POLITECNICO DI MILANO
Msc. In Electrical Engineering
School of Industrial and Information Engineering

CONNECTING PARKS TO THE SMART GRID:
A Vehicle-to-Grid feasibility study in the railway station car park of Ferrara.

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Abstract

Scopo del presente lavoro è valutare l'impatto energetico apportato alla rete di distribuzione nel punto di allaccio dell'impiato elettrico di un parcheggio ferroviario nel quale sono stati predisposti alcuni punti di ricarica per veicoli elettrici. La prima parte presenta una *summa* circa l'attuale stato di sviluppo della mobilità elettrica, descrivendo le varie tipologie di veicoli elettrici, le infrastrutture di ricarica e le possibili applicazioni nelle *Smart Grid*. Nella seconda parte, invece, viene simulata una possibile curva di carico del parcheggio in esame e, sul principio della tecnologia *Vehicle-to-Grid*, è stato messo a punto un opportuno algoritmo che, sfruttando la possibilità di un flusso energetico bidirezionale tra i veicoli parcheggiati e la rete elettrica, va a ribilanciare la curva di carico dell'impianto sotto esame al fine di evitare pericolosi picchi di assorbimento, di norma difficilmente gestibili dal DSO. Il lavoro presenta anche l'accoppiamento con un impianto fotovoltaico progettato ad hoc per il parcheggio.

The purpose of this work is to evaluate the energy impact on the distribution network at the point of connection of an electric plant of a railway car park where some charging points for electric vehicles have been installed. The first part presents a summary of the current state of development of electric mobility, describing the various types of electric vehicles, the charging infrastructure and the possible applications in *Smart Grids*. In the second part, instead, a possible load curve of the car park in question is simulated and, based on the principle of *Vehicle-to-Grid* technology, an appropriate algorithm has been developed. Such algorithm, exploiting the possibility of a two-way energy flow between the connected vehicles and the electricity grid, perform a *Peak Shaving* of the load curve of the plant under examination in order to avoid absorption peaks normally difficult to manage by the DSO. The work also presents the coupling with a photovoltaic system designed specifically for the car park.

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CHAPTER 1
ELECTRIC MOBILITY, BETWEEN PAST AND PRESENT

If compared to ten years ago, electric mobility is becoming a reality increasingly present in everyday life. However, we are still far away to talk about a real '*electric revolution*' but the steps towards this new way of conceiving mobility are begun and to date, in 2019, we can already notice the developments undertaken by this sector. If we take a careful look around us, it is now common experience to notice the ever-increasing percentage of electric cars, especially those related to car sharing fleets. Moreover, as regards the recharging infrastructures, an attentive observer can note their major widespread in our city. The following chapter presents a general discussion of the panorama concerning electric mobility, particularly, in this chapter you will find:

- A brief introduction concerning the actual devolpment of electric vehicles in the world;
- the different types of Electric Vehicles (EVs) currently present according to their hybriditation degree, the various charging methods and the related infrastructure of the electric vehicle supply equipment;
- the concept of Smart Grid will be presented, a fundamental starting point in which the idea of *Vehicle-to-Grid* is grafted .
- the basic idea of the the *Vehicle-to-Grid* will be laid, describing the basic principles, the different possible applications and the different pilot projects started.

1.1 The “innovation” of the electric vehicles

Wanting to take a long step back in time, the debate about the use of electric mobility find its roots since the end of the 19th century. Even before the manifestation of the various problems related to the massive use of a type of transport related to fossil fuels, already in 1898, following a contest in which several prototypes of cars (both electric and with internal combustion engine) were presented, the jury of the time announced, almost with a prophetic vision that:

" It seems clear that petrol coaches cannot sustain a public car operating system in a large city."[1]

In fact the first years of the '900 knew mainly the evolution of these means of electric transport [2]. Electric cars seemed preferable to petrol cars that were noisy, with the risk of fire and explosion, with annoying vibrations and smoky exhaust gases. Furthermore, manual gearbox and cranking made them difficult to use. It is true that, for the first electric cars, the distances that could be covered were small (up to 80-90 km) but since the mobility of the time was still confined to a purely citizen transport, this did not constitute an obstacle, at least in an initial phase. But then, the situation seemed destined to change in favor of means of transport with internal combustion engine, following:

- The advent of massive mass production introduced by Ford with the famous T model;
- the reduction of the oil price;
- the extension and improvement of the road network which allowed ever greater distances to be traveled.

All these factors turned the needle of the balance towards fossil fuel mobility which became predominant throughout the 20th century up to the present day.
The oil crisis of the 70s and the consequent economic crisis, however, put in evidence the fragility of an economic system based mainly on fossil fuels which, in addition to their obvious limitations and being heavily polluting the environment, find their main location in territories characterized by profound political instability. This crisis prompted world governments to radically change their assets with the aim of reducing the dependence of the western economy on Middle Eastern oil sources, through the reduction of consumption, the reorganization of industrial production, the search for alternative energy sources. The crisis obviously also

[1] Original version: “Il semble désormais acquis par l’expérience que le fiacre à moteur à essence de pétrole ne saurait constituer un système d’exploitation de voitures publiques dans une grande ville” [1].

involved the transport sector and the switch to an electric transport mode, until then relegated to niche applications, began to be taken into consideration again.

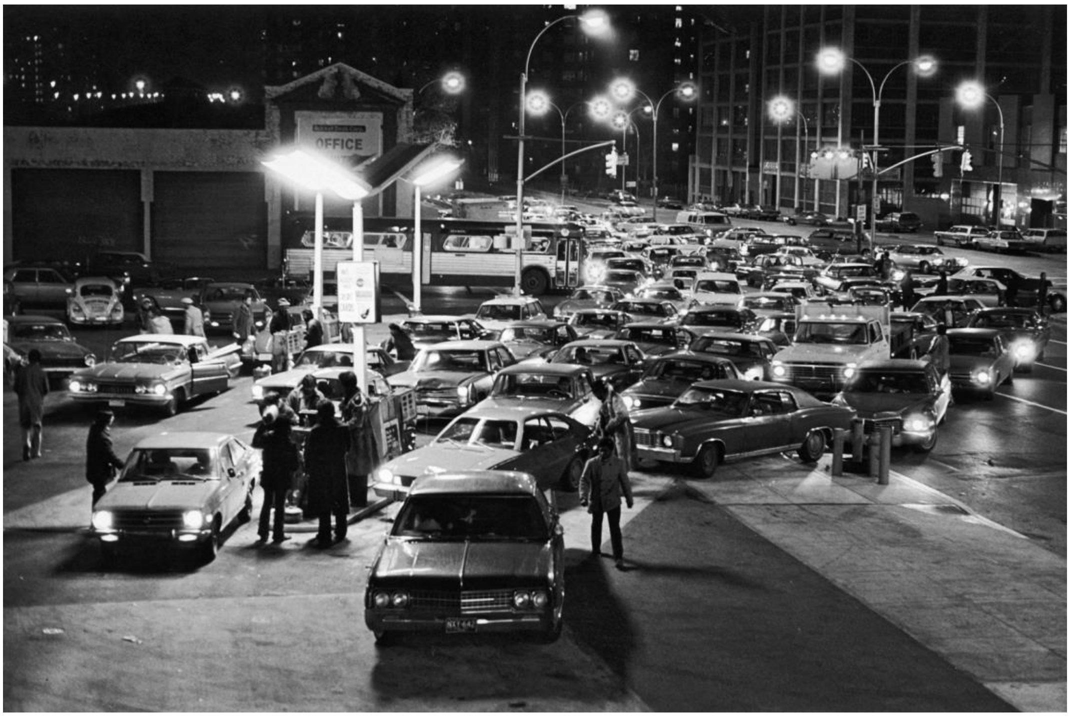


Fig 1.1 Cars lining up at a gas station during the 1973–74 oil shortage, Brooklyn, New York, U.S. [2].

As mentioned in the introduction to this chapter it is not yet possible to talk about a real '*electrical revolution'*, although the environmental theme is becoming nowdays more prominent than ever, together with the fact that fossil fuels will become an increasingly rare resource[2] so, the switch to an electrical type of mobility has become the hot topic of the last ten years. As stated in [3], currently, concerning the Europe panorama, the transportation sector occupy the fourth place as greenhouse gas emitter with a share of 14%. A greater diffusion of an electric type mobility could therefore reduce this portion by also going to mitigate the increasingly critical problem of pollution in urban centers. This diffusion is however discouraged, today, by factors of different nature including:

- the still **high costs** of electric vehicles available on the market compared to traditional vehicles with internal combustion engines (ICE);
- the **charging times** that are still too high;

[2] An oil reserve of 70-100 years is estimated, considering the current consumption rate and the oil fields known so far.

- the **anxiety range** as the energy that can be stored in the batteries allows to reach, in the average, a distance between 100 and 300 km;
- the **charging points** are present but still not so widespread;
- the **production and disposal of batteries** which raises various environmental and ethical problems.

On the other hand, cars powered exclusively by electricity have several advantages, such as:

- They do **not need fossil fuels** to work and therefore can be charged exploiting renewable sources;
- introduce **zero pollutants** at the local level;
- they are **much less noisy** than their rivals with internal combustion engine;
- they enjoy **many incentives** that somehow go to buffer the initial purchase costs;
- Moreover, even the **price per kilometer** traveled is **cheaper** compared to petrol transport.

Despite the initial problems and criticalities linked to the switch from thermal towards electric mobility, to accelerate and control the deployment of electric vehicles worldwide, since 2009 a multi-governmental[3] initiative began, under the clean energy Ministerial, the so-called Electric Vehicles Initiative (EVI) [5]. The most recent initiative proposed by the EVI is the EV30@30 Campaign [6], launched at the Eighth Clean Energy Ministerial in 2017 in Beijing (China); the aspirational goal of this campaign is to reach 30% sales share for electric vehicles by 2030. The main actions to reach this include:

- Provide support to the governments in need of policy and technical assistance;
- Promote programs (such as Global EV Pilot City Programme) to facilitate the exchange of experiences in the EVs field and propose the best practices for the promotion of EVs in cities;
- Encouraging public and private sector commitments for EV uptake in company and supplier fleets;
- Supporting the deployment of EV chargers and tracking progress.

According to [5] in 2017 the global stock of electric passenger cars reached 3.1 million (Figure 1.2), with a relevant increase of 57% with respect to 2016 and approximately two-thirds of the world's electric car fleet are battery electric vehicles (BEVs). In addition to the 3.1 million

[3] Governments currently active in the EVI include Canada, the People's Republic of China ("China"), Finland, France, Germany, India, Japan, Mexico, Netherlands, Norway, Sweden, United Kingdom, United States, Chile and New Zeland.

passenger electric cars, there were nearly 250,000 electric light commercial vehicles (LCVs) on the road in 2017. The largest electric LCV fleet is in China (170,000 vehicles), followed by France (33 000 vehicles) and Germany (11 000 vehicles). Electric LCVs are often part of a company or government fleet. For instance, the DHL Group, a major logistics company, operates with the largest electric vehicle fleet in Germany (16 000 electric vans, bicycles and tricycles). It has also undertaken in-house development and manufacturing of its own electric vans (see fig 1.3) tricycles and bicycles as part of this vision. Strong of the success obtained the company is now selling its electric vehicles to third parties (mainly municipalities and other businesses) [7].

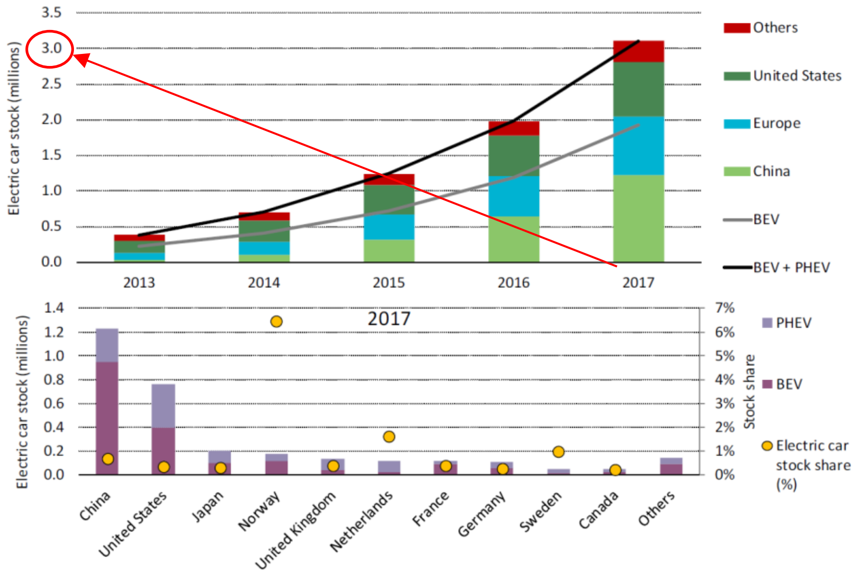


Fig 1.2 Passenger electric car stock in major regions and the top-ten EVI countries [5].

Fig 1.3 StreetScooter was the best-selling electric vehicle of 2017 in Germany with a market place for 473 vehicles [7].

Regarding the sales of EVs, the 2017 was marked by over one million vehicles sold worldwide, an increase of about 50% compared to the previous year even if the total number of sales is still modest to be able to talk about an electric mobility revolution. As it is possible to see from figure 1.4 the two leading nations in this sector are Norway and China, for different merits. Regarding China, it has the largest car market and nearly 580.000 electric cars were sold there in 2017. On the other hand, Norway can boast greater market penetration for electric vehicles as about 39% of vehicles sold in 2017 were electric.

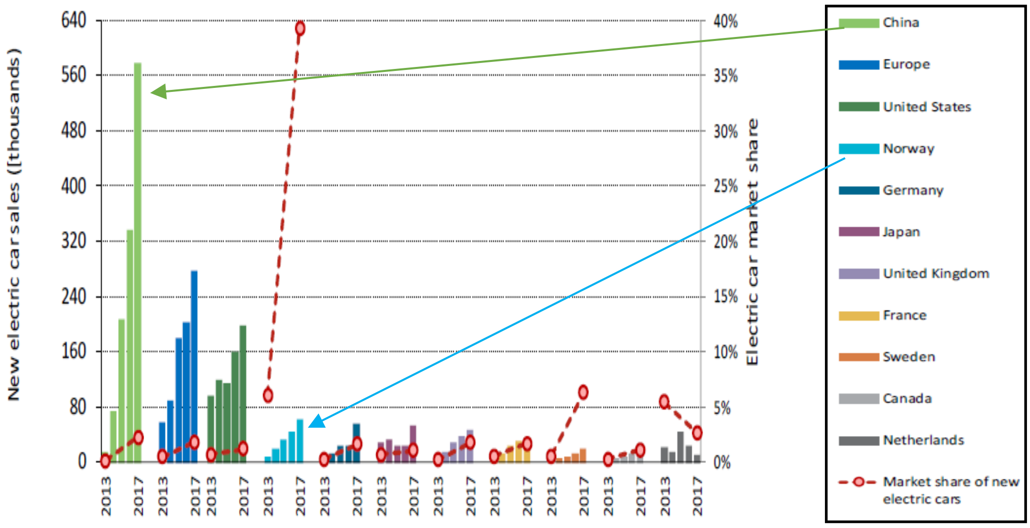


Fig 1.4 Electric car sales and market share in the top-ten EVI countries and Europe, 2013-17 [5].

1.2 Types of electric vehicles

So far we have analyzed the evolution and current spread in the world of electric vehicles, but as we will see in the following paragraph, their typology is quite varied. So let's start by draw out a possible definition of an electric vehicle. In general, an electric vehicle is that vehicle that exploit some form of energy to fed electric motor for the propulsion. Not all electric vehicles are all the same but differ according to the so-called hybridization degree (Figure 1.5), the ratio between the secondary source and the total power. it is therefore possible to recognize 5 main categories based on the type of power supply:

- Hibrid electric vehicle (HEV)
- Plug-in hybrid electric vehicle (PHEV)
- Extended Range hybrid electric vehicle (EREV)
- Battery electric vehicle (BEV)
- Fuel Cell electric vehicle (FEV)

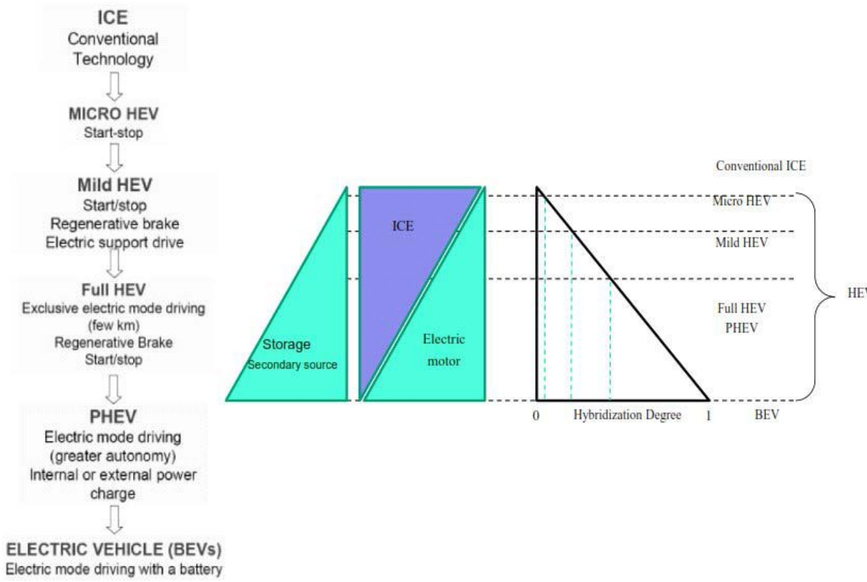


Fig 1.5 Hibridization degree of different vehicles [8].

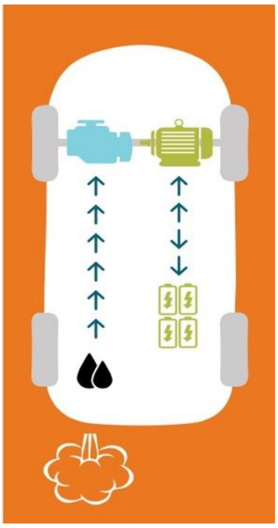


Fig 1.6 Non plug-in Hybrid veichle [9].

- ### Hybrid Electric Vehicle (H-EV)

HEV exploit, simultaneously or separately, the combination of the internal combustion engine (ICE) and the electric motor. The presence of the electric powertrain is intended to achieve either better fuel economy than a conventional ICE vehicle or better performance. For instance, Many HEVs reduce idle emissions by shutting down the engine at idle and restarting it when needed (start-stop system). the electric powertrain is used to deliver a high torques during the vehicle start-up phase reducing fuel consumption. The batteries are not rechargeable from mains, but only by the regenerative braking system and from the ICE equipped with a suitable generator. A hybrid-electric produces less tailpipe emissions than a comparably sized gasoline car, since the hybrid gasoline engine is usually smaller than a comparably sized, pure gasoline-powered vehicle and if not used to directly drive the car, can be geared to run at maximum efficiency, further improving fuel economy.

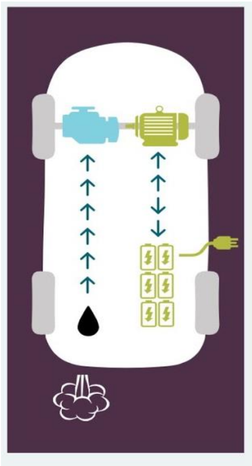


Fig 1.7 Plug-in Hybrid vehicle [9].

- **Plug-in Hybrid Electric Vehicle (PH-EV)**

PH-EV is based on the same concept of HEV. but, while in a normal hybrid vehicle the battery cannot be recharged from the outside, in the case of a PH-EV the vehicle is also equipped with a socket that allows the recharge of the battery from an external source. This allow to increase the driving range of the vehicle and decrease the cost of charge (wrt. HEV) since the electric energy produced by the main network is cheaper than the electric energy produced on board. running on electricity until their battery pack is depleted: ranges vary from 15 kilometers to over 65 [11].

However, depending on the type of connection it is possible to recognize three different arrangement: Series PHEV, Parallel PHEV and Series-Parallel PHEV. Figure 1.8 shows schematically the configuration of PHEV series. In this example the vehicle has one electric traction motor. The energy is provided by the generator linked to the ICE or by the storage system.

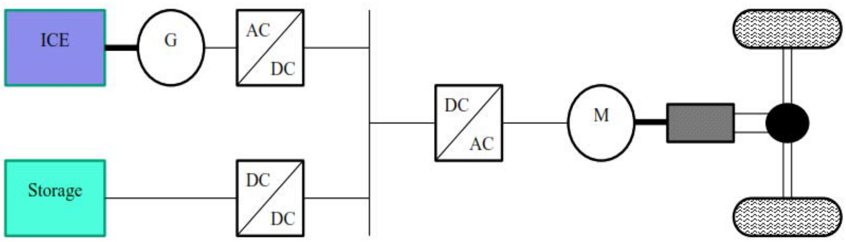


Fig 1.8 Series PHEV configuration [8].

Figure 1.9 shows, instead, a Parallel PHEV configuration. It is possible to have three different arrangement:

- In **Case A**, the mechanical transmission receive power both from the ICE and the electric motor.
- In **Case B**, ICE and electric motor are mounted on the same shaft. This configuration allows also to recharge the storage system when the car is stopped, since the motor can act also as generator.

- In **Case C** the two motor are decoupled. The rear wheel-set is driven by an ICE while the front wheel-set is driven by an electric motor feeded by a storage system. This configuration doesn't allow the recharge of the battery with the ICE as in the case B.

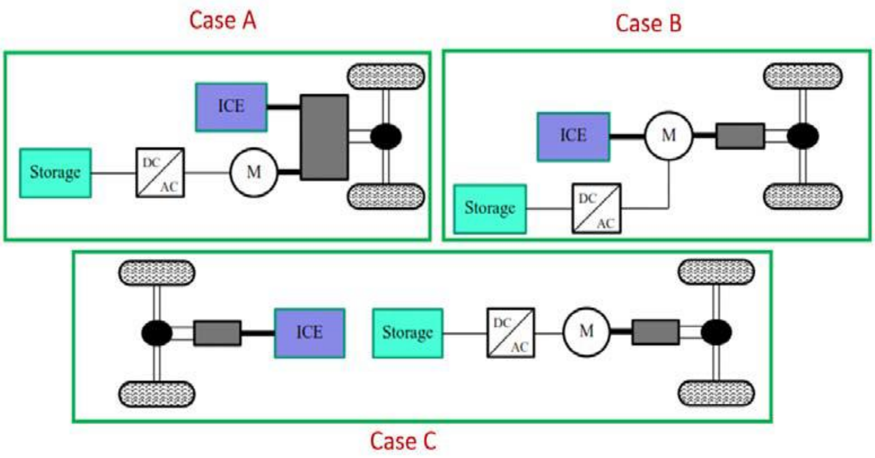


Fig 1.9 Parallel PHEV configuration [8].

Finally, it is also possible to have a combination of series and parallel configuration, as shown in figure 1.10. In this example both electric motor and ICE are linked to the same shaft, but the ICE can be decoupled from the shaft through a clutch allowing series or parallel configuration depending on the need. When decoupled, the ICE can feed the electric motor through a generator and AC/DC-DC/DC stages. Or can also recharge the battery when the vehicle remains stopped. In this case, just one system supplies the electric motor at a certain instance. In parallel configuration the traction is guaranteed both from mechanical power provided by the ice and the electric motor feeded by the storage system.

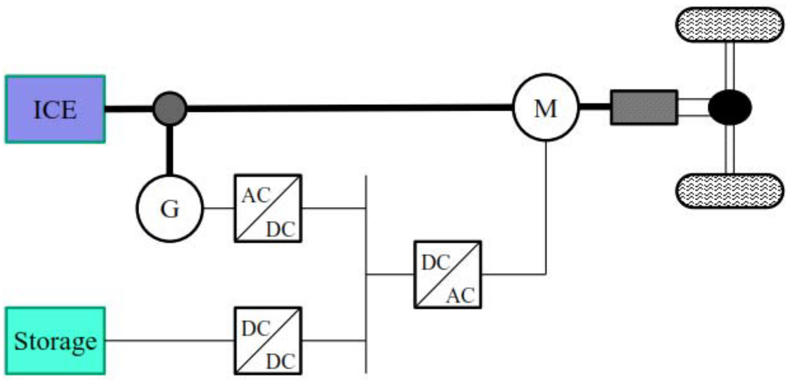


Fig 1.10 Series-Parallel PHEV configuration [8].

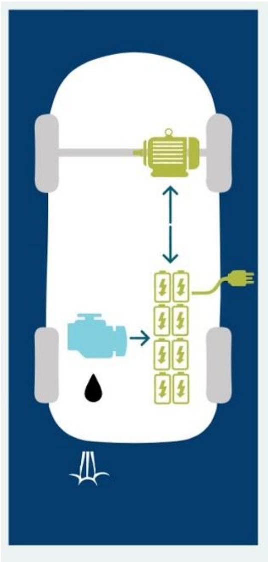


Fig 1.11 Extended range vehicle [9].

- ## Extended Range Electric Vehicle (ER-EV)

ER-EV can be considered a kind of hybrid vehicle even if this definition is not completely correct. in fact, the traction of the vehicle, in any case, relay on the electric motor. the difference between a hybrid vehicle lies in the fact that a ER-EV, is equipped with a small ICE that allows the recharge of the battery to extend the driving range. In some application it is also possible to have a fuel cell generator. The drawback is an increase of the weight of the vehicle.

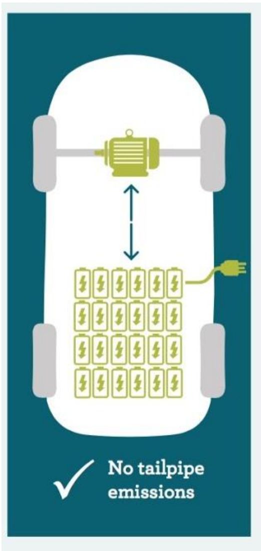


Fig 1.12 Battery electric vehicle [9].

- ## Battery Electric Vehicle (B-EV)

BEV is an electric vehicle powered integrally from the battery pack, often coupled with a regenerative braking system.
The battery is recharged by connecting the vehicle to the electric grid. BEVs don't have any tailpipe emissions and possess the highest value of hybridization degree.

- ## Fuel Cell Electric Vehicle (FC-EV)

In the case of FC-EV the electric energy is produced on board by a fuel cell generator, eventually coupled with batteries to exploit the regenerative braking and help the vehicle during the start-up phase. However, the FC-EVs presents some criticalities to overcome, such as: lack of a dedicated infrastructure, high costs of the overall system and a relative low thank-to-wheel efficiency (≈ 40%).

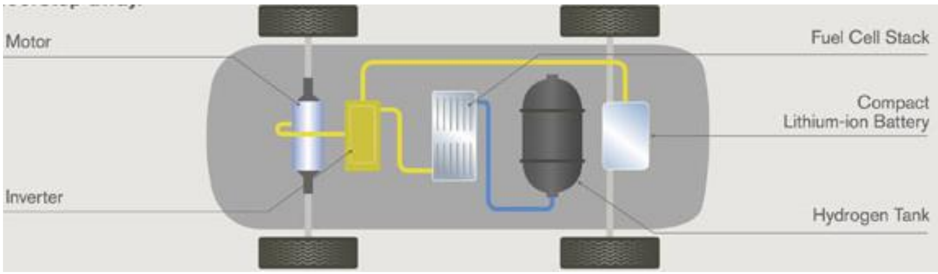


Fig 1.13 Fuel Cell vehicle [10].

1.3 Charging of electric vehicles

Obviously, when we talk about electric vehicles, beyond the vehicle itself, we cannot ignore even the *"fixed"* infrastructure part, represented by the Electric Veichle Supply Equipment (EVSE). It is clear that the batteries inside the EVs, necessary for storing energy for propulsion, have to be somehow recharged.

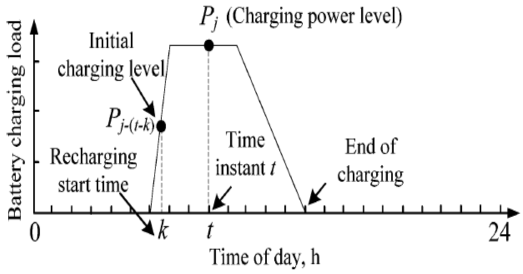


Fig 1.14 Schematic of a charging load for a generic EV [22].

And it is absolutely not to be underestimated the critical impact that such systems could determine in the distribution network. An EV, taking into account the ever increasing levels of both power and storage capacity of the various models proposed by the manufacturers, can be assimilated, from an energy point of view, a full-flegged small apartment "on wheels" [20]. It therefore appears evident that the installation of the various EVSEs, whether in a public or private environment, deserve special attention in the design stage in order to ensure optimal coordination with the distribution network as it directly impacts the power demand [21]. As an example, figures 1.14-1.15 show, respectively, a generic power curve of a battery in charge and the impact on the daily load demand in a public parking lot with an uncontrolled charge of electric vehicles at different penetration level [22].

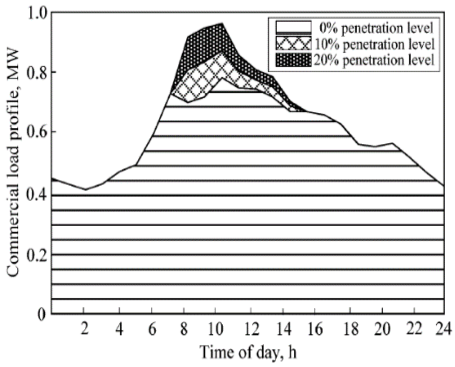


Fig 1.15 Uncontrolled public charging [22].

In the remainder of this paragraph than, we will go on to analyze the various ways of recharging foreseen by the standards and the various types of connections that are currently affirming in the market of EVSEs.

1.3.1 EV Charging Modes

Let's now analyze the the various modes of recharging foreseen by the standards. The European standard IEC 62196 [13] sets four different charging modes based on different power charging levels, protection systems and connector types:

- **Charging mode 1 (home charging without PMW)** it is the simplest way of connection. The EV is directly connected to the AC supply network (single-phase or three-phase) without any control contacts, using standardized socket outlets with a maximum current allowed of 16 A and not exceeding 230 V (single-phase) or 400 V (three-phase).

- **Charging mode 2 (home/company charging with PWM)** The EV is connected to the AC supply network (single-phase or three-phase) not exceeding 32 A and not exceeding 230 V (single-phase) or 400 V (three-phase) using standard socket (max. 22 kW). The cable is equipped with a Control Box (PWM safety system) that ensures the safety of operations during recharging.

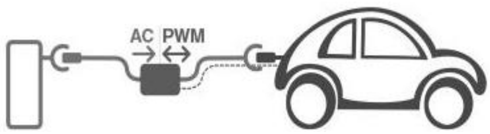
- **Charging mode 3 (public spaces charging)** this type of connection is mandatory for public places. The EV is connected to the AC supply network using Electric Vehicle Supply Equipment (EVSE). Therefore, the control pilot has also to control the safety equipment of the EVSE, permanently connected to the AC supply. The communication cable between the vehicle electronics and the charging station enables integration with *smart grids* (See par. 1.4).

- **Charging mode 4 (FAST DC connection)** The EV is connected to the AC supply network using an off-board charger where the control pilot is responsible also for safety of the equipment permanently connected to the AC supply. In mode 4 the charger is no longer in the vehicle but in the charging station.

Below, the main characteristics of the various charging modes are summarized.

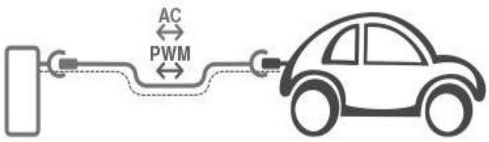
Charging mode 1

EV directly connected to the AC supply network.
No control contact.
the safety depends on the presence of adequate protections on the system side: protection against overcurrents, earthing system, protection against contacts,etc.



Charging mode 2

Ev connected to the a.c supply network.
Presence of in-cable control box to ensure safety.



Charging mode 3

EV directly connected to the grid through dedicated supply equipment. existence of a pilot control contact between the supply equipment and the EV performing different functions:

- Correct inserting of the connectors.
- monitoring of the continuity of the protective conductor.
- Performing an active control on the recharge.

Charging mode 4

EV indirectly connected to the grid through an off-board charger installed directly in the dedicated supply equipment.

1.3.2 EV Connectors type

In order to recharge the batteries present on board of the EVs a suitable connection must be made between the vehicle and the supply network. The fundamental parameters to take into account that can drastically affect the recharging time are:

- The rated **battery capacity** installed on-board (typically 20-80 kWh).
- The initial **state of charge** of the EV (SOC).
- Rated **charging power** of the Electric Vehicle Supply Equipment (EVSE).
- The **actual power** that can be withdrawn from the network.

Depending on these factors, the charging time can range from few minutes up to 10 hours or more. Table 1.1 shows typical charging times for a generic medium-sized electric car.

Tab. 1.1 typical charging times for a generic medium-sized electric car [12].

Recharge Power			**Autonomy reinstate in**		**Times required to reinstate 10 km**
			1 h	**15 min**	
AC	Slow	3.3kW	13-15 km	3-5 km	40-45 min
	Fast	22 kW	90-100 km	25-30 km	6-7 min
		43 kW	Complete	50-60 km	3-4 min
DC	Fast	50 kW	Complete	60-70 km	2-3 min

Concerning the modes of charging and the connectors currently available, as often happens when a new technology begins to develop, as there are no standards or predefined protocols, there is always a first initial phase in which different products that perform the same function take place, often independently. The same applied to electric vehicle charging systems that have experienced the development of a varied amount of connectors and protocols promoted by the various companies that have worked in the development of this new technology. But once the technology is developed, the main objective must be to achieve the interoperability of the charging systems without neglecting performance, safety and economy. At present, the European standard, which contains the requirements for charging electric vehicles, is the CEI EN 61851-1: 2012-05 Standard: "Conductive charging system for electric vehicles - Part 1: General requirements" [13].

Basically, as figure 1.16 shows, there may be three different connection configurations:

- **Configuration A:** the electric vehicle is connected to the charging point by using a power cord and a plug permanently attached to the vehicle itself.
- **Configuration B:** the electric vehicle is connected to the charging point by using a removable power cord provided with the relative plug.
- **Configuration C:** the electric vehicle is connected to the charging point by using a power cord and a plug permanently attached to the supply equipment.

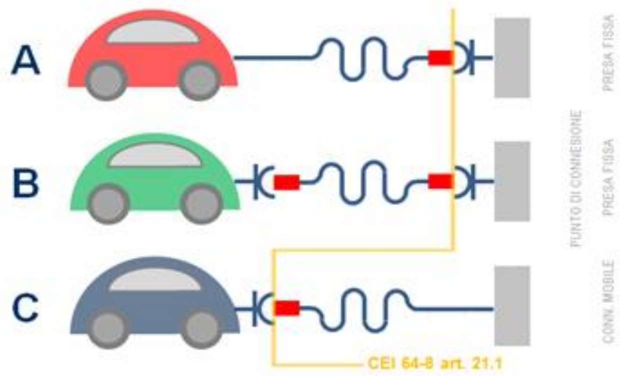


Fig 1.16 Type of connection for the recharge [12].

Beyond the type of connection, regarding the connectors, nowdays in the electric vehicle market it is possible to find different models and brands with different configurations and technical characteristics. Below, some type of connector are described:

- **Schuko plug** is the common name for a system of plug and socket for alternating current, defined as CEE 7/4, present in many European countries. It has a ground connection, two terminals and supports current of up to 16 Amps, so it is only compatible with slow recharges. It is common in some motorcycles and electric bicycles, even in some electric car like the Twizy (fig 1.18).

Fig 1.17 example of shuko-type 1 connection.

Fig 1.18 Renault twizy connected to a domestic socket.

- **Type 1 (SAE J1772)** also known as "J plug" (fig.1.19), is a North American standard for electrical connectors for electric vehicles. It is characterized by five pin-and-sleeve, two active conductors (L1-N), one for the earthgrounding (PE) two for the signaling (PP and CP). The type 1 connector can also have an additional configuration that implements the *Fast Recharge* trough a DC connection (fig.1.20) allowing the recharge of the vehicle up to 200 A (90 kW) [17]. The power pins do not carry energy until the proximity and control pins are inserted. The latter are structured in such a way as to be the first to slip off when you want to interrupt the charging process. The physical button of the connector instead acts on the proximity pin that commands the vehicle's onboard charger to open up. Once the vehicle charger is open, the control pin cause the power relay in the charging station to open cutting all current flow to the J1772 plug. This prevents any arcing on the power pins, prolonging their lifespan [14].

Fig. 1.19 Type 1 connection.

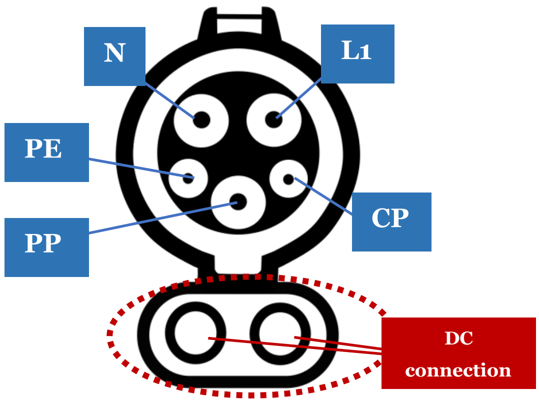


Fig.1.20 Details of the pins configuration for type 1 connection [14].

Tab 1.2 pins configurations for type 1 connection.

L1	Line 1	Single-phase AC
N	Neutral	Single-phase AC
CP	Control Pilot	post-insertion signalling
PP	Proximity pilot	pre-insertion signalling
PE	Protective earth	full-current protective earthing system

- **Type 2 (Mennekes)** also known under the name of *Mennekes*, from the name of the company specialized in industrial plugs and connectors, that proposed this configuration in 2009. Type 2 connector is a connector widely used especially in Europe. Generally, the cars that mounting this type of connector present male vehicle inlet, whilst charging station are fitted with a female outlet, either directly on the outside of the charging station, or via a flexible cable with permanently attached connector on the end. As figure 1.21 shows the type 2 connector presents 7 different pins, 4 pins for the power supply (L1,L2,L3,N), one for earth grounding (PE) and two for signaling (PP, CP). technically, this type of plug can support a maximum voltage of 480 V and absorb a maximum current of 300 A for a theoretical charging power up to 144 kW [15].

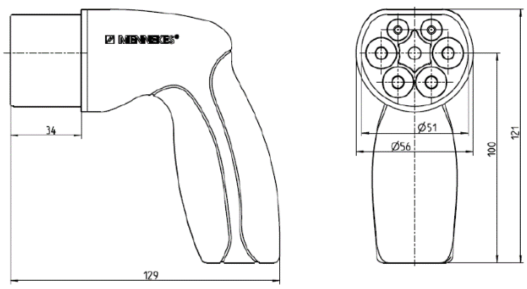


Fig.1.21 Type 2 connection.

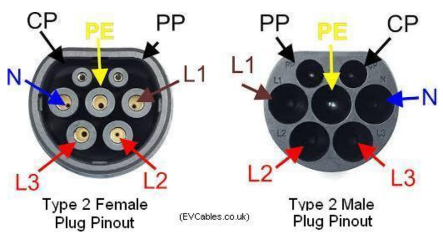


Fig. 1.22 Details of the pins configuration for type 2 connection.

Tab 1.3 pins configurations for type 2 connection.

L1	Line 1	single-/three-phase AC / DC-mid
L2	Line 2	three-phase AC / DC-mid
L3	Line 3	three-phase AC / DC-mid
N	Neutral	single-/three-phase AC / DC-mid
CP	Control Pilot	post-insertion signalling
PP	Proximity pilot	pre-insertion signalling
PE	Protective earth	full-current protective earthing system

- **CHAdeMO** is the trade name of a quick charging method proposed by an association of the same name in 2010. The origin of the name come from a Japanese phrase *"O cha demo ikaga desuka"* that literally means, "How about a cup of tea?" in order to remark the quick charge nature of this connection. Most electric vehicles have an on-board charger that uses an AC/DC rectifier in order to recharge the EV's battery pack but, since CHAdeMO works at very high power (up to in 400 kW in some tests experiments [19]) for thermal issues limit, the charger is installed directly in the EVSE, dropping the CHAdeMO charging protocol in mode 4 recharge.
  Figure 1.23 shows the design of this type of connector while figure 1.24 shows the diffusion of the EVSE that mount this technology in some part of Europe.

Fig. 1.23 CHAdeMO connector type.

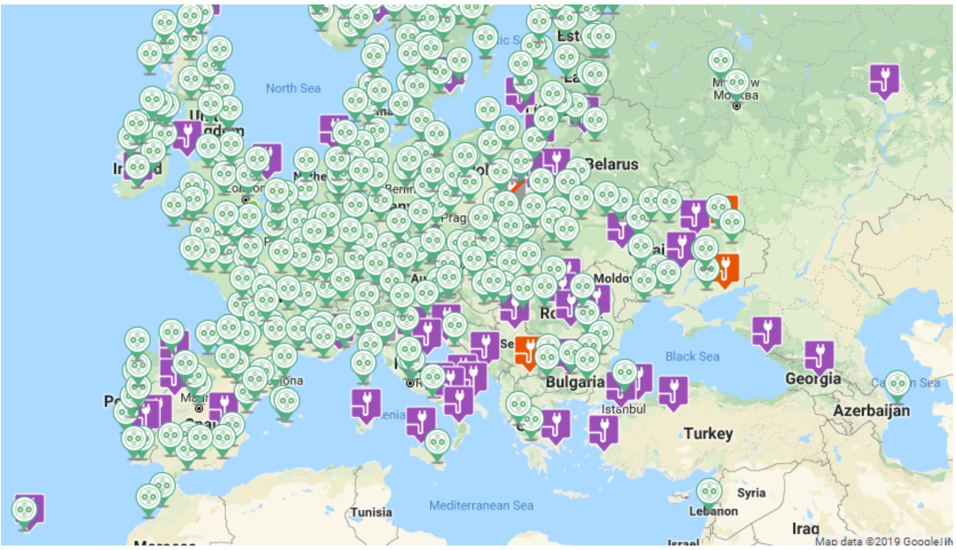


Fig. 1.24 Diffusion of the CHAdeMO charging type in Europe [16].

1.4 Electric mobility: towards the future

In paragraph 1.1 we analyzed the potential and criticality of electric mobility and its current level of penetration.
In paragraph 1.2 we discovered that the world of electric vehicles is not unique but has a varied classification within it.
In paragraph 1.3 the main charging methods and charging systems were analyzed, presenting the major technologies currently available.
In this concluding paragraph instead, we close the path focusing attention on possible future developments that electric vehicles could bring to the distribution network. Conceiving them therefore not only as mere passive loads but as active devices able to bring benefits to the electric network to which they are connected. This possible use, now established with the acronym of V2G (Vehicle-to-grid), goes directly to the more general concept of Smart Grid of which a brief summary is proposed below. Once this has been clarified, we will see what exactly is meant by the term V2G, what are its potentials and what are the current pilot projects.

1.4.1 Smart cities and Smart grid

As already underlined, electric mobility represents a necessary transition to get rid from a mode of transport still too dependt to the use of fossil fuels, harmful to the environment and whose discharges make urban centers increasingly unlivable. Electric mobility, being one of the branches of the "Smart Mobility", is therefore part of one of the pillars of the so-called "Smart Cities", that set of urban planning strategies and plans aimed at ensuring sustainable economic development and high quality of life through a skilful management of available resources (food, mining, energy, services etc.). The fundamental pillars of a Smart City are six as shown in figure 1.25 [23].

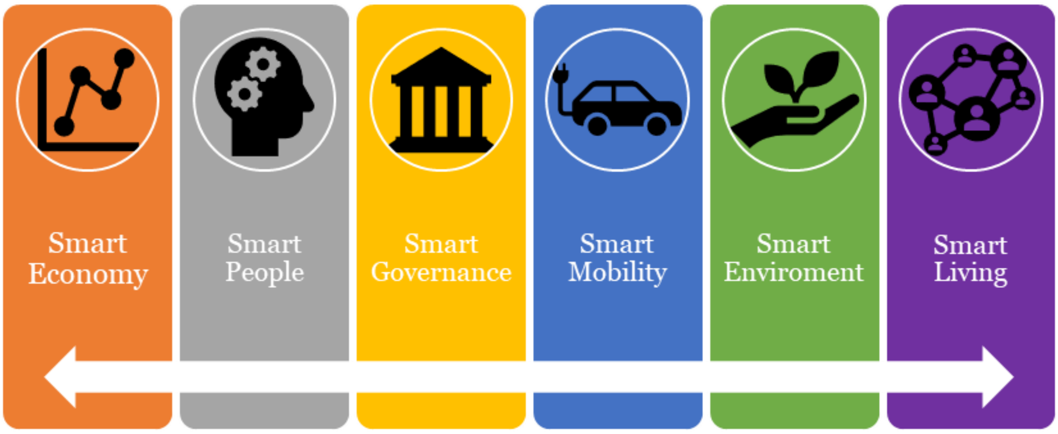


Fig. 1.25 The six pillars of a Smart City.

The pillar we are interested in is, therefore, that of the "Smart Mobility". However, it would be reductive to limit the issue of "Smart Mobility" to the mere switch from a type of transport with an internal combustion engine to one with an electric motor. In reality, the "Smart Mobility" is a much broader concept involving different stakeholders (Public administrations, private,public or mixed companies, end users etc.) and technologies/services (car sharing, autonomous drive, trip planni app etc.) but whose specific treatment is outside the scope of the following work. In this work we will deal instead with the aforementioned concept of Vehiclel-to-grid. Nowdays, in reality, the concept of the electric vehicle is still of the "passive" type, of the Grid-to-Vehicle type (G2V), coinceved to mere electric load However, this paradigm could be destined to change in the immediate future. The idea of the V2G fits into the more general concept of the so-called "Smart Grid". A possible and exhaustive definition taken from [24] of Smart Grid is the following:

"A smart grid is an electricity network based on digital technology that is used to supply electricity to consumers via two-way digital communication. This system allows for monitoring, analysis, control and communication within the supply chain to help improve efficiency, reduce energy consumption and cost, and maximize the transparency and reliability of the energy supply chain."

The current electrical system has its origins since the beginning of the 20th century and was conceived as an exclusively unidirectional system [27], consisting of relatively few production centers and many users, with all the limitations and disadvantages that this entails, including :

- High Joule losses due to the long distances that connecting production centers and end users;
- Difficulties in managing energy flows caused by the high uncertainty of the distributed generation (wind, photovoltaic, etc.) and lack of protocols in dynamic energy management;
- Response times too long in case of failures or malfunctions with consequent inefficiencies.

Therefore, its evolution in the "Smart Grid" foresees the overcoming of these limitations with the introduction in the electric network of real-time embedded sensors and automatic control systems in order to:

- realize a **real time grid monitoring** to have a permanent awareness of the network's parameters, voltage and current measurements, grid events detection etc;
- **detect any malfunctioning**, reducing repair times and maintenance costs;
- **optimize the energy consumption** of the end user who becomes more aware of his own consumption and act accordingly, even remotely;
- exploit and **better coordinate** the various small **distributed production** centers.

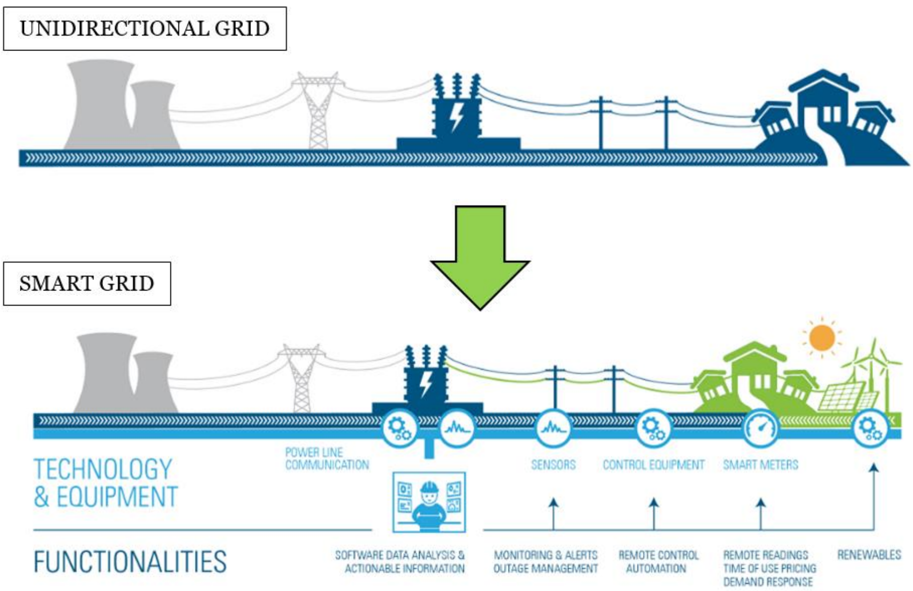


Fig. 1.26 Evolution from a traditional grid to a Smart grid [25].

1.4.2 Benefits and constraints of the V2G implementation

On the possible benefits and limitations imposed by a possible implementation of V2G there are researches on research, many of them even reaching results that are in contradiction with each others (see for instance [28]), but what are the advantages given by a possible exchange of energy between electric vehicles and the distribution network?

Let's start by saying that a hypothetical fleet of electric vehicles connected to the network could be managed as a *virtual power plant* (VPP). In this case an aggregator would be interfaced simultaneously with the electricity grid, market and connected fleet in order to maximize recharge performance (see [33] for more in-depth informations about this topic). This aggregator should therefore be able to:

- Have access to historical data concerning market prices and fleet behavior to forecasting purpose;
- Manage these data in order to achieve the fleet charging cost minimization and fulfill grid constraints;
- Interface with the EVs through the EVSE in order to analyze user preferences also and generate the optimum charging schedule.

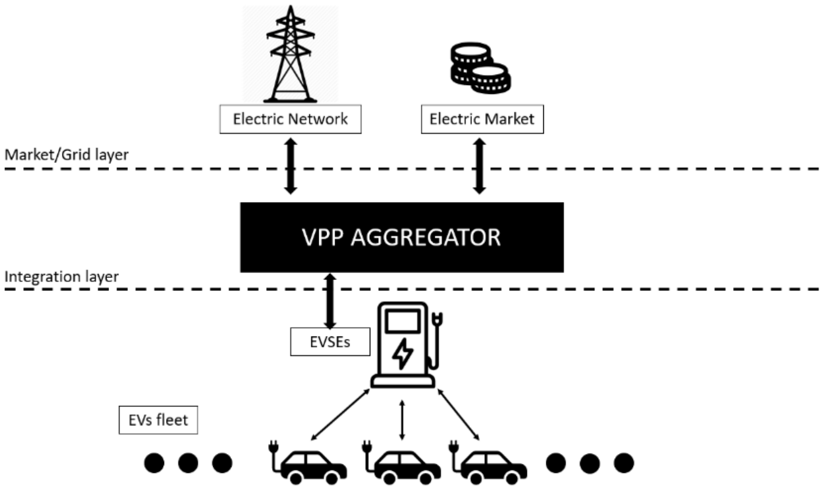


Fig. 1.27 Conceptual architecture of a VPP aggregator.

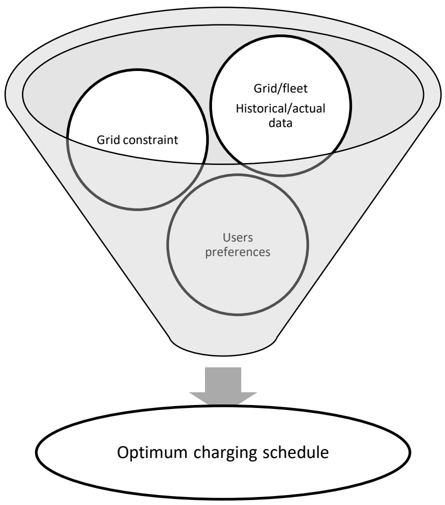


Fig. 1.28 Main aggregator functionality.

Therefore, the ultimate goal of the aggregator would be to:

- On the user side, guarantee the most convenient charging option in accordance with his charging needs.
- From the side of the network manager (DSO & TSO) should be able to exploit the VPP in order to provide ancillary services such as voltage and frequency regulation, peak shaving etc. [29]

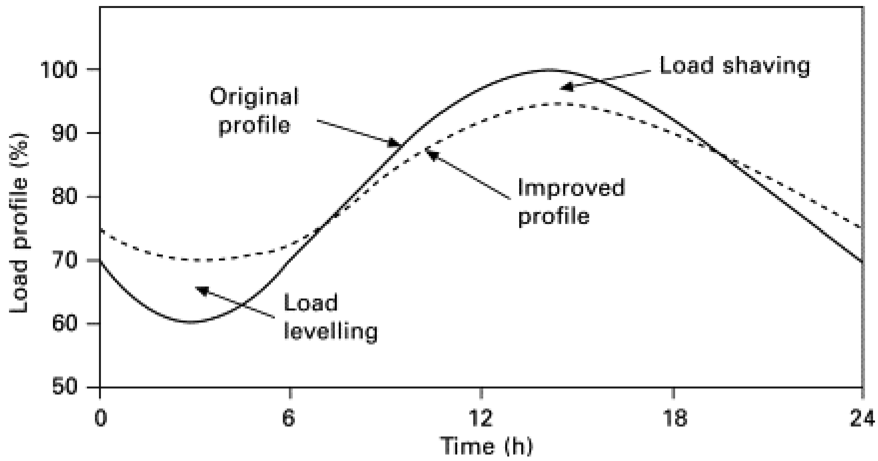


Fig. 1.29 Example of the improvement due to a Load balancing [32].

As we can guess, the V2G represents a complex systemic reality that involves different stakeholders and that today faces many challenges including, first of all, the degradation of the batteries which obviously can perform a limited number of charge/discharge processes but also the costs related to the infrastructure to be implemented and the correct management of the data to be processed to make the system reliable, secure and scalable. In particular, according to what is written in [31] to make V2G economically feasible the following must happen:

- The local utility jurisdiciton must have a need for ancillary services;
- An ancillary market should be in place;
- Battery cycle life must rise and cost must fall.

1.4.3 A taxonomy of V2G applications

The following section presents the main operational cases in which an EV could perform depending on the different connection characteristics. These differences are detailed in [26] and [28], a brief but comprehensive taxonomy is proposed.

- **Grid-to-Vehicle operation mode (G2V)**

It represents the simplest case you can imagine applied to the recharge of an electric vehicle. Essentially, it consists of recharging the battery that is connected to the Power network without considering any other operation. The EV is simply conceived as a load to the system.

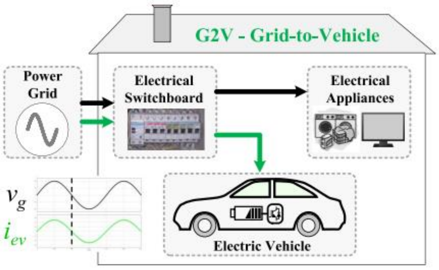


Fig. 1.30 G2V operation mode [23].

- **Vehicle-to-Grid operation mode (V2G)**

Although the G2V mode is the main operation mode for an EV, the possibility of a bidirectional energy flow can be helpful for the grid during some periods of time (i.e. stabilize the load profile and support large-scale renewable energy resources). In V2G operation mode the battery charger can be used to deliver part of the energy stored in the batteries back to the power grid. In a smart grid scenario, this operation mode is supposed to be controlled by the power grid manager and in accordance with the EV driver.

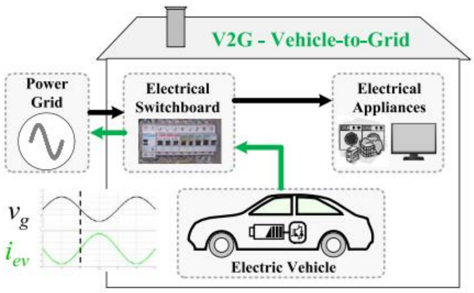


Fig. 1.31 V2G operation mode [23].

▪ Home-to-Vehicle operation mode (H2V)

Figure 1.32 shows the H2V operation mode applied both in G2V (a) that V2G (b) operation mode. In the first case the power absorbed by the EV battery take in to account the power absorbed by the electrical appliances of the home, in accordance with the maximum power signed in the contract with the electricity service provider. Therefore, a communication between the Smart-Meter of the home and the Charger of the EV must be provided. The measured signal is used by the control system of the charger to adjust its own instantaneous current in accordance with those values. This functionality aims to prevent overcurrent trips of the main circuit breaker installed in the home. Of course, the H2V operation mode can be perfectly integrated with V2G operation mode.

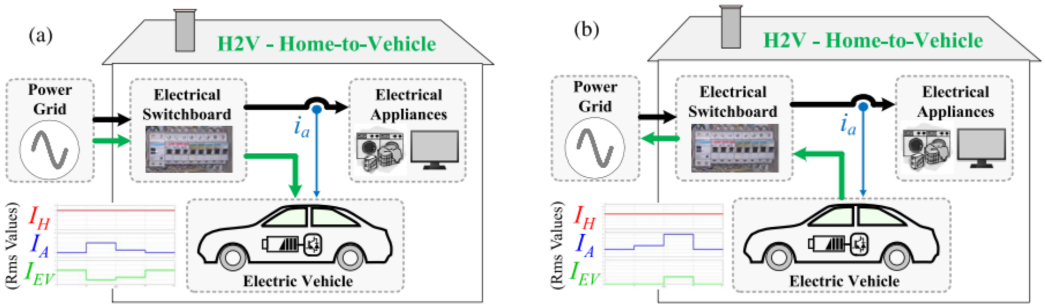


Fig. 1.32 H2V operation mode. (a) Combined with G2V. (b) Combined with V2G [23].

▪ Vehicle-to-Home operation mode (V2H)

In this case the electric vehicle connected to the home network acts as a voltage generator powered by the EV's battery. Two different operating modes can be recognized. The first operational mode (a) is that of an isolated system with respect to the power grid and all the Home appliances are fed by the EV. In the second one operational mode (b) the EV battery charger is used to operate as offline UPS.

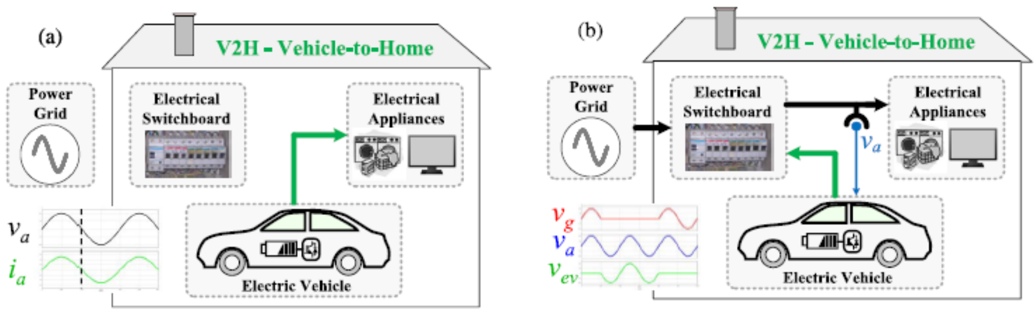


Fig. 1.33 V2H operation mode. (a) Operation in isolated system. (b) Operation as offline UPS [23].

▪ Vehicle-for-Grid operation mode (V4G)

In this operation mode the EV can perform ancillary services for the grid such as the production of inductive or capacitive reactive power, or to act as a filter to compensate current harmonics. The great advantage of this operation mode is that the total rated power of the EV battery charger can be used without using any energy from the batteries, therefore it doesn't cause age nor reduces the life span of the battery.

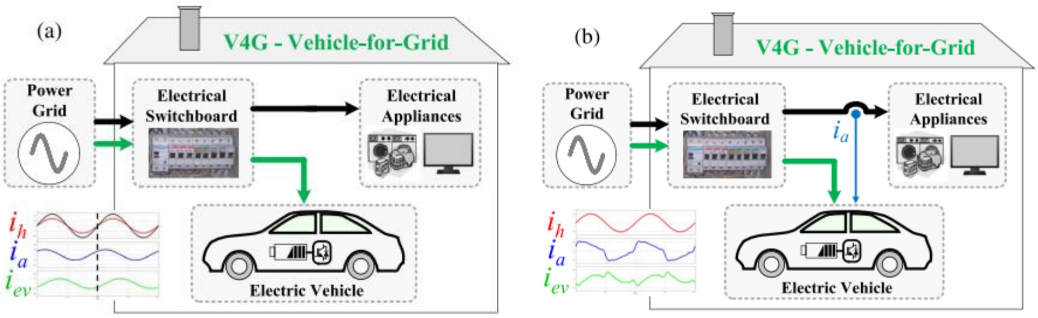


Fig. 1.34 V4G operation mode. (a) Producing reactive power. (b) Compensating current harmonics [23].

1.4.4 V2G Pilot Projects

"We proved the technical feasibility of vehicle-to-building five years ago. The next challenge is economics"
(Project representative, Mitsubishi Corp.)

At the end of this chapter we will now go on to list the main projects that have been carried out in various parts of the world in order to assess the feasibility and impact of V2G

▪ EDISON Project - Denmark

In 2007 [34] the Danish government decided to implement a long-term environmental policy with the aim to obtain a complete independence from fossil fuels, coal and natural gas. One of the various objectives to achieve was the increase of at least 30% in the penetration of renewable sources with respect to the overall production by 2025. The instability linked to renewable sources (in fig. 1.32 can be noted that in some periods of the year even exceeded the load demand) made the idea of developing and increasing the penetration of electric mobility attractive for several reasons, including:

- The low average driving distance of Danish motorists (about 40 km) ;
- The high costs of ancillary services to stabilize production from renewable sources;
- The high cost of fuel due to very high taxes.

It was estimated that if all Danish road transport had been covered by electric vehicles, total electricity demand would have seen an increase of at least 10-14 TWh / year (total Danish electricity demand was 34 TWh in 2007). It is therefore evident that the benefits promised by the implementation of the V2G represented a possibility to be examined.

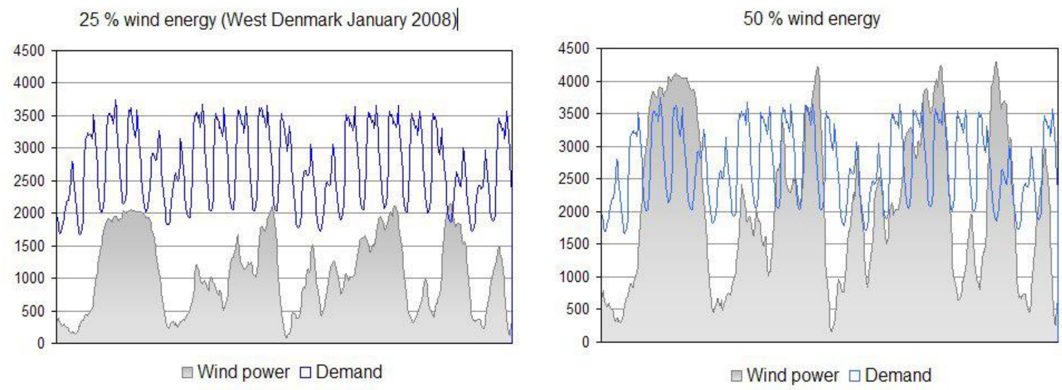


Fig. 1.31 Wind power generation and demand during 3 weeks of January 2008 in the western Danish area with: a) current wind power penetration and b) when assuming 50% wind power penetration [34].

For this purpose, in 2009 [31], EDISON project was launched with an investment of approximately EUR 6.5 million. The project conceived the fleet operator as third part among the market, the grid and the EVs as already seen in fig. 1.27. The island of Bornholm has been chosen as test site since, as an island, it was an isolated environment capable of running independently from the surrounding power system. Since at the time the penetration of vehicles was practically nil, for the EDISON project, a simulator was set up that was going to generate a virtual fleet based on statistical data representing the driving habits of the inhabitants of the island (fig. 1.32). every single vehicle connected could therefore have been constantly monitored and characteristic data viewable through an HMI such as the one in fig. 1.33.

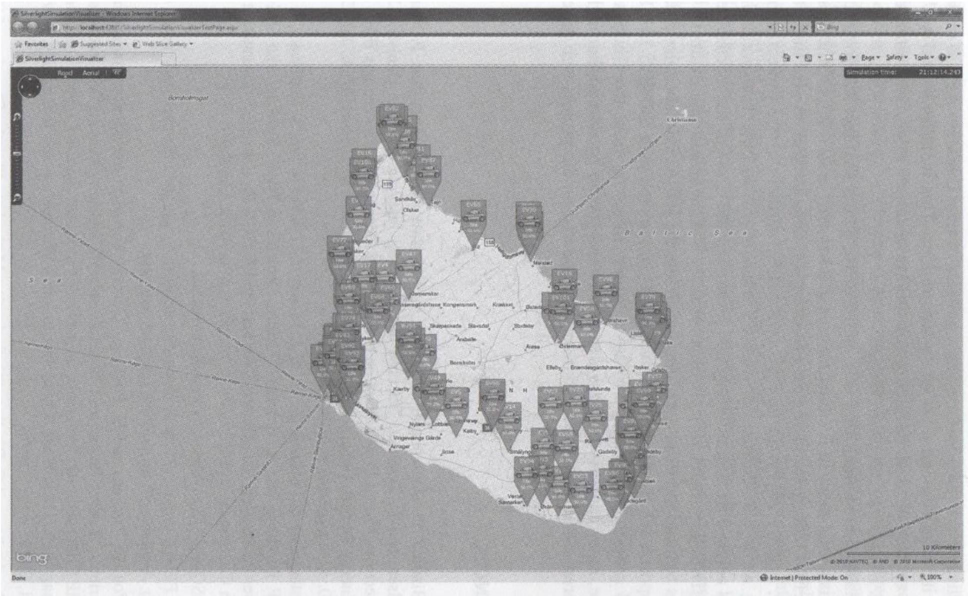


Fig. 1.32 Bird-eye view of medium-sized virtual EV fleet [31].

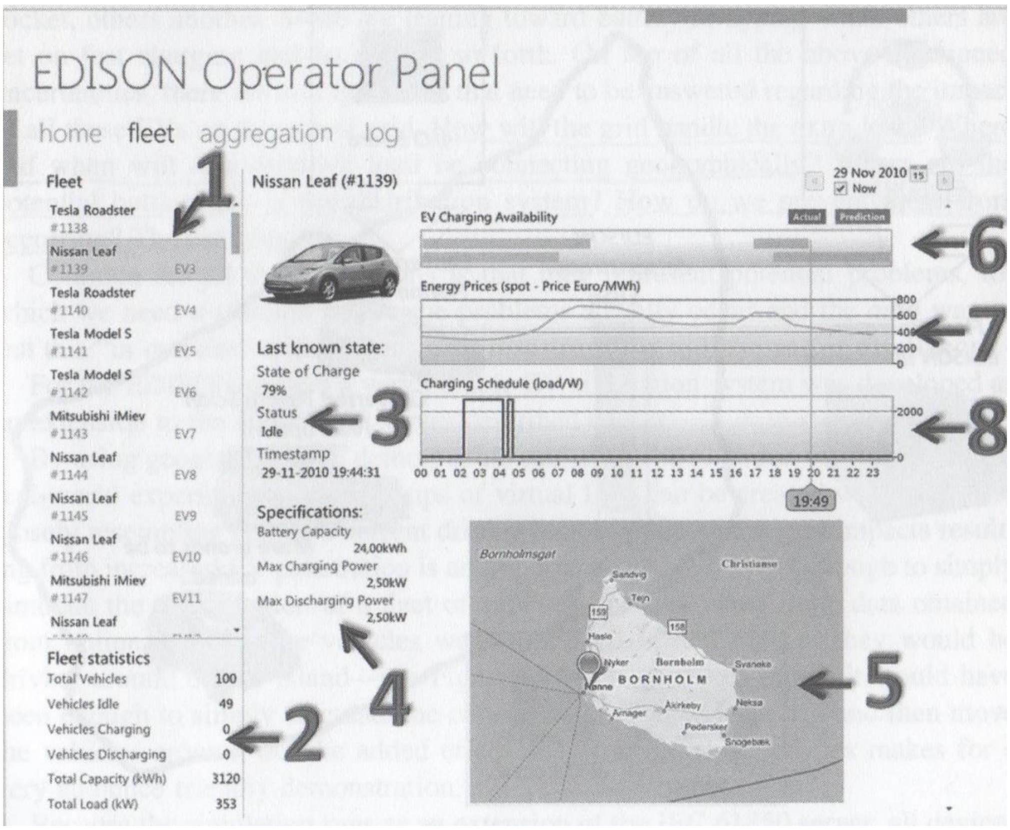


Fig. 1.33 EDISON Operator panel. 1) Selected vehicle 2) fleet summary stats 3) selected vehicle status 4) Veichle characteristics 5) EV'sGPS locations 6) recorden and predicted availability of the vehicle 7) energy prices 8) charging schedule [31].

- **ENEL-Mitsubishi Project - Netherland**

According to [35] The Netherlands presents an EVSE installation of around 40,000 of which 3,000 only in the capital, Amsterdam, which make the Netherlands the European leader in terms of car charging points: one per square km. In October 2017 [36] the Italian company ENEL, in a partnership with the Japanese Manufacturer Mitsubishi, the dutch grid operator TenneT and the American company Nuvve, started a V2G pilot project near Amsterdam. The project involved the installation of 10 EVSEs of 10 kW each for a total power of 100 kW. Mitsubishi motors provided 10 PHEV out-lander SUVs for the purposes of the project while the charging units was provided by NewMotion, a leading European supplier of smart charging solutions for electric vehicles. The intelligent management of energy flows was instead entrusted to the team of Nuvve who developed the "*Grid Integrated Vehicle platform*" (GIVe™) in order to controls the power flow to and from the cars, ensuring that the driver's mileage needs are always met and optimising the power available to the grid.

- **ENEL-Nissa Project – United Kingdom**

The British government has allocated about 10 million pounds of funds to be able to put in place perhaps one of the biggest projects in favor of V2G, foreseeing the installation of 1,000 V2G charging points during about three years:

"The project falls back on 9.9 million pounds in funding through the Office for Low Emission Vehicles and the Department for Business, Energy and Industrial Strategy. V2G provider Nuvve, the National Grid as well as UK Power Networks and Northern Powergrid are on board as well. It is not the only V2G project funded by the government at Westminster. The Octopus trial is running as well that wants to install more than 130 V2G chargers throughout 2018" [37].

- **ENEL-IIT – Italy**

The only project know in italy is ones described in [38]. The agreement between Enel X and the IIT (Italian Institute of Technology) was signed in 2016 for the development of projects related to electric mobility and energy efficiency and was implemented in 2017 with the launch of the first electric car sharing company at the Institute. A service created thanks to the collaboration of Nissan that supplied two Leaf, and with the installation of the first charging point with "Vehicle to Grid" technology.

Although the Italian legislation still does not provide the biredictional net metering for electric vehicles, recently [39] the Ministry of Economic Development [39] would have published a draft decree addressed to this issue. Future developments are expected.

CHAPTER 2
CASE STUDY: A POSSIBLE V2G IMPLEMENTATION IN THE CAR PARK OF FERRARA

In **Chapter 1** we analyzed the main notions about electric mobility and what are the possible applications in the "Smart Grid" field. In the following chapter, instead, a case study about the V2G technology will be analysed. In particular we will going to simulate a possible application of a "peak shaving" algorithm applied on the load curve of the plant of interest. The following chapter is structured as follows:

- **Paragraph 2.1:** the site of interest is presented, the parking lot adjacent to the railway station of Ferrara, which will be the site of the simulations of this work. The various electrical utilities included in the parking project designed by Metropark s.p.a. will be listed and described and a plausible daily trend of the parking energy absorption will be presented;

- **Paragraph 2.2:** the energy producibility from solar source in the site of interest is analyzed and the sizing of the relative photovoltaic power plant is carried out;

- **Paragraph 2.3:** A possible smart recharging system is implemented, following two different principle. In the first algorithm the recharge is perfomed only if the renewable resource are present in order to not impact the distribution network. The second algorithm, based on the energy absorption of the car park perform a “Peak Shaving” application exploiting the EVs bidirectional flow.

2.1 Load analysis and energy absoption of the car park

2.1.1 Introducing the setting

Ferrara is a city in Emilia-Romagna of about 132.000 inhabitants located 44 km northeast of Bologna near the river P0 (fig 2.1) . The setting of the current work is the car park adjacent to the Ferrara train station (fig 2.2). The area is marked by an intensive one modal exchange for the presence of the railway station, bus stops and terminals, bike parking and taxi stops. Recently, Metropark s.p.a., a company of *Ferrovie dello Stato* group, will open a new parking lot adjacent to the railway station consisting of 115 parking spaces, 5 of which predisposed for charging electric vehicles. The total area occupied is 4300 m^2.
Fig 2.3 shows the *ante-operam* condition of the car park, while in fig 2.4 it is possible to appreciate the plan of the executive project.

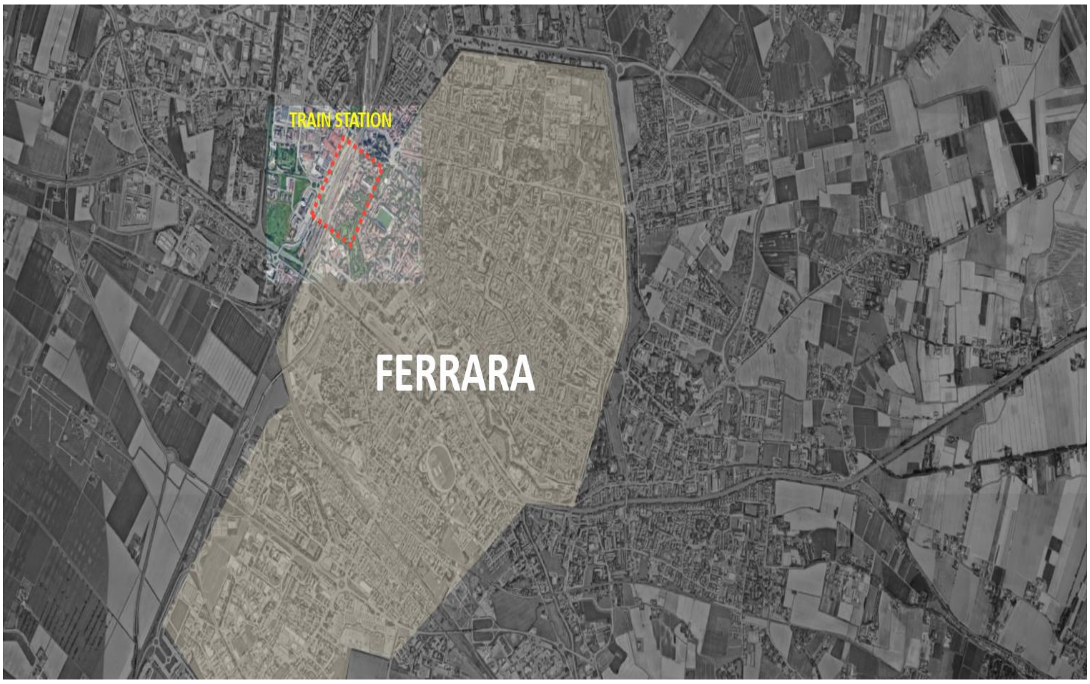


Fig 2.1 Top view of the city of Ferrara.

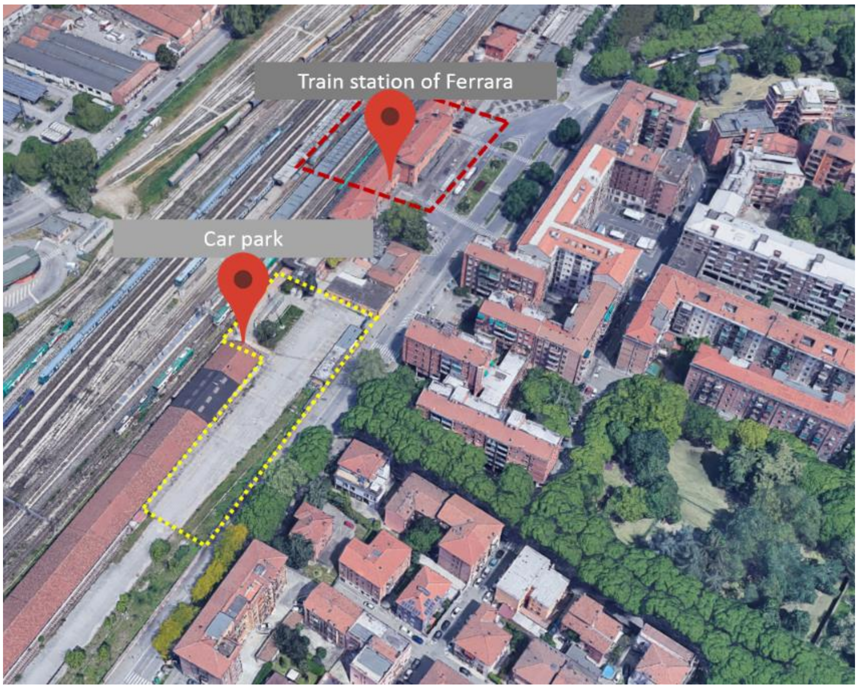


Fig 2.2 Top view of the parking lot.

Fig 2.3 Parking statuts ante-operam.

Fig 2.4 Planimetry of the executive project of Ferrara parking area.

2.1.2 Description of the electric loads of the car park

In order to be able to estimate the energy consumption of the car park an then derive the relative load curve, it is necessary to determine the electrical loads belonging to the parking lot. Then, for each utility, a hypothetical load curve will be developed in the most unfavourable conditions from a grid absorption point of view. The mash up of the various load curves will represent the effective parking absorption curve which will ultimately be the reference energy consumption used during the successive analysis.

- ### Lighting system

The optimal parking lighting is guaranteed by the presence of 18 lampposts (fig 2.5) that run along two main backbone along the entire length of the parking lot. Each lamp presents a power of 74 W for a total power of 1.3 kW.

As the most unfavourable case, it was chosen December 21st as it represents the shortest day of the year and therefore it has been hypothesized a continuous operation that goes from 16:30 p.m. at 8:00 a.m. [40].

The resulting power curve is shown in fig 2.4

The technical data useful for what concerns the lighting system are summarized in table 2.1

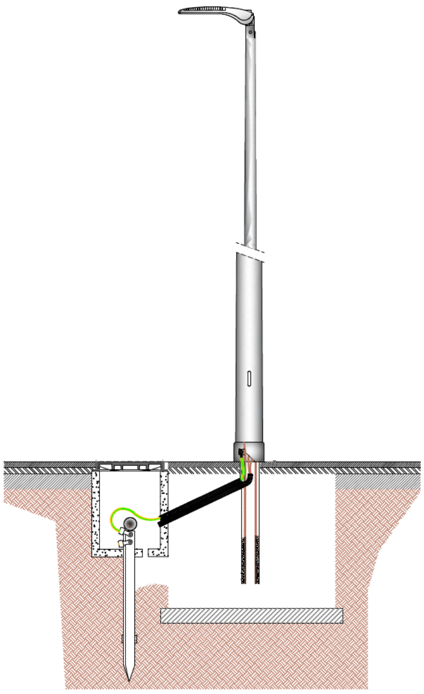


Fig 2.5 Detail of the lamp installed in the car park.

Tab. 2.1 technical data: lighting system

N° of lamps	18	
Rated Power	74	[W]
Overall Power	1,332	[W]

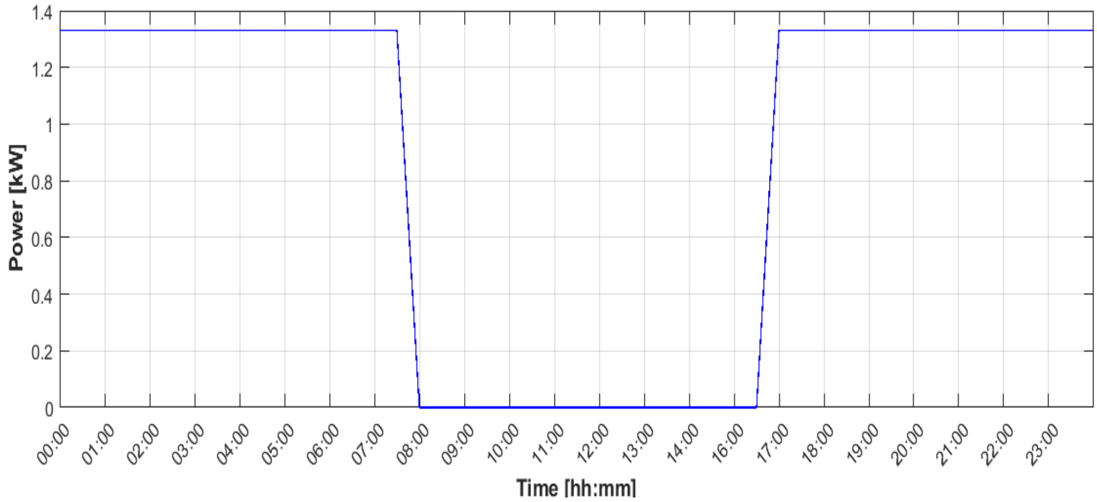


Fig 2.6 Load curve of the lighting system.

- ## Entry/exit system

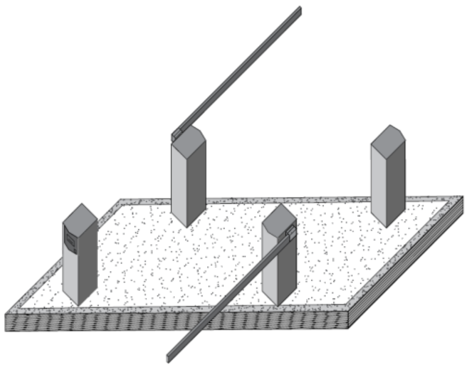


Fig 2.7 Access point of the car park.

Tab. 2.2 technical data: Access point

N° of entry	2	
N° of access	1	
Entry/exit system rated power	650	[W]

The parking access points (fig. 2.7) consist of an input gate and an output gate with a rated Power of 650 W each. For the realization of the load curve it is assumed that the greater frequency of use of the entrance gates is in the time slot 6:30-9:00 a.m.

Similarly, the second peak was assumed to be in the time slot 16:30-20:30 p.m.

This hypothesis is quite plausible if we consider that railway car parks are mainly visited by commuters, so the access/exit to the car park is conceivable to be greater in the time bands where people move to reach their place of work and when they return to go home.

The graph in Figure 2.8 shows the relative load curve.

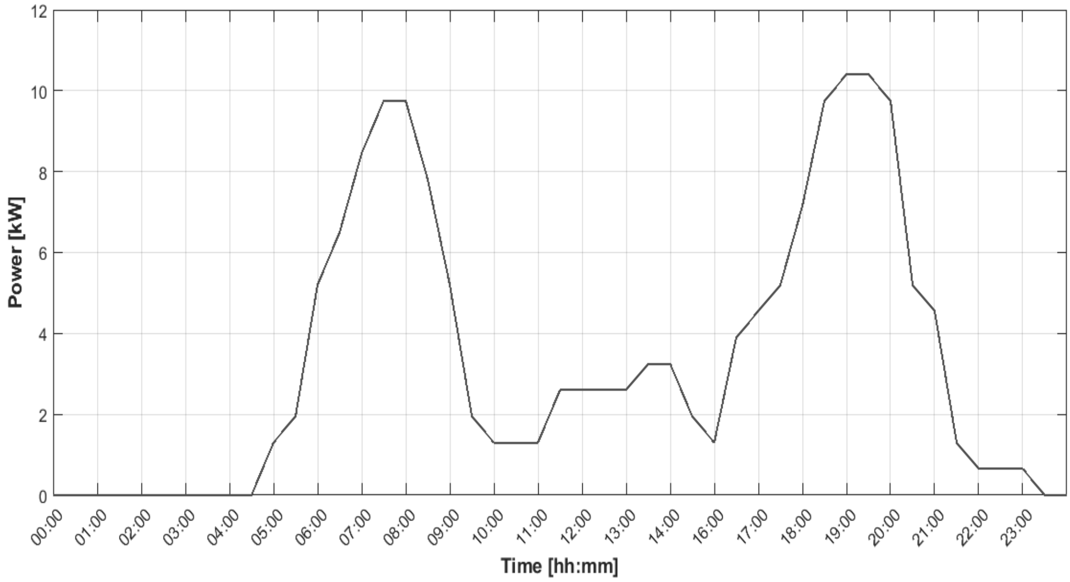


Fig 2.8 Load curve of the entry/exit system.

▪ Video surveillance system

The parking is equipped with a 24-hour video surveillance system. The total number of camera is 9; each camera absorbs a rated power of 5 W for a total absorption of 45 W, obviously, it represents a very modest load when compared to the previous loads analysed. The load curve is characterized by a constant trend as shown in figure 2.10. The technical data useful for what concerns the video surveillance system are summarized in table 2.3.

Fig 2.9 Camera of the video surveillance system.

Tab. 2.3 technical data: video surveillance system

N° of camera	9	
Rated Power	5	[W]
Overall Power	45	[W]

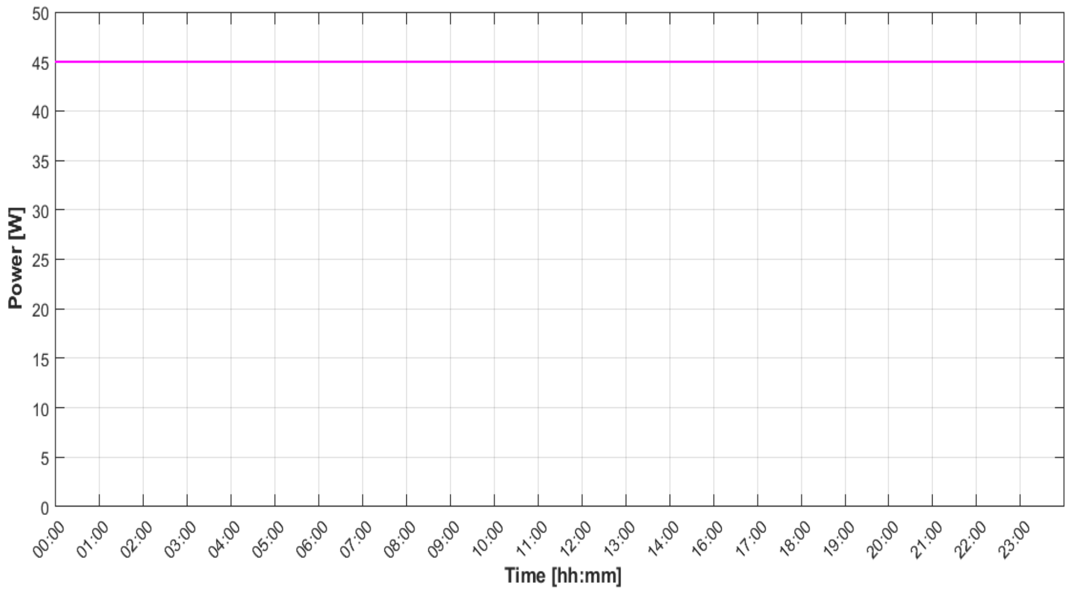


Fig 2.10 Load curve of the video surveillance system.

- ## Technical room

The parking area has a technical room at the service of parking operators (fig 2.11). The main load that can be hypothesized is the air conditioning system that is attested on a power of about 800 W. Therefore, in order to taking into account any accessory loads, is assumed a constant absorption of 1000 W over the entire period of service of the car park. fig. 2.12 shows the expected load curve.

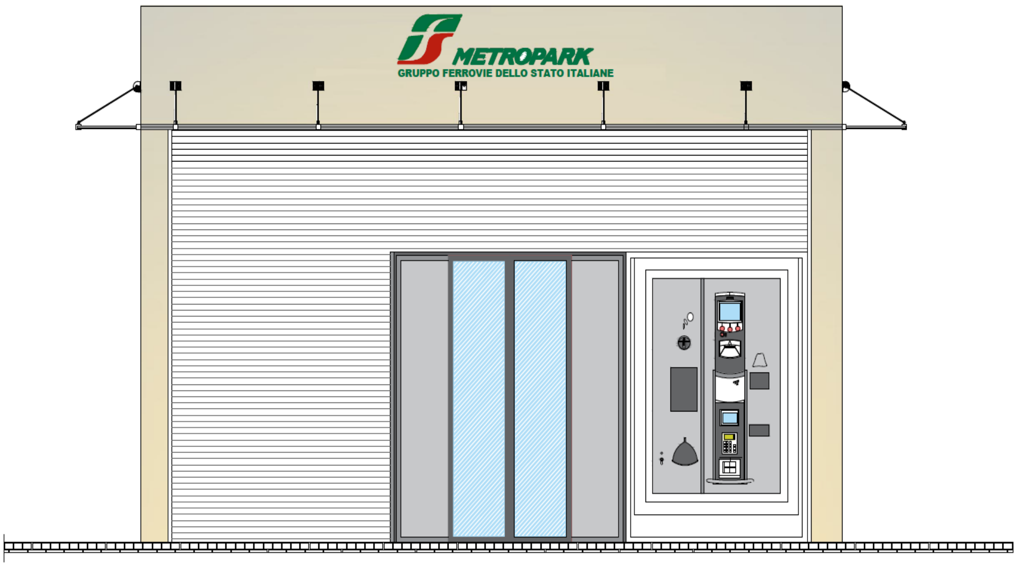


Fig 2.11 Technical room of Ferrara's car park.

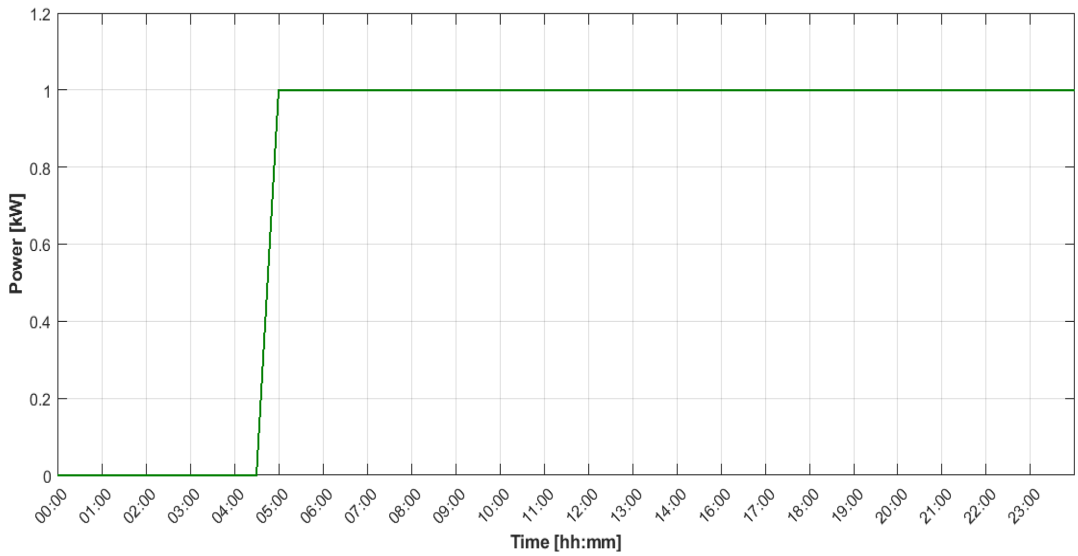


Fig 2.12 Load curve of the technical room.

- ## Electric vehicle supply equipment

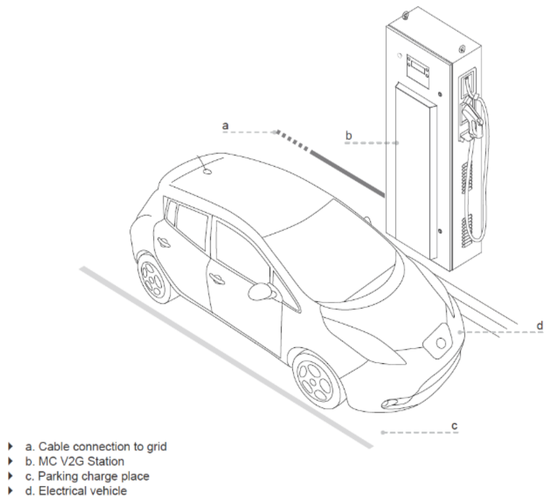


Fig 2.13 Electric vehicle supply equipment [41].

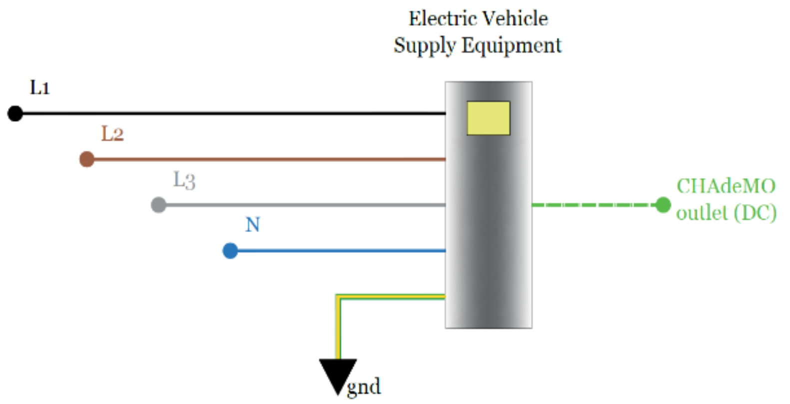
Another load to introduce is the one constituted by the electric vehicle supply equipment (fig 2.13). the car park in question allows charging for 5 vehicles at a time. As we will see later, an uncontrolled connection of 5 electric vehicles, albeit modest in number, goes to engage the distribution network. in figure 2.18, for example it is supposed the worst case, that is, the simultaneous presence of 5 vehicles that require a complete recharge (substantially, from 0% to 100%) in the load peak phase of the car park. Concerning the electric vehicle supply equipment, the one analysed in this work is the one owned by Enel, the ***MC V2G Station***. Hereafter is cited the main qualities of this EVSE taken from the brochure of the product:

*"The MC V2G bidirectional equipment is based on **CHAdeMO protocol**. It was designed to provide energy to the vehicle and supply energy to the grid or to the house, allowing getting benefits from different grid applications:*

- *Time shift*
- *Power balancing*
- *Power quality support*

With MC V2G, you may store energy in your vehicle and use it later, getting benefits in terms of energy costs, CO2 optimization, autonomy, or demand profile faltering. In addition the equipment has the possibility to be managed remotely and integrated into e-mobility or in-house control systems according to context and business model."

Therefor, the EVSE transforms the EVs in an atypical load since it allows a bidirectional energy flow. In particular, during tha charging phase the EVSE absorbs 10.5 kW of power, while, during the discharge phase, the power is 9 kW. Table 2.4 shows the technical datasheet that characterize the supply equipment.



Tab. 2.4 technical data: electric vehicle supply equipment

INPUT (AC,3 phase)		
Rated input power	10.5	[kW]
Input Voltage	400	[V] ,3 phase
Voltage range	± 10 %	
Frequency	50	[Hz]
Max AC current per phase	16	[A]
OUTPUT CHARGING (DC)		
Output Power	10	[kW]
Output Voltage	0-500	[V], DC
Maximum output current	31	[A]
Efficiency	95 %	
Power factor	0.99	
THD (measured at maximum power)	3%	
OUTPUT DISCHARGING (AC,3 phase)		
Output Power	9	[kW]
Output Voltage	400	[V], 3 phase
Efficiency	90 %	
Power factor	0.99	
THD (measured at maximum power)	5%	

- **Electric vehicle**

Regarding the electric vehicle, the reference car used in this work is the Nissan Leaf 2018. The reason for this choice is that the Nissan Leaf is , for now, one of the few electric car certified to be used in V2G applications [42]. Table 2.5 shows some technical characteristics of the car. The Nissan Leaf features two charging sockets, Type 2 and CHAdeMO. The on-board charger has a rated power of 6.6 kW. The CHAdeMO socket, instead, supports a rated output up to 50 kW.

Tab. 2.5 technical data: Nissan Leaf 2018 [43].

NISSAN LEAF 2018 - ELECTRICAL SPECIFICATIONS		
Battery Capacity	40	[kWh]
Charge Power / Type 2	6.6	[kW], 1 or 3-phase
Fastcharge Port / CHAdeMO type	50	[kW], DC
Input Voltage	360	[V]
Vehicle Consumption [1]	236	[Wh/km]

[1] 'worst-case' based on -10°C and use of heating along an higway.

Concerning the effective charging power, it is important to keep in mind that the discriminant is the minimum value of the power between the supply equipment and the charger of the vehicle itself in according of this relation (Eq. 2.1):

$$P_{charge} = \min(P_{EVSE}, P_{EV}) \qquad \text{Eq. (2.1)}$$

With:

- P_{charge}: Actual power of recharge;
- P_{EVSE} : Rated power of the electrical vehicle supply equipment;
- P_{EV} : Rated input power of the electrical vehicle charger.

In the case under examination, since the single EVSE has a recharging power of 10.5 kW, while the electric vehicle could be charged at 50 kW, the discriminant will be the rated power of the chargin point. Figure 2.14 shows the trend of the power absorbed at three different level (P_1@4 kW ; P_2@6.4 kW; P_3@10.5 kW), considering the full charge of 5 Nissan Leaf.

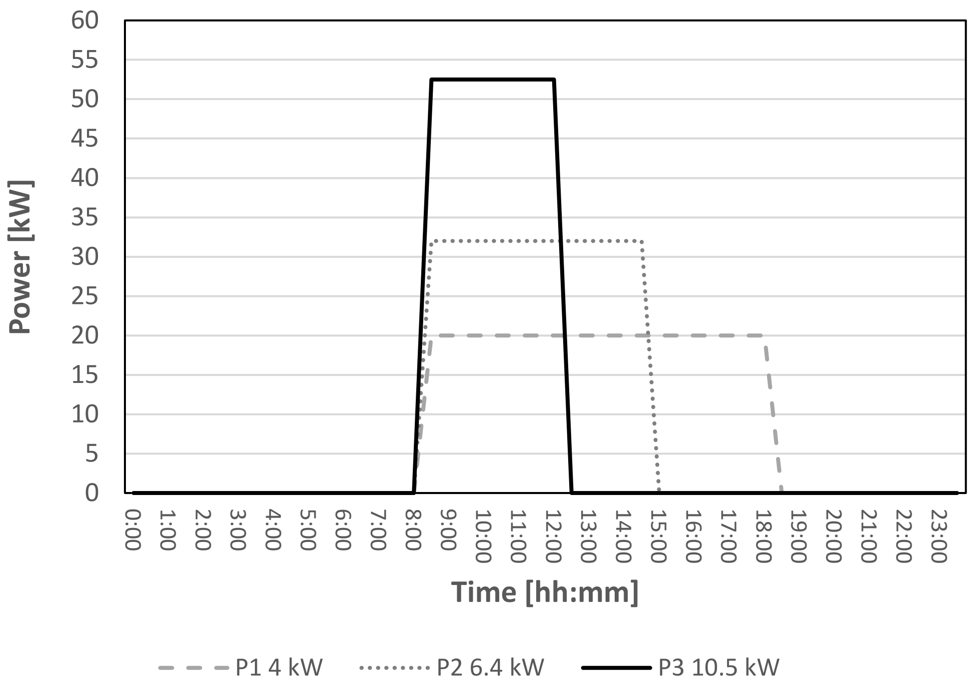


Fig 2.14 Charging load at different power levels considering 5 Nissan Leaf.

2.1.3 Analysis of the energy absorption of the car park

As we have seen so far, the car park under examination is equipped with a series of electrical loads which contribute to generate the curve shown in figure 2.15. As it is possible to appreciate, the greater energy absorption occurs in the time slots [7:00-10:00] a.m. and [17:00-20:00] p.m.

The red dotted line in figure 2.15 represents the maximum power limit that can be absorbed by the electrical system of the car park, which stands at around 14 kW. This limit is imposed by the general electric panel whose plate data are shown in figure 2.17

The total energy absorbed daily stands at around 118 kWh as shown in the figure 2.16.

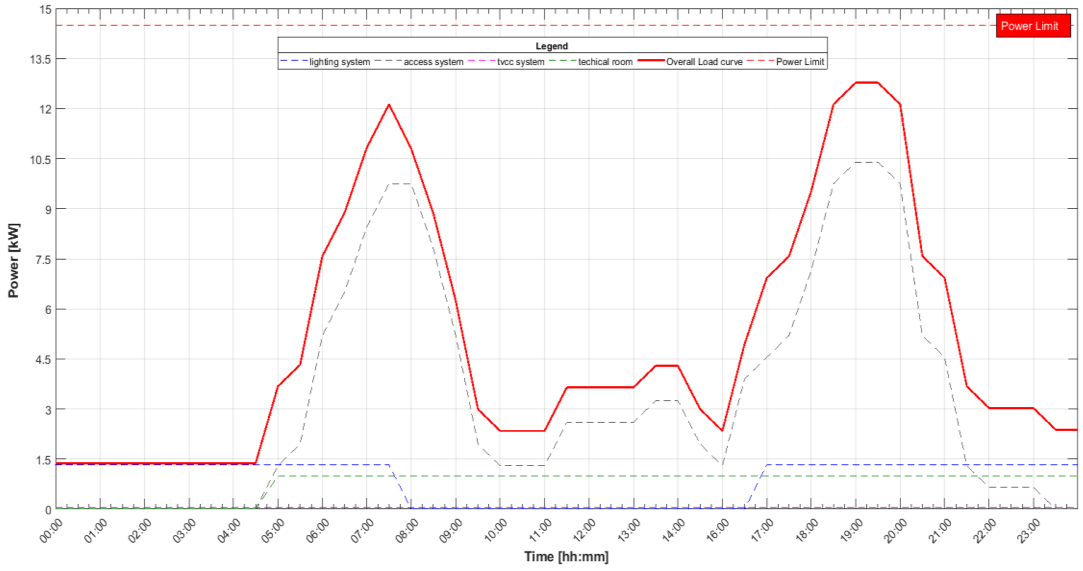


Fig 2.15 Overall load curve of the car park.

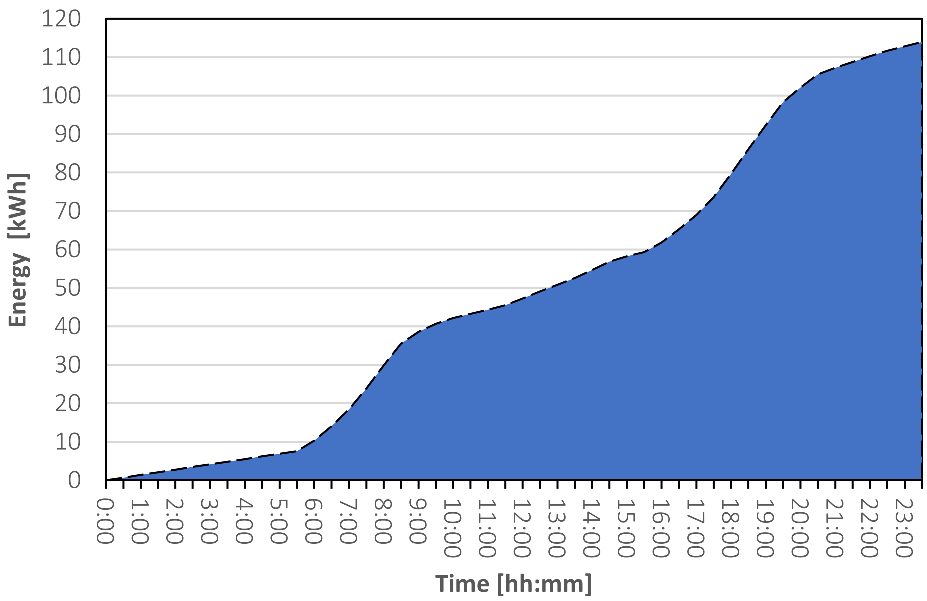
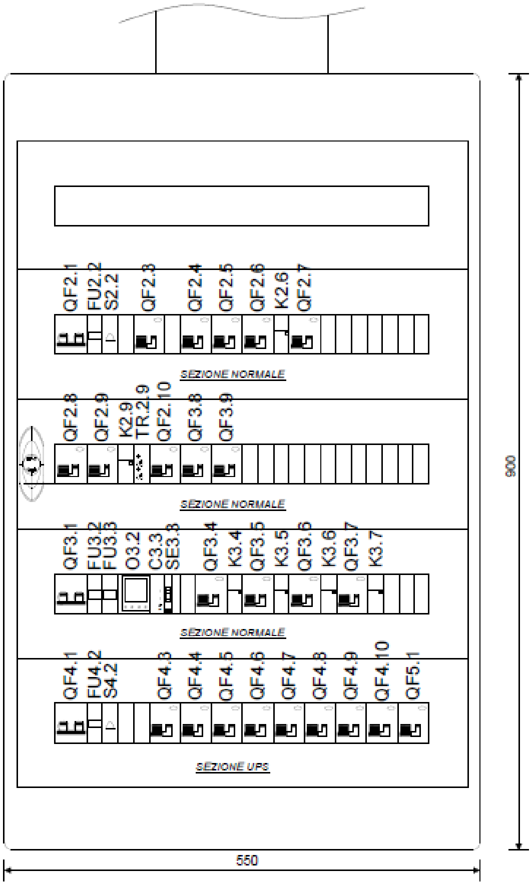


Fig 2.16 Overall daily energy absorption of the car park (without EVSE).



GENERAL ELECTRIC PANEL	
Tipology	120 (5x24) MODULES
Type of installation	to a wall
Dimensioni	550x900x173 mm
International Protection	IP40
Rated current	63 A
Rated voltage	230 V
Frequency	50 Hz

Fig 2.17 Data plate of the general electric panel of the car park.

Figure 2.15 shown the basic load of the car park. Now, if we also imagine to add the power absorbed by electric cars, we get a load curve like the one in figure 2.18 in which it was assumed the simultaneous recharge of 5 electric vehicles during the first peak. As it is possible to perceive this represents a rather burdensome situation, as a large amount of energy is required to be absorbed from the grid for a relatively long period of time. This is a classic example of an uncontrolled charging without the implementation of any smart charging feature. In **paragraph 2.3** of this chapter a possible algorithm of a smart recharge will be developed to avoid such a situation and to improve the load profile. To conclude, Table 2.7 shows a resume of the overall energy absorption of the car park.

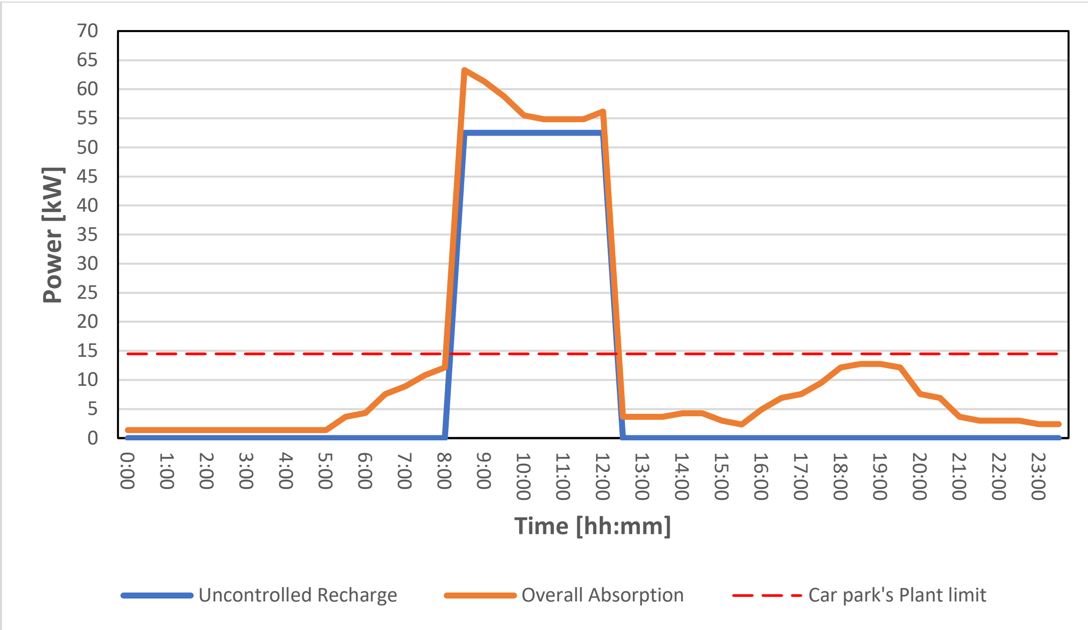


Fig 2.18 Example of unctrolled charging of the 5 EVs implemented in the car park.

Tab. 2.7 Overall energy absorption of the car park.

	Basic consumption	**Consumption with EVs**[4]
Daily energy absorption [kWh]	118.2	328.2
Monthly energy absorption [MWh]	3.55	9.85
Annual energy absorption [MWh]	43.1	119.8

2.2 Design of the photovoltaic system

One of the major criticisms and point of greatest skepticism regarding electric mobility is the fact that somewhere, the energy to recharge this fleet of vehicles must be taken. This point is not trivial, so much so that if I use electricity from plants that still use fossil fuels to obtain the energy needed to recharge my vehicle, I have not solved the problem of the environmental pollution, I have only shifted the problem in the supply chain. In fact, if we consider the tank-to-wheel transformation chain, the emission in the atmosphere of CO2 of an EV and an ICE is more or less equivalent as stated in [47]. The problem does not hold or, in any case, it is mitigated if instead, the source of energy used came from renewables. Therefore, in parallel with the widespread of the electric vehicles, it is also important to launch initiatives that aim at a greater spread of renewables. According to this, in the following section a photovoltaic power plant will be designed in order to supply the load demand of the car park.

[4] Considering a full charge of 5 Nissan Leaf for each day of the year.

2.2.1 Solar irradiance of the site of interest

As already described in **subparagraph 2.1.1** the reference car park is the parking lot adjacent to the Ferrara railway station. In this car park, designed and managed by Metropark s.p.a[5], the installation of three EVSEs with V2G technology was planned in collaboration with Enel X in view of a possible future developments of these applications. Geographically, the site of interest (fig 2.19) has an azimuth of 30 ° towards the west. The optimal tilt angle of the panels was instead set at 30 °. The average daily solar radiation of this site, characteristic for each month, was obtained from [44]. Starting from these data we obtain the graph shown in figure 2.20.

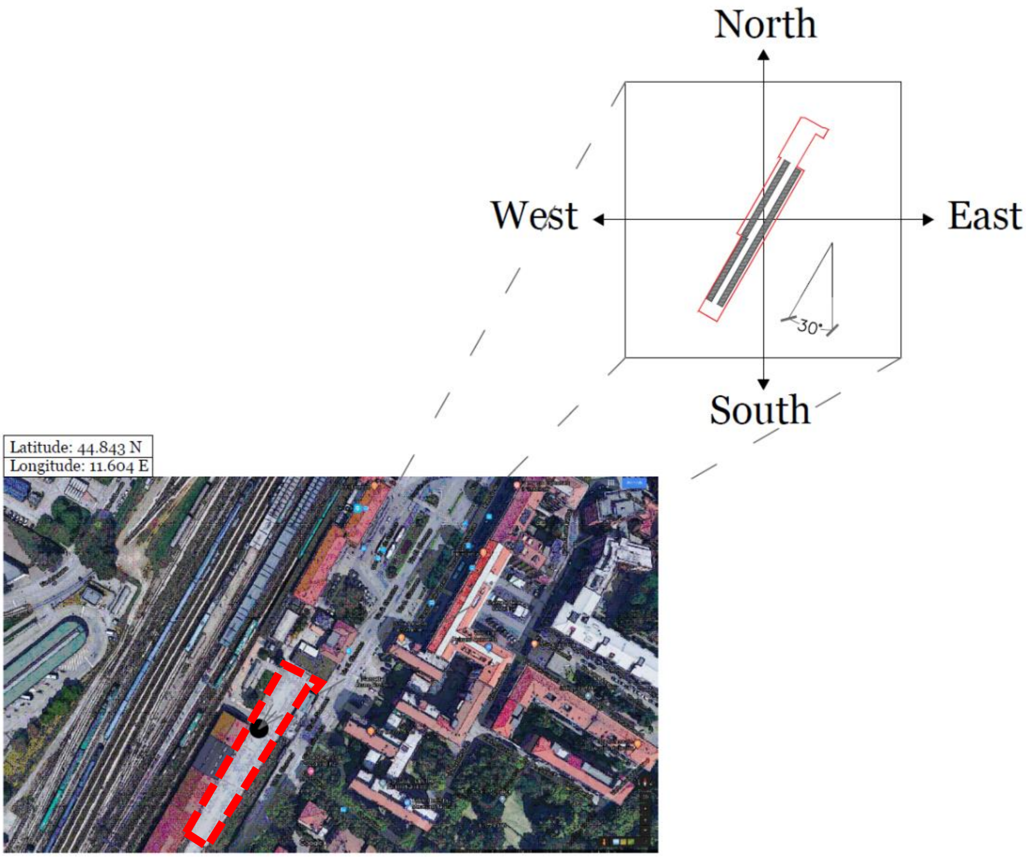


Fig 2.19 Bird-eye view for the site of interest, Ferrara car park.

[5] a company of the Ferrovie dello Stato group: http://www.metropark.it/

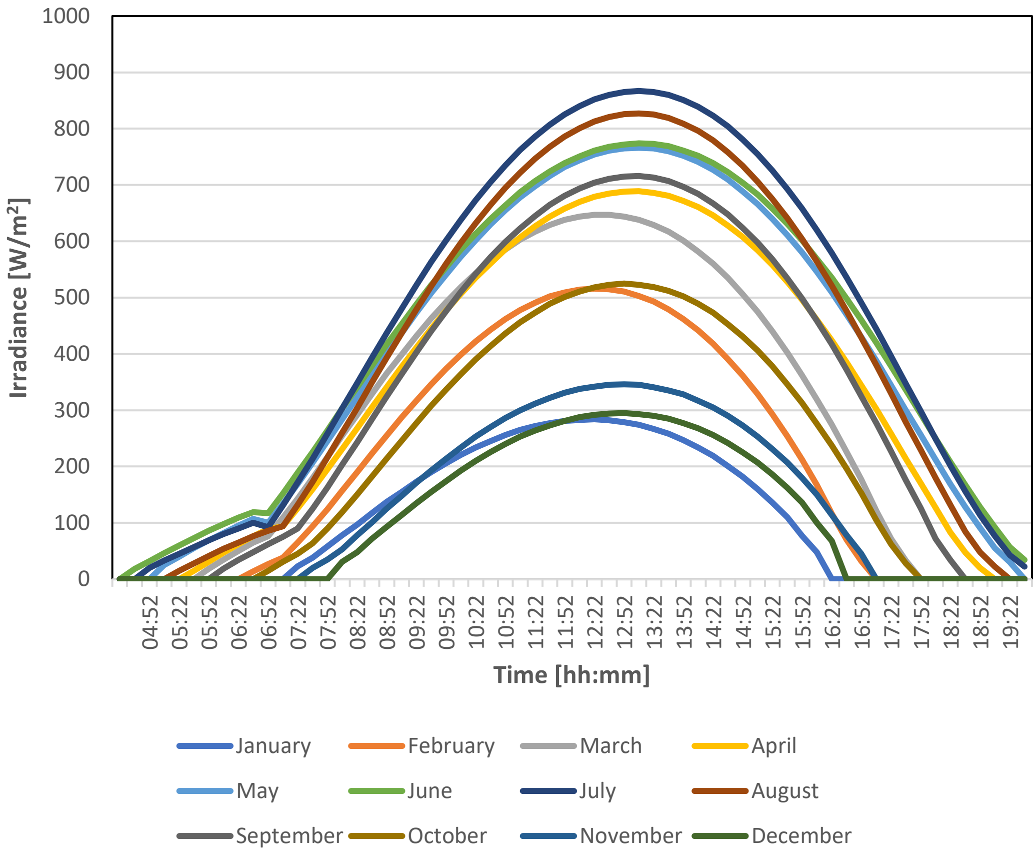


Fig 2.20 Daily Irradiance in Ferrara for each Month

From the solar irradiance dataset, exploiting equation 2.2 (taken from [45]), the associated produced power can be computed as:

$$P_{out,panel}(G_t) = \begin{cases} P_n * \left(\frac{G_t^2}{G_{std} * R_c}\right) \; for \; 0 < G_t < R_c \\ P_n * \left(\frac{G_t}{G_{std}}\right) \; for \; G_t > R_c \end{cases} \qquad \text{Eq. (2.2)}$$

Where:

- $P_{pv}(G_t)$: is the output power from a single panel as a function of the solar irradiance G_t;
- G_t: is the forecasted solar irradiance measured in W/m² at a certain time t in a day;
- P_n: is the nominal output power of the photovoltaic panel chosen;
- G_{std}: solar radiation in the standard environment set as 1000 W/m²;
- R_c: a certain radiation point set as 150 W/m²;

Considering that the data have been sampled at intervals of a quarter of an hour one from the other, the energy can be easily obtained through equation 2.3:

$$E_t = P_{out,panel}(G_t) * \Delta t \qquad \text{Eq. (2.3)}$$

2.2.2 PV panel technology

The PV panel choosen for this study case is the panel *NeON® 2 BiFacial* (fig 2.21); the peculiarity of this panel lies in its double-sided structure, that is able to exploit both direct light and reflected light. In figure 2.22 it is possible to appreciate the differences between a conventional photovoltaic module and one considered with double-sided technology. As can be noted, the bifacial cell is designed in a symmetrical structure in order to gain an additional sunlight absoption from the backside.

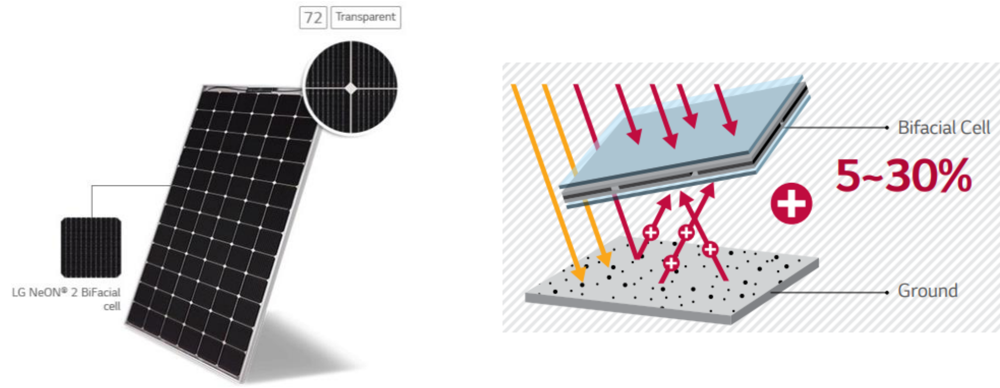


Fig 2.21 NeON® 2 BiFacial panel [46].

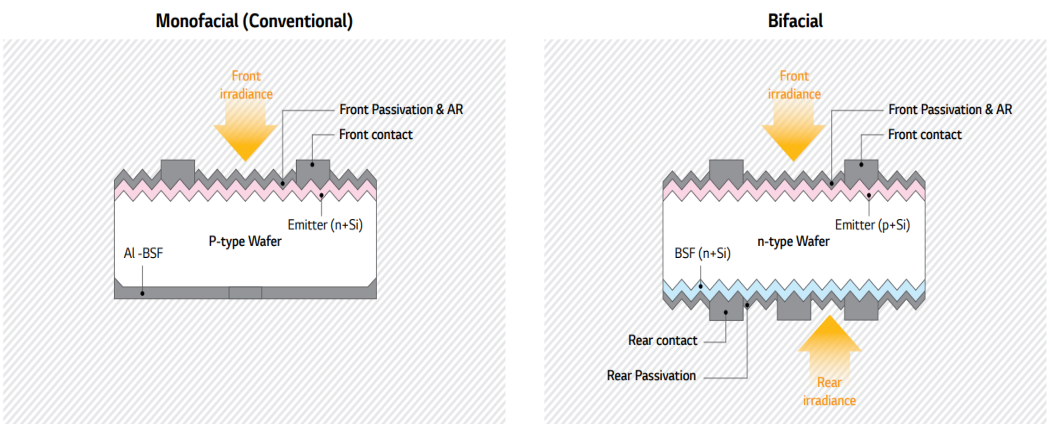


Fig 2.22 Comparison between a conventional cell and a bifacial cell [46].

The panel therefore exploits the so-called Albedo effect. The albedo is an index given by the ratio between the light incident on a surface and the corresponding reflected light[6], consequently the Albedo index can vary between 100% for perfectly reflective surfaces and 0%

[6] $Albedo = \frac{reflected\ ligth}{incident\ ligth}$

for perfectly absorbent surfaces. The graph on the left of Figure 2.23 shows different values of Albedo index for different types of surfaces, while the graph on the right shows the relative gain due to the two-sided structure of the PV panel considered.

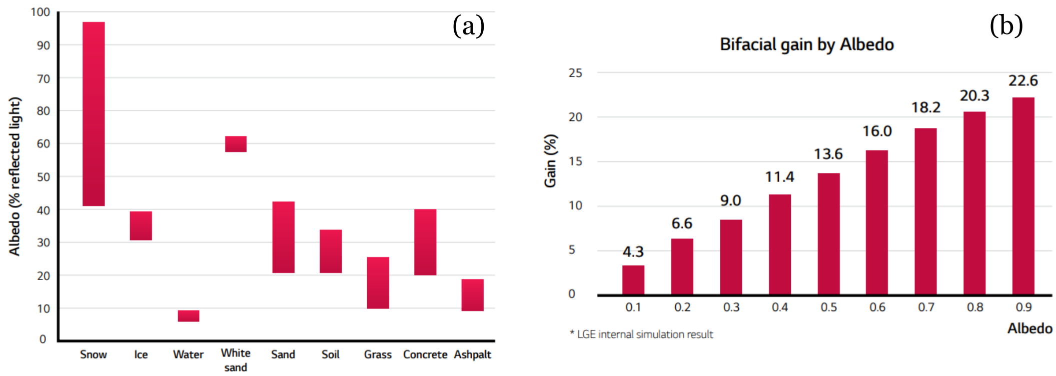


Fig 2.23 (a) Albedo index for different surfaces and (b) the relative bifacial gain [46].

In a context like the one in question, it is assumed that a large part of the surface is mostly made up of asphalt, which corresponds to an albedo between 10 and 20%. A power gain of 5% with respect to the nominal power is therefore assumed. In conclusion, in figure 2.24 and in table 2.8 it is possible to appreciate the technical characteristics of the panel.

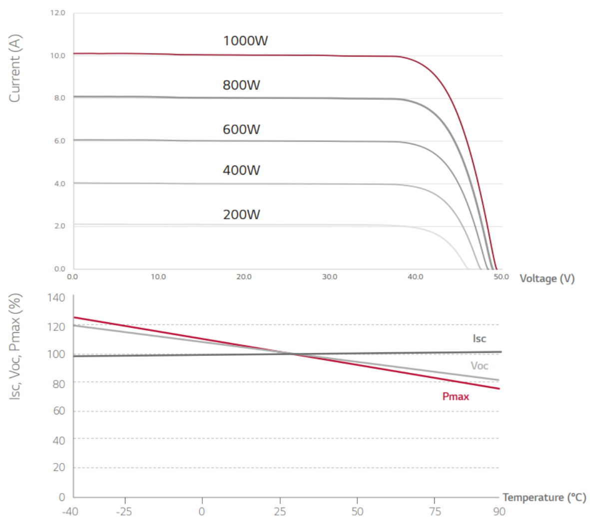
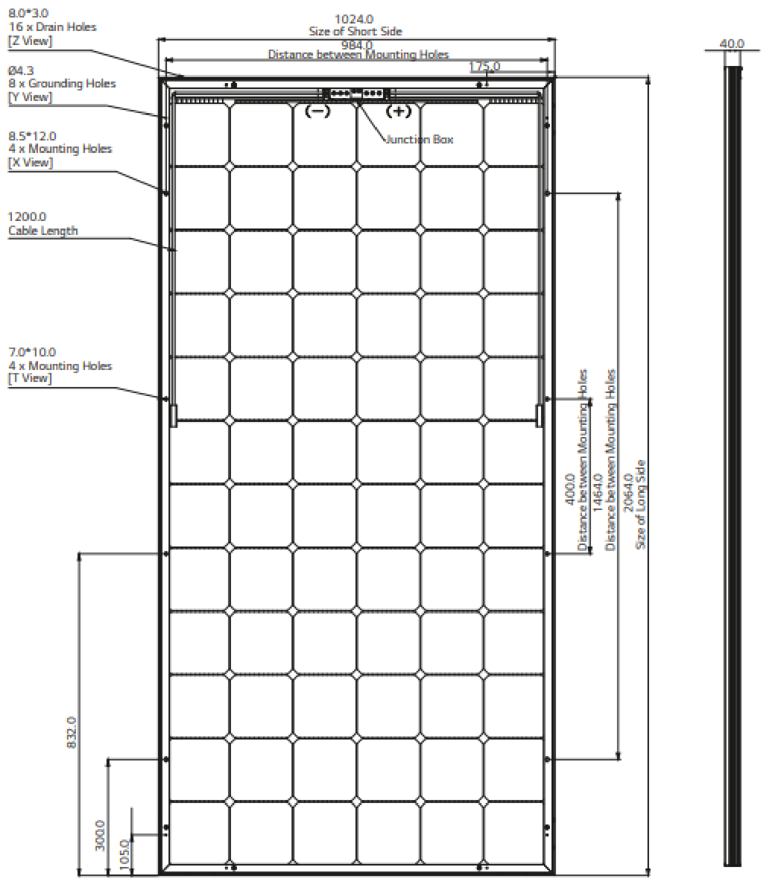


Fig 2.24 Characteristic curves of NeON® 2 BiFacial panel [46].

Tab. 2.8 technical data of NeON® 2 BiFacial panel [46].

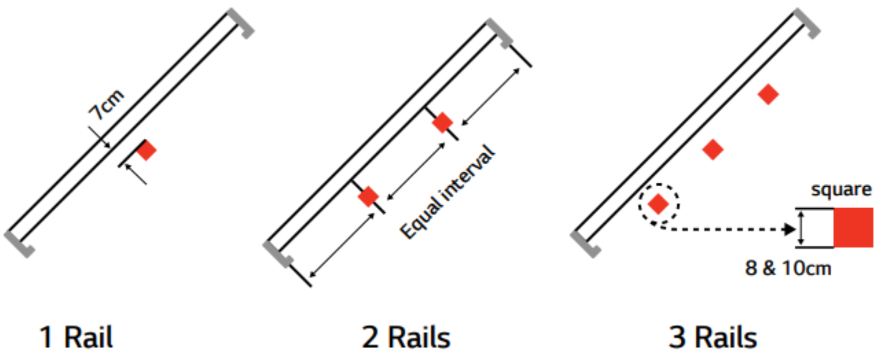


		Rated value	%5 Bifacial gain
Peak Power (P_{pk})	[W]	390	410
MPP Voltage (V_{MPP})	[V]	41.4	41.4
MPP Current (I_{MPP})	[A]	9.43	9.90
Open Circuit Voltage (V_{oc})	[V]	49.2	49.2
Short Circuit Current (I_{sc})	[A]	10.15	10.15
Module Efficiency	[%]	18.5	19.4
Operating Temperature	[°C]	-40° ÷ +90°	
Maximum System Voltage	[V]	1000	
Maximum Series Fuse Rating	[A]	20	
Estimated annual degradation	[%]	0.5	
Voltage temperature coefficient ΔV_T	[V/°C]	-0.133	

2.2.3 Support structure

the project involves the installation of specific support structures for the PV modules to allow an optimal exploitation of the available surface. The proposed structure is the one shown in figure 2.26. It is a modular solution that occupies two parking spaces at a time and can hold up to 9 PV panels at a time. The steel structure guarantees the best balance between lightness of the structure and strength. The presence of the support rails obviously, due to their shadowing, implies an inversely proportional impact on the power gain of the double-sided technology as shown in the technical data sheet in fig 2.25. For the present work a gain in power of 5% will be cautiously considered.

Mounting conditions



Bifacial Gain by Mounting

Rail size	Rail reflectivity	Bifacial gain [%]			
		No Rack	1 Rail	2 Rails	3 Rails
8 cm / 3.15 in	30 %	5.95	5.62	5.14	4.79
	50 %		5.65	5.30	5.01
10 cm /3.94 in	30 %		5.42	4.96	4.52
	30 %		5.53	5.16	4.78

Fig 2.25 Bifacial gain considering the mounting conditions [45]

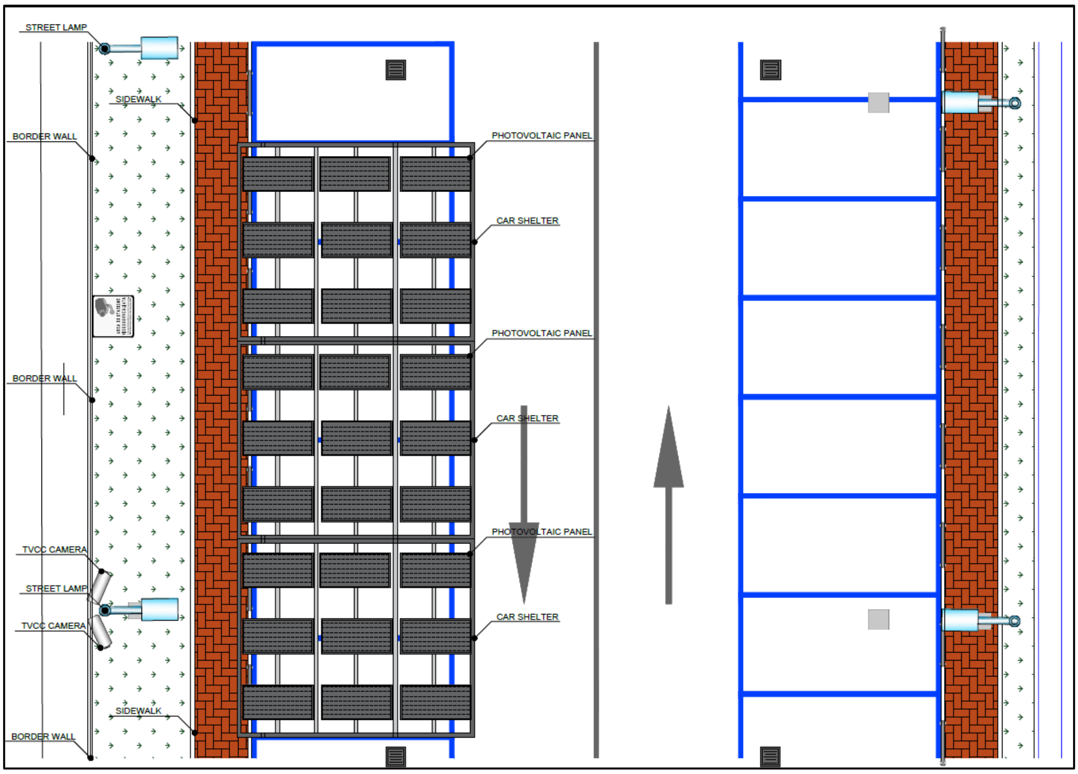


Fig 2.26 Concept of installation (top view).

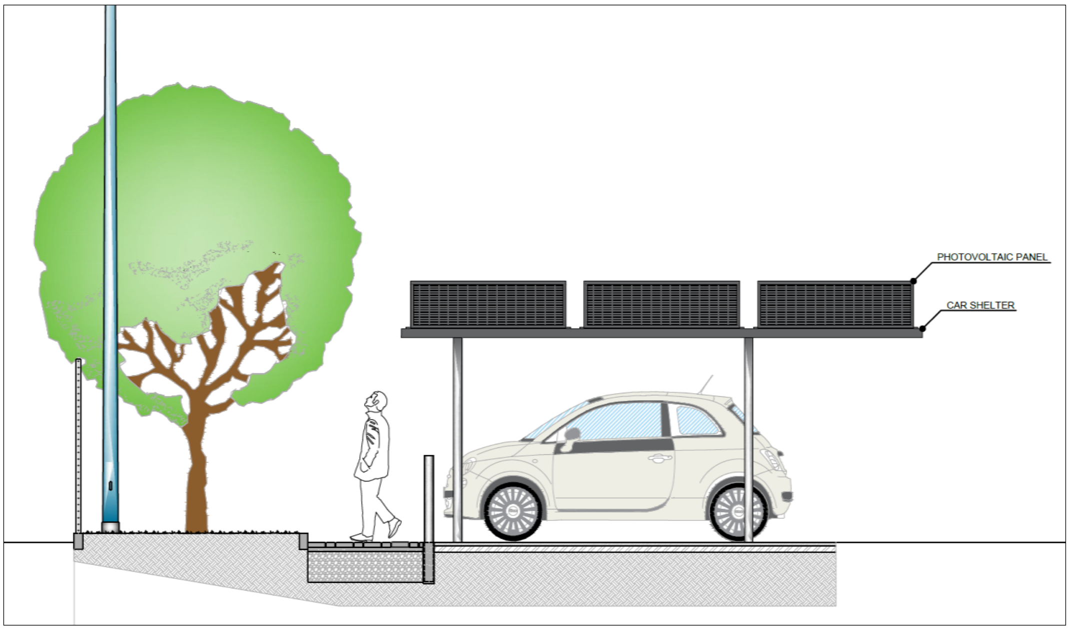


Fig 2.27 Concept of the installation.

2.2.4 Matching panels/inverter

the car park has 114 parking spaces. the maximum number of shelters will therefore be 57 for a total number of PV panels to be installed equal to 513. Therefore, the maximum peak power of the generation plant will be equal to 200 kWp. It was decided to divide the plant on three inverters of equal size, each with a rated power of 70 kW. therefore, 171 PV panels will be connected to each inverter. the 171 panels are divided into 10 strings in parallel. 9 strings consist of 17 panels in series and the tenth, 18 panels. Table 2.9 presents a summary table of the aforementioned data. Table 2.10 shows some useful data for the inverter [48]. Figures 2.28-2.30 show the topological schemes of the proposed system.

Tab. 2.9 project summary data

Parking spaces	114	
N° of Sheleters	57	
N° of Panels	513	200 kWp
N° of Inverters	3	70 kW
N° of Panels/Inverters	171	66.7 kWp
N° of Strings/Inverter	10	

Tab. 2.10 Main data for the matching panels/inverter [48].

Model:	ZS-60000TL		
Rated Power:	70	[kW]	
Maximum DC input voltage:	1000	[V]	
Activation voltage:	350	[V]	
MPPT voltage interval:	250-960	[V]	
Maximum input current:	120	[A]	
Efficiency:	98.4	%	

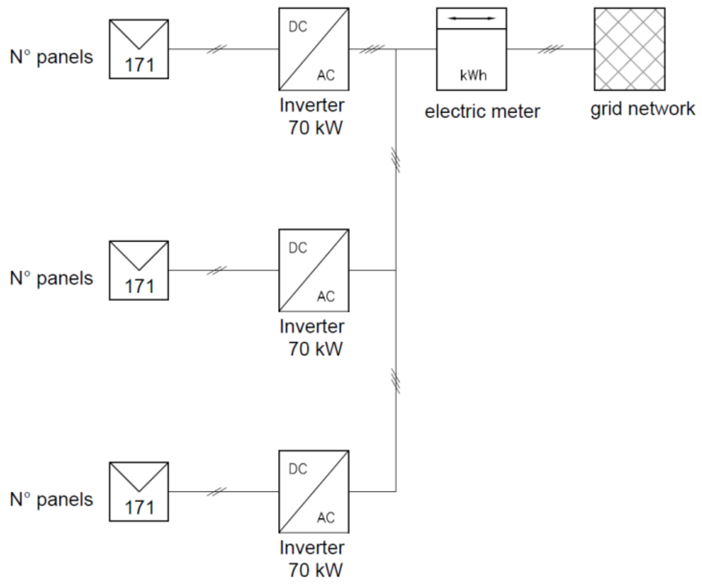


Fig 2.28 Main topology of the PV system.

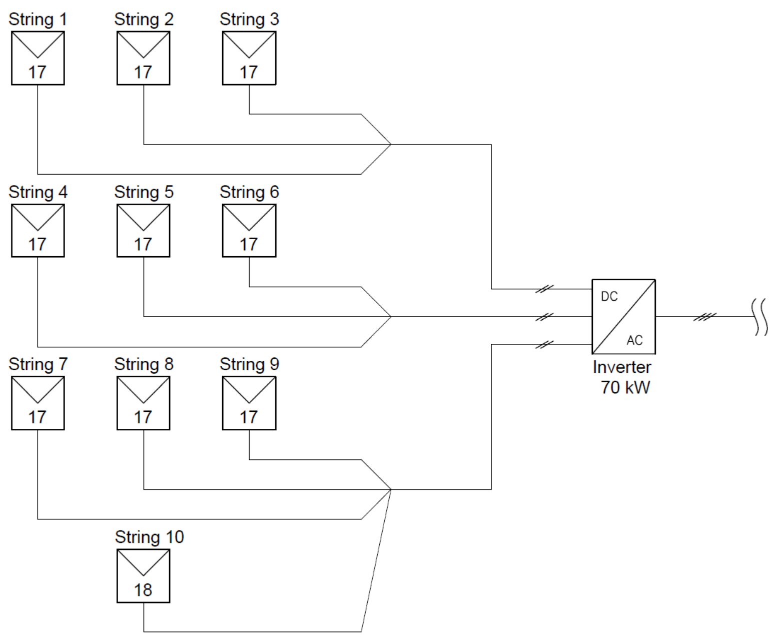


Fig 2.29 Arrangement of the strings.

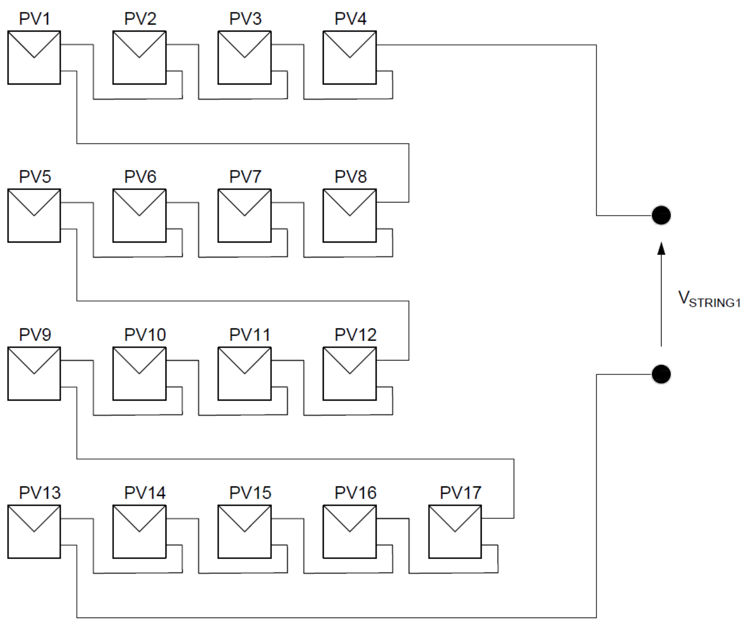


Fig 2.30 Arrangement of the panels in series in one string.

We proceed now with the verification of correct matching string/inverter, considering the limit temperatures of + 70 ° C and -10 ° C. the conditions are summarized in table 2.11.

Tab. 2.11 String/Inverter Matching conditions.

	String		Inverter	Condition
1.	$V_{MPP,min,STR}$	>	$V_{activation}$	The minimum output voltage of the string (the one corresponding to + 70 ° C) must be greater of the activation voltage of the inverter.
2.	$V_{MPP,MAX,STR}$	<	$V_{MPP,MAX,INV}$	The maximum output voltage of the string (the one corresponding to -10 ° C) must be lower than the maximum MPP input voltage tolerable by the inverter.
3.	$V_{OC,STR}$	<	$V_{MAX,INV}$	The maximum open circuit voltage of the string (the one corresponding to -10 ° C) must be lower than the maximum input voltage tolerable by the inverter.
4.	$\sum_{k=1}^{N} I_{MPP,STR-k}$	<	$I_{MPP,INV}$	the sum of all the N-string currents must be lower than the maximum input current tolerable by the inverter.
5.	$\sum_{j=1}^{M} P_j$	<	$P_{n,INV}$	the total power of the M panels connected to the inverter must be less than its nominal power

In particular:

$$V_{MPP,min,STR} = N_{panels} * [V_{MPP}(25°C) + (70°C - 25°C) * \Delta V_T] \quad \text{Eq. (2.3)}$$

$$V_{MPP,MAX,STR} = N_{panels} * [V_{MPP}(25°C) + (-10°C - 25°C) * \Delta V_T] \quad \text{Eq. (2.4)}$$

$$V_{OC,STR} = N_{panels} * [V_{OC}(25°C) + (-10°C - 25°C) * \Delta V_T] \quad \text{Eq. (2.5)}$$

So, doing all the calculations the matching conditions are verified:

Tab. 2.12 String/Inverter Matching conditions (calculations).

String			Inverter
	$V_{MPP,STR} = 18 * 41.4 = 745\ V$ @25°C		
	$V_{OC,STR} = 18 * 49.2 = 885.6\ V$ @25°C		
✓	$V_{MPP,min,STR} = 637.6\ V$ @70°C	>	$V_{activation} = 350\ V$
✓	$V_{MPP,MAX,STR} = 828.9\ V$ @-10°C	<	$V_{MPP,MAX,INV} = 960\ V$
✓	$V_{OC,STR} = 969.3\ V$ @-10°C	<	$V_{MAX,INV} = 1000\ V$
✓	$\sum_{k=1}^{10} I_{MPP,STR-k}$ =94.3 A	<	$I_{MPP,INV} = 120\ A$
✓	$\sum_{j=1}^{171} P_{pk,j} = 66.7\ kW$	<	$P_{n,INV} = 70\ kW$

2.2.5 Producibility of the designed PV plant

Once the system is dimensioned, it is possible to evaluate which is the producibility, that is the energy that this plant is able to supply in the calendar year. We have seen that the power generated by a single panel is given by equation 2.2, which does not take into account any loss factors. So, in order to evaluate the actual power generated, we need to consider equation 2.4:

$$P_{out} = \eta * N_{panels} * P_{out,panel}(G_t) \quad \text{Eq. (2.4)}$$

$$\eta = \eta_{el} * \eta_{Mismatching} \quad \text{Eq. (2.5)}$$

Where:

- η_{el}: it is a factor including all electrical losses (cables, inverters, etc.);
- $\eta_{Mismatching}$: it is a corective factor affecting the output power of the panels due to various causes including, difference in thermal gradient of the modules, different shading of the modules for passing clouds, accumulation of dirt, intrinsic differences of the modules etc.

A correction factor η = 0.85 was supposed for this project. Taking into account equation 2.4, the values shown in table 2.13 are obtained. The Table shows an estimate of the power supplied and the relative energy that can be produced by the PV plant.

Tab. 2.13 PV Plant producibility.

	Daily Average Power [kW]	Peak Power [kWp]	Monthly Energy [MWh/m]	Energy Produced [MWh/y]	Net energy available[7] [MWh/y]
Jan.	18.4	48.6	8.7	**277.9**	**245**
Feb.	36.6	88.3	15.6		
Mar.	51.9	110.7	24.5		
Apr.	59.2	117.9	27.1		
May	69.9	131.0	33.0		
Jun.	73.0	132.4	33.4		
Jul.	78.6	148.3	37.2		
Aug.	71.3	141.5	33.7		
Sept.	58.5	122.5	26.8		
Oct.	38.8	89.8	18.3		
Nov.	23.4	59.2	10.7		
Dec.	18.7	50.5	8.8		

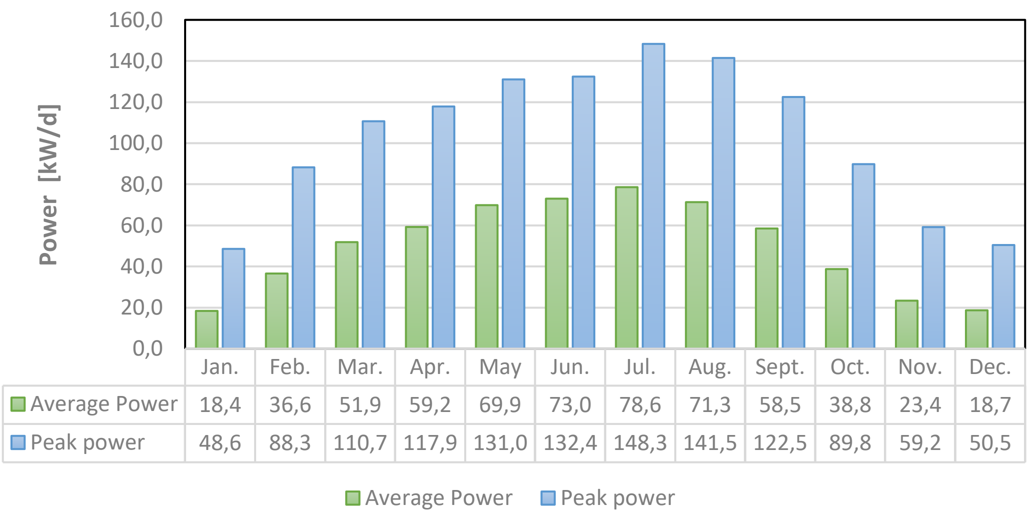


Fig 2.31 Daily output power of the PV plant month by month.

7 Considering only the Basic Load.

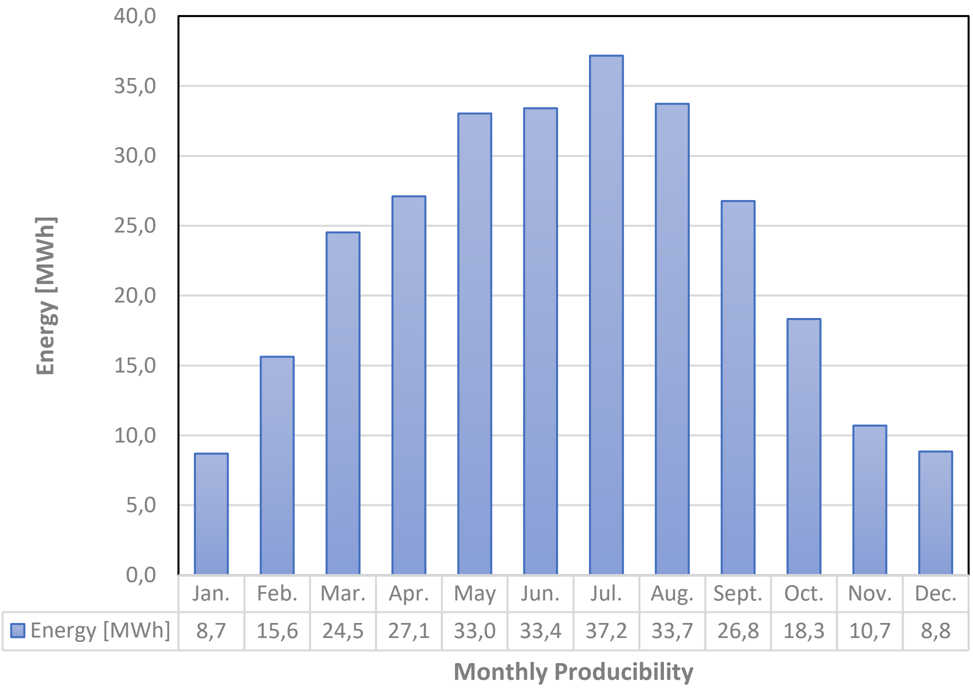


Fig 2.32 Overall monthly producibility of the PV plant.

2.3 Smart charging of the electric vehicles

In conclusion of this chapter we will now go on to evaluate a possible algorithm for optimizing the charging process of electric vehicles. As has already been discussed during the present work, the implementation of the Smart charge for electric vehicles is a must in order to avoid situations of dangerous overloads for the distribution network. However, the management of energy flows is only possible in a mature context that presents a reliable and stable *Smart Grid*. In the following paragraph two separate optimization algorithms are proposed, which exploit two different principles:

- **"Green" algorithm:** the first algorithm proposed is based on a very simple principle. Given the presence on the site of interest of a photovoltaic system, the charging of the electric vehicles is entrusted only to this last resource. In this way, their recharge does not affect the distribution network. It is easy to see that if the generation system does not work (at night, or in a cloudy day), this algorithm is no more valid. In this case we could think of a different principle as the one explained later.

- **"Peak shaving" algorithm:** this algorithm is applicable regardless of the presence of the renewable resource. Basically, based on the energy absorption from the network and based on the presence of the electric vehicles parked, the controller will decide whether to extract energy from the vehicles in order to reduce the peak of energy absorption or whether to recharge them. The ultimate goal is therefore to level the power peaks and obtain a load curve that is as smooth as possible.[8]

2.3.1 "Green" Algorithm

This algorithm allows to take advantage of the renewable resource in order to recharge the electric vehicles. This algorithm, whose basic principle is shown in the flowchart of Figure 2.33, is structured in such a way to perform the recharge only if the energy comes from the photovoltaic system, otherwise the vehicles are not recharged. In this way, the recharging phase minimize the impact on the distribution network.

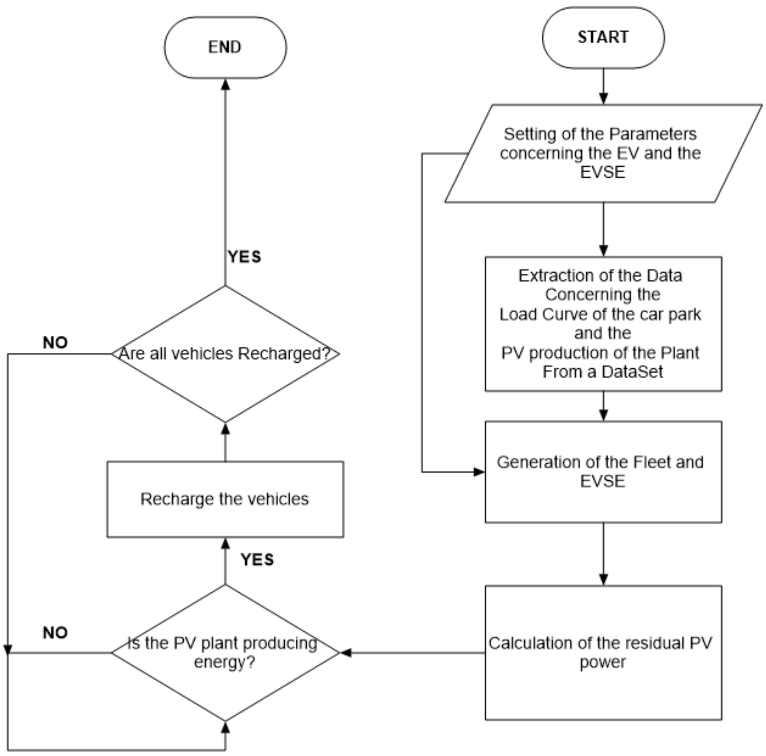


Fig 2.33 Flowchart of the Green Algorithm.

[8] Both algorithms were developed in Matlab language. The source codes can be viewed in the appendix.

Let's therefore see a practical application of the "Green algorithm" to the case in question. In the previous paragraphs both the energy absorption of the car park under analysis and the photovoltaic production of the designed power plant were analyzed. Figure 2.33 shows a comparative analysis of both. As a reference month, January was chosen because it has the lowest amount of energy produced and therefore represents the most critical case. It was also assumed the presence of a fleet of 5 vehicles. A 25% charge was arbitrarily set for each vehicle. In figure 2.34 the orange boxes shows the load curve of the parking lot while the green boxes shows the power generated by the photovoltaic system. As one could summarily note visually, even considering the low producibility of January, photovoltaic production appears to be able to effectively compensate for the parking energy demand, thus leaving a good margin of power in order to recharge the EVs. Figure 2.35 shows the load curve before and after the energy introduced by the the PV plant. Once the energy has been used to power the car park, the remaining one (shown in figure 2.36) can be used to recharge the car fleet.

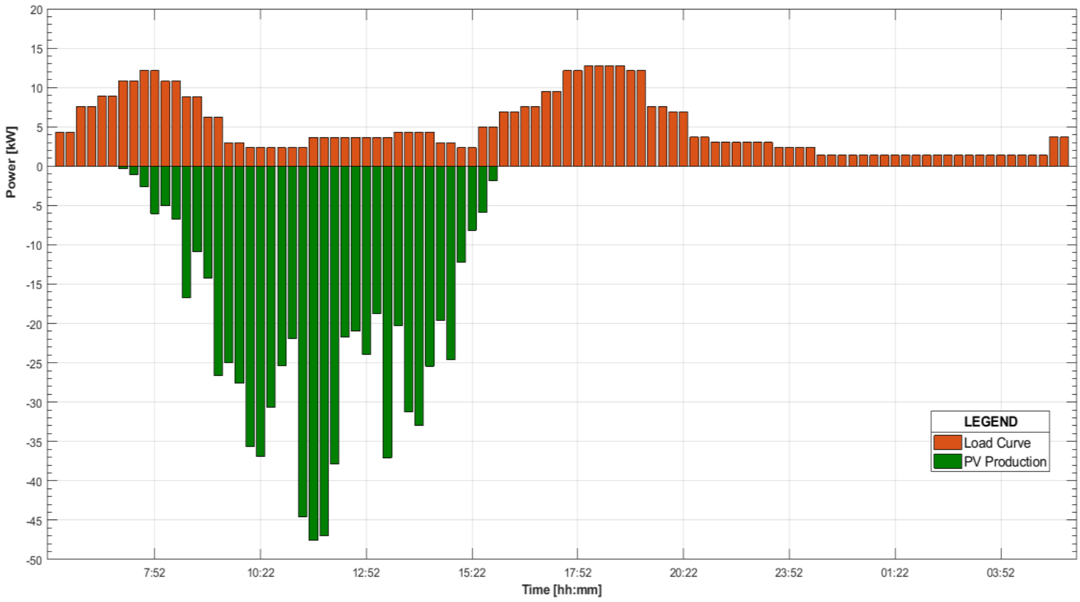


Fig 2.34 Load Curve of the car park and PV production compared.

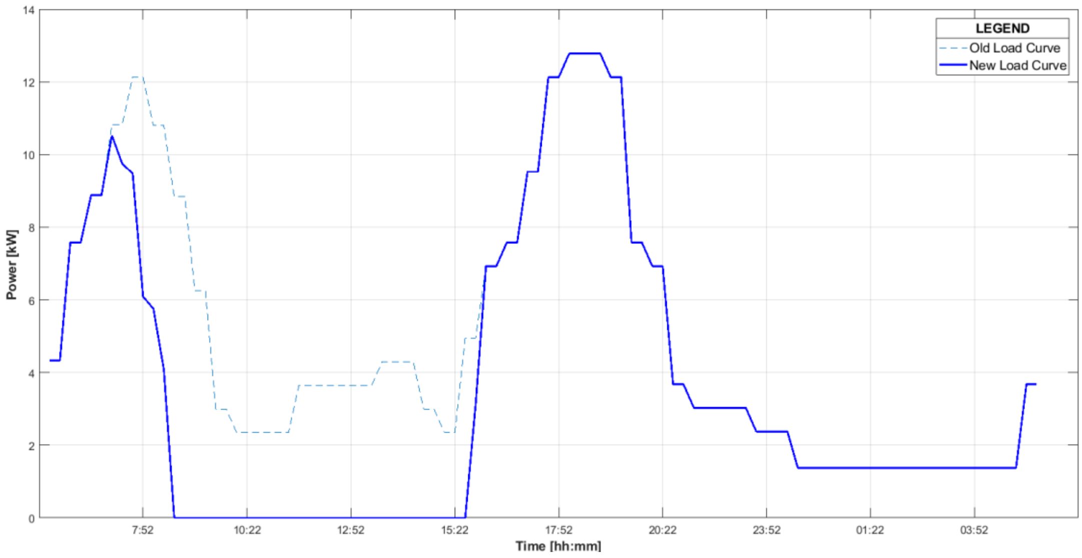


Fig 2.35 Comparison between the old load curve and the new one.

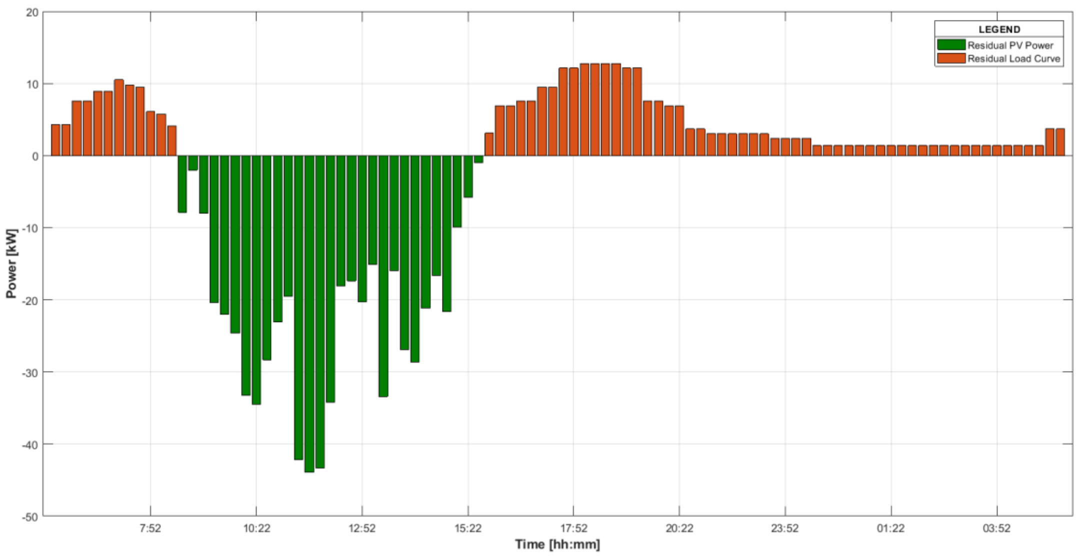


Fig 2.36 Net power production and Power absorption.

Thanks to the residual energy produced it is possible to recharge the fleet of vehicles in more or less 5 hours as it possibile to appreciate in figure 2.37. The red curve shows the power used to completely recharge the fleet composed of 5 vehicles. This power is not absorbed by the network but entirely produced on site. The green curve represents instead the residual photovoltaic energy still usable. From the producibility analyzes carried out in the other months, it can also be shown that the addition of the new electric load still leaves a good margin of unused power which can therefore be transferred to the network, for example, through the net-metering[9]. Alternatively it could also be assumed the design of a suitable energy storage system. In January, for example, photovoltaic production is able to cover 75% of energy needs. Instead, if we consider the highest producibility month, the estimated average daily producibility would be around 0.77 MWh, subtracting then, the energy needed to feed the parking lot and the EVs, the part of energy that can be exchanged with the network would result equal to 0.58 MWh. So almost three times the energy actually needed.

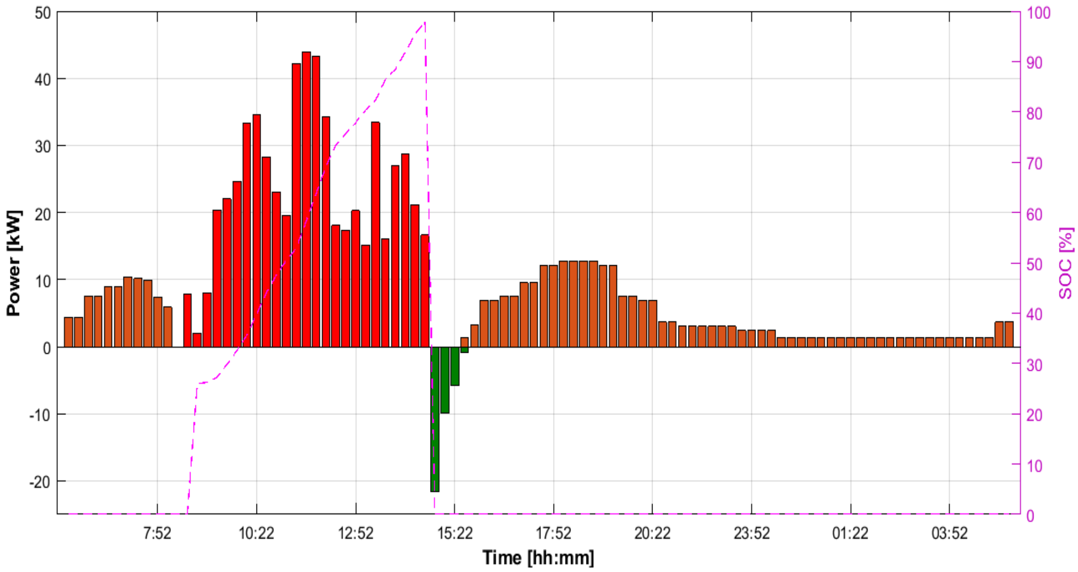


Fig 2.37 Final energy absorption of the car park.

2.3.2 "Peak shaving" algorithm

As already discussed in Chapter 1, a different paradigm with which it is possible to conceive Electric Vehicles is to consider them,not also as a passive load, but as possible active elements of the electric network in order to be able to exploit their storage capacity. In the present paragraph we will try to implement a possible Peak Shaving algorithm. To do this, the energy stored in the batteries of cars connected to the EVSEs will be exploited. Based on the value of the power required by the car park's utilities, the controller will make an evaluation whether

[9] The net-metering service is a particular form of on-site self-consumption that allows you to compensate for the electricity produced and fed into the grid at a certain point in time with that taken and consumed at a different time from that in which the production takes place.

to take the energy required from the network or extract it from the vehicles. In order to have a clearer idea of the applied operating principle, let's consider the graph shown in figure 2.38. the red dashed line represents the maximum allowable power absorbable before the protections are activated. The two dotted lines in blue instead, P_{ref1} and P_{ref2} , represent the two control values of the algorithm. In particular, if the energy demand is higher than P_{ref1} then the energy is taken from the car rather than from the grid. If the requested power is below P_{ref1} then the cars are loaded, on the whole, with a power equal to P_{ref2}. Obviously the nominal power of the supply equipment must always be respected.

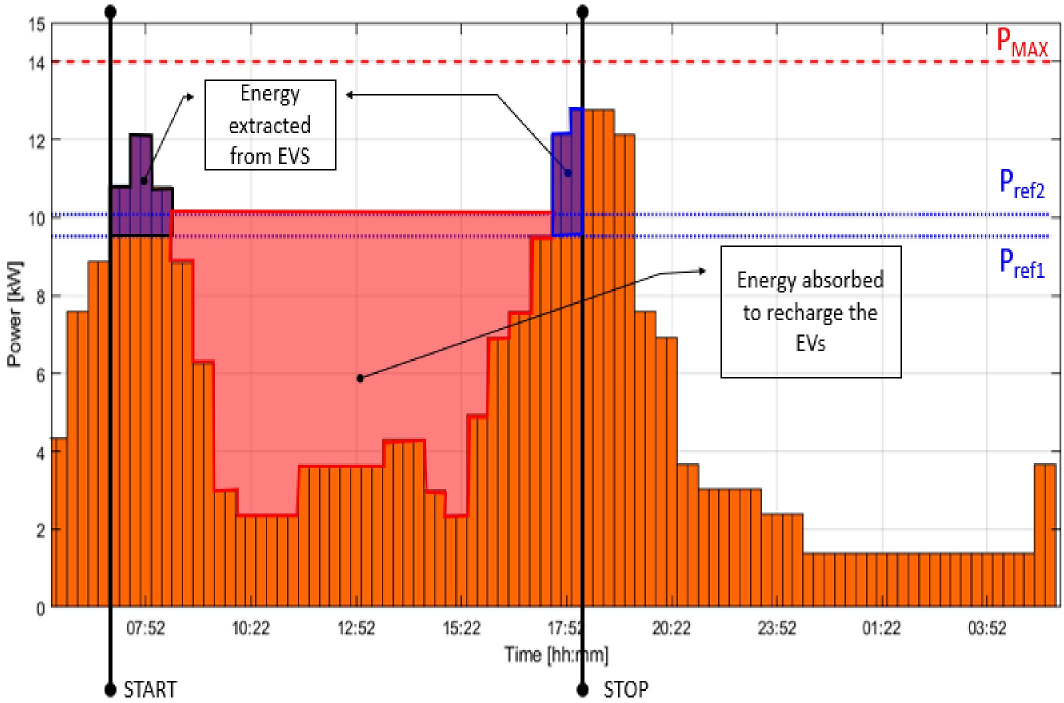


Fig 2.38 Operating principle of the "Peak Shaving" algorithm.

In figure 2.39 it is possible to appreciate the final result of this algorithm. The dotted gray line represents the old load curve while the red one shows the new load curve after the Peak Shaving algorithm is applied. The blocks in green represent instead the energy extracted from electric vehicles to feed the parking in the phases of greater absorption while the line dashed in blue the trend over time of the fleet's SOC. As can be noted, through this algorithm the charging of electric vehicles can be extended up to 10÷11 hours. For conclusive purpose, in figure 2.40 the flowchart related to "Peak Shaving Algorithm" is shown.

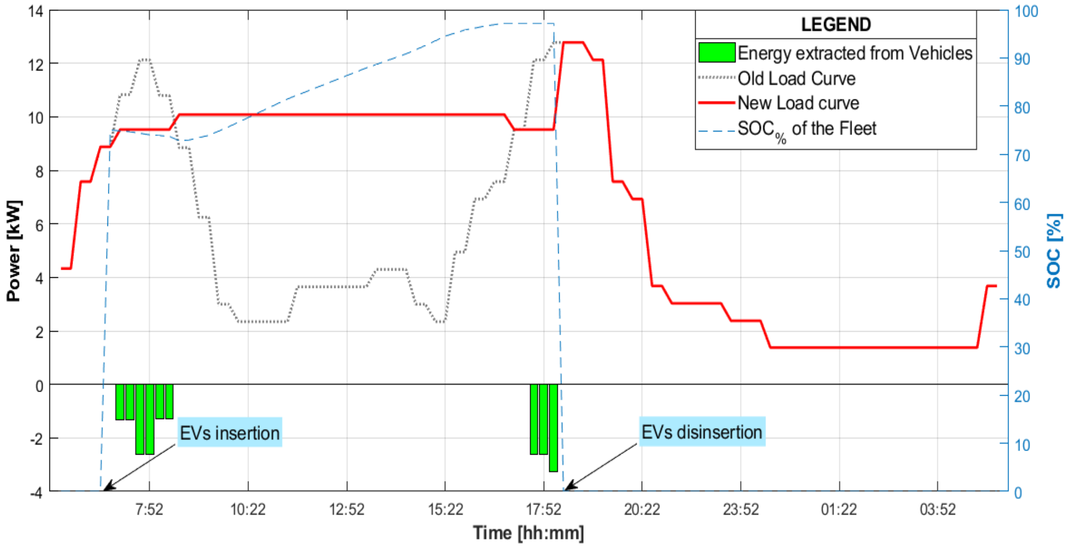


Fig 2.39 Comparison between the Old Load curve and the New Load Curve.

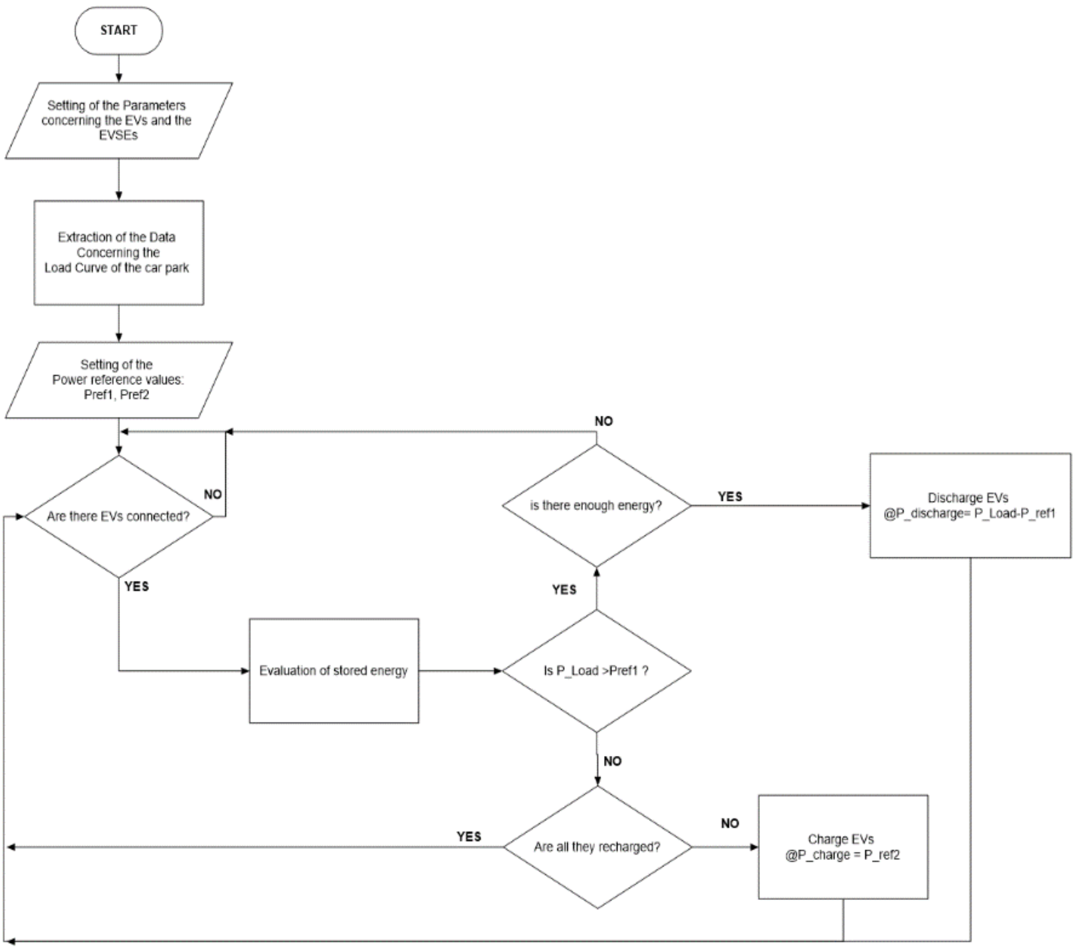


Fig 2.40 Flowchart of the Peak Shaving Algorithm.

CHAPTER 3
CONCLUSION

During the following work, an attempt was made to outline the current status and possible future trends regarding electric mobility in the most complete and concise way possible. To date, the spread of electric vehicles is, overall, still modest, although, as we have seen, their market would seem to grow year after year. The increasingly frequent cases of extreme meteorological phenomena related to climate change due to greenhouse gases and the continuous and constant reduction of fossil fuel deposits are not only necessary but it's becoming a duty to switch to more sustainable forms of transport. But the wild introduction of electric vehicles on our roads could lead to dangerous overloads and sudden voltage drops for the distribution network, thus increasing the risks of disservice. It has therefore been seen that, in parallel with their diffusion, it is also necessary to envisage the implementation of an appropriate scheduling of the recharging process, through intelligent recharging systems able to predict and analyze the situation on the distribution network side and act accordingly. Moreover, every new electric vehicle that comes into circulation also means a new load that needs electricity to be recharged. Consequently, careful planning of renewable energy plants is also necessary with their diffusion in order to make the huge amount of energy that these new *"wheeled loads"* will need as sustainable as possible. In the second part of this work, we have seen a practical application of this. The electrical producibility of a photovoltaic system designed specifically for the car park of Ferrara railway station was analyzed and it was seen that, not only this plant was able to supply for the basic load of the parking, but it was also able to satisfy the energy request needed to recharge the electric vehicles. Furthermore, leaving an additional residual energy to be exploited through on-site exchange. In conclusion, it remains to say that, to date, the biggest challenges facing V2G technology are of different nature:

- From technical point of view the evolution of Smart Grids has yet to prove their robustness and reliability;

- From a regulatory point of view a correct regulatory plan must still be defined in order to regularize the introduction of this new *"active"* load;

- From the economic side, in order to exploit all the possible monetary advantages linked to this new paradigm. So through the draft of appropriate business plans and launching appropriate marketing campaigns that encourage the end user to connect their vehicles and to allow the operator to perform such activities described;

- Finally, from a political point of view, as, in fact, it is the public administrations that should first be sensitive to a change of direction towards more sustainable modes of transport. Encouraging and supporting these technologies and providing appropriate planning, both from a logistical and infrastructural point of view.

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APPENDIX A
GLOSSARY

Below the source codes used in this work and relative comments are shown.

A.1 Source Code: Green Algorithm

```
clear; clc;close all;
%% ------ START  OF SECTION 1: Setting of the inizial paramaters -----------------%
%% in this section the technical data concerning electric vehicles and supply
equipment are inserted
%//////////////////////////// NISSAN LEAF 2018 DATA \\\\\\\\\\\\\\\\\\\\\\\\\\\\\\

P_Leaf_charger=50; %[kW]  Rated Power of the Nissan Leaf 2018 Charger
B_Leaf=40;   %[kWh] Rated Capacity of the Nissan Leaf 2018 Battery

%/////////////////////////////////////////////////////////////////////////////////

%//////////////////////////////////  EVSE DATA \\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\

P_evse = 10.5;  %Rated Charging Power of the EVSE

%/////////////////////////////////////////////////////////////////////////////////

%% ------------------------------------------------------- END OF SECTION 1 ------%
%% ------ START  OF SECTION 2: Data Acquiring ------------------------------------%
%% in this section the data concerning the Load curve of the car park and the
%PV production are extracted by a dataset.xlsx file

%//////////////////////////////// FILE SPECIFICS ////////////////////////////////
fileName= 'dataSet.xlsx';  % <-- File name
col1='B2:B97'; % <-- Load Curve of the car park
col2='C2:C97';  % <--PV production of the plant  [C2:C97 Jan ... N2:N97 December]
%/////////////////////////////////////////////////////////////////////////////////

% The ExtractData() function receives as input the file name and the
% columns to be extracted and returns respectively:

% 1) P_BasicLoad --> the Load curve of the car park
% 2) P_PV        --> the daily Power trend of the PV plant

[P_BasicLoad,P_PV] = ExtractData(fileName,col1,col2);

% The DisturbancesAdder() function add a uniformly distributed noise to the
```

```
% PV production in such a way as to make it more realistic.
% [Setting of the disturbances: 0% = zero disturbances --> 100% = maximum
disturbances]
P_PV = DisturbancesAdder(P_PV,60); % <-- 60% of disturbs

% The PowerAnalyzer() function receive as input the load curve and the PV
% production and return respectively:

% 1) P_Load_res --> the residual load curve
% 2) P_PV_res --> the residual PV power still available.
[P_Load_res,P_PV_res] = PowerAnalyzer(P_BasicLoad,P_PV);

%% ------------------------------------------------------- END OF SECTION 2 ------%

%% ------ START  OF SECTION 3: GREEN ALGORITHM -----------------------------------%
%% in this section an algorithm of Smart Charging is implemented.
%  The "GREEN ALGORITHM" analyze the resiudual PV production and according
%  to this recharge the EVs only if the renewable resource is available.

%////////////////////// GENERATION OF THE FLEET ////////////////////////////START

SOC=0.25;           % <-- Initial State of Charge of the single vehicle
dim_fleet=5;        % <-- Setting Dimension of the EVs fleet

% The FleetGenerator() function receive as input the rated Power, the Battery
Capacity and the SOC
% of the EV considereded and also the dimension of the fleet we want to generate.
% (!!! Attention: for simplicity purposes each fleet vehicle starts with the same
SOC but a randi funtion for the SOC coul be easily implemented !!!)
% The function return:

% 1) Leaf_fleets --> a fleet of Nissan Leaf 2018
% 2) Leaf_eq  --> the equivalent electric vehicle. (The EVs fleet, by an energetic
point of view, is seen as a single entity)


[Leaf_fleets,Leaf_eq]= FleetGenerator(P_Leaf_charger,B_Leaf, SOC, dim_fleet);

P_Leaf_eq_charger=Leaf_eq(2); % [kW]  Maximum total power absorbable by the fleet
B_Leaf_eq=Leaf_eq(3);         % [kWh] Maximum Storage Capacity of the batteries of
the fleet
B_act_Leaf_eq =Leaf_eq(4);    % [kWh] Actual Energy stored in the batteries of the
fleet
%/////////////////////////////////////////////////////////////////////////////END


%/////////////////////////////// GENERATION OF THE EVSE ///////////////////START

% The EvseGenerator() function receive as input the rated Power of the
% single EVSE an the number of the Supply Equipments and return the
% equivalent power of the supply system.

N_evse=5; % <-- Number of EVSE considered
[P_evse_eq]=EvseGenerator(P_evse,N_evse);
%/////////////////////////////////////////////////////////////////////////////END


%////////////////// SMART CHARGING OF THE FLEET/////////////////////////////START
% The VehicleCharger() function receive as input an electric vehicle or a
% fleet of EVs,the Power of the EVSE and the Power of the charger of the EV
% and it returns:
% 1) SOC_t --> the trend in time of the SOC of the EV
% 2) B_act_Leaf_eq  --> the actual Energy stored in the battery after the
recharging
% 3) P_charge_t  --> the trend of the Power Charging
% 5) P_PV_res2  --> the residual PV energy still available

[SOC_t, B_act_Leaf_eq,P_charge_t,P_PV_res2]=
VehicleCharger(Leaf_eq,P_evse_eq,P_PV_res);
%/////////////////////////////////////////////////////////////////////////////END
```

A.2 Source Code: Peak Shaving Algorithm

```
clear; clc;close all;
%% //   PEAK SHAVING ALGORITHM   // %%

%Description:
% Questo algoritmo analizza una certa curva di carico.
% analizza la potenza e le risorse date dai veicoli elettrici.
% in base alle due curve ottimizza il processo di ricarica.

%% ------ START  OF SECTION 1: Setting of the inizial paramaters -----------------%
%% in this section the technical data concerning electric vehicles and supply
equipment are inserted.
% The reference parameters for the recharging rate are also set.

%////////////////////////// NISSAN LEAF 2018 DATA \\\\\\\\\\\\\\\\\\\\\\\\\\\\\\

P_Leaf_charger=50; %[kW]  Rated Power of the Nissan Leaf 2018 Charger
B_Leaf=40;   %[kWh] Rated Capacity of the Nissan Leaf 2018 Battery

%///////////////////////////////////////////////////////////////////////////////////

%///////////////////////////////////  EVSE DATA \\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\

P_evse = 10.5;  %Rated Charging Power of the EVSE

%///////////////////////////////////////////////////////////////////////////////////

%///////////////////////////////////  REFERENCE PARAMETERS \\\\\\\\\\\\\\\\\\\\\\\

P_lim =14;      % [kW] Rated power of the general panel

ref2= 0.72;     %Corrective facotr for P_ref_2
ref1 = 0.68;    %Corrective facotr for P_ref_1

P_ref2 = P_lim*(ref2); % [kW] Upper reference limit
P_ref1 = P_lim*ref1;   % [kW] Lower reference limit

%//////////////////////////////////////////////////////////////////////////////////




%% ------------------------------------------------------- END OF SECTION 1 ------%
%% ------ START  OF SECTION 2: Data Acquiring ----------------------------------%
%% in this section the data concerning the Load curve of the car park are
% extracted by a dataSet.xlsx file

%///////////////////////////////// FILE SPECIFICS ////////////////////////////////
fileName= 'dataSet.xlsx';  % <-- File name
col1='B2:B97'; % <-- Load Curve of the car park
col2='C2:C97';  % <--PV production of the plant  [C2:C97 Jan ... N2:N97 December]
%///////////////////////////////////////////////////////////////////////////////////


% The ExtractData() function receives as input the file name and the
% columns to be extracted and returns respectively:

% 1) P_BasicLoad --> the Load curve of the car park
% 2) P_PV        --> the daily Power trend of the PV plant
```

```
[P_BasicLoad,P_PV] = ExtractData(fileName,col1,col2);

%% ------------------------------------------------------- END OF SECTION 2 ------%
%% ------ START  OF SECTION 3: PEAK SHAVING ALGORITHM  ---------------------------%
% in this section an algorithm of Smart Charging is implemented.
% The "PEAK SHAVING" algorithm  analyze the Load Curve of the car park and
% the energy availabe stored in EVs fleet.
% if the energy demand is higher than Pref1 then the energy is taken from the
% car rather than from the grid. If the requested power is below Pref1 then
% the cars are loaded, on the whole, with a power equal to Pref2.

%///////////////////// GENERATION OF THE FLEET /////////////////////////////START

SOC=0.75;           % <-- Initial State of Charge of the single vehicle
dim_fleet=5;        % <-- Setting Dimension of the EVs fleet

% The FleetGenerator() function receive as input the rated Power, the Battery
Capacity and the SOC
% of the EV considereded and also the dimension of the fleet we want to generate.
% (!!! Attention: for simplicity purposes each fleet vehicle starts with the same
SOC but a randi funtion for the SOC coul be easily implemented !!!)
% The function return:

% 1) Leaf_fleets --> a fleet of Nissan Leaf 2018
% 2) Leaf_eq  --> the equivalent electric vehicle. (The EVs fleet, by an energetic
point of view, is seen as a single entity)


[Leaf_fleets,Leaf_eq]= FleetGenerator(P_Leaf_charger,B_Leaf, SOC, dim_fleet);

P_Leaf_eq_charger=Leaf_eq(2); % [kW]  Maximum total power absorbable by the fleet
B_Leaf_eq=Leaf_eq(3);         % [kWh] Maximum Storage Capacity of the batteries of
the fleet
B_act_Leaf_eq =Leaf_eq(4);    % [kWh] Actual Energy stored in the batteries of the
fleet

%////////////////////////////////////////////////////////////////////////////////END

%/////////////////////// GENERATION OF THE EVSE ///////////////////////////START

% The EvseGenerator() function receive as input the rated Power of the
% single EVSE an the number of the Supply Equipments and return the
% equivalent power of the supply system.

N_evse=5; % <-- Number of EVSE considered
[P_evse_eq]=EvseGenerator(P_evse,N_evse);

%/////////////////////////////////////////////////////END

%/////// SMART CHARGING OF THE FLEET//////////////////START
%% The PeakShaving() function receive as input:
% P_BasicLoad <-- The Load Curve of the car park
% Leaf_eq      <-- The Fleet of EVs
% P_evse_eq     <-- The total power of the EVSEs
% P_ref1,P_ref2  <-- The two reference parameters of the algorhitm
% and returns as output:
% P_sh_LOAD   --> A Shaved remodeling of the Load Curve of the car park
% P_ex_t       --> The Power exctacted by the EVs
% SOC_t         --> The trend in time of the State of Charge

[ P_sh_LOAD,P_ex_t,SOC_t] =
PeakShaving(P_BasicLoad,Leaf_eq,P_evse_eq,P_ref1,P_ref2);
%/////////////////////////////////////////////////////END
%% -------------------------------- END OF SECTION 3 ------%
```