many other consumer products. It is based on a comparison of advantages and disadvantages, for example utility vs. costs, that is made to identify the most cost-effective vehicle that will complete the required function. That is why EVs, in order to be taken into consideration in this decision process, should offer equivalent, or better, utility conditions and lower overall costs with respect to Internal Combustion Vehicles. However, at the moment they have limited range and complexively higher costs of ownership, not to mention the limited presence of charging infrastructures.

Currently, in many countries, EVs adoption has been encouraged by governments, forcing manufacurers to reallocate capital in order to provide an EV offering, and with economic incentives for buyers.

For example, the Chinese government targeted 2 million New Energy Vehicle (NEV) units by the end 2020 to comply with emissions targets; in order to reach this objective, subsidies and non-financial incentives are being offered in order to generate demand, and carmakers receive economic rewards for the number of NEV produced.

Another strategy is the one applied by the European Union, which imposes lower and lower average fleet CO2 emission targets to car manufacturers (for example, by 2020/21 it is required to reduce it to 95g/km). That leads to carmakers pushing low- and zero-emission vehicles sales. Furthermore, another method applied by authorities to reduce emission in cities is the application of Low Emission Zones, limiting the freedom of using ICE vehicles in certain situations.
There are aspects of Electric Vehicles that consumers prefer. According to a survey conducted by a group of car manufacturers and EV organizations, which takes into account opinions of over 850 EV drivers, in North America and Europe, the 85% of them is happy with the choice they made. A true mass adoption of EVs (with neither regulation nor incentives needed) will be possible in the future, but all the negative aspects should be overcome; actually, in the minds of consumers, the negative aspects of EVs overcome the benefits they offer (low fuel costs, quieter drive experience and environmental benefits) [13].

1.5 Barriers to Mass Adoption

As explained in the introduction, there are several reasons that slow down the process of mass adoption of Electric Vehicles. According to the results of various surveys, the main three barriers of mass adoption are prices, charging infrastructures and range anxiety. About the latter, it emerges that consumers want the possibility of driving long distance, but the average trip length (around 11km in Europe) can be easily covered by current BEVs [14].
Another aspect is the long time needed to recharge an EV. While a traditional vehicle needs just few minutes to refuel, a Battery Electric Vehicle can take hours to have its battery fully charged, and this aspect does nothing but feed the doubts about range, since, although the car can be recharged when it is parked, in some situations there may not be enough time to fully recharge the battery, thus having as a result an even less autonomy.
The one about autonomy is a challenge that car manufacturers are facing. Over the years, important steps forward have been made in order to improve the range that the vehicle can cover with a single full charge. Figure 1.3 shows how in the past years some

of the most important car manufacturers improved the autonomy of their EV models and the trend is continuously increasing.

BEV Model	2011	2012	2013	2014	2015	2016	2017	2018	2019	Increase in Miles	% Increase	Avg Annual Range Increase: Thru 2019
Kia Soul EV					93	93	93	111	186	93	100%	33.3%
Ford Focus Electric	76	76	76	76	76	76	115	115	115	39	51%	8.6%
Nissan LEAF	84	84	84	84	84	107	151	151	225	141	168%	21.0%
BMW i3				81	81	81	115	115	153	72	89%	17.8%
Tesla Model S		265	265	265	294	294	335	335	335	70	26%	5.3%
Volkswagen eGolf					83	83	125	125	125	42	51%	25.3%
Average	80	142	142	127	119	122	156	159	190	110	137%	17.2%

Figure 1.3. Battery range increase across the years (Source CleanTechnica)

In order to increase the autonomy of a battery there are three main aspects that must be taken into consideration: Battery size, efficiency (and so charging time) and costs.
An increase in battery size implies an increase in weight, which reduces the vehicle's performance, so it would be better to increase energy density, reducing charging times; however, that would generate more heat. That is why it is not easy to find a perfect balance between all these aspects. Furthemore, bigger batteries surely lead to longer ranges but also to higher costs. The same happens with efficiency of batteries, which is still proportional to costs.

1.6 The Problem of Ageing of Batteries

Another fear of customers that influences their choice of vehicle at the expense of the Electric is that related to the longevity of the battery.
In some cases this fear is unfounded, in fact statics conducted by Tesla on the Tesla model S, show that after 300,000km the battery is able to operate at 93% of its original range.
However, from another study conducted on the Nissan Leaf model, problems of battery degradation emerge. In fact, the 24kWh leaf batteries decrease their autonomy by 3%

every year, while the 30kWh batteries even decrease by 7%.
Nissan stated they are aware of these issues and they are trying to improve this decline with the new 40kWh and 60kWh battieries launched in 2019 [15].
A technology that could help safeguard the capacity fade could be the Vehicle-to-grid, in which energy is transferred from EV batteries to the power grid when it is not required by the vehicle.
A recent study has shown that the process can improve battery life by 9% over a year, and this suggest the non-irreversibility of the decline in health of a battery.
To overcome this problem and to reinforce confidence in the longevity and quality of their products, warranties are offered by some carmakers on the batteries contained within their EVs. Each of them defines a threshold which, if a battery fails once capacity has degraded below it, it can be changed for free [16].

1.7 Charging Infrastructures Around the World

As previously mentioned, charging infrastructures are another important aspect that influences decisions about EV adoption of customers.
Motorists accustomed to IC vehicles would like to have the same comforts and, in addition to a good autonomy, also the possibility of refueling in the shortest time possible and finding charging stations easily, without having to deviate too much from their original route.
At the end of 2018, around 540,000 public charging points were estimated worldwide, of which around 140,000, fast charge, i.e. with power exceeding 22 kW, an increase of about 25% compared to 2017, as can be seen in Figure 1.4 [10].

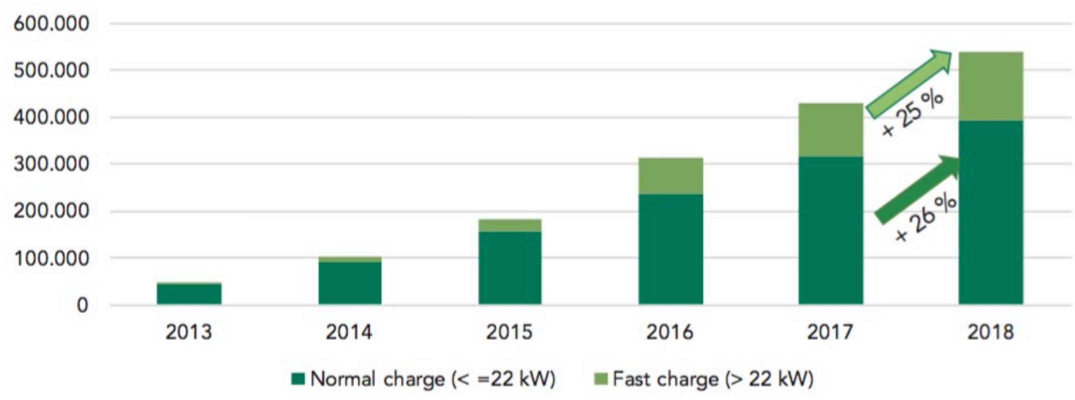

Figure 1.4. Growth of the number ofcharging points around the world (source: Smart Mobility Report)

China is the first nation in the world in terms of number of charging stations, both with reference to the normal charge and fast charge infrastructure, with a market share of 41% and 77% respectively.

On the normal charge infrastructure, the United States (13%) and Holland (9%) follow, while the scenario for the fast charge infrastructure is rather fragmented (follow Japan, with 5%

of the total, and the United States, with 3%).

In Europe, an estimated 160,000 public charging points are currently estimated, of which about 15% fast charge, an overall increase of 14% compared to the previous year. In the first eight months of 2019, approximately 15,000 public charging points were installed, bringing the total to more than 176,000.

The growth of the fast charge points was much more marked than that of the normal charge points in percentage terms (respectively 30% and 12%), albeit on lower absolute values.

However, these values take into account only absolute numbers, those corresponding to the recharging points present in a single territory. It is a good idea to take into consideration, as mentioned above, a habitual driver is willing to switch to the novelty of the electric vehicle only in conditions of equal comfort.

In this regard, compared to the absolute number of charging stations in a country, the ratio between this value and the number of inhabitants is much more interesting, since the driver is used to having a large number of petrol stations distributed throughout the territory, and the absence of long queues for refueling.

As can be seen in Figure 1.5, the number of charging points per million inhabitants (with the exception of Holland and Norway) is decidedly low if compared to the number of petrol stations. Just Italy alone has more than 20 thousand petrol distributors with a population of over 60 million inhabitants, a ratio that is more than double than that between charging stations for electric vehicles in the world and the world population.

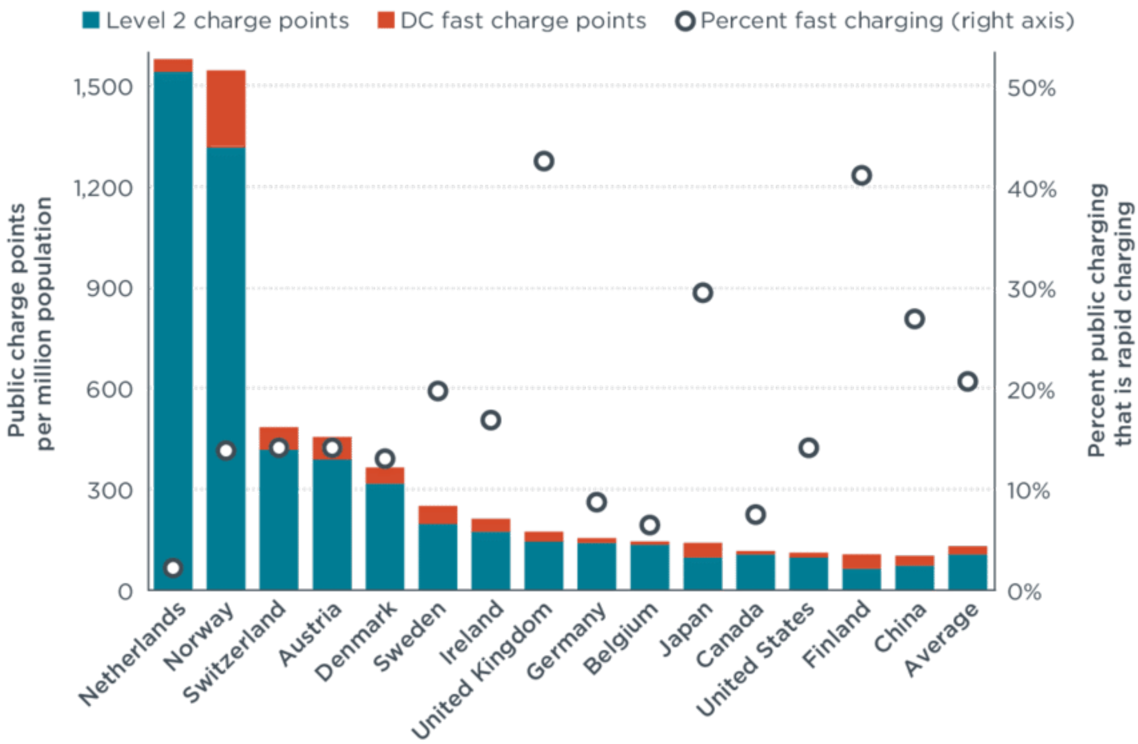

Figure 1.5. Public charging stations distribution (Source Researchgate)

In addition, long charging times must be taken into account. As can be seen from the graph, only a small percentage of charging stations for electric vehicles are equipped with fast charging systems, most of them are slow systems, which can take hours to fully recharge a battery. An advantage of electric vehicles, compared to IC ones, is the possibility of recharging at home, therefore with the possibility of always having a 100% battery before starting a journey; despite this, it seems clear that an increase in the number of public charging stations would convey more tranquility to potential buyers of EVs.

In fact, according to a survey conducted by the EV website Zap Map in 2016, the 81% of respondents have access to chargers at home and only 15% charge their cars at work [17]. Furthermore, it emerges that only 18% of the EV owners interviewed have the possibility to recharge their vehicle at the workplace, therefore, about 80% of those who have this possibility decide to do so.

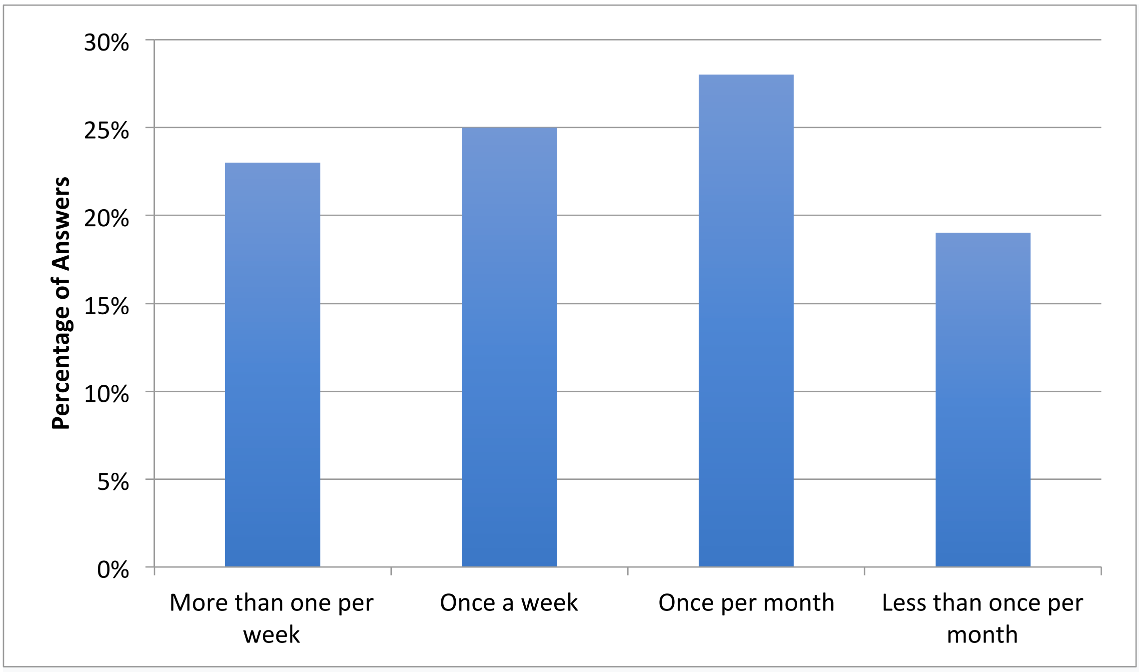

Figure 1.6. Frequency of use of public charging stations

Secondly, the results shown in Figure 1.6 suggest that, despite the fact that most of them recharge their vehicles at work or at home, almost half of the interviewees also use public charging stations at least once a week. These results may decrease in the event of an increase in range, but are currently an important need for drivers, and consequently it is a factor that affects range anxiety.

However, in many countries the ratio of electric vehicles in circulation is relatively low if compared to the number of charging stations. For example, comparing the situations of Norway and Holland, which, as mentioned above, are the countries with the largest number of charging stations in relation to the population, it is obtained that in Norway there is a public charging station every 19 EVs circulating, while in Holland the value of this ratio is only 4:1, which is currently excessive, a sign that there is still room for improvement in the spread of electric vehicles and already having a good supply network available is certainly an incentive. Worldwide, the ratio is approximately 10:1.

CHAPTER 2: Charging Systems

Charging stations are of central importance in the development of the EV Market; however, there are many types of them and nowadays it is an international topic of discussion to define standards, due to the interest of each nation and company to impose theirs on the market.
In order to solve this problem, some international standards have been defined by the International Electrotechnical Commission (IEC), which classifies charging systems in terms of charging mode, connections and plugs and sockets used.

2.1 Charging Modes

Charging systems are classified in 4 modes, according to the IEC 62851 standard.
Each mode can be distinguished in terms of type of current (AC, DC), maximum current, type of connector/plug and characteristics of communication/control between the vehicle and the charging station. Each charging mode has its own pros and contras which will be explained in this paragraph [18].

- Mode 1

In Mode 1, the Electric Vehicle is directly connected to the power supply by using regular sockets. These sockets are the ones for domestic use (in Italy conform to the standards CEI 23-50), or industrial use (CEI EN 60309-2), or special plugs and sockets which, however, must be conform to the international normative IEC.
This charge is usually at 16 A in AC, (32 A industrial sockets are allowed too) and it is generally slow (it can take from 6 to 8 hours to fully charge a vehicle).
Actually the charging Mode 1 is the most immediate option for charging EVs, but it has potential security problems. In fact, the good functioning in terms of security depends on overcurrent protections, earthing system and contact protections of the electric

system; and in some old systems it may be difficult for the users, when connecting their electric vehicle, to know whether the power supply system is adequately protected or not.
In countries where it is allowed, the use of charging mode 1 could, for a certain period, remain the most popular charging method for privates (for example residential garages and company car parks) thanks to its simplicity and affordable costs.
The cable used in Mode 1 is represented in Figure 2.1.

Figure 2.1. Mode 1 charging cable (source: www.esl-emobility.com)

- Mode 2

In Mode 2, the connection is made by using regular sockets too, and, as in Mode 1, it is at 16 A in AC and it is slow.
Additional protection is provided by a control box located on the cable between the electric vehicle and the charging station, less than 30 cm from the plug and containing, in addition to the devices for some control functions, also a 30 mA differential.
In addition to the obvious disadvantages of having a control device positioned on the cable, the main disadvantage of Mode 2 is that the control box protects the downstream cable and the vehicle, but not the plug itself, which in reality turns out to be the part that is most subject to wear.

The cable used in mode 2 is represented in Figure 2.2.

Figure 2.2. Mode 2 charging cable (source: www.esl-emobility.com)

- Mode 3

The charging mode 3 provides a direct connection between the AC power supply and the EV by using a specific EV multi-pin socket with control and protection functions.
This charging mode can be used either in private or public systems and allows not only a slow charge, but also a fast one at 63 A and 400 V (which can take a time between 30 minutes and 1 hour).

- Mode 4

This charging mode is used for DC charging, and provide the use of dedicated sockets for EV charging like mode 3. With Charging mode 4, the charger has a charging cable with a plug, and the control, communication and protection functions are built into the charging station.
The AC/DC convertion is provided by a converter located within the charging station.

These particular technologies allow a super rapid charge (between 5-10 minutes) in DC at 200 A and 400 V [19].

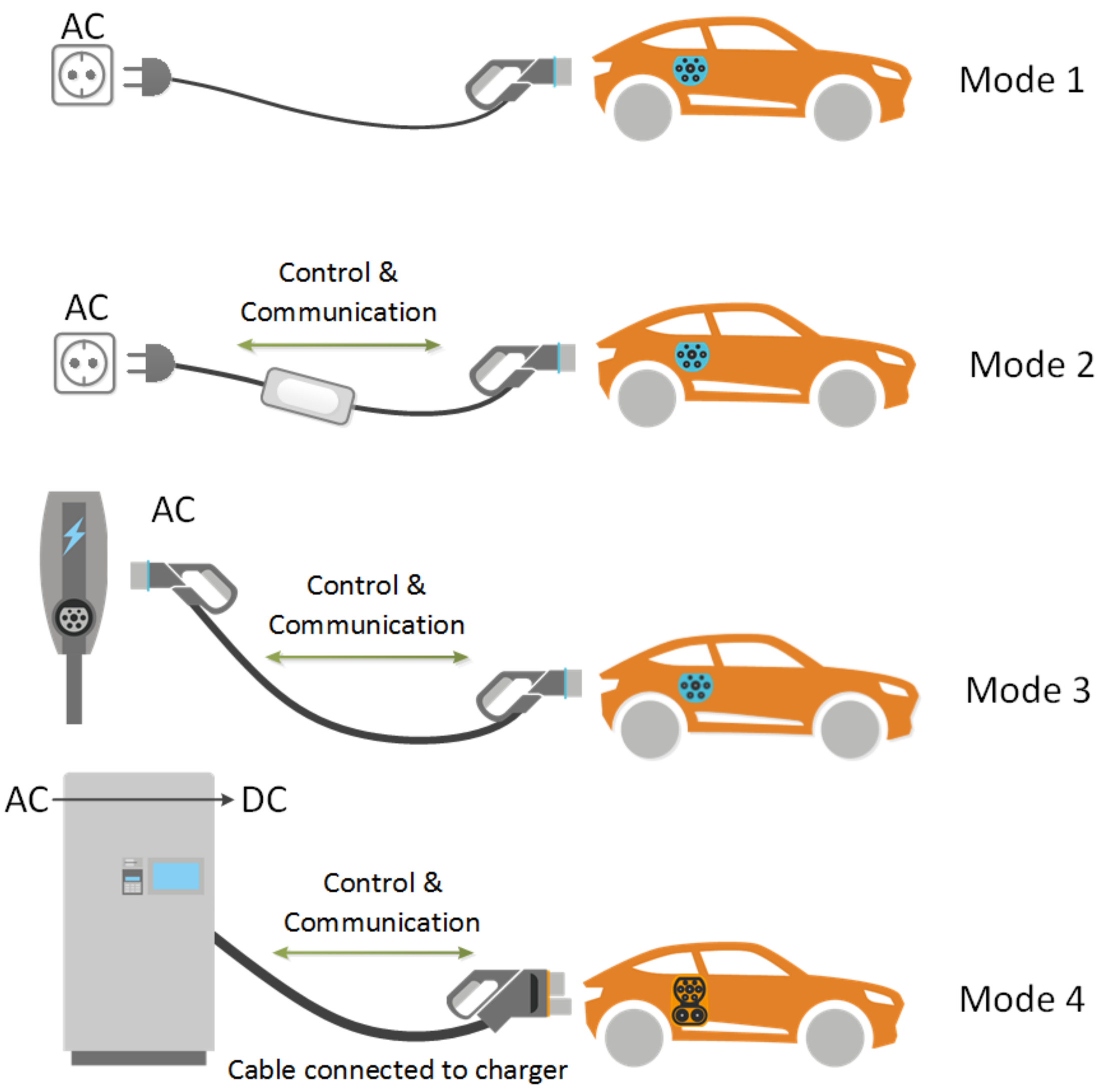

Figure 2.3. Scheme of the four charging modes (source: www.ocw.tudelft.nl)

All the characteristics of the four charging modes are represented in Figure 2.3 and Table 2.1.

Table 2.1. Charging modes summary

MODE	Specific Connector	Type of charge	Maximum current	Protections	Special features
Mode 1	NO	Slow in AC	16 A per phase (3,7KW – 11KW)	Differential and magnetic protections	EV connection to the AC network using standard power connection
Mode 2	NO	Slow in AC	32 A per phase	Differential and magnetic protections	Special cable with intermediate electronic device with pilot control function and protections
Mode 3	YES	Slow or Fast in AC	In accordance with the connector used (up to 63 A)	Included in the special infrastructure for EV	EV connection to the AC power supply using a specific device
Mode 4	YES	Fast in DC	In accordance with the charger	Installed in the infrastructure	EV connection using a fixed external charger

2.2 Connection cases

Following the previously described charging modes, IEC standards define three types of connections [20]:

- Case A

The electric vehicle is connected to the charging point using a power cable and a plug, which is permanently fixed to the vehicle itself.
This case is usually associated with modes 1 or 2.

- Case B

The electric vehicle is connected to the charging point using a removable power cable equipped with a mobile connector and plug for connection to the AC power socket.
This case is usually associated with mode 3.

- Case C

The electric vehicle is connected to the charging point using a power cable and a mobile connector permanently fixed to the power supply equipment.
Case C refers itself mainly to charging mode 4.

In addition to the obvious, but important, practical considerations related to the need to carry the power cable or not, there is an important difference in terms of responsibility amongst the various types of connection.

2.3 Other classifications: SAE International standard

Another classification, is the one applied by the US-based SAE International (Society of Automotive Engineering), which divides the types of charging in three levels, mainly taking into account voltage [21-22]:

- Level 1

Level 1 is defined as charging the electric vehicle by using a standard 120 V AC house outlet. As a matter of fact, level 1 is not used in countries where houses have a voltage of 200-240 V. This level leads to long charging times.

- Level 2

Level 2 implies an AC charging up to 240 V, a voltage that is commonly used in North and South America for household appliances. Level 2 chargers are used both for private charging systems and relatively slow public charging systems. They can take from 4 to 10 hours to fully charge an electric car battery.

- Level 3

Level 3 refers to DC charging, which generally supports up to 500 V for electric cars; however, some new EV trucks and buses can use DC charging with a nominal voltage of 700 V or higher, but always below a 1000 V peak.

All the features of the three charging levels are summed up in the Figure 2.4.

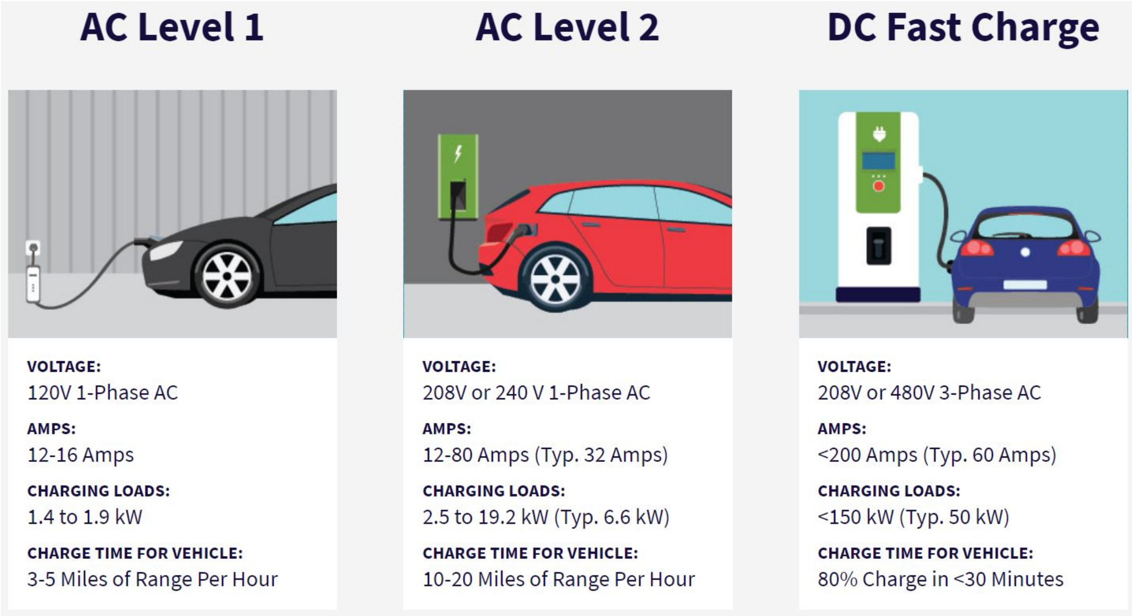

Figure 2.4. Scheme of the three charging levels (Source: www.advancedenergy.org)

2.4 Italian application of IEC 61851

Currently, the Italian edition of the international IEC standard 61851-1, which contains the necessary requirements for charging electric vehicles, is the CEI EN 61851-1. It has the purpose of adapting the international standard to the Italian territory, introducing some limitations.

For example, it states that, in order to guarantee the necessary safety during the conductive charging of electric vehicles, the AC charging must be adopted only with mode 3 when it is carried out in environments open to third parties.

Charging mode 1 is allowed only in strictly private areas not open to third parties, such as environments whose access requires keys only owned by its owner; it is allowed with a limited current of maximum 16 A, in compliance with the standard, which makes it possible to assimilate the electric vehicle to a load for "domestic and similar uses".

The charging mode 2 is not recommended by the standard for places "not open to third parties" but it is not prohibited because in terms of safety it does not have the necessary requirements to guarantee a recharge in places "open to third parties" such as Mode 3, but has the requirements to be considered safer than Mode 1. That is why the standard subjects Charging Mode 2 to the same limitations as Mode 1, even if it is foreseen by it with a maximum current of 32 A [23].

2.5 Connectors, plugs and sockets

Vehicle connectors, plugs, socket-outlets and vehicle inlets designs and characteristics are defined in the IEC 62196 standards.

The first configurations, described in the IEC 62196-2 standard, are used for AC charging of electric vehicles in the modes 1, 2 and 3 mentioned in IEC 61851-1.

According to this standard, there are 3 types of configurations [24].

- Type 1

This configuration is based on a design made by the manufacturer Yazaki and published for the first time in the SAE J1772 standard.

The standard foresees an operating current up to 32 A for this configuration; however, in order to comply with SAE standards, it allows a maximum current of 80 A for applications limited to the United States.

It has a round housing with a notch on the vehicle inlet and five contacts for two AC conductors, a protective conductor and two signal pins that are used for the control pilot function and for proximity detection. There is a mechanical latch that holds in place the connector when it is inserted into the vehicle inlet.

This configuration is commonly used in the United States and in Japan.

- Type 2

The type 2 configuration gets its idea from the design made by manufacturer Mannekes, even if it presents some changes.

This configuration has a plug and socket outlet that support the mode 3 charging and a vehicle coupler which supports charging in either mode 2 or mode 3. Even if a connector that supports mode 1 is allowed by the standard, this is not used.

The standard foresees an operating current up to 63 A for this configuration, but it allows a maximum current of 70 A for single-phase applications.

The design consists in a round housing with one side flattened, up to seven contacts for up to four AC conductors, a protective conductor and two signal pins that are used for the control pilot function and for simultaneous proximity detection and current coding. There are locking mechanisms, one attached to the inlet that holds the connector in place and the other one to the socket-outlet that holds the plug in place.
This configuration is the most used within the European Union.

- Type 3

This configuration is based on the original design made by the manufacturer Scame.
There are three possible cases described by the standard, each one of which consists of a plug, a socket-outlet and a vehicle couple:

- An up to 16 A single-phase charging (without control pilot contact)
- An up to 32 A single-phase charging
- An up to 63 A three-phase charging

The design consists of an oval housing with one side flattened, up to seven contacts for up to four AC conductors, a protective conductor and one or two signal pins that are used for the control pilot function and for simultaneous proximity detection and current coding. There are locking mechanisms, one attached to the inlet that holds the connector in place and the other one to the socket-outlet that holds the plug in place.

In addition to the previously mentioned configurations included in IEC 62196-2, all of which refer to an AC charging, the IEC 62196 standard has been further extended with IEC 62196-3, which takes into account the DC charging in mode 4 and considers several configurations.

- AA

The AA configuration is better known as "Chademo connector" due to the fact that it was designed by the Chademo organization and published by them in the Japanese standard JEVS G105-1993.
It is mostly used in Japan, but, due to the power of japanese car manufacturers in the market, many countries include this configuration in their charging systems.

- BB

The BB configuration is mostly used in China, and it is defined by their own standard. It is quite not used by other countries manifacturers.

- EE

The EE configuration is also called "Combo 1 connector" or "CCS1 connector", it is used in the Combined Charging System and extends the type 1 coupler.
This configuration is described by the standard SAE J1772 and is mostly used in the United States.

- FF

This configuration is known as "Combo 2 connector" or "CCS2 connector" and it is used in the Combined Charging System and extends the type 2 coupler.
It is the most used DC configuration within the European Union.

For years Tesla, had its own special connector, nowdays the company adapted to the previously mentioned standard by using a type 2-shaped connector.
To sum up, Figure 2.5 shows all the connectors described before.

Figure 2.5. Connectors defined by IEC 62196-2 (Source: pinterest)

Car manufacturers generally adopt the type of charger mostly used in their own country, principally for historical reasons. That is why American and Japanese companies use mainly Type 1 chargers, European manufacturers use Type 2 and Chinese ones use chargers conform to their standard GB/T.
The most used types of chargers in the strongest countries in terms of vehicles production, are shown in Table 2.2.

Table 2.2. Most used types by countries

	USA	**JAPAN**	**EUROPE**	**CHINA**
AC	Type 1	Type 1	Type 2	GB/T
DC	COMBO 1	CHAdeMO	COMBO 2	GB/T

The other nations, which do not have a strong automobile production, generally tend to conform to European or American standards, mainly due to the widespread use of vehicles from these areas in the countries themselves. An example is the situation of the DC charging connectors, where the CCS-1, which, used in the USA, is also used throughout North America. While the European CCS-2, it is the connector mainly used also in South America, Asia and Africa.

2.6 Italian application of IEC 62196-2 and IEC 62196-3

The IEC 62196-2 and IEC 62196-3 international standards about sockets, plugs and connectors have been adapted to the Italian territory in the CEI EN 62196-2 and CEI EN 62196-3 standards.
These standards identify in detail which connector and socket can be used to recharge a vehicle and which requirements must be respected for their construction.

In particular, CEI EN 62196-2 concerns connectors for AC charging of electric vehicles, while CEI EN 62196-3 defines characteristics of DC connectors, exactly like the respective IEC standards.
These standards provide 3 main types of sockets, plugs and connectors specific for charging electric vehicles, differentiated according to the current, the rated voltage, the number of phases and the number of pilot contacts. In more detail it provides a type 2 connector for generic AC charging electric vehicles, a type 3a connector for light vehicles (for example scooters) and a COMBO 2 connector for DC charging.
Unfortunately, on the market there are still today electric vehicles with various types of connectors that do not conform to this regulations and this can be a problem in terms of safety of the charging system, which is also linked to the connector on the vehicle.

CHAPTER 3: Public Charging Infrastructures in Italy

As explained in Chapter 1, since drivers would be willing to switch to electric as long as they do not lose the comforts of combustion engines, a good distribution of Charging Stations (CSs) providing adequate power is needed in order to ensure a good recharge in short times. This is a hard challenge especially in countries like Italy, where a high percentage of petrol service stations are distributed in a capillary way and the drivers of IC vehicles are used to having the possibility of refueling very easily and in a short time.

Despite this, Italy is moving in the right direction, although many aspects are still to be improved. In fact, it is possible to demonstrate how the number of electric charging stations is constantly growing by analyzing the data provided in the following paragraphs, which have been obtained thanks to mappings carried out through websites and applications that provide the position and characteristics of the charging stations in the area, comparing them with previous survey data provided by the Motus-E association.

3.1 Definitions

In Italy, with regard to the design, placement and activation of charging infrastructure for electric vehicles, reference is made mainly to two regulations: the AFID (Directive 2014/94 / EU, implemented in Italian legislation with Legislative Decree 257/2016) and law no. 134 of 7 August 2012, Art. 17, also known as PNIRE (Piano Nazionale Infrastrutturale per la Ricarica dei veicoli alimentati ad energia Elettrica).

From these laws it is possible to infer the definition of charging station, which is considered to be the infrastructure that can host one or more charging points.

A publicly available charging or refueling point is defined as a charging or refueling point for the supply of alternative fuel or electricity, which guarantees a non-discriminatory access to all users.

The charging points can be classified according to the power supplied. They can be of standard power, if they transfer electricity to an electric vehicle with power equal to or less than 22 kW, or of high power, if they allow the transfer of electricity to an electric vehicle with power greater than 22 kW. The legislation divides the high power charging points into two further following types: the fast type, if the power is greater than 22 kW and equal to or less than 50 kW, and the ultra-fast type, if the power is greater than 50 kW.

The standard power category includes all alternating current charging systems, which, as mentioned in chapter 2 and according to CEI EN 61851, are in AC – Mode 3, and all direct current charging systems with power up to 22 kW, which are in DC – Mode 4.

The high power category includes all direct current charging systems with power exceeding 22 kW, always in DC - Mode 4 according to CEI EN 61851.

3.2 The Current Trend

There are currently 7203 public charging stations in Italy with a total of 13721 charging points. These data consider the number of infrastructures installed up to February 2020, although some are still being connected to the network for activation.

The survey carried out by Motus-E at the end of September 2019 recorded 5246 infrastructures and 10647 charging points: this means that, in just 6 months, there has been an increase of 1957 infrastructures and 3074 charging points, which means an average growth of 37% for the former and 29% for the latter.

A percentage of similar value was obtained with the previous survey, indicating that the growth trend is constant.

The 73% of the indicated infrastructures are located in a public place (e.g. on the road), while 27% of them is on private place for public use (e.g. supermarkets or shopping centers).

Figure 3.1 shows the growth between 2019 and 2020 in both the number of charging stations and the number of charging points also distinguishing the percentage of those present in public places (blue) and those in private places (red).

It should be noted that the term charging station stands for the infrastructure, while the charging point represents the connection available for a single vehicle (for example, a charging station can have multiple charging points, allowing multiple vehicles to be charged simultaneously).

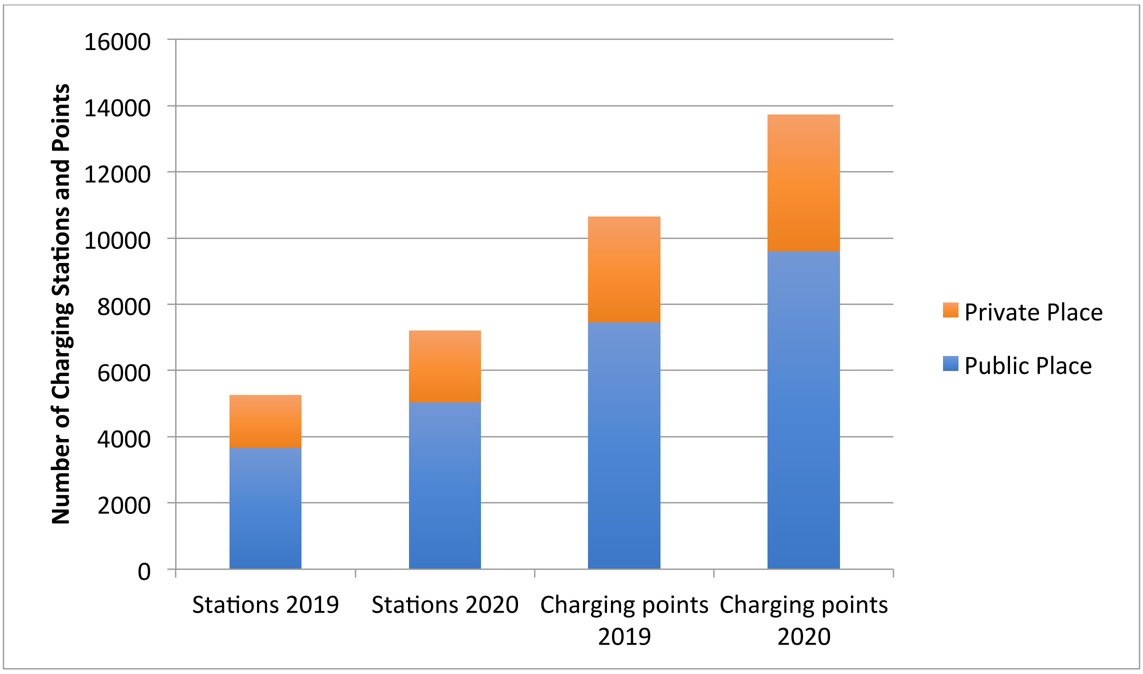

Figure 3.1. Growth of public stations and charging points between the end of 2019 and the beginning of 2020

Despite these excellent results, the growth of high power direct current charges remains weak. In fact, the percentage of fast charging points (with power between 44kW and 100kW) remains constant at 3%, while the percentage of the ultrafast ones (power over 100kW) is negligible, just 16 in the whole country, only 4 more than in September 2019.

From Table 3.1, which shows the powers supplied by the charging points in percentage distribution of the total, it can be seen that the growth is rather stable and linear with respect to the type of infrastructure [25].

Table 3.1. Percentages of powers delivered by charging points

Power delivered (kW)	% September 2019	% February 2020
≤ 3,7	25%	23%
3,7 < P ≤ 7,4	3%	3%
7,4 < P ≤ 21	0%	0%
21 < P ≤ 43	69%	71%
44 < P ≤ 100	3%	3%
P > 100	0%	0%

There is a slight decrease in slow charges, with power less than 3.7 kW, which corresponds to a slight increase in quick charges (power supplied between 21 and 43 kW).

However, most of the charging points at 3.7 kW, which are of 3A type, cannot be used by cars, but only by two-wheeled electric vehicles or light quadricycles.

3.3 Territorial Distribution

The mapping highlights an uneven distribution of charging points on the national territory, with a big difference between the northern and the southern regions.

The region that sees the highest result is Lombardy, with 2467 charging points, a thousand more than Tuscany, which occupies the second place in this ranking with 1420 charging points.

Piedmont and Emilia-Romagna follow with 1330 and 1311 charging points respectively.

The non-northern region with the largest number of charging points is Lazio, which is fifth overall with 1179 points, while Veneto counts 1130 points. In these six regions one can find more than half of all the charging points in the country.

All the numbers of charging points per region are shown in Table 3.2.

Table 3.2. Number of charging points per region

Region	Charging Points
Lombardy	2467
Tuscany	1420
Piedmont	1330
Emilia	1311
Lazio	1179
Veneto	1130
Sicily	650
Trentino Alto Adige	630
Puglia	617
Liguria	425
Sardegna	413
Calabria	396
Umbria	364
Abruzzo	314
Marche	297
Campania	274
Friuli	183
Valle d'Aosta	109
Basilicata	106
Molise	106

It is possible to observe that there is a relatively high number of charging points in Trentino-Alto-Adige (almost like Sicily), especially if one takes into consideration the overall population of the region. Such a high Charging Points / Population ratio demonstrates the region's commitment to promoting electrification in the context of mobility.

The distribution and the differences between the northern and central-southern regions can be seen in the map represented in Figure 3.2. In fact, the blue color prevalent in the central-southern regions in contrast to the red and orange colors present in the North is easily noted.

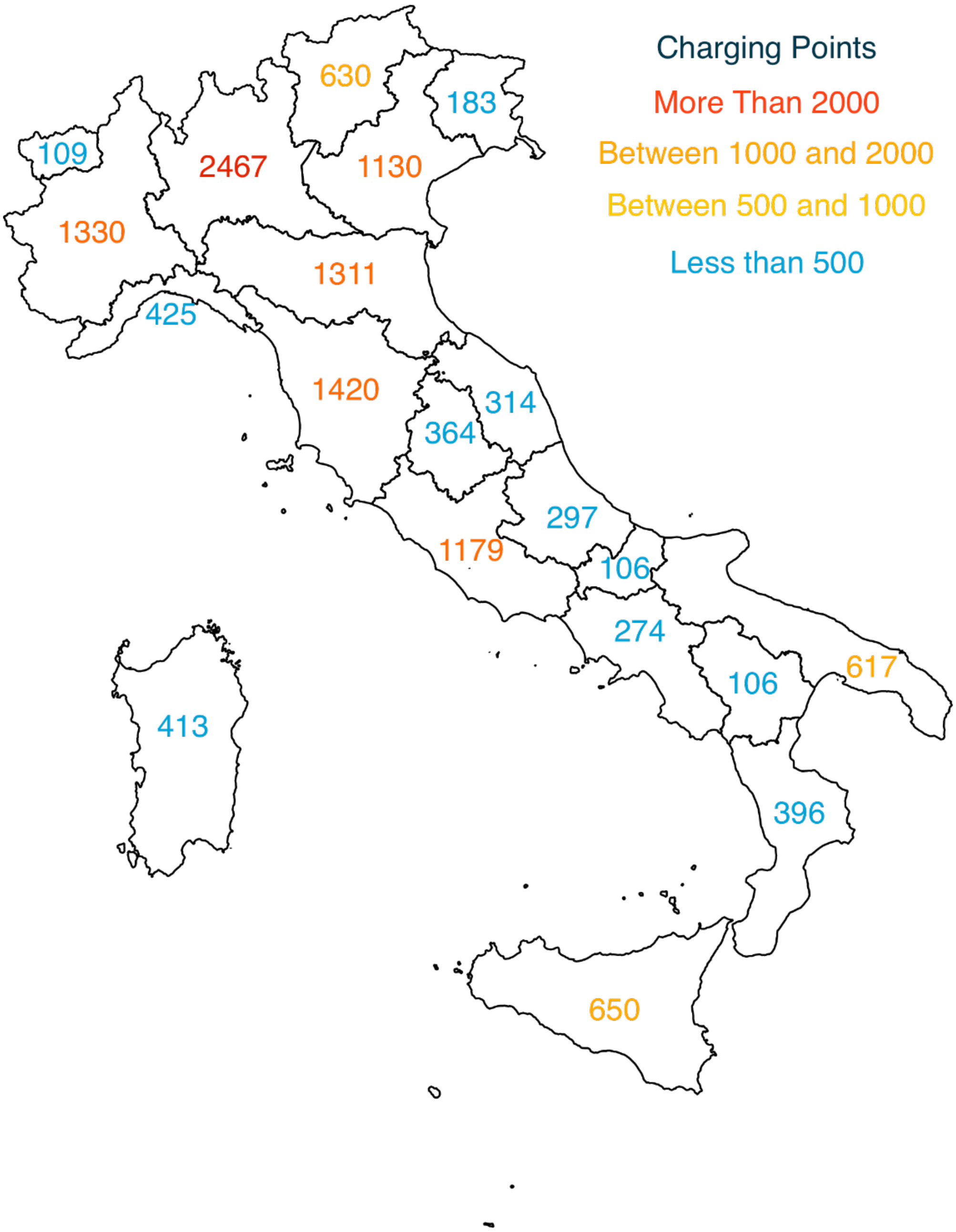

Figure 3.2. North vs Central-South Regions Percentual distribution

Moving to the growth level, the region that registers the greatest increase compared to September 2019 is still Lombardy, with an increase of 637 charging points. The growth of the other regions remains moderate or stable.
These results are in line with the ones of vehicle sales, which in the first months of 2020 saw the North-Eastern and North-Western regions occupying a market share of 75% of the total electrical car registrations in Italy for the period. All these values can be seen in Table 3.3.

Table 3.3. Car Registrations per Area in the first months of 2020

Area	Car Registrations
North-West	2255
North-East	2927
Center	1420
South	341
Islands	181

Finally, it should be underlined the fact that the diffusion of infrastructure along highways is still very limited.
This is a negative aspect for the growth of electric users, since it limits the possibility of using an electric vehicle for long-distance journeys.

3.4 Operators

From the mapping work carried out through Openchargemap.org and Goelectricstations.it emerges the great work and investment made by some operators in the installation of new charging infrastructures.
In fact, many of them, in view of an increase in the electric vehicle market in the near future, aim to create an efficient network, which can be profitable from the point of view of incomes. In a future in which most of the vehicles will be electric, they will find themselves ahead with respect to competitors, having moved ahead and positioned their

infrastructures in greater quantities and in the most strategic positions.

The investment of Enel X stands out among all operators. With 6811 charging points, it alone possesses almost half of the public charging points in Italy. Adding them to those located abroad, Enel X, which one of its charging stations is shown in Figure 3.3, reaches 15621 charging points in Europe, making it one of the largest operators of charging infrastructures in the continent.

Figure 3.3. Enel X charging Infrastructure (Source: www.autoblog.it)

All the other operators have significantly lower numbers than Enel X, reaching a maximum of a few hundred charging points. This does not mean less interest, but a different strategy. While the infrastructures of Enel X are positioned more or less uniformly on the national territory, the other operators seem to concentrate their resources in particular geographical areas.

An example is that of A2A, which owns 268 charging points, all located in Lombardy and mainly concentrated in the cities of Milan, Bergamo, Cremona and Brescia. The different strategy becomes clear as you compare A2A and Enel X charging points in these areas. Considering for example the entire province of Milan, the total number of charging stations for Enel X is 120, while that for A2A is 48, but if the field is restricted to the city of Milan alone, the latter are all located in the the interior of it, while only 6 Enel X points can be found in the city.

Other important operators are BeCharge, which owns 314 charging points between Lombardy, Piedmont, Veneto and Emilia-Romagna; Neology, which is the largest operator in Trentino-Alto-Adige with 260 points all located in the region; Ressolar, with 130 charging points, in the province of Bergamo and surroundings; and Duferco, which has 140 charging points, mainly concentrated in Liguria, Piedmont and Valle d'Aosta.

Also noteworthy is the action of Tesla, which with its "Supercharger" recharge system has 283 recharge points in our country.

As anticipated in paragraph 3.2, there is a 27% of recharging points that are intended for public use, but are located on private land or are managed by private individuals who make them available to any customers.

Of all the charging points in Italy, in fact, 1327 are owned and managed by hotels and 1097 by supermarkets and shopping centers. Only a small part are owned by restaurants (254) and private car parks (304). All the data mentioned above are expressed in the graph in Figure 3.4.

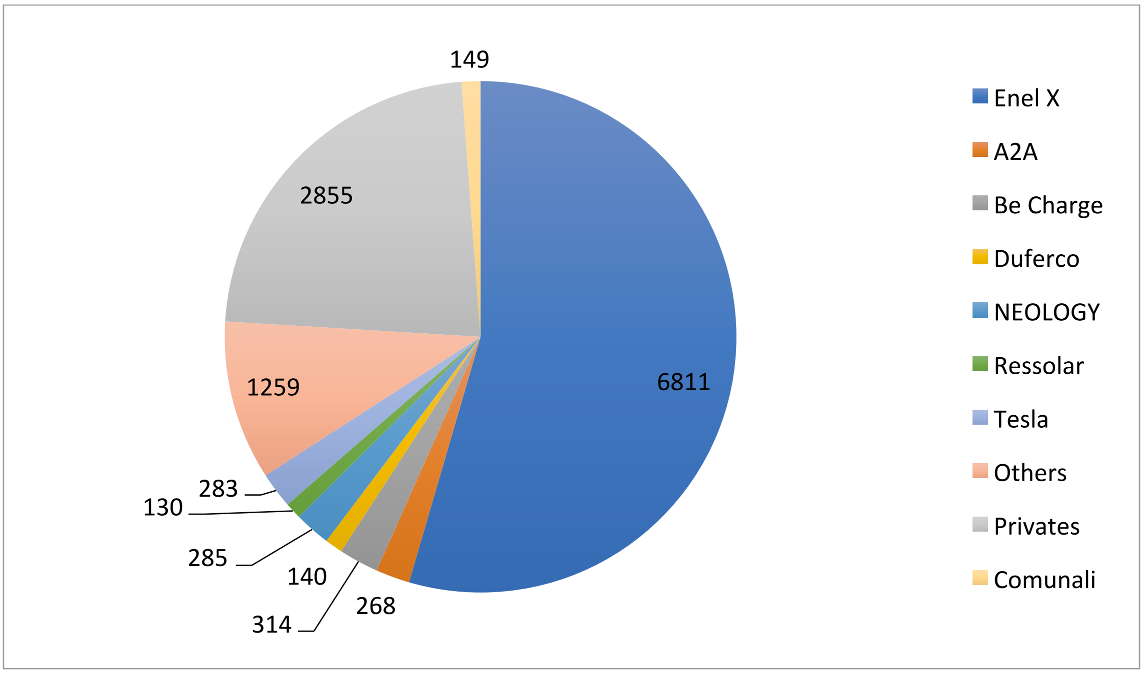

Figure 3.4. Charging points per opearator

As mentioned in the previous paragraph, at the moment there is a serious lack of charging infrastructures along the Italian motorways. In this regard, the Ionity project, which is installing high-power infrastructures along the highways, should be highlighted. The project envisages a station with six charging points available every 120 km along the crossing corridors identified and co-financed by the Europ-e program [26].

3.5 Focus on Lombardy

As explained in the previous paragraphs, Lombardy qualifies as the first region for the number of charging infrastructures present in its territory. Analyzing the data relating to the region, there is a disparity in the distribution of charging stations, with provinces with a high number of points, and others that instead highlight important shortcomings. The province with the highest number of charging points is obviously Milan, with 866 points, followed by Bergamo with 427 and Brescia with 296, while those with fewer charging points are Sondrio with 79, Mantova with 69, Lecco with 59 and Lodi with 33. From these numbers we can see the contribution given by the previously mentioned

A2A, which together with Enel X, Emobitaly, Ressolar, Route 220, and, for the Brescia side of Lake Garda, GardaUno, manages most of the charging points of the region.
The powers mainly used are in line with national statistics: there is a great use of 22kW systems, while only 72 points owned by Enel X and A2A have a high power direct current systems (In some provinces such as Lecco or Sondrio, they are not even present).
The connectors used, represented in Figure 3.5, are, as per national regulations, type 2 for cars and type 3a for two-wheeled vehicles, while for the majority of the 72 cases of charging in DC there is the double possibility of Combo 2 and Chademo.

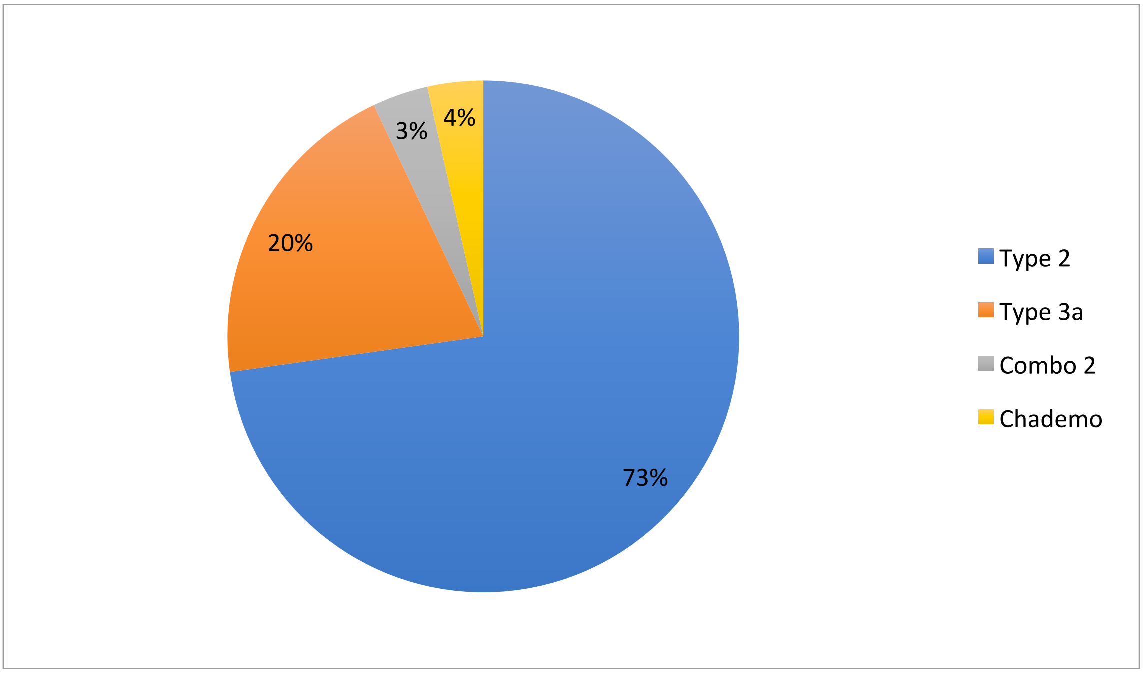

Figure 3.5. Plugs used in Lombardy

3.6 The Problem of Mapping

In the first place, a difficulty in accurate mapping of the data must be underlined. Although there has been talk of the construction of the "PUN" (Piattaforma Unica Nazionale) for a long time, the absence of an official platform makes it particularly difficult to reconstruct a reliable and precise picture of the location of the infrastructures in Italy.

At the moment the data can be obtained from two types of maps: those made available by the operator (which however provide locations and data only for the stations owned by the operators themselves, not indicating those of potential competitors), and those based on databases in which the users can insert stations they are aware of with related information (which however can sometimes be inaccurate, due to the fact that they can be entered by anyone and not by people competent in the matter).

A comparison between these two types of maps is done in Figure 3.6 and Figure 3.7. Focusing on the province of Milan it can be seen the great difference in terms of density of points (especially considering the fact that the Enel X shows the single charging points, while the Openchargemap shows the overall charging infrastructure).

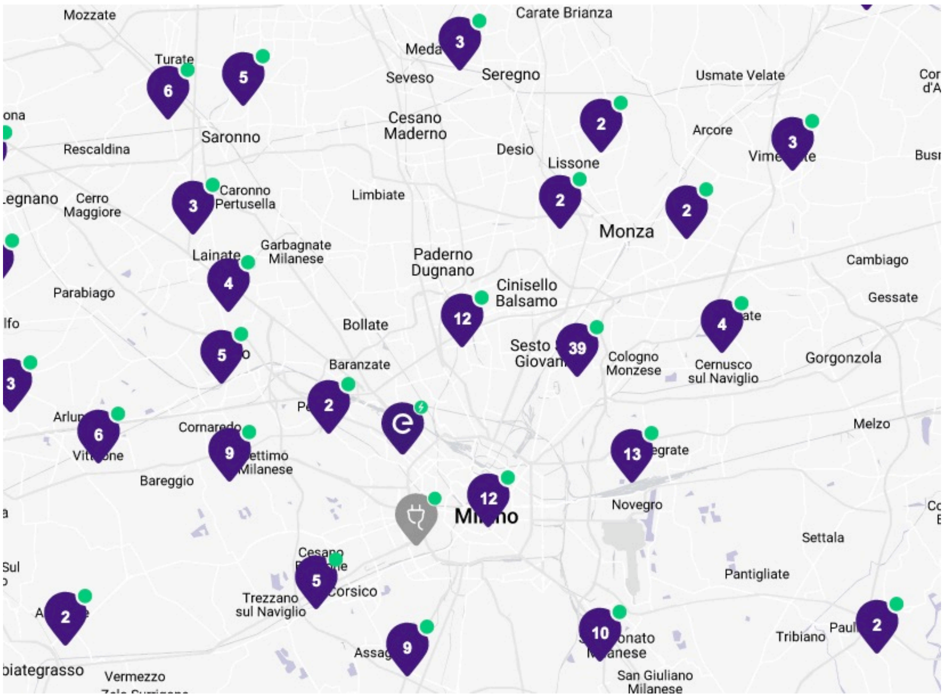

Figure 3.6. Milan focus from Enel X map (Source www.enelx.com)

It also emerges, from a graphic point of view, at first glance how openchargemap highlights the situations of the charging stations, indicating them with a green icon if free, orange if occupied or gray if not active.

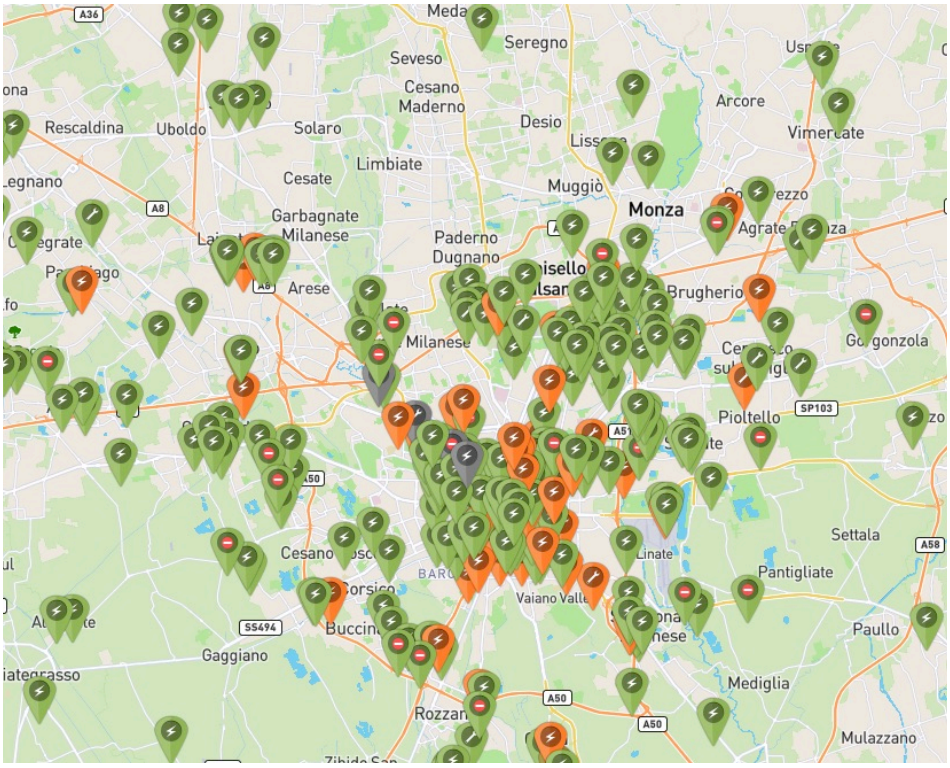

Figure 3.7. Milan focus from Openchargemap (Source www.openchargemap.org)

In our case, the two websites used (Goelectricstations.it and Openchargemap.org) belong to the second category. These websites have been chosen because they proved to be the most reliable and complete both in terms of number of stations detected and for the information provided on the individual station. Datas from these websites have been reworked and compared with others provided by the Motus-E association, in order to have the clearest and most realistic picture of the situation. In addition to this, it must be added the fact that the scenario is constantly evolving, which, although it is certainly a positive aspect as it highlights how Italy is moving in the direction of EVs, makes it difficult to elaborate a completely correct mapping since new charging stations are being activated at a very fast rate.

CHAPTER 4: Travel simulator

Since the distribution of charging infrastructures is not uniform neither at a national, nor at a local level, it is useful to identify which are the most supplied areas and which are still in backward conditions. A first analysis has already been carried out in the previous chapters using the data obtained from the maps. However, since the final objective is to encourage the use of electric vehicles by putting the driver in the most optimal and comfortable conditions possible, it is also good to carry out an analysis from the driver's point of view. Obviously, a driver who travels regularly in areas without recharging points for electric vehicles will be unwilling to undertake the use of an EV; viceversa, those who have the opportunity to find easily accessible recharging points along the daily routes and therefore do not waste too much time will be much more inclined to accept the novelty of the EV.

In this regard, an Excel program has been implemented in this thesis work. This program works by simulating a trip: the user has to enter the coordinates of the starting and destination points, provide the percentage of remaining battery and select a vehicle model among more than 50 possibilities; as a result, the program shows all the possible charging stations located nearby.

This chapter will aim to illustrate all aspects and functioning of the developed program.

4.1 User Interface

A "User Interface" page, shown in Figure 4.1, has been included in the program. This page allows the user to enter the data required to carry out the various simulations and allows him to view some results.

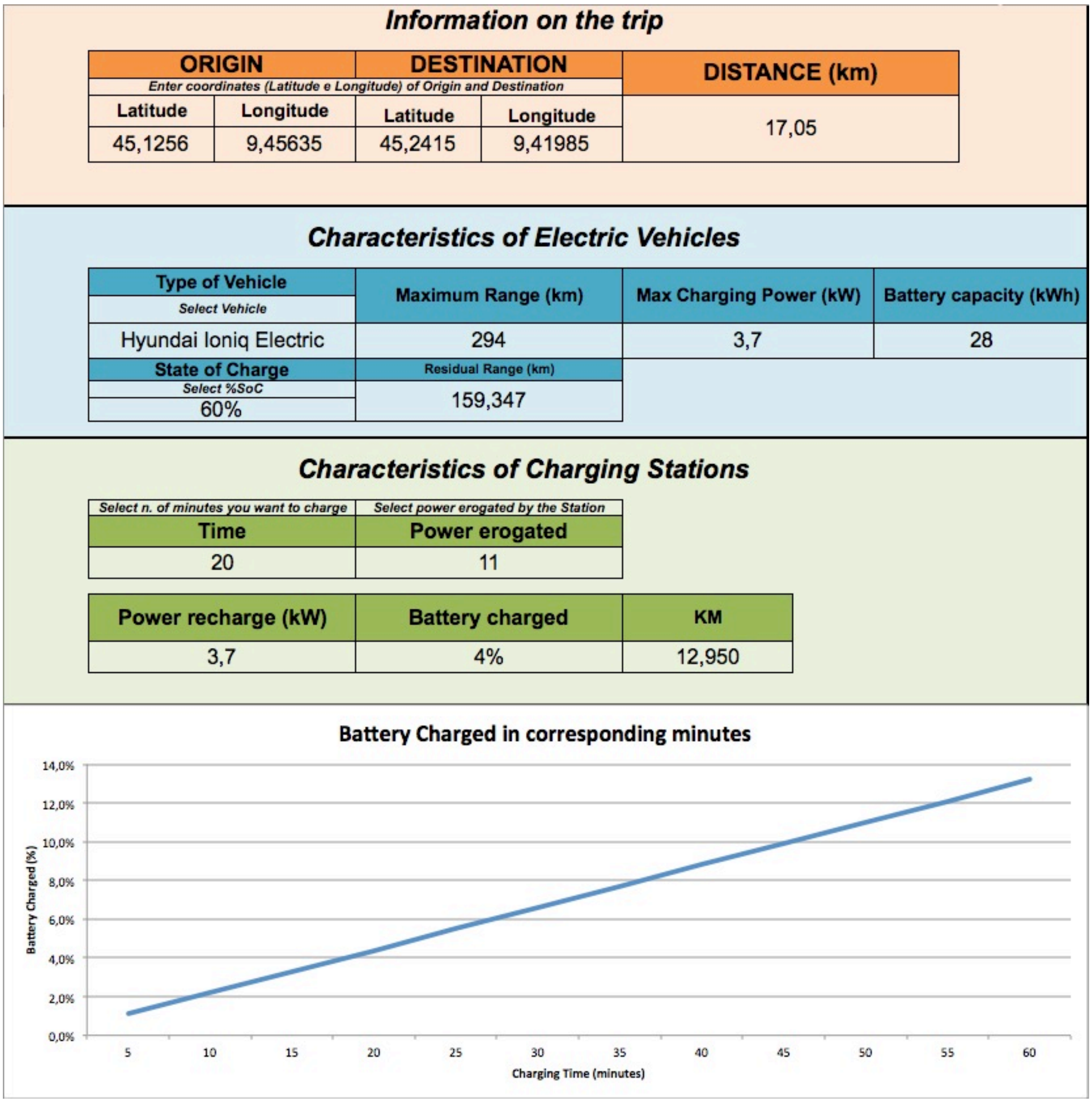

Figure 4.1. The User Interface

This page is divided into three sections: The first is related to the trip information, the second is dedicated to the choice and related information of the vehicle to be used in the simulation, while the third deals with the information of the charging stations and the charging times.

4.1.1 Information on the Trip

The first section (shown in figure 4.2), dedicated to the information on the trip, allows the user to manually enter the geographical coordinates (Latitude and Longitude, expressed in degrees) of the Origin (A) and Destination (B) points, subsequently showing the total distance (in km) between the two points by applying an equation which will be explained in the "Algorithm" paragraph.

Information on the trip

ORIGIN		DESTINATION		DISTANCE (km)
Enter coordinates (Latitude e Longitude) of Origin and Destination				
Latitude	Longitude	Latitude	Longitude	63,94
44,1256	9,45635	44,5637	9,56765	

Figure 4.2. Information on the trip interface

4.1.2 Characteristics of Electric Vehicles

The second section (shown in figure 4.3), dedicated to the characteristics of Electric Vehicles, allows the user to manually choose the vehicle to use for the simulation. By selecting the corresponding box, a drop-down menu containing 53 possible models opens.

Characteristics of Electric Vehicles

Type of Vehicle	Maximum Range (km)	Max Charging Power (kW)	Battery capacity (kWh)
Select Vehicle			
Fiat 500e	320	11	42
State of Charge	Residual Range (km)		
Select %SoC	144,058		
65%			

Figure 4.3. Characteristics of Electric Vehicles

Each vehicle corresponds to a maximum range of autonomy (in km), a maximum charging power (in kW), and a battery capacity (in kWh), which are the ones declared by the manufacturers.

This information is contained in another page that acts as a database regarding the vehicles, so that it is possible to insert other vehicles with the corresponding information's if necessary.

The currently inserted models and the respective ranges are expressed in the Table 4.1.

Table 4.1. Car models inserted and corresponding informations

Car model	Max Range (km)	Max Charging Power (kW)	Battery Capacity (kWh)
Audi E-Tron	400	22	95
Audi E-Tron Sportback	371	22	71
BMW i3	260	7,4	36,8
Citroen C-Zero	150	50	16
Citroen E-Mehari	200	3,7	30
DS 3 Crossback	320	11	50
Fiat 500e	320	11	42
Ford Focus Electric	162	7,4	23
Ford Mustang Mach-E ER	600	150	98,8
Ford Mustang Mach-E SR	450	115	75,7
Honda E	220	7,4	32
Hyundai Ioniq Electric	294	3,7	28
Hyundai Kona Electric 64	449	70	64
Hyundai Kona Electric 39	289	70	39,2
Jaguar I-Pace	480	100	90
Kia E-Niro 39	289	70	39,2
Kia E-Niro 64	400	70	64
Kia E-Soul 39	277	70	39,2
Kia E-Soul 64	452	70	64
Mazda MX-30	200	7,4	30
Mercedes EQC	300	110	80

Mercedes Classe B Electric	200	11	28
Mini Full Electric	261	50	32,6
Mitsubishi I-MiEV	150	50	16
Nissan Leaf	270	50	30
Nissan Leaf e+	385	50	60
Opel Ampara-e	520	50	60
Opel Nuova Corsa E 7,4	337	100	50
Opel Nuova Corsa E 11	337	100	50
Peugeot e-2008 7,4	320	100	50
Peugeot e-2008 11	320	100	50
Peugeot iOn	150	50	16
Porsche Taycan 4S	407	270	93,4
Renault Fluence ZE	185	3,7	22
Renault Twingo ZE	180	22	22
Renault Zoe Q210	210	44	22
Renault Zoe Q90 22	210	44	22
Renault Zoe Q90 (Z.E. 40-41kW)	395	22	41
Renault Twinzy	100	2,3	6,1
Seat MII Electric	260	40	36,8
Smart Fortwo EQ (22 kW)	160	22	17,6
Smart Fortwo EQ (4,6 kW)	160	4,6	17,6
Skoda Citgoe	265	40	36,8
Tesla Model 3	560	120	75
Tesla Model S	610	120	100
Tesla Model X	542	120	100

Tesla Model Y	505	250	75
Volkswagen E-Golf	190	40	24,2
Volkswagen E-Up	260	40	36,8
Volkswagen ID.3 (45 kWh)	330	100	45
Volkswagen ID.3 (58 kWh)	420	100	58

It should be specified that as maximum charging power, if the vehicle allows a high power DC charge, the value indicated is the one corresponding to this one.
Once the model has been selected, the State of Charge (SoC) in percentage value that is had at the start must be chosen through another drop-down menu.
The program consequently calculates the value of the residual range (ie the range that will be passable with the residual SoC, or that which will remain after the trip entered in the first section). In case of too low SoC values (even if it is a very borderline situation), which would not allow to reach the set destination, the message "Charge Needed!" Appears. as can be seen in Figure 4.4.

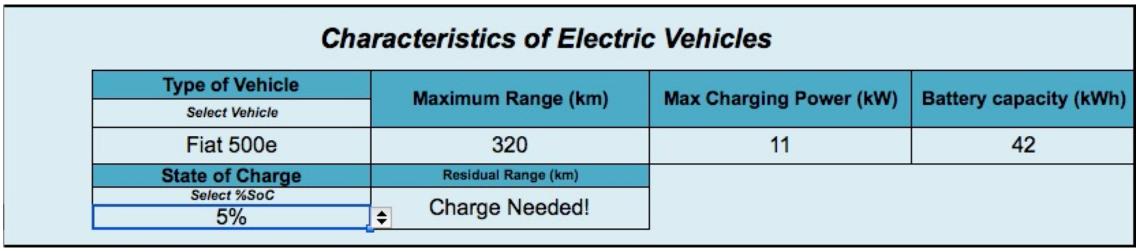

Figure 4.4. SoC conditions too low

4.1.3 Characteristics of Charging Stations

The third part (shown in figure 4.5), dedicated to the characteristics of the charging stations, allows the user to select, through two other drop-down menus, both the time in minutes, which he is willing to use for charging the vehicle, and the power supplied by the identified charging station.

Once these two values have been set, the system will show the power to which the charging will take place (comparing the set value with that of the maximum power of the vehicle previously selected, the charging power will in fact be the lower of these two values), it will also show the percentage of rechargeable battery in the selected time interval and the corresponding number of kilometers that can be covered with this recharge.
There is also a graph which, based on the power at which the recharge occurs, shows the time necessary (on the abscissa) to recharge a certain percentage of the battery).

Characteristics of Charging Stations

Select n. of minutes you want to charge	Select power erogated by the Station
Time	**Power erogated**
20	11

Power recharge (kW)	Battery charged	KM
3,7	4%	12,950

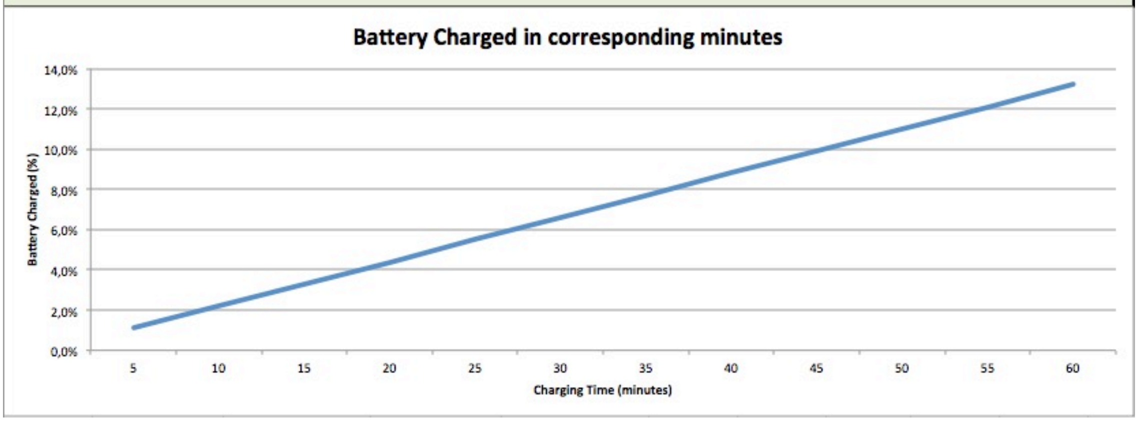

Figure 4.5. Characteristics of Charging Stations

4.2 Trip Cases

As anticipated at the beginning of the chapter, the main objective of the software, in addition to providing the information specified above, is to identify the charging stations present in a given area by simulating the trip.
These results are based on two main driver behavioral scenarios. In the first scenario (Case A) the driver opts, if it is possible to do so thanks to the autonomy of the battery,

to recharge the vehicle after reaching the destination and carrying out his commitments. In this case the overall route will be Origin – Destination - Charging Station.

In the second scenario (Case B), the driver opts to stop to recharge its vehicle before reaching the destination; the total route in this case will be Origin - Charging Station - Destination.

It should be noted that in the situation in which the residual battery range is not sufficient to cover the distance between origin and destination, the occurrence of case A will not be possible, but case B will be obliged.

Analyzing the case A, the simulation will provide the number of total stations that can be reached from the destination with the remaining autonomy, having already traveled the origin – destination stretch.

As can be seen in figure 4.6, in the mask it is possible to set a filter in order to limit the number of stations indicated in the result to those contained within a radius of the selected value, which can be selected by choosing a value between 1km and 5km at 0,5 km intervals through a drop-down menu.

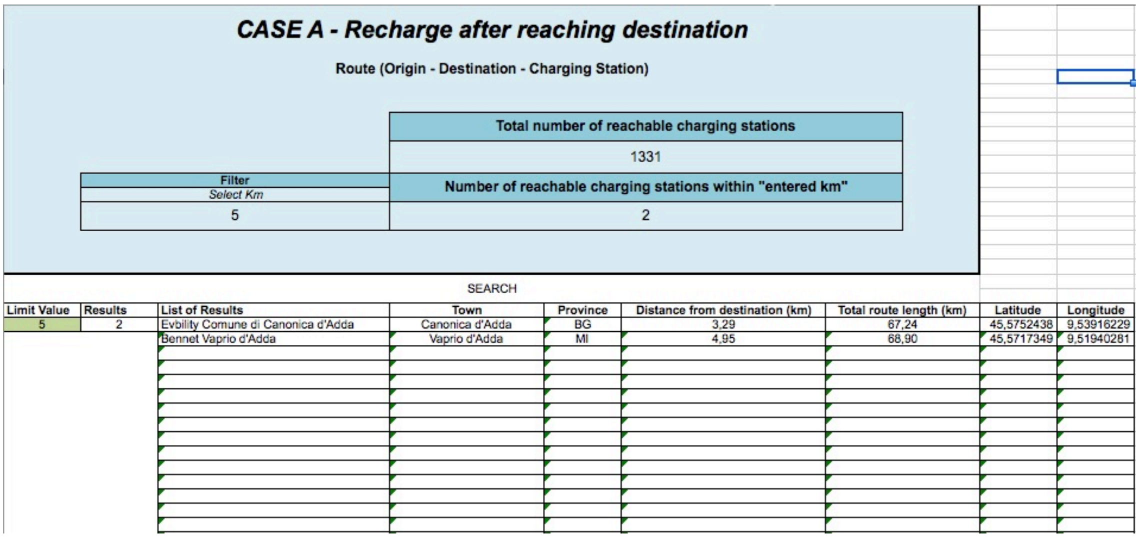

Figure 4.6. Case A interface

In case B, on the other hand, the simulation will result in the total number of stations that can be reached from the start of the trip with the remaining autonomy and which are located along the route, i.e. implying a not excessive deviation from the original route, which can be set in the corresponding filter.

In fact, as can be seen in figure 4.7, in the mask it is possible to select the number of kilometers corresponding to the maximum deviation.

The filter allows to choose the value in the same way as the case A one.

CASE B - Recharge before reaching destination

Route (Origin - Charging Station - Destination)

Filter *Select km*	Number of reachable Charging Station along the route
1	19

RICERCA

Limit Value	Results	List of Results	Town	Province	Distance from Origin (km)	Deviation (km)	Total route length (km)	Latitude	Longitude
1	19	Casirate Industria	Casirate D'adda	BG	53,40	0,01	63,95	45,4910772	9,55260509
		Treviglio Colombo	Treviglio	BG	59,30	0,75	64,69	45,5283226	9,58554855
		Ekomobil - 22kW	Montanaso Lombardo	LO	28,89	0,67	64,61	45,3265813	9,4604099
		Ekomobil - 22 Kw	Montanaso Lombardo	LO	28,79	0,68	64,62	45,325889	9,46001163
		Crema Diesel S.p.A	Pieve Fissiraga	LO	22,07	0,44	64,38	45,2791566	9,45915004
		U2 Supermercato Treviglio	Treviglio	BG	59,27	0,78	64,73	45,5280154	9,58614577
		Spino d'Adda Ragazzi del '99	Spino d'Adda	CR	39,82	0,28	64,23	45,4012319	9,49655455
		COOP Lodi	Lodi	LO	25,54	0,07	64,02	45,3021361	9,48583038
		Centro Sportivo Comunale di Spino d'Adda	Spino d'Adda	CR	39,72	0,63	64,57	45,4013527	9,4820019
		Municipio di Spino d'Adda	Spino d'Adda	CR	39,17	0,33	64,27	45,3969144	9,49301937
		Centro Ricreativo Sportivo Casirate	Casirate d'Adda	BG	53,82	0,23	64,17	45,4917156	9,56954074
		Negozio Enel di LODI	Lodi	LO	26,30	0,02	63,97	45,3046329	9,51052933
		Fiera di Treviglio	Treviglio	BG	57,41	0,88	64,82	45,5142722	9,58880482
		Treviglio PalaFacchetti	Treviglio	BG	57,83	0,45	64,39	45,5187996	9,57929117
		EnelX EVA+ ADS IP Cornegliano Laudense	Cornegliano Laudense	LO	23,67	0,21	64,15	45,2898573	9,47269813
		Evbility Rivolta d'adda	Rivolta d' Adda	BG	49,83	0,34	64,28	45,469822	9,51595017
		Decathlon Pieve Fissiraga	Pieve Fissiraga	LO	22,30	0,42	64,36	45,2807031	9,46037135
		Volkswagen Grioni Domenico	Rivolta d'Adda	CR	50,60	0,50	64,44	45,4755019	9,51186783
		Scuola Media Statale Leandro Berinzaghi	Pandino	CR	41,59	0,22	64,16	45,4069459	9,55354968

Figure 4.7. Case B interface

For both cases, under the masks there is a table that returns the information of the locations that are obtained as a result. The table provides the name of the location, the municipality and the province of belonging, the distance from the origin or destination (depending on the case) and the coordinates. In case B it also provides the corresponding deviation

4.3 The Map

The operation of this program rests on a page that acts as a database, which contains the information of the various charging infrastructures.

This database, provided by Motus-E, derives from the complete extraction through a script of the data contained in the map on the website Openchargemap.org. It provides the exact information that the site is able to give, in particular the exact position of the charging infrastructures (through the geographic coordinates latitude and longitude), the address, the municipality and the province to which they belong, the operator and the number of charging points that the infrastructures have.

This map indicates a total of 12803 charging points in whole Italy, thus proving to be the most complete, as well as precise, in providing the exact positions.

	A	D	E	F	G	H	I	K	L	M	N
1	N	NumberOfPoints	Title	Provider	AddressLine1	Town	Province	Latitude	Longitude	Latitude Correct	Longitude Correc
2	1	2	La Cave Des Amis Ristorante Pizzeria	Ristorante	Località Soleil, 3	Châtillon	AO	45750204455533	76211341317462	45,75020446	7,621134132
3	2	2	LIDL Formia	Supermercato	Via del Commercio, 6	Formia	LT	41267273451013	13674155414554	41,26727345	13,67415541
4	3	2	LIDL Castelfranco Emilia	Supermercato	rue Grand Paradis	Castelfranco Emilia	MO	44602958921089	11031417091687	44,60295892	11,03141709
5	4	1	Apartment 7***s	Hotel	Schennastraße 43	Schenna	BZ	46681214978350	11190344361132	46,68121498	11,19034436
6	5	2	Medicina Parcheggio via Fava	ENEL X	Via Licurgo Fava	Medicina	BO	44480218385922	11638686128959	44,48021839	11,63868613
7	6	2	LA THUILE Piazzale Fiera	ENEL X	Via Marcello Collomb SS26	La Thuile	AO	45719211391767	69471356664353	45,71921139	6,947135666
8	7	2	Romano Stadio	Ressolar	Via Stadio	Romano di Lombardia	BG	45526134864528	97583408334019	45,52613486	9,758340833
9	8	2	McDonald's San Benedetto Del Tronto	ENEL X	Via Liberazione, 14	San Benedetto del Tronto	AP	42941057539276	13880072378386	42,94105754	13,88007238
10	9	2	Zogno Mercato	Ressolar	Via Pietro Ruggeri, 45 a	Zogno	BG	45792764985874	96693929248427	45,79276499	9,669392925
11	13	2	Conad Châtillon	ENEL X	Frazione Perolle, 21	Châtillon	AO	45750204650027	76237401204262	45,75020465	7,62374012
12	14	2	Cefalù Colombo	ENEL X	Piazza Cristoforo Colombo	Cefalù	PA	38037594239070	14019977026079	38,03759424	14,01997703
13	15	2	Centro Commerciale Elisa	ENEL X	Via Acquicella Porto, 25	Catania	CT	37489186280080	15079843224113	37,48918628	15,07984322
14	16	2	Campi Sportivi Castel Maggiore	ENEL X	Via Lirone	Castel Maggiore	BO	44574453242591	11358433584749	44,57445324	11,35843358
15	17	2	Campi Sportivi Casalincontrada	ENEL X	Via Aldo Moro	Casalincontrada	CH	42292992230931	14135015724169	42,29299223	14,13501572
16	18	2	CASALE CORTE CERRO Via Novara	ENEL X	Via Novara, 25	Casale Corte Cerro	VB	45911784555795	84237219845577	45,91178456	8,423721985
17	19	2	Cannobio Stadio Comunale	ENEL X	Via Carlo Alberto Dalla Chiesa	Cannobio	VB	46067588920976	86981509069385	46,06758892	8,698150907
18	20	2	Cimitero di CAMPOBASSO	ENEL X	Largo Elio Di Mella	Campobasso	CB	41553682973438	14682197638133	41,55368297	14,68219764
19	21	2	Concessionaria Mercedes-Benz	ENEL X	Via Castronella, 164	Campi Bisenzio	FI	43830203340103	11124361275327	43,83020334	11,12436128

Figure 4.8. Database containing charging stations

As shown in Figure 4.8, the latitude and longitude, as they were extracted from the script, are not represented in degrees and present a different number of digits from station to station. For this reason, the first operation made was to correct and converse these data, carried out in the green columns, dividing the exported latitude and longitude values by an exponential of base 10 with an appropriate exponent, in order to bring them back to values corresponding to those of Italy.

4.4 Algorithm

In this paragraph, it has explained how the algorithm processes all the data used and the various steps and formulas that allow it to be reworked, as regards both cases A and B.

4.4.1 Data

The data used in the various steps are as shown in Table 4.2.

Table 4.2. Data used

Nomenclature	**Description**	**Measure Unit**
$latA$	Origin point Latitude (input)	Degrees
$lonA$	Origin point Longitude (input)	Degrees
$latB$	Destination point Latitude (input)	Degrees
$lonB$	Destination point Longitude (input)	Degrees
$latCS$	Charging Station Latitude (database)	Degrees
$lonCS$	Charging Station Longitude (database)	Degrees
$Rmax$	Maximum Range (database) Depends on the vehicle selected	km
SoC	State of Charge (input)	%
R	Vehicle Range	km
$D_{A\to B}$	Distance between the origin and the destination	km
$D_{B\to CS}$	Distance between the destination and the charging station	km
$D_{A\to CS}$	Distance between the origin and the charging station	km
$limA$	Limit distance from the destination when searching for nearby stations in case A (input)	km
$limB$	Maximum deviation from the original path when searching for nearby stations in case B (input)	km
Dev	Actual deviation from the original path in order	km

	to reach a certain station in case B	
BC	Battery Charged	%
$time$	Charging Time	minutes
CP	Charging Power	kW
Cap	Battery Capacity	kWh

4.4.2 Distances calculation

The three distances ($D_{A\to B}$, $D_{B\to CS}$, $D_{A\to CS}$) are calculated starting from the coordinates of the origin and destination inserted and the ones of the charging stations present in the database.

The calculation is done through the following equations:

$$D_{A\to B} = 1{,}29 \cdot \sqrt{((latA - latB) \cdot 111{,}42)^2 + ((lonA - lonB) \cdot 77{,}41)^2}$$

$$D_{B\to CS} = 1{,}29 \cdot \sqrt{((latB - latCS) \cdot 111{,}42)^2 + ((lonB - lonCS) \cdot 77{,}41)^2}$$

$$D_{A\to CS} = 1{,}29 \cdot \sqrt{((latA - latCS) \cdot 111{,}42)^2 + ((lonA - lonCS) \cdot 77{,}41)^2}$$

These formulas contain the following steps within them:

The difference between the latitudes of the two points is calculated (therefore expressed in degrees), then it is converted into km by multiplying it by the constant value of 111.42: this value represents the distance expressed in km of a degree of latitude. It derives from the ratio between the circumference arc measurement relative to the distance traveled on the earth's surface from the northern to the southern pole, and the total number of parallels (being the degree of latitude none other than the distance between one parallel and another). This calculation is based on the hypothesis that the earth is perfectly spherical, while it is known that it is slightly flattened near the poles; nevertheless, this approximation leads to a negligible error.

The same operation is done with longitude. In this case the difference between the two values is multiplied by the value of 77.41 in order to convert the distance from degrees to kilometers. This value, which therefore represents the value in kilometers of a degree of longitude, is not constant in every point of the earth. The distance between one meridian and another, unlike what happens with the parallels, is maximum at the equator and decreases moving towards the poles. It is therefore deduced that this value, used in the simulation, is valid only on the national area considered in the simulations. In fact, considering it constant, it introduces an error, which is negligible since we have operated on a small area.

The values obtained from these operations represent the distances between the two points in terms of latitude and longitude expressed in km. Placing these data on a map, it would be noticed how the two values obtained represent the cathects of a right triangle and the hypotenuse of the latter would be the effective distance in the airline between the two points. Obviously, it should be noted that the values obtained would relate to circumference arcs traveled on the Earth's surface, but since we are operating on a national scale, the distances are relatively short, and these arcs can be considered linear segments. All the errors due to the approximations mentioned above are all in the order of meters, therefore negligible.

Thanks to this further approximation it is possible to calculate the distance between the two points by simply applying the Pythagorean theorem.

The values obtained in this way would however be the distances in the overhead line between the two points considered, which, not taking into account curves, deviations, etc., are much lower than the actual distance that should be covered with a vehicle. For this reason, these values are multiplied by a corrective factor of 1,29. To determine this value, 50 distances calculated in the previous way were taken and compared with the distances given by google maps (relative to the shortest routes). By averaging the errors obtained, this corrective factor was estimated, thanks to which in all the cases considered, the error was reduced to a maximum of 5 km.

4.4.3 Case A

In case A, the driver first reaches the destination and then reaches a charging station to recharge its vehicle.

It should be noted that this scenario can only be verified if the condition :

$$R > D_{A\to B} + D_{B\to CS}$$

is satisfied, i.e. that the maximum range (R) that can be traveled with the residual autonomy is sufficient to allow both to travel the stretch from the origin to the destination, and that from the destination to the charging station. If the autonomy is not sufficient to cover that distance the vehicle may stop. If R is minor than $D_{A\to B}$, the vehicle will not even be able to reach the destination, while if it is greated than $D_{A\to B}$but minor than the sum of $D_{A\to B}$ and $D_{B\to CS}$, the vehicle will reach the destination, but will not be able to reach any charging station, and so to move to another place.

For case A, once a specific route has been set from origin to destination, the program returns as a result all the charging stations that can be reached with the remaining autonomy and those within a certain radius from the destination, the value of which must be inserted.

To do this, it performs the following steps:

It calculates R by multiplying the maximum range with the SoC:

$$R = R_{max} \cdot SoC$$

It applies the following equation to each charging station in the database:

$$R - (D_{A\to B} + D_{B\to CS})$$

Then, if this last equation returns a positive result, then the charging station considered will be reachable after traveling the origin-destination section, if it returns a negative result then the case A condition will not be satisfied, and that charging station will not be reachable.

Thanks to the "conta.se" function, all the stations that return a positive result, and consequently are reachable, are counted, and this value is shown in the Case A mask as final result.

By inserting in the same mask, the number of kilometers from the arrival to which is wanted to limit the search ($limA$), the program shows the number of stations limited to the circular area that has as its center the destination and radius of $limA$ length. This value is given by a second "conta.se" function to which, in addition to the condition:

$$R - (D_{A \to B} + D_{B \to CS}) > 0$$

is added the condition:

$$D_{B \to CS} < limA$$

The results of this latter search and the respective information's can be viewed in a list obtained through an aggregate function.

4.4.4 Case B

In case B the driver stops to recharge the vehicle before reaching the destination.
This scenario is possible if the remaining battery is sufficient to reach the charging station directly from the start, that it means if the value of R is higher than the one of $D_{A \to CS}$, otherwise the vehicle will not be able to reach this charging station and will stop before; it is also deduced that the lower the autonomy of the vehicle, the more the charging stations at which it will be possible to stop will be close to the origin point.
For case B, once a specific route has been set from origin to destination, the program returns as a result the charging stations that can be reached with the remaining autonomy and imply a maximum deviation from the original path equal to a value that must be inserted.
To do this, it performs the following steps:
It calculates R with the equation:

$$R = Rmax \cdot SoC$$

It applies the following equation to each charging station in the database:

$$R - D_{A \to CS}$$

Then, if the formula returns a positive result, then the charging station considered will be reachable from the origin, if the formula returns a negative result then the condition previously mentioned will not be satisfied and that charging station will not be reachable.
Furthermore, the program calculates the deviation from the path Origin - Destination inserted for each charging station contained into the database, by applying the equation:

$$Dev = (D_{A\to CS} + D_{B\to CS}) - D_{A\to B}$$

By inserting in the case B mask the number of kilometers corresponding to the maximum deviation we want to do ($limB$), the system gives the number of stations that are reachable with the remaining battery and imply a deviation lower than the value inserted.
The number of charging station is given by a "conta.se" function with conditions

$$R - (D_{A\to CS}) > 0$$

and

$$Dev < limB$$

The results of this search and the respective information's can be viewed in a list obtained through an aggregate function, same as case A.

4.4.5 Calculations in the "Characteristics of Charging Stations" part

As anticipated in sub-paragraph 4.1.3, the program allows you to calculate the percentage of rechargeable battery in a specific time interval selected by the user, and against a selected charging power.
The choice of making the charging power supplied by the station selectable by the user is mainly due to two reasons: the first is due to the fact that the charging stations could offer the possibility to choose different powers, the second is due to the fact that the Openchargemap map, from which the data was extracted, although being very precise

for the number of stations present and in indicating the position of them, in different situations it does not provide the power supplied.

Once the required input data has been selected, the program compares the value selected for the power supplied by the station with the maximum power allowed by the selected vehicle, indicating as a result the power to which recharging will take place, which corresponds to the smaller value between the two.

Then calculate the percentage of battery recharged in the set time interval, using the following equation:

$$BC = \left(\frac{time}{60}\right) * CP * \frac{100}{Cap}$$

Then, it calculates the range that can be traveled with the recharged battery percentage, multiplying the BC value obtained, by the maximum range corresponding to the vehicle.

Under the user interface, there is a linear graph that on the abscissa axis shows the time variable, while on the ordinate axis it shows the rechargeable percentage in this time interval according to the selected power.

CHAPTER 5: Simulations

The software presented in the previous chapter, has been tested and operated in order to carry out various simulations aimed at assessing the presence of charging stations along some routes within the Lombardy region, and in order to identify both optimal areas and critical areas.

The simulations presented in this chapter were made using different vehicle models, with different ranges and different SoCs, although some of them were kept constant in the various sections analyzed in order to obtain the possibility of a more accurate comparison for both A and B cases.

5.1 Route Chignolo d'Isola – Orio al Serio

The first simulation was carried out considering my home in Chignolo d'Isola (BG) as the starting point, and the Orio Center (Orio al Serio, BG) as the destination; therefore, taking into consideration a relatively short section.

The coordinates entered are shown in Table 5.1.

Table 5.1. Coordinates of simulation Chignolo d'Isola - Orio Center

Origin Latitude	Origin Longitude	Destination Latitude	Destination Longitude
45,6628	9,52893	45,6651	9,69073

The distance between origin (*A*) and destination (*B*) calculated by the program is equal to 16 km. Several simulations have been carried out, with different vehicle models and battery levels.

Considering both case A and B, the results are shown in Table 5.2.

Table 5.2. Results of Chignolo d'Isola - Orio Center simulation

Test	Vehicle model	Autonomy	Total reachable stations (case A)	Reachable stations within 5 km (case A)	Reachable stations with max deviation of 5 km (case B)
1	Nissan Leaf	50%	1176	29	38
2	Nissan Leaf	25%	363	29	38
3	Nissan Leaf	10%	76	29	38
4	Nissan Leaf	5%	0	0	18
5	Fiat 500e	50%	1871	29	38
6	Fiat 500e	25%	875	29	38
7	Fiat 500e	10%	152	29	38
8	Fiat 500e	5%	14	14	38
9	Smart Fortwo	50%	601	29	38
10	Smart Fortwo	25%	152	29	38
11	Smart Fortwo	12%	7	7	38
12	Smart Fortwo	10%	0	0	34
13	Smart Fortwo	5%	0	0	6
14	Honda E	50%	980	29	38
15	Honda E	25%	223	29	38
16	Honda E	10%	35	29	38
17	Honda E	8%	3	3	38
18	Honda E	5%	0	0	11

As it was foreseeable, given the reduced distance between origin and destination, case A is almost always feasible (except in the cases with Nissan Leaf and Honda E with 5% battery and Smart Fortwo with 10% battery are selected).
Given the reduced distance, cars with a low maximum range have been chosen and despite this, the scenario cannot be implemented only in extreme conditions. In addition to the distance, however, these excellent results are also given by the high presence of charging stations near the destination. As can be seen from Figure 5.1, there are 29 Charging Stations within 5 km from the destination (The purple point, with tag *B*).

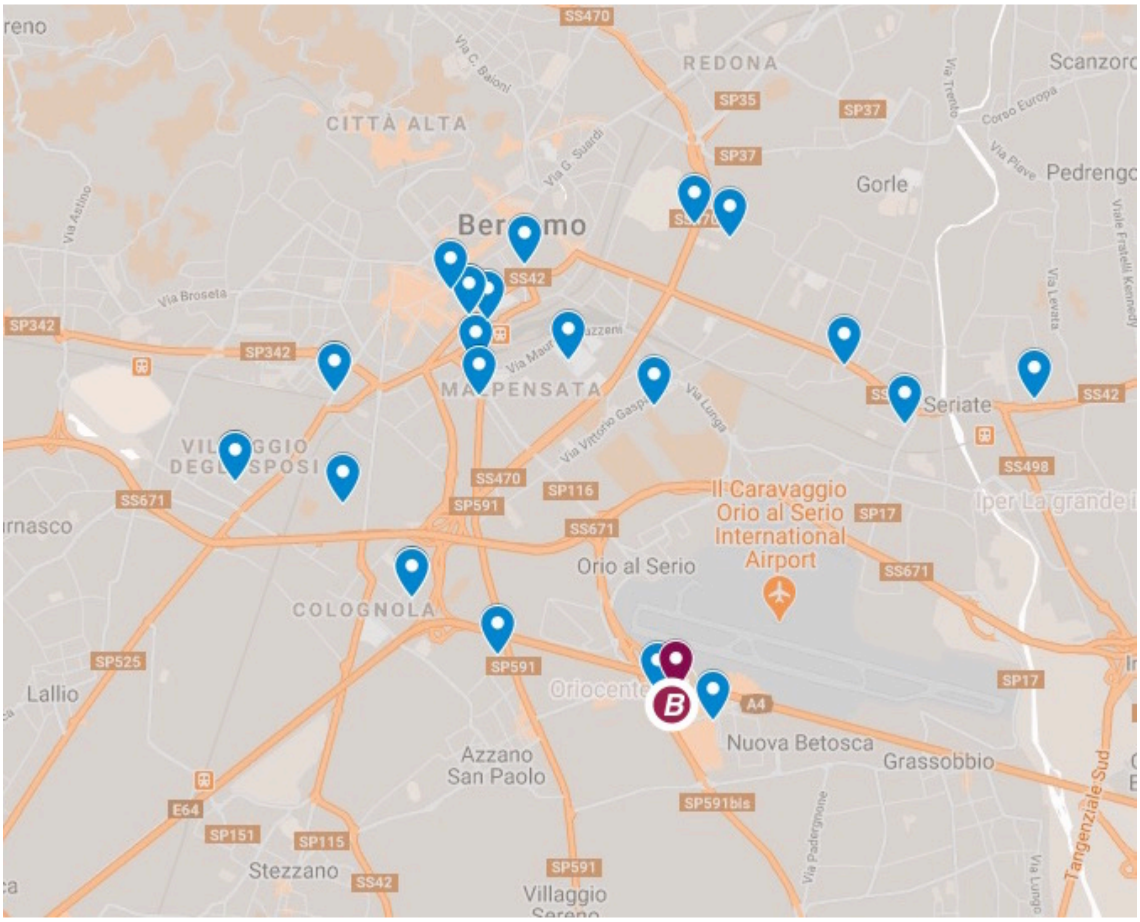

Figure 5.1. The closest charging stations to Orio Center (within 5 km)

Furthermore, considering case B, another excellent result emerges. As can be seen in Figure 5.2, there are 38 charging stations that can be reached without having to deviate more than 5 km, from the route (represented by the blue line that goes from *A* to *B*).

Considering therefore a maximum route (deviation included) of 21 km, an average of one station every 750 m is obtained.

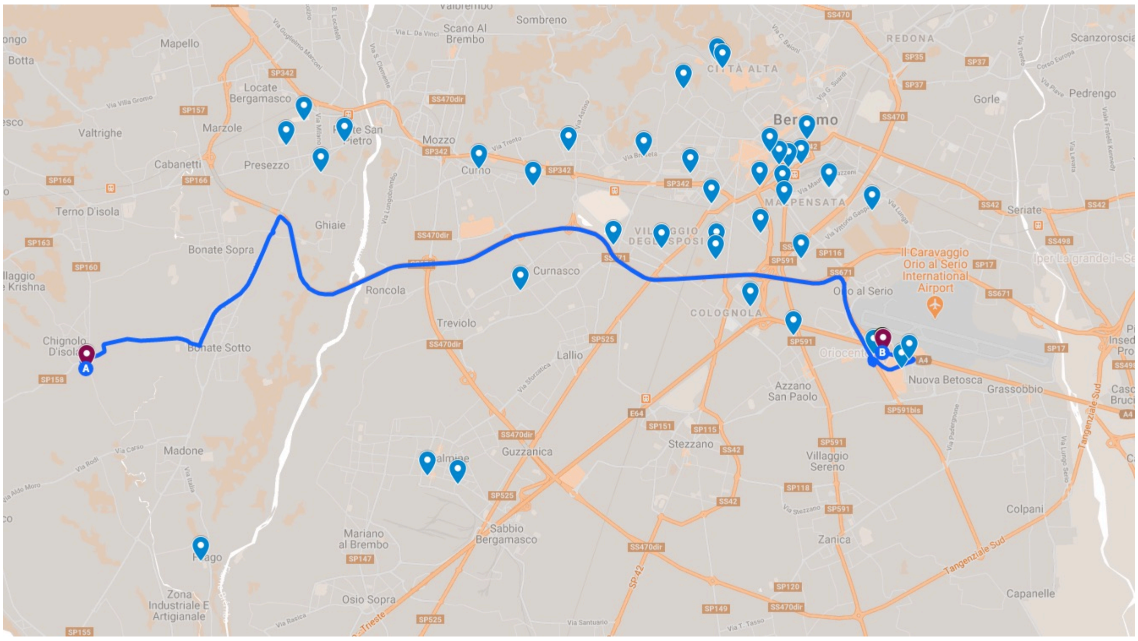

Figure 5.2. The stations along the route Chignolo d’Isola – Orio Center with a maximum deviation of 5 km

In conclusion, the Chignolo d'Isola - Orio al Serio section is not critical at the moment; on the contrary, it provides the driver with many possible solutions to recharge his electric vehicle.

5.2 Route Chignolo d’Isola – Politecnico di Milano (Leonardo)

The second simulation was carried out considering my home in Chignolo d'Isola (BG) as the starting point and the Politecnico di Milano campus in Piazza Leonardo da Vinci as the destination, therefore taking into consideration a longer route.

The coordinates entered are shown in Table 5.3.

Table 5.3. Coordinates of simulation Chignolo d'Isola – Polimi Leonardo

Origin Latitude	Origin Longitude	Destination Latitude	Destination Longitude
45,6628	9,52893	45,4784	9,22615

The distance between origin and destination calculated by the program is 40 km. Considering both cases A and B and applying different scenarios, the simulation have been carried out and the results are shown in Table 5.4.

Table 5.4. Results of Chignolo d'Isola – Polimi Leonardo

Test	Vehicle model	Autonomy	Total reachable stations (case A)	Reachable stations within 5 km (case A)	Reachable stations with max deviation of 5 km (case B)
1	Nissan Leaf	50%	1090	67	110
2	Nissan Leaf	25%	317	67	110
3	Nissan Leaf	15%	2	2	95
4	Nissan Leaf	10%	0	0	29
5	Nissan Leaf e+	50%	1053	67	110
6	Nissan Leaf e+	25%	643	67	110
7	Nissan Leaf e+	15%	246	67	110
8	Nissan Leaf e+	10%	0	0	88
9	Smart Fortwo	50%	438	67	110
10	Smart Fortwo	30%	131	67	110

11	Smart Fortwo	25%	0	0	91
12	Smart Fortwo	15%	0	0	21
13	Volvo XC-40	50%	1644	67	110
14	Volvo XC-40	25%	701	67	110
15	Volvo XC-40	15%	267	67	110
16	Volvo XC-40	10%	0	0	91
17	Volvo XC-40	5%	0	0	12

In this simulation, case A is not feasible if the battery is not already quite charged. Despite this, in the scenarios where it is possible, as can be seen in Figure 5.3, there is a good number of reachable charging stations (67) that are located near the destination (the purple point, with the *B* tag), and this means that the center of Milan offers many possibilities to recharge electric vehicles.

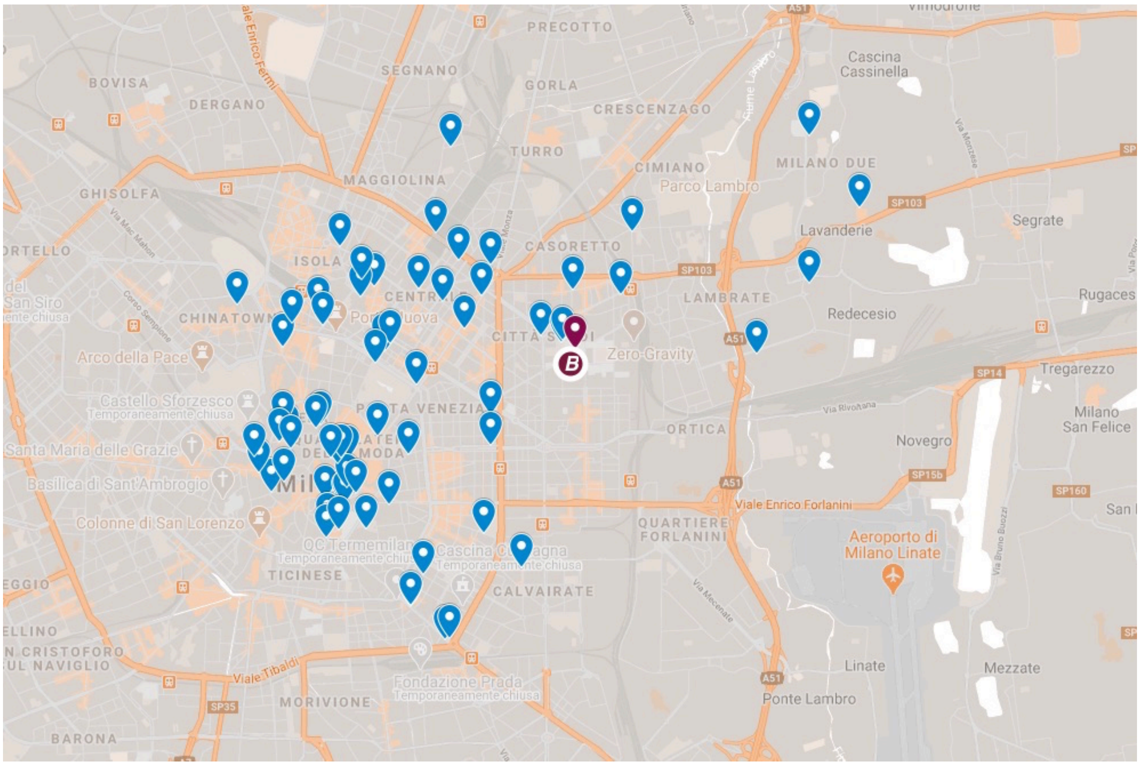

Figure 5.3. The closest charging stations to the Politecnico di Milano (within 5 km)

Further narrowing the research field, it appears that there are 4 charging stations within 1 km from Piazza Leonardo da Vinci, which are shown in Figure 5.4.

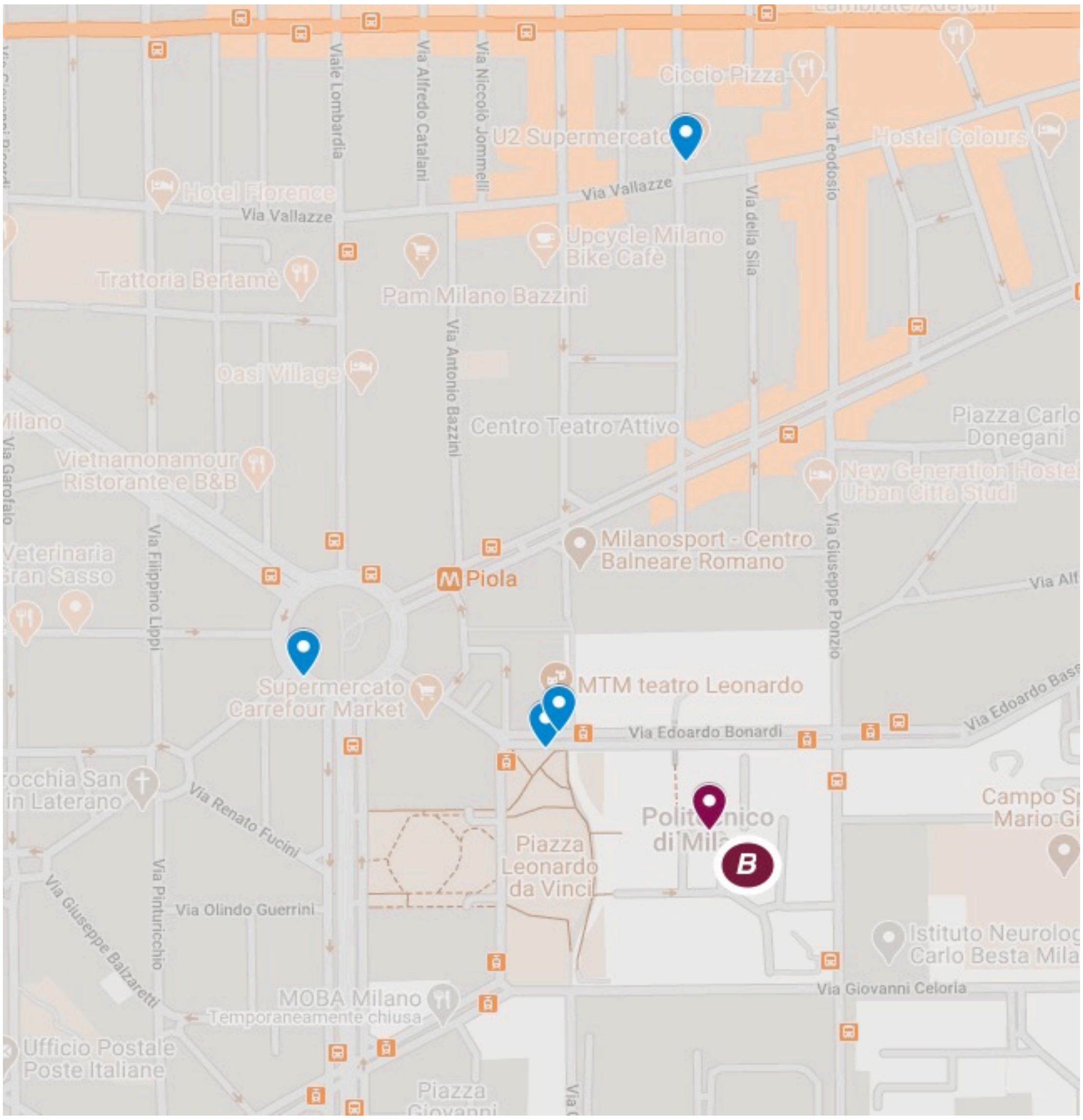

Figure 5.4. The four closest charging stations to the Politecnico di Milano (within 1 km)

Considering case B, as can be seen from Figure 5.5, 110 charging stations emerge along the route (represented by the blue line that goes from *A* to *B*), but only a few of them are reachable in case of limited autonomy. In fact, it emerges that they are located towards the city of Milan and the number of stations decreases moving away from the city, as can be seen from the map. It is also possible to note the absence of charging infrastructures along the highway, demonstrating what was said in chapter 3.

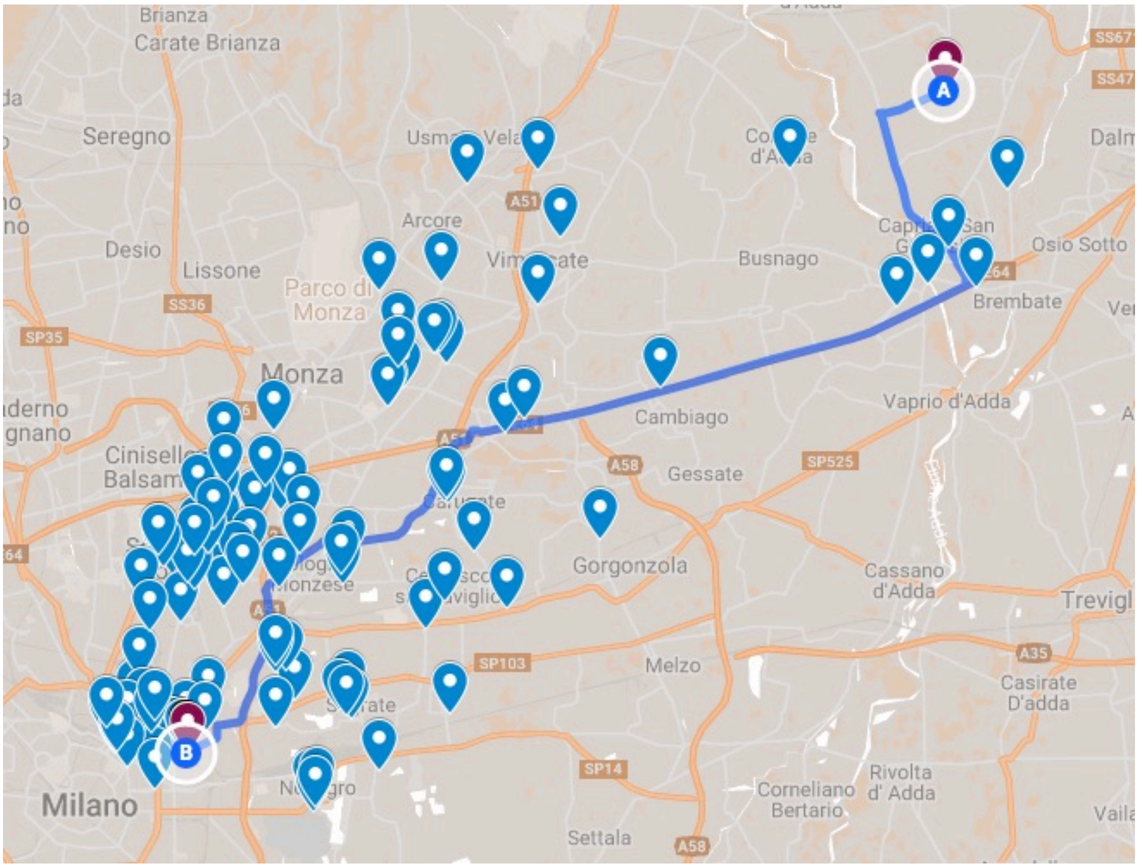

Figure 5.5. The stations along the route Chignolo d'Isola – Polimi Leonardo with a maximum deviation of 5 km

In conclusion, the route Chignolo d'Isola – Politecnico di Milano (Leonardo), at the moment, highlights good recharge possibilities in both cases.

5.3 Route Chignolo d'Isola – Politecnico di Milano (Bovisa)

The third simulation was carried out considering my home in Chignolo d'Isola (BG) as the starting point, and the Politecnico di Milano Bovisa campus as the destination (It must be specified that the coordinates entered as "Bovisa campus" are those corresponding to via La Masa).

The coordinates entered are shown in Table 5.5.

Table 5.5. Coordinates of simulation Chignolo d'Isola – Polimi Bovisa

Origin Latitude	Origin Longitude	Destination Latitude	Destination Longitude
45,6628	9,52893	45,5029	9,15339

The distance between origin and destination calculated by the program is 44 km.

Considering both cases A and B and applying different scenarios, the simulation have been carried out, and the results are expressed in Table 5.6.

Table 5.6. Results of Chignolo d'Isola – Polimi Bovisa

Test	Vehicle model	Autonomy	Total reachable stations (case A)	Reachable stations within 5 km (case A)	Reachable stations with max deviation of 5 km (case B)
1	Nissan Leaf	50%	1019	32	141
2	Nissan Leaf	25%	318	32	141
3	Nissan Leaf	15%	0	0	108
4	Nissan Leaf	10%	0	0	28
5	Renault Zoe	50%	1481	32	141

6	Renault Zoe	25%	649	32	141
7	Renault Zoe	15%	240	32	141
8	Renault Zoe	12%	15	15	141
9	Renault Zoe	10%	0	0	100
10	Smart Fortwo	50%	412	32	141
11	Smart Fortwo	30%	19	19	141
12	Smart Fortwo	20%	0	0	45
13	Smart Fortwo	10%	0	0	6
14	Tesla X	50%	2195	32	141
15	Tesla X	25%	935	32	141
16	Tesla X	15%	382	32	141
17	Tesla X	10%	84	32	141
18	Tesla X	5%	0	0	23

As the previous simulation, due to the similar lenght of the route, case A is not feasible if the battery is not already quite charged.

Compared to Milan Leonardo, the density of recharging infrastructures near the destination is lower, as shown in Figure 5.6 they are just 32 within a radius of 5 km from the Destination (the purple icon with B tag), indicating that the number decreases moving away from the city center. This also confirms what was said in chapter 3 in relation to the city and province of Milan and the strategies of A2A and Enel X.

This simulation highlights the presence of a single charging station within 1 km from the Bovisa campus, shown in Figure 5.7.

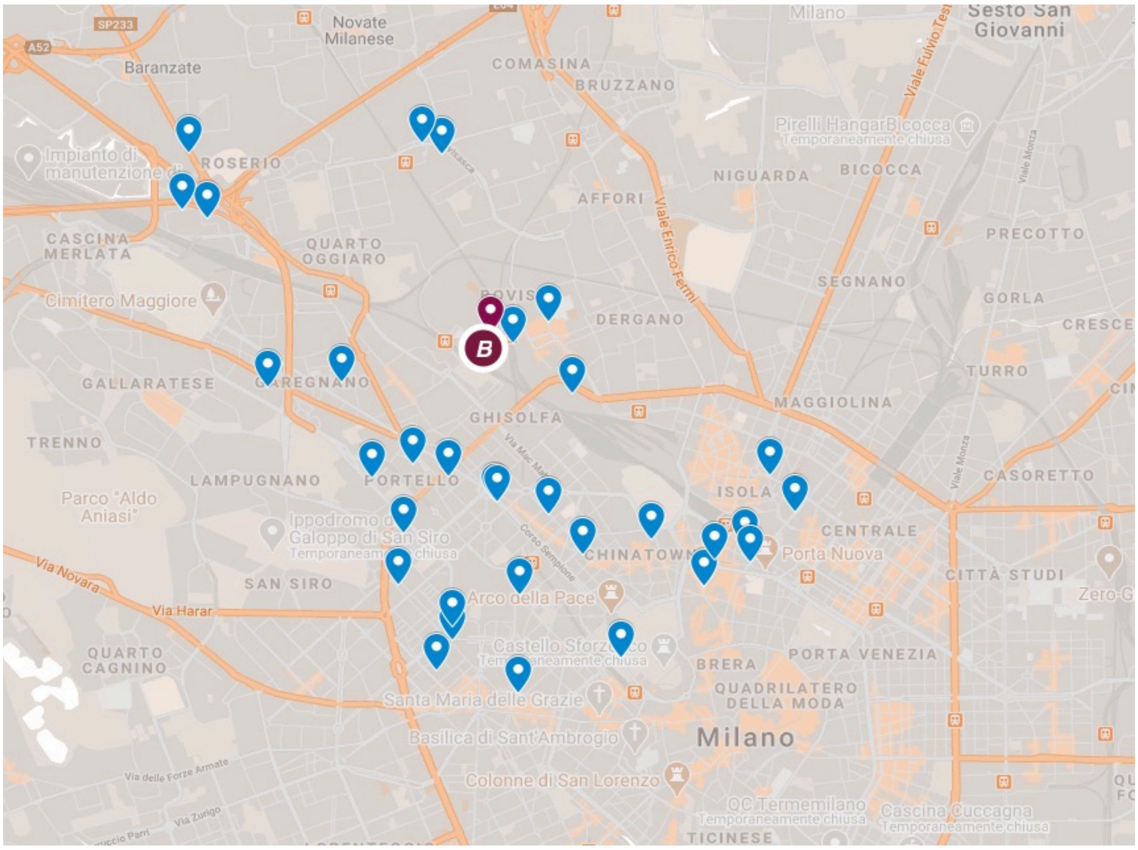

Figure 5.6. The closest charging stations to the Politecnico di Milano - Bovisa (within 5 km)

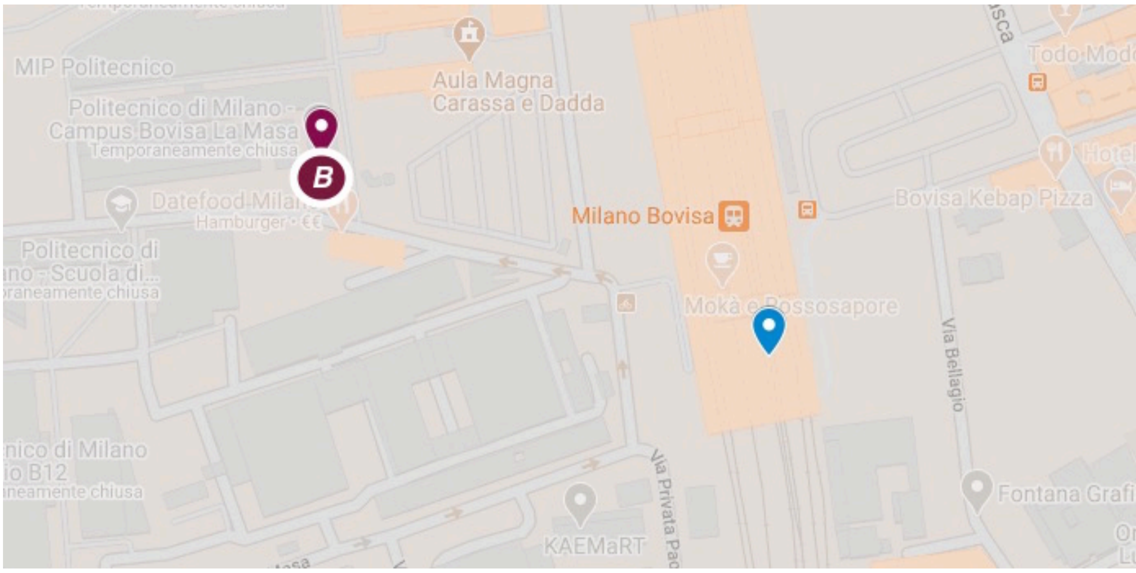

Figure 5.7. The closest charging station to the Politecnico di Milano (within 1 km)

Considering case B, as can be seen in Figure 5.8, 141 charging stations can be found along the route (represented in by the blue line from *A* to *B*). This number is very similar to the one that emerged in the previous case, due to the fact that the travel is directed to the same city and starting from the same origin (*A*).

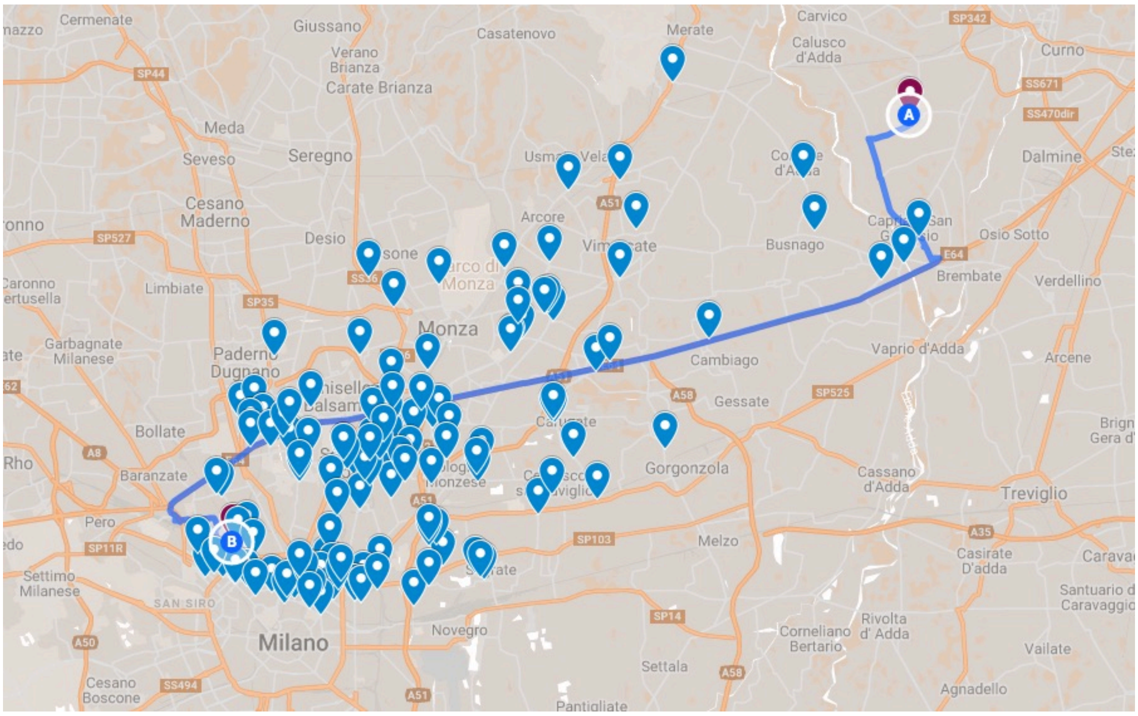

Figure 5.8. The stations along the route Chignolo d'Isola – Polimi Bovisa with a maximum deviation of 5 km

To conclude, the route Chignolo d'Isola – Politecnico di Milano (Bovisa), highlights good recharge possibilities, even in greater number than the Chignolo d'Isola – Politecnico di Milano (Leonardo) case, thus making it more easy and comfortable for EV drivers to recharge their vehicles in less than optimal battery situations. However, the fact that moving away from the city center the number of stations decreases becomes more evident, which, in addition to the cases B of the two simulations, can be deduced by comparing the two different cases A.

5.4 Route Politecnico di Milano (Bovisa) – Malpensa Airport

The fourth simulation was carried out considering the Politecnico di Milano Bovisa campus as the origin, and the Milan Malpensa Airport as the destination.
The coordinates entered are shown in Table 5.7.

Table 5.7. Coordinates of simulation Polimi Bovisa – Malpensa Airport

Origin Latitude	Origin Longitude	Destination Latitude	Destination Longitude
45,5029	9,15339	45,6301	8,72334

The distance between origin and destination calculated by the program is 46,7 km. Considering both cases A and B and applying different scenarios, the simulation have been carried out, and the results are expressed in Table 5.8.

Table 5.8. Results of Polimi Bovisa – Malpensa Airport simulation

Test	Vehicle model	Autonomy	Total reachable stations (case A)	Reachable stations within 5 km (case A)	Reachable stations with max deviation of 5 km (case B)
1	Nissan Leaf	50%	853	3	109
2	Nissan Leaf	25%	84	3	109
3	Nissan Leaf	20%	10	3	109
4	Nissan Leaf	15%	0	0	103
5	Nissan Leaf	5%	0	0	42
6	Renault Zoe	50%	1494	3	109
7	Renault Zoe	25%	501	3	109

8	Renault Zoe	15%	30	3	109
9	Renault Zoe	10%	0	0	103
10	Renault Zoe	5%	0	0	57
11	Smart Fortwo	50%	221	3	109
12	Smart Fortwo	30%	0	0	106
13	Smart Fortwo	25%	0	0	103
14	Smart Fortwo	20%	0	0	88
15	Smart Fortwo	10%	0	0	52
16	Tesla X	50%	1932	3	109
17	Tesla X	25%	797	3	109
18	Tesla X	10%	3	3	109
19	Tesla X	5%	0	0	68
20	Tesla X	2%	0	0	25

Since the route is not short in length, case A is not always applicable, unless you have cars with a good residual range.
Note also the presence of only three charging stations (shown in Figure 5.9) within 5 km from the airport, a decidedly low number if you consider the importance of it as an international airport and the number of flights it has every day.
It must be specified that the airport covers a very large area (the longest dimension is of 3,9 km), so the destination point (represented in the figure by the purple icon with tag B) has been taken in a central position of it.

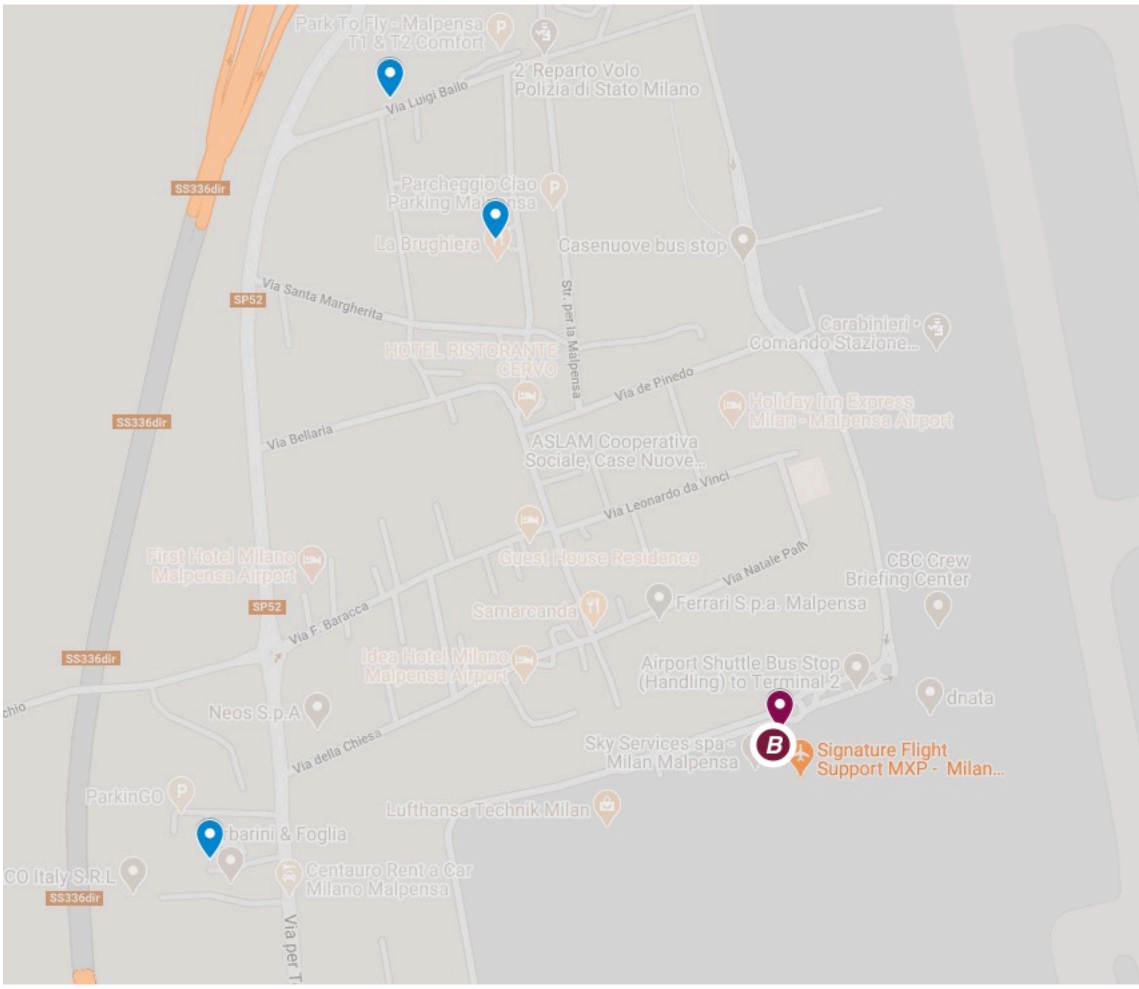

Figure 5.9. The three closest charging stations to the Malpensa Airport (within 5 km)

On the other hand, considering case B, shown in Figure 5.10, it emerges that there are 109 charging stations along the road (the blue line that goes from *A* to *B*), reachable with a maximum deviation of 5 km; a very large number which underlines the excellent results in having recharging infrastructures, carried out in the provinces of Milan and Varese.

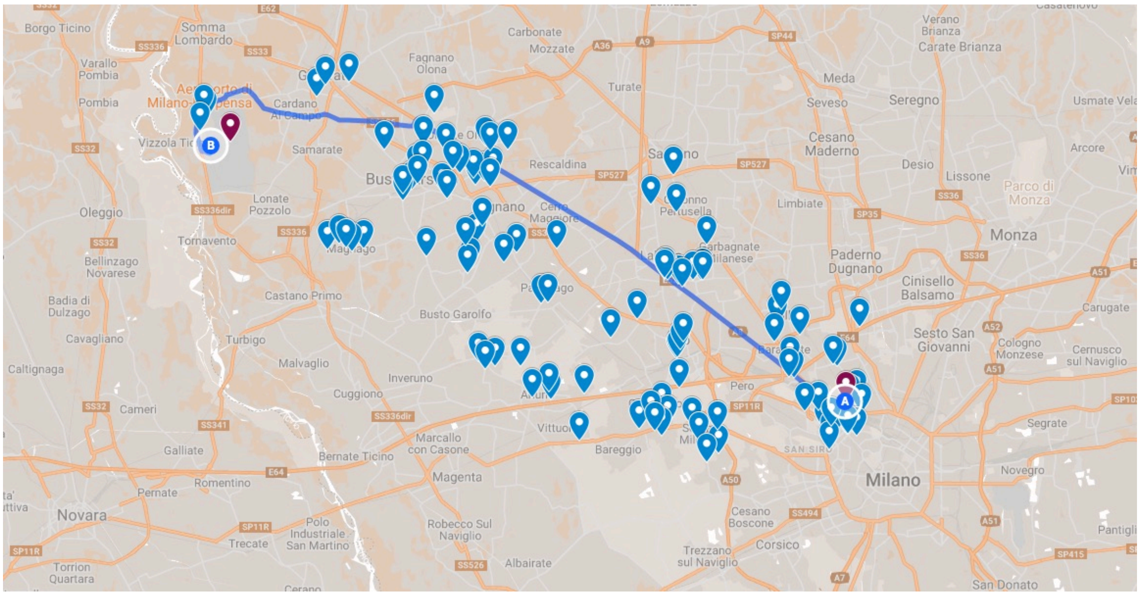

Figure 5.10. The stations along the route Polimi Bovisa – Malpensa Airport with a maximum deviation of 5 km

To conclude, the route Politecnico di Milano (Bovisa) – Milan Malpensa Airport, highlights a great number of recharge possibilities, even if it must be underlined the criticality found near the airport.

5.5 Route Chignolo d'Isola – Foppolo Ski Facilities

In the last simulation, a different situation was considered, with a destination located in a mountain resort. In order to assess whether areas far from city centers were easily accessible to EVs, the town of Foppolo, a ski destination in the province of Bergamo, was taken as a destination. The starting point considered is again Chignolo d'Isola.

The coordinates entered are shown in Table 5.9.

Table 5.9. Coordinates of simulation Chignolo d'Isola - Foppolo

Origin Latitude	Origin Longitude	Destination Latitude	Destination Longitude
45,6628	9,52893	46,0434	9,75274

The distance between origin and destination calculated by the program is 59 km.
Several simulations have been carried out taking into consideration different vehicle models and battery levels.
Considering both case A and B, the results are shown in Table 5.10.

Table 5.10. Results of Chignolo d'Isola - Foppolo simulation

Test	Vehicle model	Autonomy	Total reachable stations (case A)	Reachable stations within 5 km (case A)	Reachable stations with max deviation of 5 km (case B)
1	Nissan Leaf	50%	332	0	32
2	Nissan Leaf	25%	0	0	32
3	Nissan Leaf	10%	0	0	29
4	Nissan Leaf	5%	0	0	18
5	Fiat 500e	50%	1268	0	32
6	Fiat 500e	25%	57	0	32
7	Fiat 500e	10%	0	0	31
8	Fiat 500e	5%	0	0	25
9	Smart Fortwo	50%	5	0	32
10	Smart Fortwo	25%	0	0	31

11	Smart Fortwo	10%	0	0	25
12	Smart Fortwo	5%	0	0	6
13	Tesla S	50%	2556	0	32
14	Tesla S	25%	552	0	32
15	Tesla S	15%	36	0	32
16	Tesla S	10%	0	0	32
17	Tesla S	5%	0	0	31

The first fact that the simulation highlights, considering case A, is the complete absence of charging stations within a radius of 5 km from the destination. The nearest infrastructure for charging electric vehicles is 17 km away. This is a very negative result, especially considering the fact that the ski resorts in Foppolo are very popular during the winter season and skiers who possess electric vehicles would find it quite difficult to recharge their vehicle.
The distance from the destination (The B point, this time coloured in green to underline the different situation) and nearest charging station is graphically shown in Figure 5.11.

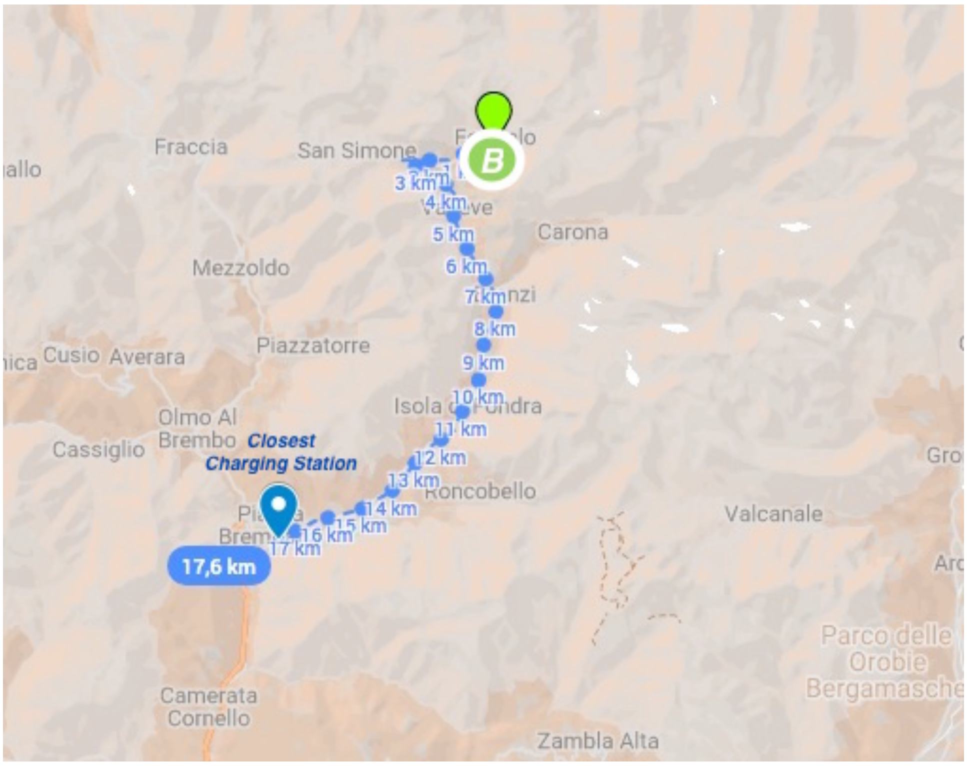

Figure 5.11. Distance between Foppolo and the closest station

Considering case B, which results corresponds to the ones in Figure 5.12, on the other hand, it can be seen that, as one moves away from the origin (point *A*) and enters Val Brembana, the density of charging stations decreases, thus indicating that in the whole valley there is a real lack of infrastructure for electric vehicles.

In fact, as the figure shows, from the beginning of the valley (which is in proximity of the corresponding tag) to Foppolo (point *B*), there are just 5 stations in a 36 km route (which corresponds to the blue line).

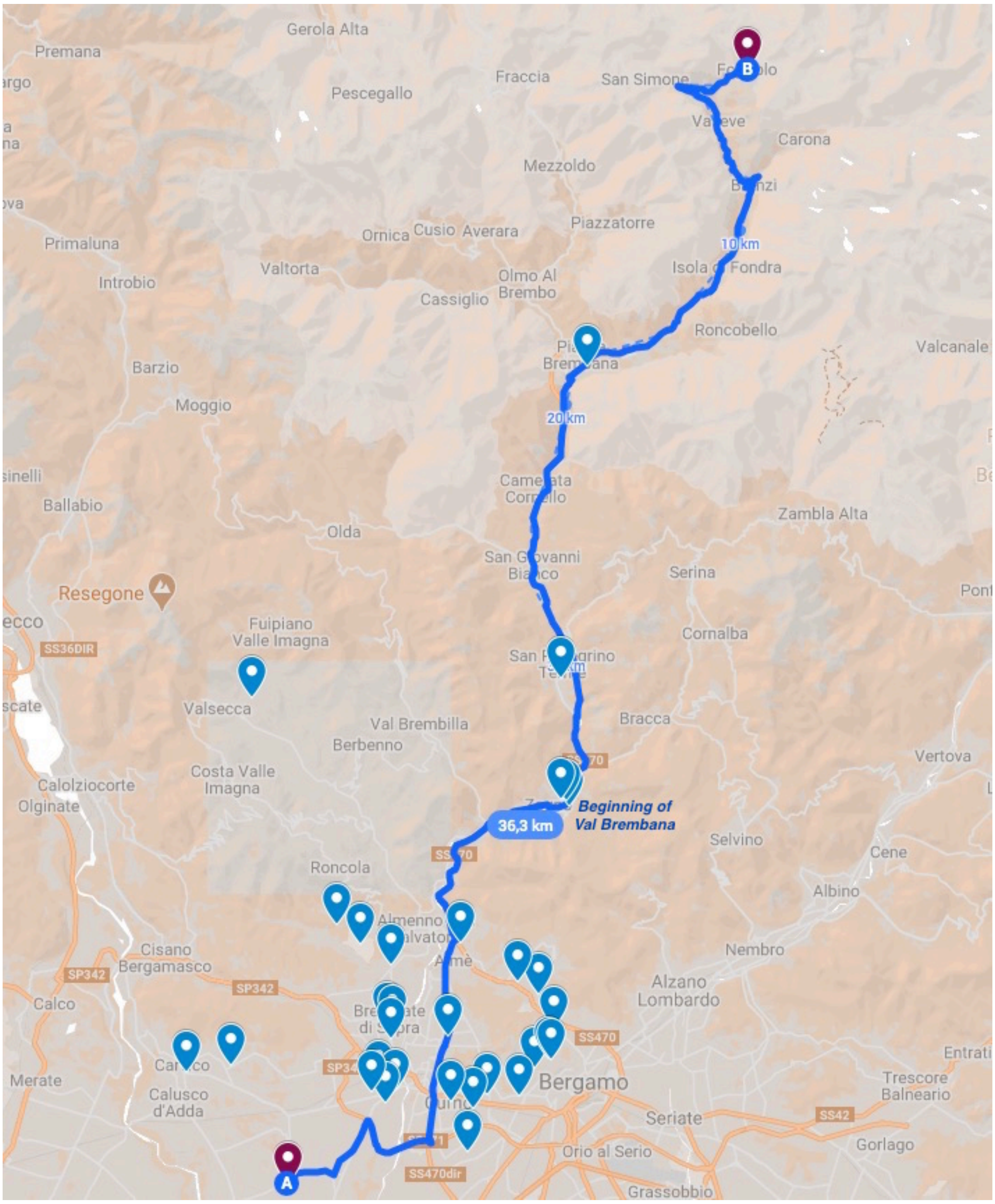

Figure 5.12. The stations along the route Chignolo d'Isola – Foppolo with a maximum deviation of 5 km

To assess this critical situation more accurately, a further simulation was carried out by setting the Foppolo ski resorts as the origin.

5.5.1 Route Foppolo Ski Facilities – Closest charging station

In this additional simulation, as said before, the skii of Foppolo, has been set as the Origin, while the closest charging station (which is located in Lenna) as the Destination. The coordinates entered are shown in Table 5.11.

Table 5.11. Coordinates of simulation Foppolo – Lenna Charging station

Origin Latitude	Origin Longitude	Destination Latitude	Destination Longitude
46,0434	9,75274	45,9438	9,67836

The distance between origin and destination calculated by the program is 17 km. Simulation have been made with the same vehicles models as the previous one, in order to find out in which SoC condition they are not able to reach the charging station. Considering both case A and B, the results are shown in Table 5.12.

Table 5.12. Results of Foppolo – Lenna Charging station simulation

Test	Vehicle model	Autonomy	Total reachable stations (case A)	Reachable stations within 5 km (case A)	Reachable stations with max deviation of 5 km (case B)
1	Nissan Leaf	5%	0	0	0
2	Fiat 500e	5%	0	0	0
3	Smart Fortwo	10%	0	0	0
4	Smart Fortwo	5%	0	0	0

In this simulation emerges that in four cases the vehicle is not able to reach the neither the destination and the closest charging station, it means that after a certain range it will stop.

It must be underlined that these are borderline cases, which are unlikely to be encountered in reality, but which clearly highlight the lack of stations in the area.

As can be seen in Figure 5.13, the first car to stop will be the Smart Fortwo with 5% SoC, which, having a maximum range of 160 km, will stop after 8 km.

Subsequently the Nissan Leaf with 5% SoC will stop after 13.5 km (its maximum range is 270 km), finally the Smart Fortwo with 10% SoC and the Fiat 500e with 5% SoC will both stop after 16 km (the 500e has a maximum range of 320 km).

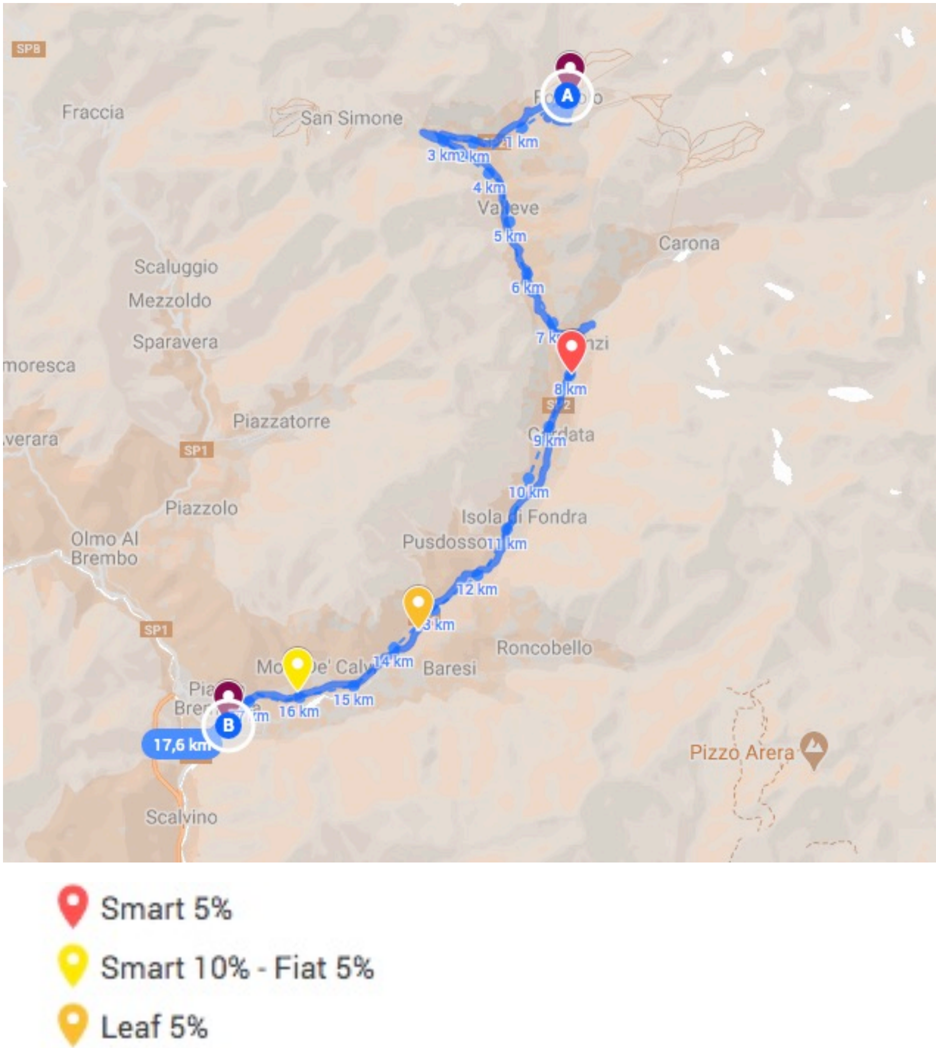

Figure 5.13. Distances at which the vehicles will stop

In conclusion, it emerges from the simulation that although the province of Bergamo has a good number of charging stations, it is quite lacking in some particular areas, such as the Val Brembana, which being a fairly frequented holiday resort in certain seasons, would need a marked improvement in terms of number of charging infrastructures.

5.6 Considerations

The simulations confirmed the fact, already described in chapter 3, of how the Lombardy region, and in particular the area between the Provinces of Milan and Bergamo, is at the forefront as regards the planning of charging stations. This situation certainly offers several convenient possibilities for electric vehicle drivers. However, some critical areas emerge, mainly in mountain areas (The same problem also occurs in Val Chiavenna and Vatellina for example), where, there is still a lot of work to be done, if the electric vehicle market is to be spread uniformly, and in the future to replace internal combustion vehicles the as soon as possible.
Considering, for example, the aforementioned case of the Brembana Valley, in an optimal scenario it would be advisable to have some charging stations near the ski resorts and at least 2 or 3 more charging stations located along the route.

CONCLUSIONS

The goal of this work was to develop a method of evaluation for the planning of charging stations in a specific area, taking the point of view of a hypothetical electric vehicle driver.

Indeed, in an international scenario where the aim is to get to the heart of the concept of smart mobility, of which the mass adoption of electric vehicles would be a key element, it is extremely important to analyze the drivers' point of view, in fact, to encourage mass adoption, it is necessary to act on the that.

In this regard, the software I developed can be a very useful tool since it makes it possible to simulate trips in different conditions with different vehicles and on different scenarios.

Through the simulations carried out, this software has made it possible to evaluate the planning of charging stations in Lombardy and to draw conclusions from them. Apart from this, it can be used in many other situations and applications: it can be applied to other geographical areas simply by suitably modifying the constant for which the longitude is multiplied and by inserting the charging stations corresponding to the countries considered in the database; it allows users to enter other types of vehicles on which to perform tests; finally, it also allows to make a study on the effectiveness of a single station by evaluating its charging times, rather than by studying the overall number of stations in a given area.

The results obtained from the simulations underline the excellent results of Lombardy, and of Italy in general in spreading electric mobility and these outcomes are consistent with progress made at European and global level. Nevertheless, they also made it possible to identify some areas where improvements should be made, such as mountain areas, like the Val Brembana (BG) case or centers of great importance, such as near Malpensa airport.

Overall, however, given the growth trend of power stations in recent years, a scenario in the near future is undoubtedly bright for the spread of electric vehicles.

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