APPUNTI DI ENERGIA

The integration of electric vehicles into the grid and the smart charging

October 2025

What it's about

Energy and mobility systems are undergoing a massive electrification process, with a significant increase expected in the coming years in the number of low-emission vehicles and charging points. This growth is driven by ambitious policies aiming for a climate-neutral European energy and transport system by 2050. Such rapid development brings several challenges, including a notable rise in household electricity consumption, but also great opportunities.

The energy system faces a crucial question: are electric vehicles a risk for the grid or a new opportunity?

To answer this, we need to look beyond the battery and vehicle range, and to focus on how and when these vehicles absorb energy—or potentially return it to the grid. This is where smart charging comes into play, a key element for integrating transportation and the power system. Today, most charging happens in an unmanaged way: the car is plugged in and charges at the maximum available power, often during evening hours when many users return home. This simultaneous behavior can create load peaks and stress the grid.

What is called smart charging (V1G) introduces a concept of "intelligent" charging: the vehicle charges by adjusting power and timing, shifting consumption to hours that are more favorable for the system—for example, when demand is low or when there is more renewable energy production. A further step is the V2X, where energy can flow from the vehicle to the grid (Vehicle-to-Grid, V2G) or to the home (Vehicle-to-Home, V2H), turning the car into a mobile battery capable of providing additional flexibility services to the power system.

Unidirectional and bidirectional charging

Electric vehicles can be an important source of flexibility for the grid, depending on how their charging is managed

Let's go into more detail to distinguish between the two types of charging: unidirectional (V1G) and bidirectional (V2G). Unidirectional charging (V1G), the smart charging mentioned earlier, means adjusting the timing and power of the vehicle's charging without changing the direction of the flow: the energy always goes from the grid to the battery. In this case, the vehicle remains a consumer, but becomes a smart load, able to absorb energy when it's most convenient for the user or for the power system. With bidirectional charging (V2G), the vehicle can also return energy to the grid or to a local user. The car thus becomes a distributed storage unit, expanding the flexibility services it can offer and, as a result, the economic returns for the owner, who could sell these services to the power system.

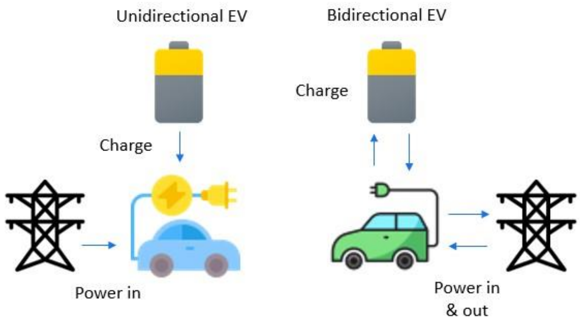


Figure 1 – Types of EV recharge

Impact of EVs on electricity markets

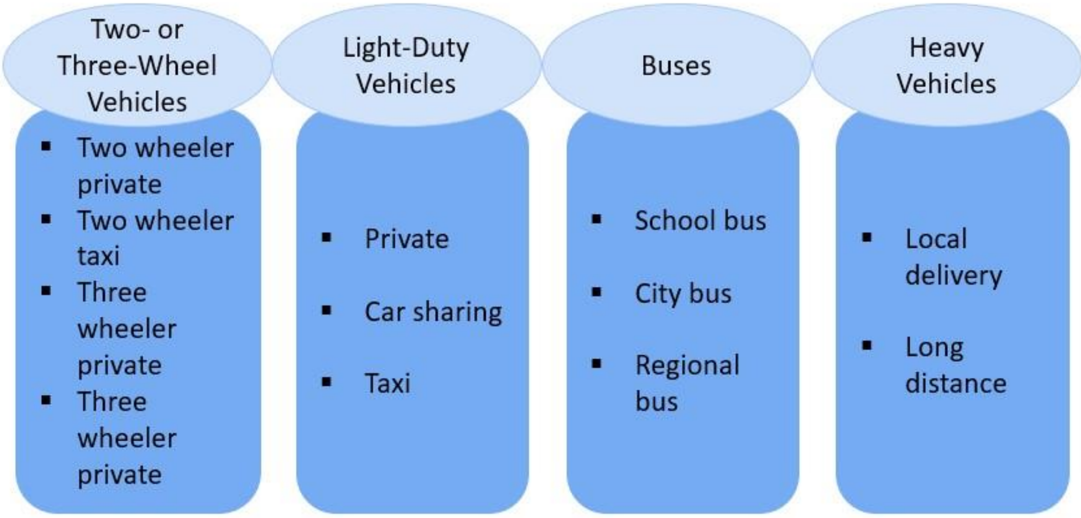
IEA

Electric vehicles in Italy are expected to reach a total load of 15 TWh by 2030 under the NCEP scenario, distributed among passenger cars, heavy-duty vehicles, buses, and motorcycles.

An important aspect lies in evaluating the impact of electric vehicles within the context of energy markets, in order to draw regulatory considerations accordingly. RSE has carried out a dedicated study using a tool developed in-house, which takes as input the charging demand profiles provided by the International Energy Agency (IEA). This tool was then combined with RSE's own software, sMTSim (stochastic Medium Term Simulator), to simulate the operation of a generic day-ahead market over a one-year horizon.

The first step was to estimate the impact on load profiles of different charging modes (vehicle type, charging time window, strategy, etc.).

The various vehicle types are shown in the following figure.



EV types

Each vehicle type is assigned to a specific battery with a defined capacity (kWh), a specific energy consumption for travel (kWh/km), and a travelled average distance, which differs between weekdays and holidays.

Once the vehicles are defined, the tool allows for the definition of "charging opportunities," meaning the various places where the vehicle can be charged, as shown in the following table:

Home charging	Charging at the driver's residence.	Default charging location for private vehicles.
Workplace charging	Charging at the driver's workplace.	Main alternative to home charging for those who commute daily to an office or site.
On street charging	Charging in public or private parking spaces along streets.	Default option for those without a dedicated parking space.
Destination charging	Charging at points of interest, i.e., the trip destination, outside home and work.	Additional option for partial charging during parking time.
En-route charging	Charging at a station located along the route to the destination, e.g., on highways.	Additional option for partial charging, possibly multiple times during the day.

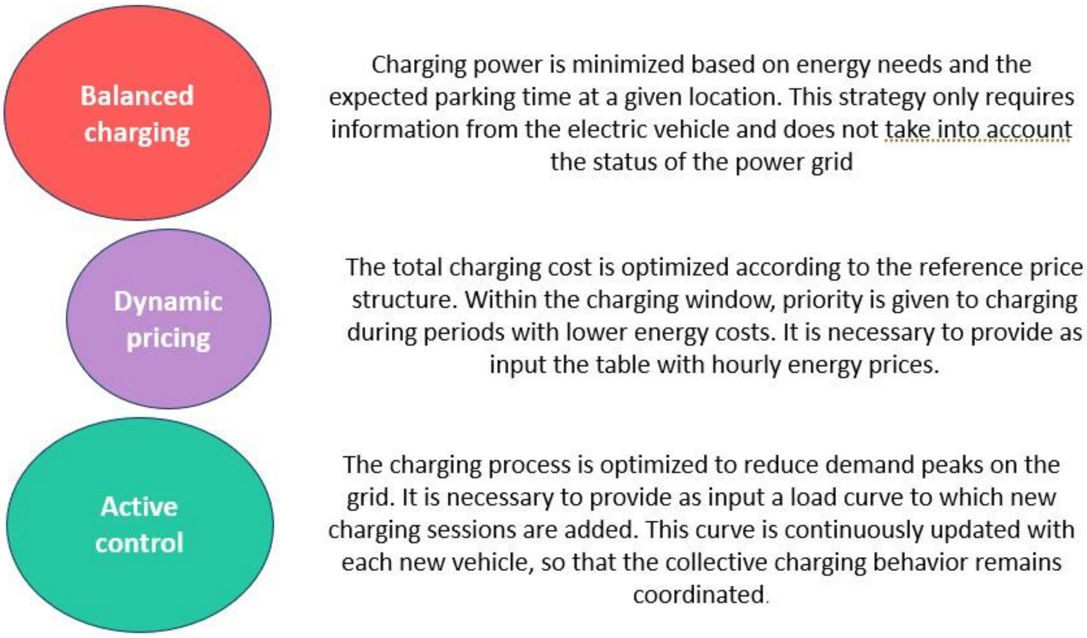
Charging opportunities

Not all vehicles have access to all five charging types mentioned above. For each type, it is assumed that charging occurs once per day; therefore, a charging window can be defined (arrival time range, and parking duration).

Finally, to estimate the typical load profiles of electric vehicles –and consequently to develop regulatory considerations on how to manage these new transport systems– it is important to identify charging strategies. In addition to the "unmanaged" charging demand, where each vehicle fully recharges its battery immediately after each trip, it is possible to define "managed" charging strategies that allow energy to be shifted within the parking period at a charging point, while keeping the total withdrawn energy unchanged.

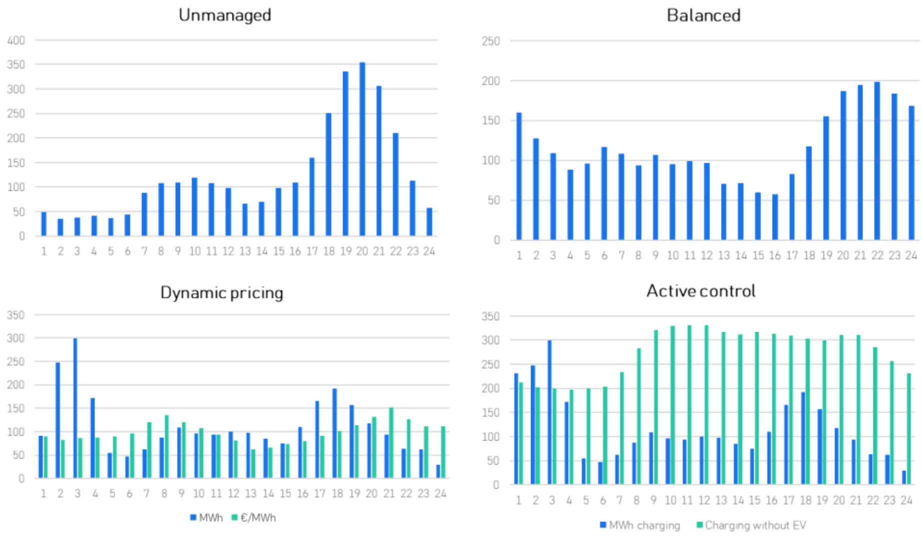
The goals of the managed charging can vary: reducing peak power when the grid is overloaded, lowering the contractual power of the charging point, increasing the share of energy charged from renewable sources, or charging when energy prices are more favorable.

Here, "price" refers to the wholesale price of the energy commodity.



The hourly distribution of load on the power system changes depending on the chosen strategy. In the figure below, we show the daily load for the Central-Northern area, corresponding to around 40,000 light-duty private electric vehicles (a total of 2,700 MWh), which 90% can charge at home, and 50% also have the possibility to charge on the street or at their destination.

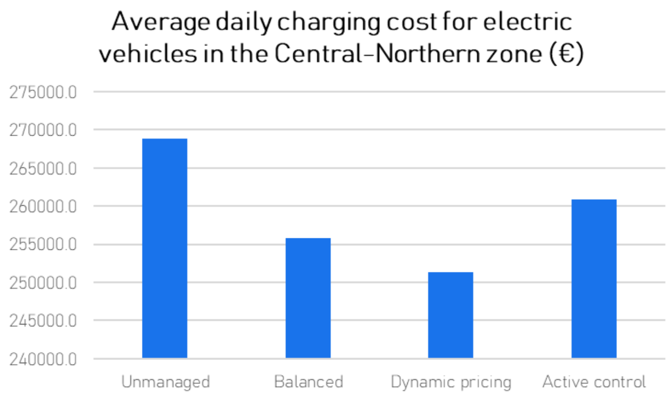
For the price-driven charging mode, the energy cost (€/MWh) from the Day-Ahead Market was used, referring to a selected weekday in 2024. For the demand-driven mode –based on the electricity demand in the absence of electric vehicles– the total energy requirement (MWh) of the entire market zone was considered, again for the same day in the Central-Northern area.



---------------------------- Load Profile with Different Charging Strategies ----------------------

From the graphs shown above, it is clear that unmanaged charging leads to sharp load peaks during specific time slots (from 5:00 PM to 10:00 PM), while balanced charging results in a more evenly distributed load profile, reducing those peaks. The strategy based on hourly energy prices, as expected, causes a charging peak during the hours when energy is cheapest and the vehicles are connected at home. Conversely, with the active control, the charging profile increases when the grid load is at its minimum (during the first three hours of the day).
In summary, smart charging strategies allow for the optimization of the periods during which electric vehicles are charged, reducing the impact on the power grid during critical hours or enabling users to benefit from lower energy costs. The load from electric vehicles is present on the grid at all times, since at any hour of the day, at least a portion of the vehicles is connected to a charging point.

Using the above mentioned sMTSim software (stochastic Medium-Term Simulator), developed by RSE to simulate the operation of a generic day-ahead market over a one-year horizon, it was possible to study the impact of these strategies on energy prices. Specifically, we report an estimate of the daily energy component costs in euros (excluding system charges, transmission, distribution and metering fees, retail and sales costs, excise duties and VAT) incurred by electric vehicles for charging. These costs were calculated as the average of the product between the energy commodity price and the energy used for charging.
The scenario considered is the one outlined in the National Integrated Energy and Climate Plan for 2030, which foresees 6 million electric vehicles in circulation, with a total annual electricity demand of 15 TWh on the grid.



--***Costs based on the charging strategy*** --------------------------

The benefits of managed charging are not limited to the grid –where it helps reduce congestion and makes the load profile more uniform– but, as shown in the graph, they also significantly affect the costs borne by users. The unmanaged strategy, which leads vehicles to charge even when energy is expensive –either because the user ignores the price or has no alternative- is economically the least convenient. On the other hand, the strategy based on energy prices is, as expected, the most cost-effective.

Balanced charging and active control strategies not only reduce the impact on the grid, but also lower vehicle charging costs. First of all, during periods of high demand, the system must activate more expensive generation plants to maintain the balance between supply and demand, which leads to an increase in the marginal price of energy. Moreover, when the grid is congested— meaning transmission lines are saturated— it becomes impossible to import energy from cheaper zones. As a result, local production with less efficient resources becomes necessary, causing price spikes in the affected areas. It is also necessary to consider the impact of charging on the distribution grid, which is not included in the model described above. This impact may require reinforcement and expansion of the infrastructure—especially when charging occurs during periods of demand from other types of loads, such as heat pumps.

It should also be noted that charging driven by wholesale prices could itself lead to local congestion, in cases where many vehicles charge simultaneously to take advantage of lower prices.

Pilot projects for flexibility service

In this regard, the Italian national regulatory authority (ARERA) has launched in 2021 a pilot program that, until June 30th, 2027, allows users to increase free of charge the available power up to 6 kW during off-peak hours (*F3* time slot: 11:00 PM–7:00 AM, and holidays). This initiative supports smart charging of electric vehicles and encourages shifting consumption to hours when the grid is less congested.

Directive 944/2019

In addition to charging strategies based on prices, energy or tariff components (*implicit* demand response), electric vehicles can also participate in the aforementioned flexibility services, both for the transmission grid and the distribution grid. Smart charging strategies must therefore combine all these inputs, shifting energy consumption to take advantage of lower costs and to deliver the agreed services.

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This work has been financed by the Research Fund for the Italian Electrical System under the Three-Year Research Plan 2025-2027 (MASE, Decree no.388 November 6th, 2024) , in compliance with the Decree April 12th, 2024.