Flexible energy systems Leveraging the Optimal integration of EVs deployment Wave

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Deliverable D5.4

Key recommendations on new policies and regulation to boost effective VGI of millions of EVs

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List of Acronyms

Acronym	Meaning
AC	Alternating Current
BC	Balanced Charging
BESS	Battery Energy Storage System
BSP	Balance Service Provider
BTM	Behind-the-Meter
CDM	Clean Development Mechanism
CINEA	European Climate, Infrastructure and Environment Executive Agency
CPO	Charging Point Operator
DC	Direct Current
DSO	Distribution System Operator
EMS	Energy Management System
eMSP	e-Mobility Service Provider
ETS	Emissions Trading System
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
FLOW	Flexible energy system Leveraging the Optimal integration of EVs deployment Wave
IEA	International Energy Agency
ISO	International Organization for Standardization
JI	Joint Implementation
LDV	Light-duty Vehicle
NECP	National Energy and Climate Plan
OEM	Original Equipment Manufacturer
O&M	Operation & Maintenance
OCPP	Open Charge Point Protocol
PA	Public Administration
PTDF	Power Transfer Distribution Factor
PU	Public
PV	Photovoltaic
RES	Renewable Energy Sources
RIA	Research and Innovation Action
RSE	Ricerca sul Sistema Energetico
sMTSIM	stochastic Mid-Term SIMulator
TSO	Transmission System Operator
ToU	Time-of-Use
UC	Use Case
V1G	Smart Unidirectional Charging
V2B	Vehicle-to-Building
V2G	Vehicle-to-Grid
V2H	Vehicle-to-Home
V2X	Vehicle-to-Everything
VGI	Vehicle-Grid Integration
WG	Working Group
WP	Work Package

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Executive Summary

The rapid growth of electric vehicles (EVs) represents both a challenge and an opportunity for European energy systems. While uncontrolled EV charging can exacerbate peak demand, grid congestion, and price volatility, smart and bidirectional charging strategies can transform EVs into a valuable source of flexibility, supporting grid stability, market efficiency, and renewable energy integration. This deliverable presents the results of Task 5.4 of the FLOW project, with the objective of identifying policy and regulatory measures capable of accelerating effective Vehicle-Grid Integration (VGI) at scale.

The first part of the report assesses the impact of different EV charging strategies on the energy market, using the Italian electricity system in a 2030 scenario as a case study. A modelling framework combining a zonal electricity market simulator with an EV charging demand tool was developed and applied to simulate unmanaged charging, balanced charging, tariff-based charging, and active control strategies. The results show that unmanaged charging tends to concentrate demand during evening peak hours, increasing system costs and electricity prices. In contrast, smart charging strategies consistently reduce peak demand, smooth load profiles, and lower charging costs for users. Tariff-based and active control strategies are particularly effective during peak load periods, while active control performs best during hours of high renewable generation by aligning EV demand with renewable availability and reducing curtailment.

The second part of the deliverable focuses on identifying the main barriers to VGI diffusion and on defining targeted policy and regulatory recommendations. This process was supported by three complementary instruments: a questionnaire addressed to EV and energy system experts, inputs from the European V2X Cluster, and a dedicated Policy and Regulation Working Group within the FLOW consortium. The collected evidence confirms a broad consensus on the relevance of EV-based flexibility, the importance of dynamic tariff schemes, and the strategic role of bidirectional charging, while also highlighting uncertainties related to market rules, business models, and user acceptance.

Based on these inputs, the report proposes a set of seven key recommendations aimed primarily at policy makers and regulators. These include supporting the installation of smart chargers in locations suitable for daytime charging, adopting tariff schemes that strongly differentiate prices according to system conditions, promoting harmonization of communication protocols and interoperability, simplifying flexibility market rules for aggregators, removing regulatory and fiscal barriers to bidirectional charging, increasing user awareness and fostering further research and pilot projects. To enhance their practical relevance, the recommendations are mapped to fifteen concrete use cases, covering different charging locations, charging modes, and levels of market participation.

Overall, the deliverable provides evidence based insights and a structured framework to support the progressive and effective integration of EVs into future energy systems, maximizing their contribution to flexibility, decarbonization, and system resilience.

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1. Introduction

Today, the majority of Electric Vehicle (EV) charging processes still occur in a so-called “uncontrolled” manner. In this context, uncontrolled refers not to the absence of power electronics or charger level control, which is always present, but to the fact that the charging power typically follows a simple rule: the vehicle charges at the maximum available power and for the shortest possible time. This approach, imagined in the first years of EVs deployment to guarantee sufficient driving range with “short” stops, is not the optimal one in most charging situations, as it can create high peaks of power demand and then leave a fully charged and inactive vehicle connected to the charging stations even for many hours. More advanced solutions consider the possibility to modulate the charging power and to shift in time the charging process, to optimize different parameters: charging costs, grid congestion, environmental impact, revenues from grid services provision and others. The adoption of these schemes represents a real game-changer when analysing the potential risks and opportunities for the energy systems generated by a massive diffusion of EVs in the next years. An additional benefit could come by the adoption of “bidirectional charging”, that allows EVs not only to modulate their charging power, but also to discharge their batteries and feed energy back to the grid.
Despite being conceptualized and studied since many years, together with their advantages, smart and bidirectional charging are still in a first phase of diffusion, lacking real commercial solutions that can be proposed to final users. That means that the flexibility potential by EVs is still not completely unleashed.

Task 5.4 of the FLOW project had the objective to identify the elements that still limit the diffusion of EV-based flexibility and to suggest potential solutions to effectively implement the most promising charging strategies. The focus of the task was not so much on technical aspects, but rather on the elements that can be solved through regulatory or policy interventions. Accordingly, the final output is a set of recommendations mostly targeted to policy makers and regulators.

The Task activities were divided in two main parts, both summarized in this report. The first part, reported in Section 2, was focused on analysing how modelling could support decision makers in understanding the impact of innovative charging strategies, compared to the uncontrolled strategy. In particular, it was considered important to take into consideration not just the impact of charging strategies on the electricity grids (already addressed by Task 5.1), but their impact on the energy markets. A model able to perform these analyses for a 2030 energy scenario has been developed and applied within the Task. The model was tested in an Italian scenario against a series of charging strategies suggested by the IEA and proved to be a valuable tool for evaluating the benefits of the different strategies, which can vary significantly depending on the day or the time of the day. While several specific certain strategies were tested for this deliverable, the model is suitable for testing additional strategies and should be considered for follow-up activities, particularly those emerging from the findings and policy recommendations formulated within this same Task. The second part of the activities, summarized in Sections 3 and 4, dealt with the identification of the most important elements that can influence Vehicle-Grid-Integration (VGI) and EV-based flexibility services and on the definition of the final recommendations. Section 3 presents the instruments put in place to gather information and expert opinions on VGI characteristics and limits, while Section 4 presents the final recommendations and the methodology to define them, based on the analysis of 15 use cases.

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2. Modelling the impact of EV charging strategies on the Energy Markets

This chapter analyses the impact of different smart charging strategies on the Italian energy market, assessing their effects on system load and electricity prices. The analysis considers the NECP (National Energy and Climate Plan) 2030 scenario, where the total EV load is expected to reach 15 TWh (around 5% of Italy's total electricity demand). To carry out the simulation, a software aiming at optimizing hydro-thermal dispatch taking into account unit commitment constraints is adopted, which can optimally dispatch resources while minimizing overall system costs. The strategies are derived from different charging time frames and types of charging points, using data from a tool developed by IEA (IEA, 2023), which quantifies and visualizes EV charging demand profiles for various vehicle types. The analysis also accounts for other market dynamics, such as renewable energy production. The results provide insights that can support policy design aimed at enhancing EV integration into the energy system and advancing toward a fully decarbonized world. Understanding how EV charging interacts with broader electrification trends is therefore essential to contextualize the impact of smart charging strategies.

Energy and mobility systems are undergoing a profound 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 to achieve 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: will electric vehicles be a burden or a benefit? To answer this, we need to look beyond battery capacity and driving range and focus on how and when these vehicles consume energy or even return it to the grid. This is where smart charging becomes essential, acting as a key element for integrating transportation with the power system. Today, most charging occurs in an unmanaged way: vehicles are plugged in and charge at maximum available power, often during evening hours when many users return home. This simultaneous behaviour can create load peaks and stress the grid. Smart charging (V1G) introduces the concept of "intelligent" charging: vehicles adjust power and timing, shifting consumption to hours that are more favourable for the system.

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. In the 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 (Figure). 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 (Figure 2-1). 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.

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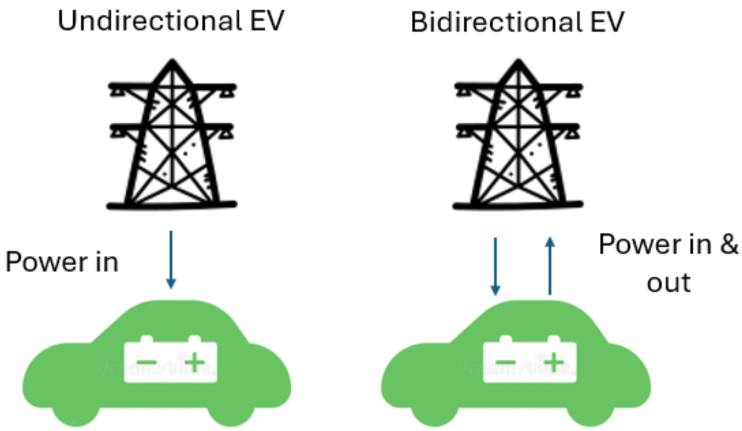

Figure 2-1. Types of EV recharge

The first part introduces an explanation of the model architecture then the simulation scenarios, and the charging strategies. Finally, the last section presents and discusses the simulation results.

2.1. Model architecture and adopted tools

To analyse the impact of EVs on the energy market and derive key regulatory insights, it is essential to accurately model both the market framework in which EVs operate and the EVs themselves. The market framework has been modelled thanks to a RSE tool called sMTSIM (stochastic Mid-Term SIMulator) while the EV load is extrapolated by the IEA Electric Vehicle Charging and Grid Integration tool[1].

For conducting simulations and assessing the effects of proposed reforms on the Italian energy system, a platform based on optimal unit commitment considering the 2030 energy scenario is employed.

sMTSIM is a zonal electricity market simulator able to calculate the hourly clearing of the market over an annual time horizon, calculating the zonal prices and taking primarily the following into account as input:

- Variable fuel costs of thermal power plants;
- Other variable costs that affect power plants (such as O&M, CO_2 emissions, etc.);
- Bidding strategies put in practice by producers, in terms of mark-ups over production costs;
- The generation mix for the target year;
- Expected renewable energy output;
- Non-flexible demand profiles;
- Flexible demand (EVs);
- Network expansion.

[1] https://www.iea.org/data-and-statistics/data-tools/electric-vehicle-charging-and-grid-integration-tool

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The model can handle several types of constraints, such as:

- Power transfer capacity on the interconnections between market zones; the equivalent transmission network is modelled using the so-called Power Transfer Distribution Factors (PTDF1) and sMTSIM can model active power flows by calculating a DC Optimal Power Flow; in this way, transmission bottlenecks can be identified and the needs for network reinforcement can be quantified;
- power plants unforced and scheduled unavailability, as well as start-up and shut-down flexibility;
- constraints on plant operation (e.g. “must-run”) and on fuel consumption over a certain time period (this feature has been used to model the gas shortages);
- Emission constraints and related trading of emission allowances at an exogenous price set in the relevant international markets (e.g. ETS, CDM, JI).

The tool has been used to simulate the optimal behavior of the modeled European power system having as objective function the cost minimization which includes:

- Generation costs of thermoelectric units
- Charging and discharging costs of storage systems
- Costs for curtailment of renewable generation
- Costs related to Demand Side Response
- CO_2 emission costs
- Costs for expanding interzonal connection capacity
- Costs for overgeneration, which are penalties applied when there is an excess amount of renewable energy beyond the system’s capacity.
- Costs for load shedding

In the sMTSIM model, overgeneration represents the hours in which the available renewable generation exceeds the zonal demand. Overgeneration is therefore “purchased” by the model as a quantity that cannot find a place within the system, since renewable generation is not fully flexible. By assigning it a cost, the model seeks to minimize the implicit curtailment of RES and to prefer solutions that make better use of the network, storage systems, demand flexibility, and other available resources.

The most significant outputs analyzed for making considerations are:

- The hourly power system dispatch
- The overall costs of the system
- Energy prices
- The resource revenues

IEA Electric Vehicle Charging and Grid Integration Tool

Another fundamental aspect of the model architecture is to represent accurately the different types of electric vehicles and the charging location which will form the load profile.

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To do that, a tool provided by the IEA has been used. The tool is developed to present the impacts of EV's in the electricity grid, estimating the demand profile according with the vehicle's characteristics and the type of charging point. A specific module of the tool generates a weekly electricity demand profile corresponding to EV charging that will have to be supplied by the power system. The module simulates the driving and charging behavior of a given fleet, by considering the energy characteristics of the EV fleet and the charging opportunities.

The tool allows modeling the following vehicle segments presented in Table 2-1.

Table 2-1. List of vehicles

Vehicle	Type of vehicle
Two and three-wheeler	Private – Taxi – Last mile delivery
Light - Duty	Private – Car sharing – Last mile delivery
Buses	School – Intra city – Regional
Trucks	Local distribution – Regional long-haul delivery

For each vehicle or fleet, the user can specify the average battery capacity (kWh), the energy consumption (kWh/km), the average weekday driving, and the average weekend driving.

Another module contains the settings for the available charging infrastructure and charging preference of EV drivers. The charging locations can be chosen from six different types:

1) Home/Depot charging: Charging at the driver's residence or in a dedicated building for commercial fleets, buses, or trucks equipped with multiple charge points. It is the default charging location for private and fleet vehicles.
2) Work charging: Charging at the driver's workplace. This is the primary alternative to home charging for daily commuters.
3) Roadside charging: Charging at a public or private parking space next to the road, typically in urban environments. It is the default option for drivers without a dedicated parking place.
4) Destination charging: Charging at a place of interest such as a shopping mall, restaurant, or public institution—the destination of a journey outside home and work. Often used for partial charging during the stay.
5) Enroute charging: Charging at a station along the way to the destination, usually on highways or travel corridors. Commonly used during long trips or when no charging options are available at the destination.
6) Opportunity charging: Partial charging outside the base location for fleets, buses, or trucks. This strategy often involves multiple short charging sessions throughout the day.

The user can select an available charging power for each charging location type. This power value corresponds to the maximum charging power at the location type and will be used (as constant value) for unmanaged charging.

Combining sMTSim with the IEA tool a detailed analysis of the impact of EVs on the electricity market can be performed.

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2.2. Scenarios and geographical context

As anticipated, although the general methodology remains valid for different countries and different target years, the modeling activity has been focused on Italian power market and on a 2030 scenario. By 2030, achieving the announced climate pledges will significantly increase electricity demand for road transport, accounting for nearly 4% of total power consumption. In Italy, electricity demand is projected to reach between 360 TWh and 380 TWh, with electric vehicles contributing approximately with 15 TWh.

For this reason, the 2030 scenario has been explicitly developed using the sMTSIM market model. While long-term planning tools are well suited to capture structural evolutions of the energy system, they are not designed to represent hourly market dynamics and operational constraints in sufficient detail. sMTSIM can therefore be used in combination with the TIMESRSE model, exploiting the outputs of the latter namely electricity demand and the long-term evolution of the generation as inputs for the market simulations. By focusing exclusively on the target year, sMTSIM allows for a more detailed and accurate representation of power system operation, price formation, and flexibility needs, which are essential to assess the system-level impacts of largescale electric vehicle integration.

The procedure adopted in this analysis is defined as follows:

1. a scenario analysis is first carried out using the national long-term TIMES-RSE model [29] to determine electricity demand and the generation fleet in 2030;
2. based on internal analyses, information provided by Terna, and study-specific assumptions, the spatial and temporal distribution of the input parameters for sMTSIM are defined;
3. simulations are then performed using sMTSIM to identify critical issues arising in the operation of the power system;
4. the simulations are repeated by applying targeted interventions to the capacity and spatial distribution of storage systems until the target objective of a maximum overgeneration of 1 TWh per year is achieved.

The estimated 15 TWh from EVs are distributed among cars, motorcycles, trucks, and buses, as shown in Table 2-2.

Table 2-2. EV's load in Italy in 2030

Vehicles	Energy (TWh)	%
Cars	12	80
Motorbikes	0.3	2
Buses	1	6.7
Trucks	1.7	11.3

Although the EV load in 2030 will still represent a relatively small share of total demand (around 4%), it is expected to grow substantially in the following years. Therefore, it is crucial to study its impact on the electricity sector in advance.

The forecasted supply mix will consist of 53% from renewable energy sources (RES), 34% from thermoelectric power plants, and roughly 13% from imports.

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Among renewables, solar power will provide the largest share, complemented by substantial contributions from wind and hydro generation as reported in Figure 2-2Figure .

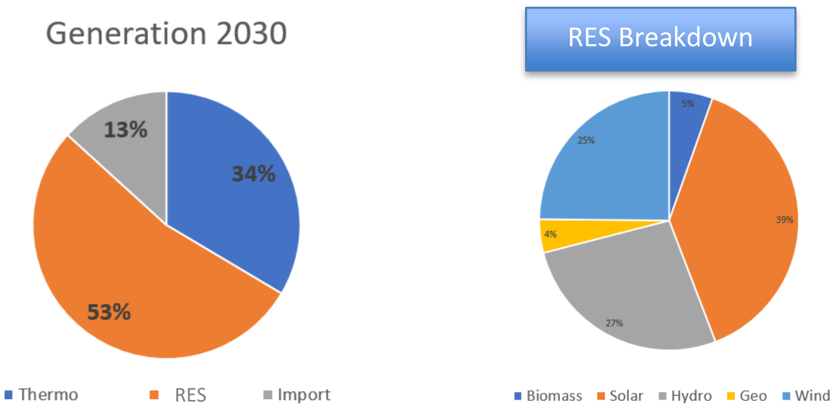

Figure 2-2. Generation forecast for the 2030 Italian scenario

An important aspect of the Italian energy market is its division into seven market zones with the relative connections (Figure 2-3), which complicates energy transmission across the country. While the highest energy production is concentrated in the northern zone, the southern regions and islands play a crucial role in hosting new wind and solar generation.

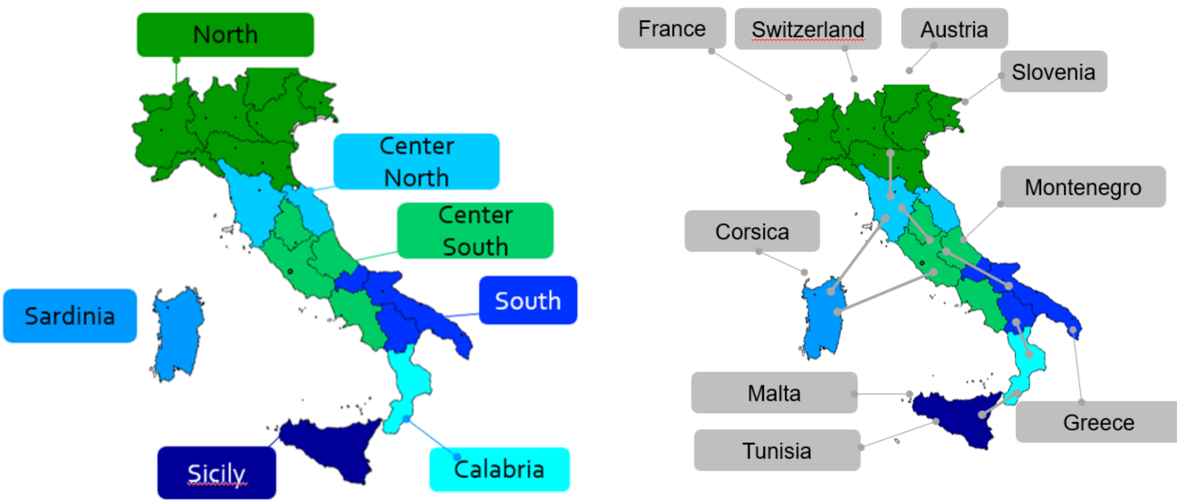

Figure 2-3. Italian market zones and Italian connections

Regulatory measures should address the timing windows for EV charging, taking into account the availability of renewable energy resources strictly related to the energy prices and the capacity of the transmission system.

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2.3. Simulated charging strategies

The growing penetration of EVs in Italy and across Europe has driven the need for smart charging strategies to meet vehicle demand while minimizing the impact of this new technology on the electricity system. Several factors must be considered to determine the most effective way to integrate smart charging into the market. Key aspects include the baseline load curve without EVs, hourly energy price variations, and the production of renewable resources, which also influence price dynamics. Based on these considerations, the IEA tool adopts three different smart charging strategies.

Balanced charging (BC): The charging power is minimized according to energy needs and the expected dwelling time in a certain location. This local optimization only requires information from the EV and does not consider the state of the grid.

Time-of-use tariffs (ToU): The charging cost is optimized according to a reference tariff schedule. Within a charging window, charging during lower tariff periods is prioritized. The user can provide as input the hourly tariff schedule.

Active control: The charging process is optimized to smooth the variations of the electricity demand. The user can provide as input a reference electricity (non-EV) demand curve which is continuously updated with every additional vehicle that charges, such that the collective charging behavior is coordinated.

Beyond technical charging strategies, the effective integration of EVs into the electricity system also depends on grid constraints, flexibility markets (not analyzed in this report), regulatory frameworks, user behavior, and interaction with renewable energy production. These aspects determine the real potential of smart charging to reduce system costs, mitigate congestion, and contribute to the decarbonization of the energy sector.

2.4. Simulations results

All charging strategies were simulated over a full year for each market zone to assess their impact on the hourly distribution of the system load. For illustrative purposes, the results reported in the following focus on the Central-Northern area (Figure 2-4), as the outcomes for the remaining bidding zones are broadly comparable and thus not shown.

In particular, the daily EV load corresponds to around 400,000 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.

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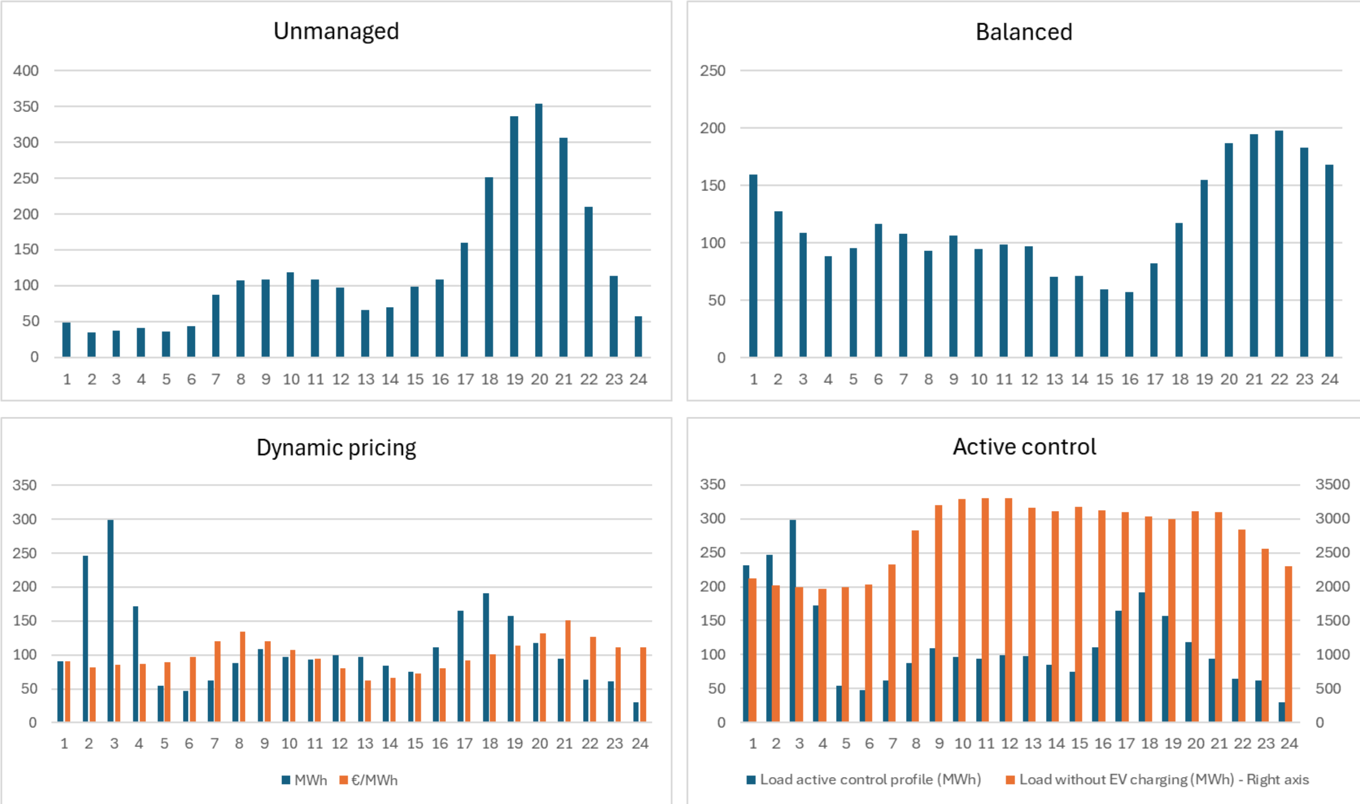

Figure 2-4. Load profile (MWh) with different charging strategies

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 always present on the grid, since at any hour of the day, at least a portion of the vehicles is connected to a charging point.

Using sMTSim software (stochastic Medium-Term Simulator -Chapter 2.1), it was possible to study the impact of these strategies on zonal electricity 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, presented in 2.2.

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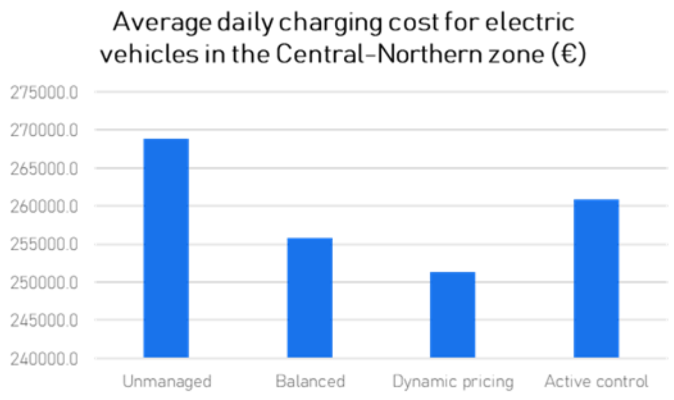

Figure 2-5. Costs based on the charging strategy

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, 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.

Another analysis carried out in this work concerns the impact of different smart charging strategies at every hour of the day. In particular, the study highlights the hours of minimum peak load, maximum peak load, and peak renewable energy production. Focusing on these timeframes is essential because it shows how EVs interact with the grid when it is lightly loaded, heavily stressed, and when renewable generation is at its highest.

Several days were analyzed, but for clarity only two representative ones are reported. January was selected as a typical winter month, when electricity demand is generally higher due to heating needs and when renewable generation, especially solar, is significantly lower. This allows us to evaluate smart charging performance under conditions of high grid stress and limited availability of renewable energy. In contrast, May was chosen as an illustrative month in which renewable resources, particularly solar PV, are abundant and daytime loads are moderate. This provides a meaningful comparison, showing how the same charging strategies behave when renewable production is predominant and the grid operates under more favorable conditions.

Each charging strategy modifies the zonal load profile and consequently affects the determination of hourly zonal prices. The figure below shows the most favorable hours (with lower hourly costs) and the least favorable hours, which increase the energy costs. It is important to note that these analyses are not intended to create a system in which users must adjust their charging strategy every hour

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based on energy price fluctuations. Rather, the key takeaway is that different strategies are preferable under different yearly conditions. For instance, during periods when the overall load is low (such as weekends), one strategy is likely to perform better. When renewable generation is high (for example in May), a different strategy becomes more advantageous, and yet another one may be preferable during high-load periods. To further improve readability, for each plot showing the base load, an additional figure is provided comparing the most favorable and the most unfavorable charging strategy in terms of energy price. In this context, the worst strategy in a given hour is the one that results in the highest electricity cost for that hour, while the most favorable strategy is the one that allows the market to clear at the lowest cost.

In Figure 2-6, the 24-hour load profile for a winter day in January is shown together with the most unfavorable charging strategies.

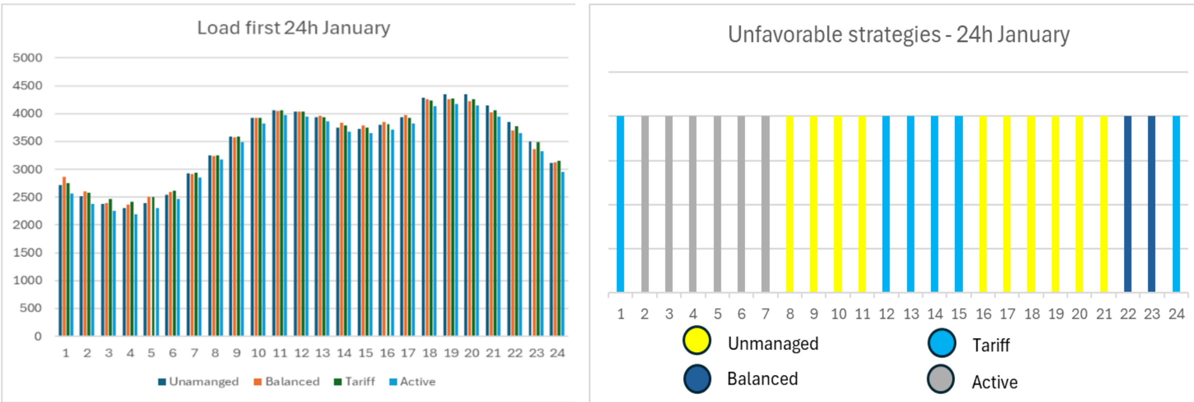

Figure 2-6. Unfavourable strategies considering the base – load (MWh)

During the minimum-load hours (2 a.m.–7 a.m.), the Active strategy results as the most unfavourable, whereas during peak-load periods (11 a.m.–12 p.m. and 6 p.m.–8 p.m.) the Unmanaged strategy performs the worst.

Figure 2-7 presents the same daily load profile combined with the most favorable strategies.

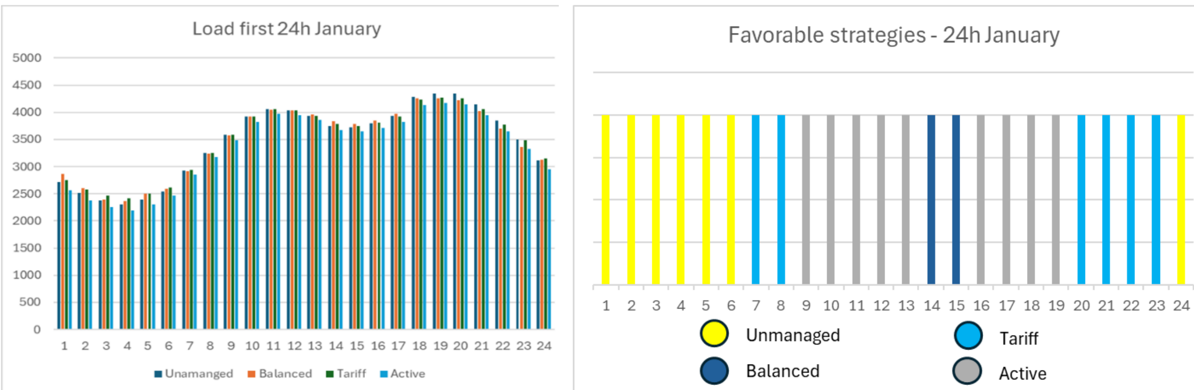

Figure 2-7. Favourable strategies considering the base – load (MWh)

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During minimum-load hours, the Unmanaged strategy proves to be the most advantageous, while during peak-load periods the most favourable approaches are the Active and Tariff-based strategies.

The next plot illustrates the favourable and unfavourable strategies throughout the day, this time considering the renewable energy production profile.

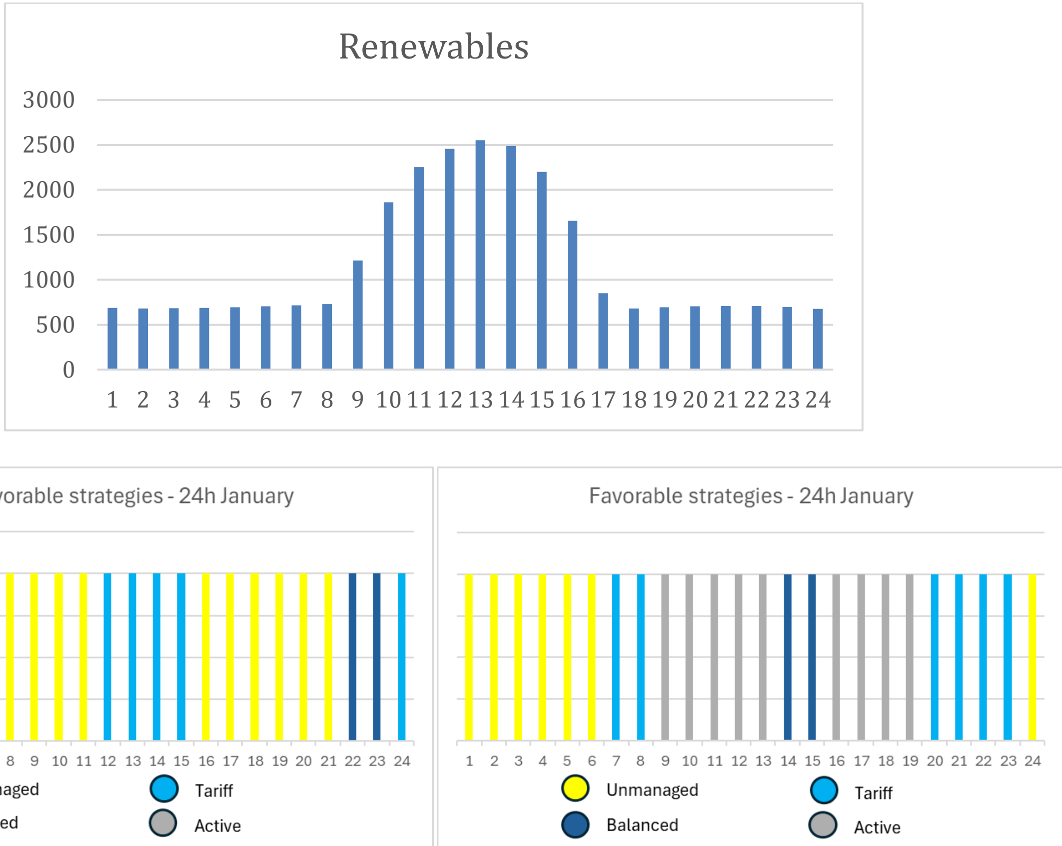

Figure 2-8. Favourable and unfavourable strategies combined with renewable energy production (MWh)

During the hours of peak renewable generation, the least advantageous strategies are the Unmanaged and Tariff-based ones, whereas the most favourable are the Balanced and Active strategies.

The final group of plots helps clarify which charging strategy performs best across different time periods when examined alongside the load profile and renewable generation levels. Figure 2-9 illustrates the cost differences between the smart charging strategies and the unmanaged approach, highlighting the periods in which adopting a smart strategy is advantageous and those in which it is not.

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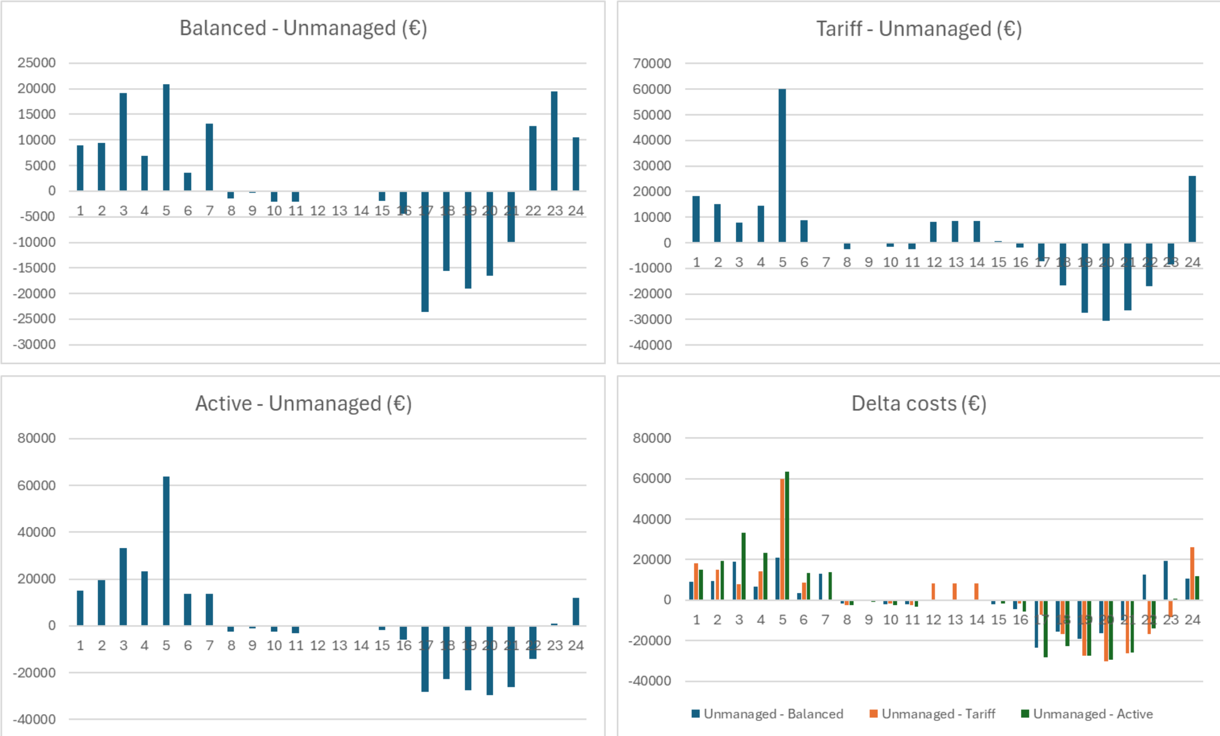

Figure 2-9. Economic advantage between unmanaged and smart charging strategies

Plots show that smart charging helps the system when it is subjected to peak load while they are not necessary during period of minimum load. Comparing the Figure 2-9 and Figure 2-8 it is not immediate to understand why for hours 7 the best strategy is the tariff one, for hours 12 and 13 is active and for hours 14 is balanced since the differences in values is very small. To do so, values of the simulations are reported in Table 2-3.

Table 2-3. Economica advantage between unmanaged and smart charging strategies for hours 7,12,13 and 14

	Hours 7	Hours 12 & 13	Hours 14
Tariff vs Unmanaged	-66 €		
Active vs Unmanaged		-25€ & -7€	
Balanced vs Unmanaged			-5€

The same analysis was performed for a representative day in May. The following figure shows the most unfavourable strategies with respect to low and peak load periods.

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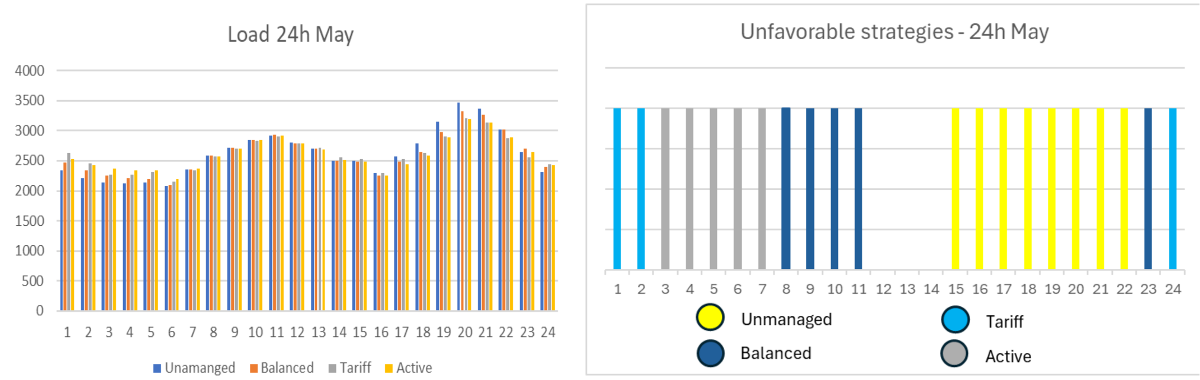

Figure 2-10. Unfavourable strategies considering the base – load (MWh)

During the minimum-load hours (3 a.m.–7 a.m.), the Active strategy is the least favourable, while during peak-load periods (7 p.m.–9 p.m.) the Unmanaged strategy performs worst. Between 12 p.m. and 2 p.m., electricity prices fall to zero due to the very high solar production; therefore, no meaningful comparison can be made for the strategies during this interval.

The next figure reports the most favourable strategies for the same May Day.

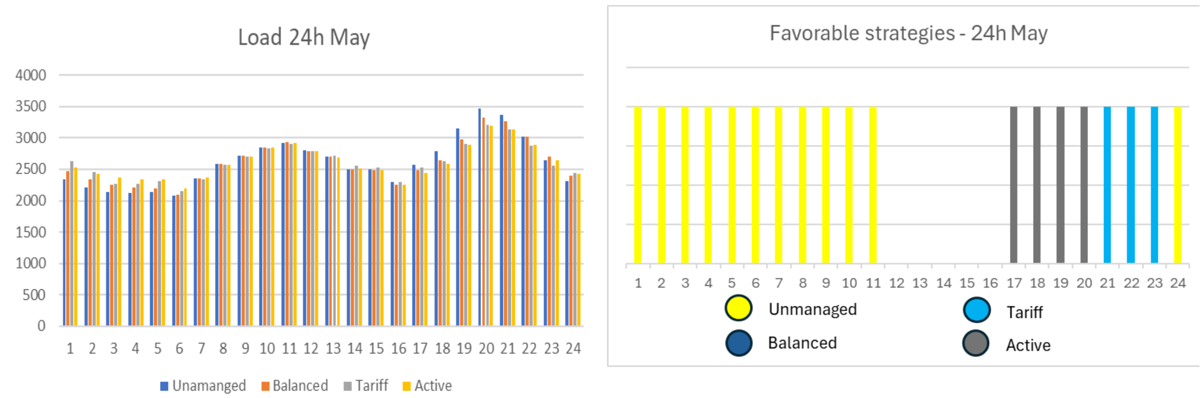

Figure 2-11. Favourable strategies considering the base – load (MWh)

During low-load hours, the most advantageous strategy is the Unmanaged one, while during peak-load periods the best results are obtained by the Tariff-based and Active strategies.

Then again a figure that shows the favorable and unfavorable strategies compared to the renewable production profile.

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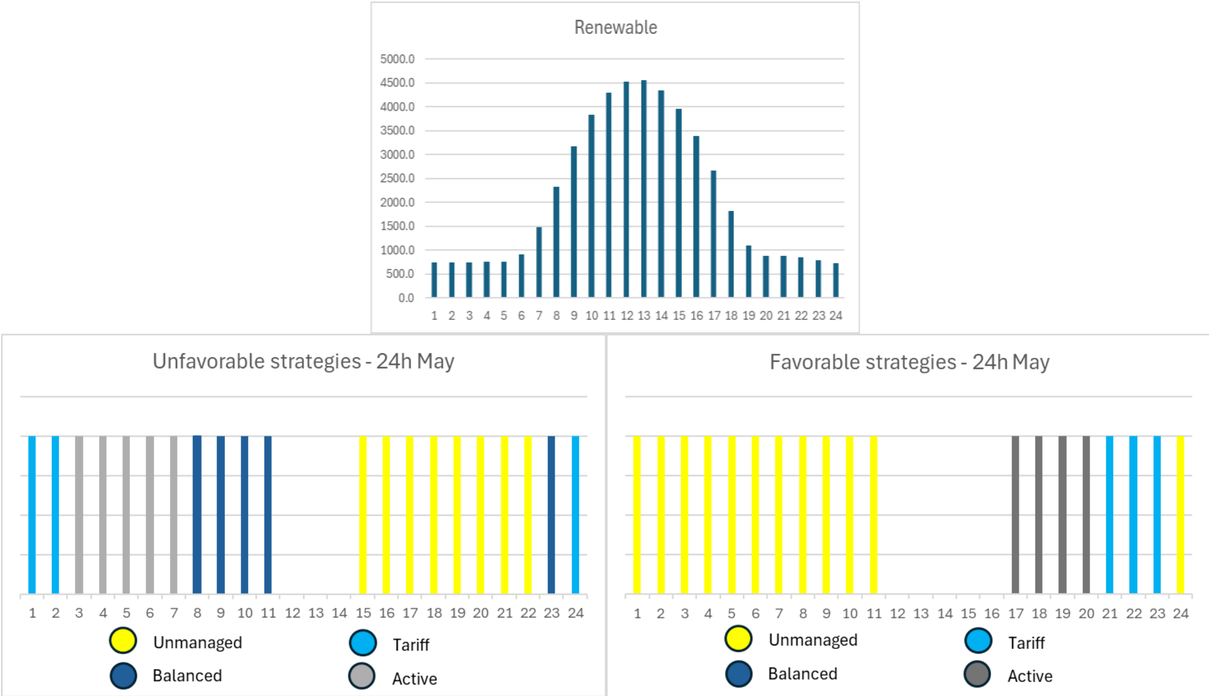

Figure 2-12. Favourable and unfavourable strategies combined with renewable energy production (MWh)

During periods of peak renewable generation, the Active strategy proves to be the most advantageous, while the Unmanaged strategy is the least favorable.

The last group of plots highlight again the economic advantage between an unmanaged strategy and a smart charging one.

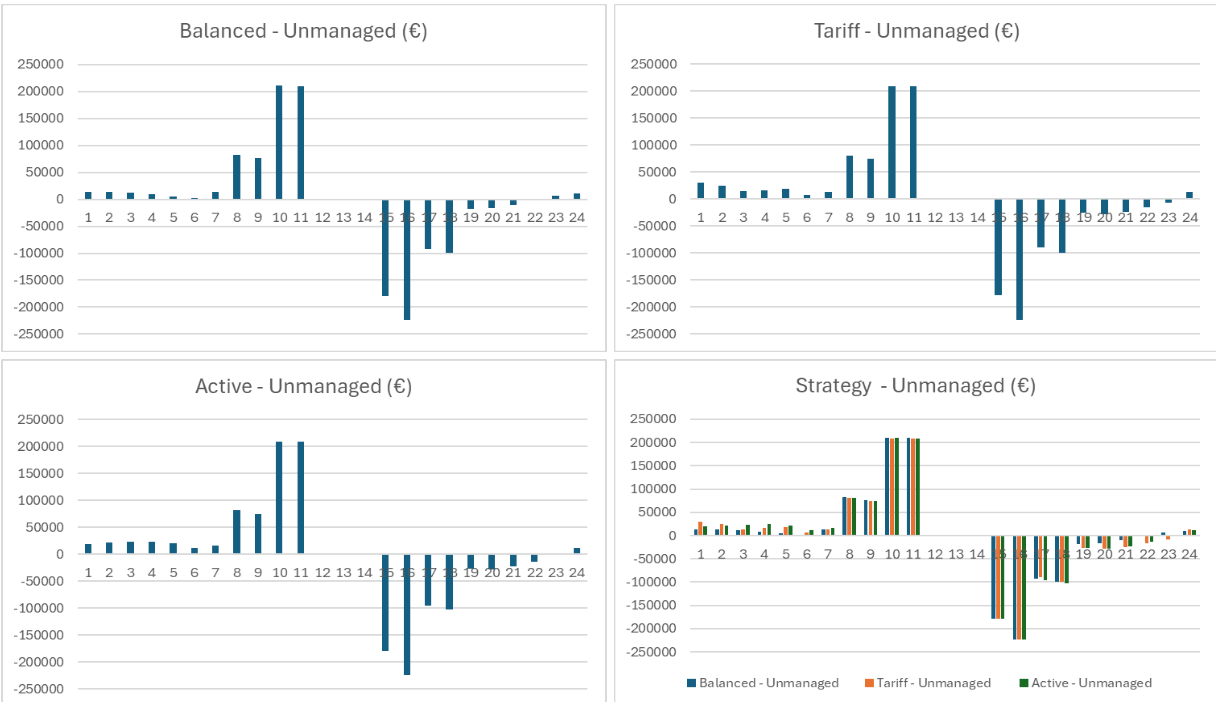

Figure 2-13. Economic advantage between unmanaged and smart charging strategies

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Again Figure 2-13 shows that smart charging helps the system when it is subjected to peak load while they are not necessary during period of minimum load. In hours 15 and 16 all smart charging strategies present a price of 0€, that is why Figure 2-13 shows an economic advantage while Figure 2-12 do not highlight one most favorable strategy.

To provide a clearer overview, a summary table reporting the results for both January and May is presented below.

Table 2-4. Resume of strategy evaluation for January (V – favourable; X – unfavourable)

	Minimum Load	Peak Load	Peak Renewable
Unmanaged	V	X	X
Balanced			
Tariff		V	X
Active	X	V	V

Table 2-5. Resume of strategy evaluation for May (V – favourable; X – unfavourable)

	Minimum Load	Peak Load	Peak Renewable
Unmanaged	V	X	X
Balanced			
Tariff		V	
Active	X	V	V

During periods of minimum load, the unmanaged strategy is the most advantageous in both scenarios. This happens because all other strategies intentionally shift charging into these low-demand hours. As a result, competition for this favorable time window reduces the relative benefit of managed approaches, whereas the unmanaged strategy naturally places most charging when the grid is least stressed and energy prices are already low.

During peak load periods, the unmanaged strategy becomes the least favorable in both scenarios. In contrast, the active and tariff-based strategies consistently perform best, as they are specifically designed to avoid charging when the grid is heavily loaded and electricity prices are high. By shifting demand away from these critical hours, they effectively minimize costs and support grid stability.

During periods of peak renewable production, the active strategy emerges as the most beneficial. In this timeframe, electricity prices are already very low due to the abundance of renewable generation, making the tariff-based strategy less impactful. The active strategy, however, directly targets moments of high renewable availability, thereby maximizing the use of clean energy. Conversely, the tariff-based approach optimized around cost signals provides its greatest advantage during high-price periods rather than during renewable surpluses.

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2.5. Results discussions and in-depth analyses

The results of the analysis reveal clear behavioural patterns in the performance of different EV charging strategies under varying grid conditions. Their relative advantages shift depending on system load, price dynamics and renewable energy availability, highlighting the importance of contextualizing charging behaviour within broader grid constraints.

- **Minimum Load Periods: Unmanaged Charging as the Unintended Optimum**

During low-demand hours, the unmanaged strategy emerges as the most advantageous in both January and May scenarios. This result may appear counterintuitive, but it is a direct consequence of how managed charging strategies are designed.

All smart strategies: active, tariff-based, and balanced intentionally allocate charging to these low-load intervals to minimise system stress and reduce costs. This creates a form of "competition for the same valley hours", diluting the comparative advantage of smart charging.

Meanwhile, the unmanaged strategy naturally distributes charging during these favourable hours simply because vehicles are typically plugged in at night. Energy prices are already low, and grid stress is minimal, allowing unmanaged charging to match or occasionally outperform cost-optimised strategies in this specific context.

In essence, minimum-load periods represent a best-case scenario for unmanaged charging, as the misalignment between user behaviour and grid conditions is minimal.

- **Peak Load Periods: Smart Charging as an Essential Tool**

The situation changes drastically during peak load hours. In these periods, unmanaged charging becomes the least favourable strategy in all scenarios. Charging during peak times directly increases demand when the grid is already under stress, thus elevating both system costs and user costs.

In contrast, the active and tariff-based strategies consistently perform best. Their logic is inherently designed to detect and avoid high-price, high-load hours:

- Active strategy shifts charging dynamically based on grid stress and flexibility signals.
- Tariff-based strategy shifts charging away from expensive hours, which usually coincide with peak system load.

By systematically avoiding peak periods, these strategies reduce both operational costs and system stress. Their behaviour demonstrates the core value of smart charging as a tool for peak shaving, not only improving user economics but also contributing to grid stability.

These results align with broader smart grid objectives, confirming that unmanaged charging poses a risk to grid reliability, whereas smart charging offers a flexible resource that can reduce critical peaks.

- **Renewable Peak Periods: Prioritising Clean Energy Integration**

A different pattern emerges during hours of high renewable energy production. Here, the active strategy becomes the most favourable, outperforming both unmanaged and tariff-based approaches.

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This is because renewable peaks, especially solar surpluses, drive electricity prices close to zero. Tariff-based strategies lose relevance under such conditions: if the cost signal is already minimal, there is no incentive to shift behaviour further.

The active strategy, however, is designed to prioritise moments of high renewable availability, regardless of price. This allows it to:

- Maximise consumption of clean energy
- Reduce renewable curtailment
- Align EV charging demand with renewable production
- Lower CO_2 emissions associated with charging

The unmanaged strategy, once again, performs poorly, as it has no mechanism to synchronise with renewable surpluses. It charges at the user's plug-in time, which rarely aligns with midday or early-afternoon solar peaks.

These results highlight the strategic value of EVs as flexible loads capable of supporting renewable integration when appropriate control strategies are applied.

- **Cross-Scenario Interpretation: January vs. May**

Even if results comparing winter (January) and spring (May) conditions are similar, results shows that the relative value of each strategy depends on some seasonal dynamics:

- In winter, low renewable production and higher evening peaks increase the value of tariff-based and active strategies.
- In spring, abundant solar production makes the active strategy particularly effective, while unmanaged charging becomes even less aligned with renewable availability.

This seasonal dependency suggests that optimal charging strategies are not static, and smart charging systems should incorporate both price signals and renewable forecasts to maximise system benefits.

When considering only the additional load generated by electric vehicle charging, unmanaged strategies may appear simpler but are consistently less cost-effective, whereas smart charging can significantly reduce user costs by shifting consumption to cheaper hours.

In Summary, however, when the focus expands to the entire power system, unmanaged charging may still seem acceptable during certain low-demand periods, yet it rapidly becomes inefficient as soon as the grid faces stress. In contrast, smart charging provides clear advantages precisely during these critical moments, as it reduces consumption during peak hours and high-price intervals, thereby improving overall system efficiency and economic performance.

Beyond the direct interaction with energy prices, smart charging generates value in the broader context of power system operation, particularly within ancillary services and balancing markets. By offering controllable flexibility, smart charging helps decrease peak loads, supports system stability, and alleviates stress on the electricity grid, benefits that unmanaged charging cannot deliver.

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Additional improvements can also be observed at the local market level. Strategies that reduce local peaks and make better use of renewable resources enhance grid flexibility and enable a more efficient distribution of energy within local systems, improving hosting capacity and contributing to a smoother, more resilient operation of the distribution network.

2.6. Present limitations and future developments

This work provides an assessment of the impact of different electric vehicle (EV) charging strategies, with the goal of understanding their implications from a regulatory and system-level perspective. The results obtained are coherent, robust, and offer meaningful insights into how unmanaged, tariff-based, and active charging behaviours interact with grid conditions. However, several methodological limitations must be acknowledged, as they restrict the completeness of the conclusions and highlight directions for further development.

First, the sMTSIM tool used in the market simulations is limited to the modelling of the spot market and does not incorporate the dynamics of the balancing market. As a consequence, all considerations regarding ancillary services such as frequency regulation, reserve activation, or redispatching costs remain theoretical. They are conceptually consistent but cannot be empirically validated within the present modelling framework. Since balancing services represent an increasingly relevant component of system operation, especially in high renewable contexts, this constitutes a non-negligible limitation.

Second, the IEA tool used for load and flexibility simulations allows for the implementation of a one-week representative load profile. While this provides a useful approximation of seasonal behaviour, applying the same synthetic week across all strategies and extrapolating it to the full year inevitably reduces temporal granularity. Extending simulations to the entire annual profile would offer higher accuracy, but it is currently computationally too demanding within the constraints of the tool. This limitation particularly affects the representation of rare events, extreme peak days, and the variability of renewable production.

A third limitation concerns the absence of bidirectional EVs (Vehicle-to-Grid, V2G) in the analyses. Bidirectional charging is expected to play a crucial role in future power systems by providing distributed flexibility, peak shaving, voltage support, and potentially participating in ancillary service markets. Excluding this category of vehicles prevents the study from fully capturing the potential contribution of EV fleets as active grid resources.

In addition to the limitations discussed above, the simulations assume a perfectly competitive market structure. In particular, no strategic bidding behavior by market participants is represented. Generation units are modelled as price-takers, and offers are submitted strictly on the basis of short-run marginal costs, without any bid-ups or market power strategies. As a result, electricity prices reflect cost-minimization outcomes rather than strategic interactions among operators.

Future research should focus on several key directions that can significantly enhance the accuracy and scope of the analysis. A priority is the integration of bidirectional charging strategies, evaluating how V2G technologies can support system stability, reduce balancing needs, and increase the value of EVs for both users and system operators. This would allow for a more realistic assessment of the role of EVs in providing ancillary services and participating in flexibility markets.

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Additionally, expanding simulations to explicitly include the balancing and ancillary services markets is essential. Incorporating these mechanisms would allow for a more complete evaluation of system costs, enable quantification of avoided balancing actions due to smart charging, and better reflect real world regulatory frameworks.

Another important development concerns the improvement of temporal resolution. Running simulations on a complete annual load profile or at least using multiple representative weeks per season would reduce modelling simplifications and allow for the capture of temporal variability, extreme conditions, and interactions between EV charging and renewable peaks.

Finally, future work should also examine the regulatory implications of smart and bidirectional charging, analysing how market design, tariff structures, and capacity mechanisms may evolve to better reward flexibility. Understanding these interactions is crucial for designing policies capable of unlocking the full value of EV integration in modern power systems.

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3. Identifying key elements for VGI diffusion

Before providing recommendations, core output of Task activities, a remarkable effort was made to identify and understand the most relevant elements that today have impact on the diffusion of VGI solutions. Together with traditional literature analysis, three instruments have been adopted: a questionnaire, a debate within the so-called "V2X Cluster" and the creation of a "Policy and Regulation" Working Group within the FLOW consortium. This Section summarizes the aim, the characteristics and the main results of each of these instruments, providing the background for the actual recommendations described in detail in Section 4.

3.1. Questionnaire for EV experts

The first instrument that was developed to gather expert opinions on VGI and flexibility provided by EVs is a short questionnaire, originally proposed only to FLOW partners during a workshop held in Milan in February 2025. The aim of the questionnaire was dual:

- Identifying the most promising options in terms of new pricing/tariff schemes and market rules to unlock EV flexibility potential.
- Investigate expert opinions on some crucial questions about EV flexibility and V2G schemes.

The questionnaire was then circulated also outside of FLOW, as better described later in this section.

3.1.1. Structure and contents

The questionnaire is structured in 6 sections, covering the following topics:

- **Topic 1: How to support flexibility provision by EVs**
- **Topic 2: Flexibility services relevance**
- **Topic 3: V2G characteristics and opportunities**
- **Topic 4: Innovative pricing schemes and solutions**
- **Topic 5: New Ancillary Service market rules**
- **Topic 6: Future perspective**

The first topic is addressed by asking the respondents to identify in order of importance (1 the most important, 9 the least important) the factors that can favor the provision of flexibility by electric vehicles, choosing them from the following list:

- Stable long-term economic incentives
- Definition of clearer and simpler market rules
- Guarantee of a sufficient level of charge under all circumstances
- Tax incentives for the purchase of smart charging stations
- Awareness campaigns to underline the central role of users
- Standardization of technologies, infrastructures and market rules among various European countries
- Guarantee of limited variations in vehicle battery performance
- Pilot and demonstration projects
- Definition of architectures and models that ensure better privacy for vehicle owners during flexibility provision

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For Topics 2-3 it was decided to adopt a different scheme, providing a set of sentences and asking the participants their level of agreement/disagreement with each of them (5 – completely agree, 1 – completely disagree). The sentences were the following ones.

Topic 2 – Flexibility services relevance

- Flexibility services by EVs should be limited to behind-the-meter (BTM) services
- It is enough if EVs charging process is managed to avoid power peaks in the distribution grids
- It is crucial for grid stability that EV charging can be managed real-time by remote operators
- Providing frequency-related services with EVs is a key element for future energy systems
- EV charging constraints and the following rebound effect are too limiting to properly provide flexibility services to the grid
- The complexity of providing flexibility services to the grid is not adequately compensated by economic revenues
- In a fully decarbonized system, it should be compulsory to allow remote operators to manage the charging process and provide flexibility services
- In a fully decarbonized system, the lack of environmental benefit in providing flexibility with EVs will make these services pointless

Topic 3 –V2G characteristics and opportunities (meant as bidirectional charging, in all the possible use-cases)

- V2G solutions don't present a reasonable benefits/costs ratio with respect to V1G
- V2G solutions should be limited to prosumers
- V2G is a key technology to provide flexibility services to the grid
- V2G technology strongly impact the amount of flexibility services that can be provided by EVs
- V2G doesn't add many advantages for flexibility services with respect to simpler V1G solutions
- Third party controlled V2G will be accepted by a very low amount of users
- V2G should happen in AC
- V2G should happen in DC
- V2G will be a must
- V2G will be a "nice-to-have
- V2G will be rarely adopted

A similar approach was maintained for Topics 4-5, where the respondents were asked to express the relevance, according to their opinion, of possible new pricing schemes and market rules, with a 1-5 vote. The options of new schemes and rules, listed below, were selected through the authors expertise and general literature review.

Topic 4 –Innovative pricing schemes and solutions

- Multi-hour tariffs scheme with 3 static bands
- Multi-hour tariffs scheme with 4 or more static bands
- Dynamic tariffs that reflect real-time energy prices
- Dynamic tariffs that reflect real-time grid status
- Dynamic tariffs that reward the use of higher amounts of renewables
- Price signals communicated directly to home/charging control systems
- Non-firm connection agreement for public charging
- Non-firm connection agreement for private charging

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Topic 5 –New Ancillary Service market rules

- Modify entry power limits for aggregates
- Modify the minimum duration of ancillary service
- Promote asymmetric ancillary services
- Making the ancillary service market bidding closer to the real time (so aggregate can evaluate more precisely their flexibility bands)
- Modify the actors/roles that act on the market
- Bind a minimum amount of resources only to local markets (or vice versa to TSO markets)
- Introduce capacity remunerations for service provision
- Remunerate all type of ancillary service (e.g., eliminate unpaid services)

Topic 6: Future perspective

The last question was directly intended to catch participants feelings about the “readiness” of VGI and EV flexibility provision. It was indeed asked from which year substantial participation of electric vehicles and V2G technologies in energy markets will be observed, providing 5 possible answers:

1. 2030-2035
2. 2035-2040
3. 2040-2045
4. 2045-2050
5. After 2050

An important aspect of the questionnaire structure is that it was designed to be able to “categorize” the respondents, through an introductory question, in 4 different groups:

1. Grid Operators (TSO, DSO, Aggregator,...)
2. Charging operators, Manufacturers, Software Developers (OEM, eMSP, CPO,...)
3. Research Organizations (University, Research Center)
4. Other (Municipality, Agency, EV User group,...)

This allows the developers of the questionnaire to detect different positions on the proposed questions that could be linked to the specific needs of different actors involved in VGI processes. More details on this will be reported in the Results section.

3.1.2. Distribution of the survey

As previously mentioned, the Questionnaire was first circulated within the FLOW consortium. In this phase, 31 answers were collected, with the following distinction:

- 11 from Grid Operators
- 6 from Charging operators, Manufacturers, Software Developers
- 14 from Research Organizations
- 0 from Others

Given the interesting results obtained by a preliminary analysis of the first set of answers, it was decided to open-up the discussion and circulate the same Questionnaire within other expert groups.

During Autumn 2025, the Questionnaire was then circulated within two groups: the E-Mobility Europe Infrastructure Working Group and the V2X Cluster (that put together the participants of 8 European

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Projects – including FLOW – focused on VGI). This led to reach 54 total answers, with the following distinction:

- 15 from Grid Operators
- 9 from Charging operators, Manufacturers, Software Developers
- 28 from Research Organizations
- 2 from Others

It is worth noticing that the aim of the Questionnaire was to have a general picture of the point of view of experts on the already presented Topics. It was not intended as a real "statistical" instrument and therefore it was not designed to gather specific information about the respondents (age, gender, education level, experience with the topics, others). The diffusion perimeter of the Questionnaire allows anyhow to presume that most of the participants are highly educated and experts on the topic, so well suited with respect to the scope of the activity.

3.1.3. Results and discussion

In this section, the results for each of the addressed Topic are presented, together with the attempt to identify the most relevant messages that can be extrapolated by the participants' answers.

Despite all the results being available in spreadsheets for further analyses, a very good visualization of the answers is already proposed by Microsoft Forms, especially for Topics 2-5 that wanted to detect agreement or disagreement on the proposed sentences/solutions. Figure 3-1 shows a typical plot for these results, where is quite straightforward the identification of agreement/disagreement with regards to the proposed sentences.

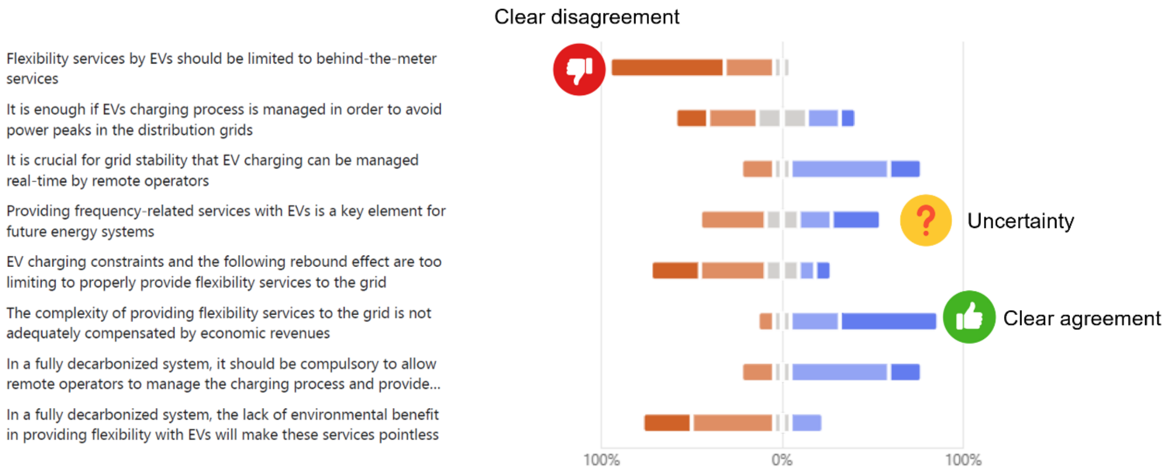

Figure 3-1. Example of results plot provided by Microsoft Forms: the bars clearly indicate if there is agreement or disagreement on the proposed sentences.

In the following pages, the plots for each Topic will be presented, in a form that is intended to allow also a comparison between the answers of different categories. Together with that, a short analysis and interpretation of the most striking results is reported; several analyses are anyhow still possible and are left to the readers or to follow-up works.

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Topic 1: How to support flexibility provision by EVs

Figure 3-2 shows the participants answers to the question "Starting from the following list, identify in order of importance (1 the most important, 9 the least important) the factors that can favor the provision of flexibility by electric vehicles". The 4 icons identify the category related to each "ranking".

For the first three groups, the top-3 list is exactly the same factors, with an agreement on the importance of "Stable long-term incentives". Second and third places include "Definition of clearer and simpler market rules" and "Guarantee of a sufficient level of charge under all circumstances". Even in the 4th group, the importance of clearer market rules and stable incentives are underlined, covering the 1st and the 3rd place in the ranking. The 2nd place in this case is taken by "Standardization of technologies, infrastructure and market rules among various European countries", actually considered relevant for all the respondents and positioned in the upper half of the ranking in all groups.

Looking at the less voted factors, a high agreement is also evident. The least important factor for all four groups was "Definition of architecture and models that ensure better privacy for vehicle owners during flexibility provision". The first 3 groups also ranked in the next to last item "Pilot and demonstration projects".

During an open discussion within the FLOW Consortium, it was clarified that being in the last position didn't mean to be irrelevant, but simply that other points were probably more urgent to create solid foundations for VGI diffusion. In particular, it emerges quite clearly that all the actors feel a strong need for stability, economic support and clarity on the overall context of using EVs as a flexibile resource. These point will indeed allow industrial actors to plan their activity and to design business models that can be stable and sustainable in the medium-long term.

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1. Stable long-term economic incentives
2. Definition of clearer and simpler market rules
3. Guarantee of a sufficient level of charge under all circumstances
4. Standardization of technologies, infrastructures and market rules among various European countries
5. Tax incentives for the purchase of smart charging stations
6. Awareness campaigns to underline the central role of users
7. Guarantee of limited variations in vehicle battery performance
8. Pilot and demonstration projects
9. Definition of architectures and models that ensure better privacy for vehicle owners during flexibility...

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4. Awareness campaigns to underline the central role of users
5. Guarantee of a sufficient level of charge under all circumstances
6. Pilot and demonstration projects
7. Guarantee of limited variations in vehicle battery performance
8. Tax incentives for the purchase of smart charging stations
9. Definition of architectures and models that ensure better privacy for vehicle owners during flexibility...

Figure 3-2. Topic 1 results for the 4 categories

Technical aspects still appear to be relevant, with two different focuses; on one side, the importance of satisfying the users by always guaranteeing their mobility needs. This is clearly perceived as an enabler to control the charging sessions and take advantage of flexibility. On the other side, the need for harmonized and widely adopted standards, whether for technology, infrastructures or market rules. Both these factors have an impact on how industries and service providers design their products and processes and on their ability to propose attractive solutions to final users all around Europe. It's interesting to notice, at last, that aspects commonly underlined as crucial, like battery degradation under smart/bidirectional charging and privacy issues are generally positioned in the low part of the ranking and therefore considered less urgent than others.

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Topic 2 – Flexibility services relevance

This part of the questionnaire had the aim to investigate the perception about flexibility provision, the most promising services and the related difficulties. Figure 3-3 shows the results for all the 4 groups and provides different possibilities of analyses and interpretations.

To try to summarize some key elements, it can be useful to separate the analyses based on two main aspects: the feasibility/need for flexibility services and the kind of services that could/should be provided. With regards to the first point, most of the participants agree on the fact that the complexity of providing flexibility services to the grid is not adequately compensated by economic revenues, highlighting the difficulties in identifying business models that present a satisfying trade-off between technical complexity and the economic flow for all the involved actors. This issue is pointed out quite horizontally by all the 4 groups. Given that, it is interesting to notice that there is a general agreement also on the importance of managing EV charging real-time and by remote operators, to guarantee grid stability both today and in the vision of a fully decarbonised system. On this aspect, grid operators appear to be more convinced than charging operators (Group 2), whose votes point out some uncertainty especially on the need to leave control to third parties.

With regards to the kind of services that should be performed, it is possible to detect some differences between grid operators and charging point operators: grid operators (Group 1) and research partners (Group 3) are more convinced that it won't be enough to provide "behind-the-meter" services and is generally positive on the need to use EV for frequency-related services, even when considering charging constraints and rebound effects. Group 2 both finds value in providing flexibility services but some respondents also think that services should be limited to BTM.

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How much do you agree/disagree with each of the following sentences? (5 – completely agree, 1 – completely disagree)

Figure 3-3. Topic 2 results for the 4 categories

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Topic 3 –V2G characteristics and opportunities (meant as bidirectional charging, in all the possible use-cases)

Bidirectional charging is a very debated solution, conceptualized more than 10 years ago but still lacking in terms of wide diffusion and implementation. The aim of this part of the questionnaire was to understand the perception of experts about this technology, both in terms of technical solutions and in terms of applications and benefits. Figure 3-4 shows the results for all the 4 groups, providing, even in this case, different possibilities of analyses and interpretations.

What emerges quite clearly from the results, is a general agreement on the importance of V2G. All groups expressed strong support for statements in favour of V2G and negative feedback on the sentences that are critical of V2G. V2G is considered a key technology to provide flexibility, with a strong impact on the quantity and temporal availability of flexibility that can be extracted by EVs. Both Grid Operators and Charging Operators are fully convinced that the extra cost of bidirectional charging with respect to "simple" smart charging is well compensated by the higher benefits. On this point, Research Organization look more cautious, with a substantial parity of votes in favour/against this sentence. An interesting follow up of the research, would be to better analyse if this caution is due to actual data coming by models or experimental activities or if is due to the substantial absence of these data. Anyhow, all the Groups agree on the fact that V2G actually adds many advantages beyond unidirectional smart charging.

Given the positive expectations for V2G, the results show a quite general uncertainty on the technical characteristics and the future diffusion of this solution. Despite being proposed in its DC version for the last decade, the respondents express a certain preference for the AC version, in particular in Groups 1 and 2. Research organizations (group 3) are in a more "neutral" position, maybe suggesting the coexistence of both AC and DC schemes. Potential reasons to prefer the AC solutions are its coherence with the kind of charging process (slow, at home or at the workplace) and the lower costs of the charging devices. In terms of future diffusion, all the Groups consider V2G as a "nice-to-have" more than a "must" or a "rarely adopted" solution and strongly disagree with the option to limit this scheme to "prosumers" (where the easiest applications and the most sustainable business models can be adopted). On the other hand, the level of acceptance of third-party controlled V2G is still quite uncertain for all Groups, opening questions about the real feasibility of domestic V2G (and therefore on the application field of AC bidirectional charging).

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How much do you agree/disagree with each of the following sentences? (5 – completely agree, 1 – completely disagree)

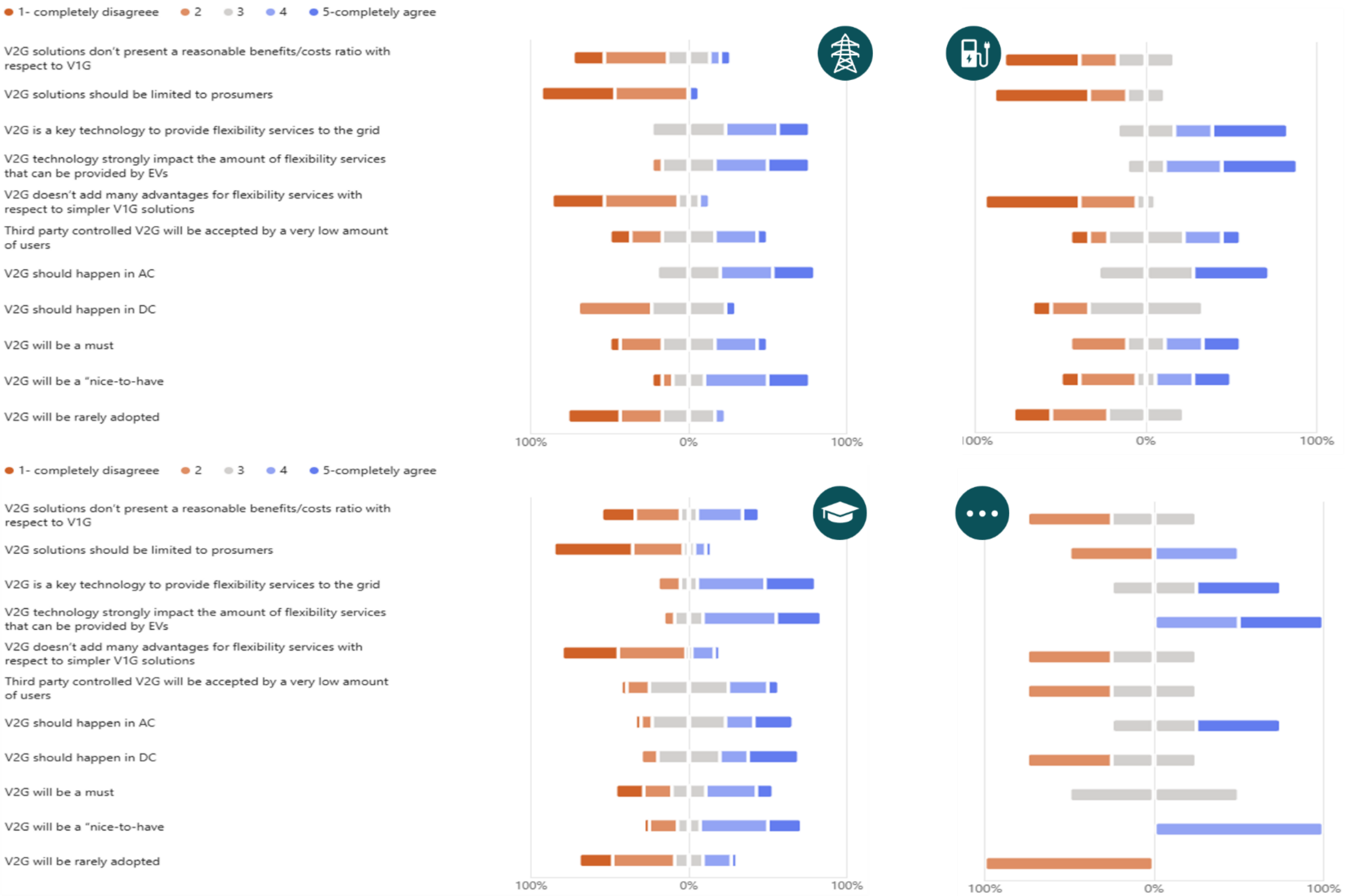

Figure 3-4. Topic 3 results for the 4 categories

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Topic 4 – Innovative pricing schemes and solutions

Topics 4 and 5 were intended to investigate the expert opinion on the most promising innovations able to foster VGI and EV based flexibility. In particular, Topic 4 is focused on pricing/tariff schemes and on the solution of Flexible Contract Agreements. As an aside, the FLOW demos include tests for these features. Figure 3-5 shows the results for all groups.

“Static tariffs”, both with three and four bands, are considered a potential solution but not a very impactful one, obtaining a substantial parity of positive and negative votes in all the Groups. Whereas “dynamic tariffs” carry much greater expectations and a much broader positive consensus. Tariffs should indeed change dynamically according to the energy price, the grid status or the amount of renewables injected in the grid. It is also seen very positively that price signals are directly communicated to home/charging control systems, bypassing the direct choice of final users on the best timeslot to charge the vehicles. While the 3 types of dynamic tariffs explored gather quite general agreement, it is interesting to notice that Grid Operators are the players less convinced about dynamic tariffs that reflect real-time grid status, despite being the theoretical beneficiaries of this scheme (relieving the stress on the grids). To clearly understand this position and the reasoning (limited visibility on LV grid status, concern about distributing information on the grid status, etc.) would be an interesting task for follow-up activities.

With regards to non-firm connection agreements, the position of the respondents is quite “neutral” in all the Groups, both for public and private charging. A possible interpretation is that this kind of scheme, despite being innovative and presenting significant potential benefits, is not a specific “enabler” for flexibility provision through EVs. On the opposite, it could be intended as an innovative scheme that is itself possible thanks to the flexibility given by EVs in their charging processes. By modulating the charging power in time and entity, it becomes possible for the charging operator to accept limited connection power in certain moments of the day and the year.

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Provide a vote 1-5 on the relevance of these possible new pricing schemes to foster VGI

Figure 3-5. Topic 4 results for the 4 categories

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Topic 5 – New Ancillary Service market rules

Ancillary service markets are governed by many rules and regulations, that specify the technical requirements for offering and activating flexibility services and define the management and the functioning of the market itself (number of sessions, methodology to determine prices, actors involved, etc.). The transformation of the energy systems occurred during the last 15-20 years and still ongoing requires reforms and updates of market rules, that are periodically put in place by regulatory agencies. There is always a risk that market rules could hinder the possibility to effectively take advantage of EV flexibility potential. Topic 5 of the questionnaire tries to gather the experts' opinion on this point and on new possible rules (Figure 3-6).

Overall, there is general uncertainty on the effectiveness of the proposed solutions. Focusing on the first 3 Groups, almost all the proposals received both positive and negative feedback, highlighting that respondents perceive that proposed solutions could significantly advance or have virtually no effect on the impact of VGI. The reason for that could be found in the complexity of market mechanisms, that makes it difficult to foresee the effect of new and innovative rules. It is worth mentioning that the proposal that received the highest number of negative feedbacks is to bind a minimum amount of resources only to local markets (or vice versa to TSO markets). This rigidity is not appreciated by grid operators and even less by charging operators, as it is probably seen as an artificial limitation of available resources on one side and of potential economic benefits on the other side. Surprisingly, the proposal to introduce capacity markets didn't find a neat consensus, even by charging operators that could (in theory) create new business models based on this kind of remuneration.

Make the ancillary service market bidding closer to the real time so that aggregators can evaluate more precisely their flexibility bands was a proposal that gathered very positive feedback. This clearly reflects the technical complexity intrinsic to EV flexibility on account of the unpredictability of EV drivers' behaviour and the need to guarantee a minimum level of charging for the vehicles.

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Provide a vote 1-5 on the relevance of these possible new market rules to foster VGI

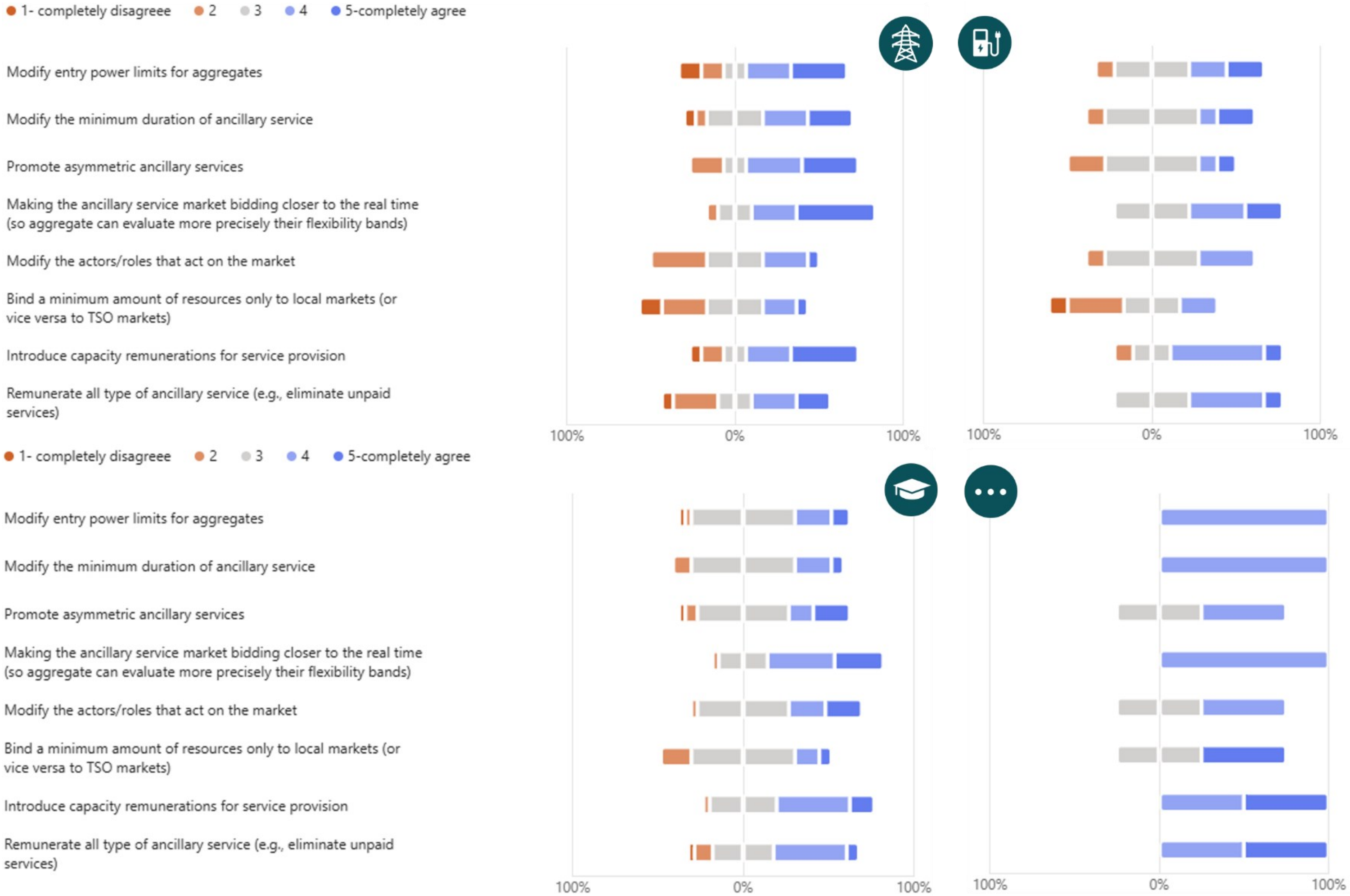

Figure 3-6. Topic 5 results for the 4 categories

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Topic 6: Future perspective

Despite the maybe overly ambitious title of this topic, the last question for the respondent was very straightforward, and was intended to clarify if VGI experts were expecting to see the proposed technologies deployed in a shorter or longer time span. Figure 3-7 shows the results for all the categories.

The most optimistic on VGI and V2X diffusion are Group 1 and 4 with approximately half the respondents pointing at 2030-2035 and the other half asserting the need for 5 more years. The same answers are the most voted even in Group 2 and 4, where also less optimistic points of view came out, suggesting 2040-2045 and even going after 2050.

In general, it could be said that players actively involved in this new process are mostly optimistic on the possibility to make VGI and V2G technologies real in a reasonable amount of time.

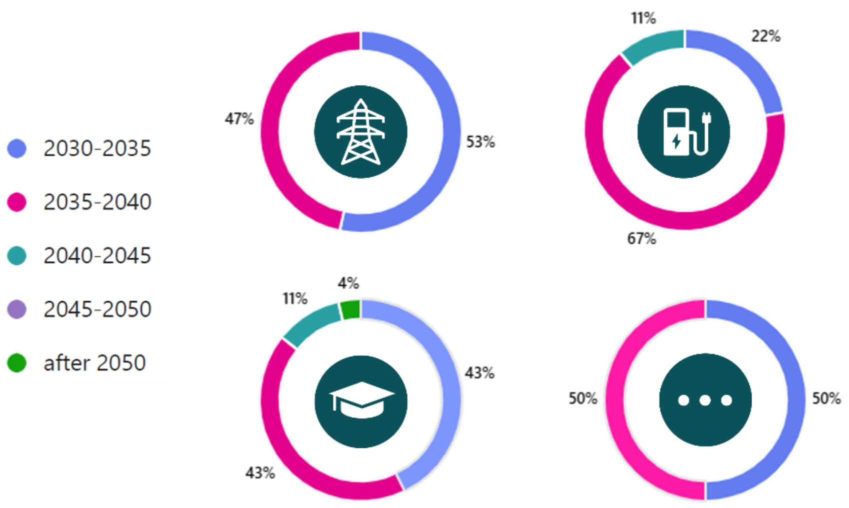

Figure 3-7. Topic 6 results for the 4 categories

3.1.4. Conclusions

The Questionnaire was a useful instrument to gather the opinions and the feelings of e-mobility experts about VGI and flexibility provision by EVs. The results allow for many interpretations and provide many starting points for follow-up analyses. In general, it could be said that they depict a situation where:

- Flexibility provision through EVs is considered a real and effective solution to manage future energy systems, even by industrial players.
- Both behind-the-meter and grid/frequency related services will be performed by EVs.
- Bidirectional charging will play a relevant role, also with the AC charging solution.
- Dynamic tariffs represent a promising solution to foster EV flexibility provision.
- Ancillary service market rules could be updated but there is uncertainty on the effects of new rules and today any solution is perceived as a game-changer.

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- VGI and EV-based flexibility will become widely diffused in the next 5-15 years.

These inputs have been helpful to set the scene for the definition of Recommendations on new policies and regulation, that will be presented in section 4.

3.2. V2X Cluster inputs

Together with the questionnaire presented in the previous section, a second instrument that was used to gather expert opinions on existing obstacles for EV flexibility diffusion and on proposals for new rules and policies was the V2X Cluster and a document that it developed during 2025.

3.2.1. The V2X Cluster

The so-called "V2X Cluster" is a collaborative initiative uniting Horizon Europe projects to accelerate the development of vehicle-to-everything (V2X) technologies and smart, interoperable, inclusive EV charging solutions. It was launched in 2023 with five related projects – EV4EU, DriVe2X, FLOW, SCALE and XL-CONNECT and then expanded in June 2025 to include AHEAD, NEVERFLAT and ePowerMove, strengthening its expertise, reach and impact. By fostering collaboration across projects, the V2X Cluster aims to accelerate the adoption of future-ready EV charging infrastructure across Europe, ensuring a more sustainable and connected mobility ecosystem.

To streamline collaboration and maximize results, the Cluster is structured around five thematic areas: Business Models, Battery Degradation, Consumer Perspective, AC vs. DC Charging and Policy and Regulation.

Cluster representatives hold regular meetings to share insights, coordinate strategies, and address common challenges, such as:

- V2X charging business models
- National and EU regulatory frameworks
- Urban-scale deployment of smart charging and V2X technologies
- Inter-regional cooperation and coordination on smart charging and V2X.

3.2.2. "Barriers and suggestions" report

During 2025, the European Commission appointed the Cluster to summarize in a working document the most relevant outcomes of the projects in terms of:

- Barriers and challenges
- Business cases and short-term solutions
- Suggestions/ideas for the use of "regulatory sandboxes"

The document prepared by the cluster discussed a broad range of topics that still need to be addressed to allow broader diffusion of VGI and EV flexibility. A detailed analysis is out of the scope of this report, but in the rest of this section the most relevant aspects are reported, as they represent a key element to identify and propose new policies and rules.

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By analysing the report and the contributions by the different projects it was possible to identify 21 significant topics (often mentioned by more than one project), that are summarized in the following list.

1. Harmonize and avoid different implementations for Communication protocols like IEC61851-1, ISO 15118, and OCPP (proposing a "certificate" for interoperability and trying to overcome closed setups).
2. Harmonize communication standards including other domains that can be connected to EV charging (electricity meters, BESSs, EMSs, DSO and TSO platforms,…).
3. Identify a common plug standard for both AC and DC charging across different regions.
4. Standardize technical representation of V2X use cases using Electric Mobility Systems Architecture.
5. Update regulation on grid codes and harmonize them to unlock integration of bidirectional charging systems into the energy grid.
6. Use regulation to avoid confusion and uncertainty about roles, responsibilities, and requirements.
7. Use regulatory sandboxes to reform the market towards inclusion of V2X services.
8. Improve access to energy market mechanisms.
9. Improve access to data.
10. Implement feed-in tariffs.
11. Remove double-taxation for vehicle-to-grid use cases (issue present only in specific countries).
12. Promote a tax exemption for a limited amount of energy supplied for EV charging.
13. Support industry to reduce costs on V2X chargers (especially DC).
14. Incentivize grid-forming inverters integrated with charging points.
15. Include limits in new EU regulation to drastically reduce standby losses in e-vehicles.
16. Provide incentives for bidirectional charging parks in company parking lots.
17. Prioritize bidirectional charging with fleets as a promising early market.
18. Include smart and bidirectional charging as a requirement in public procurement of charging infrastructure.
19. Increase scientific consensus and consumers' awareness on battery degradation in V2X (that can also impact EV warranties).
20. Develop research actions that tackle the role of users in V2X, looking into alternative ownership structures (car sharing and leasing).
21. Further refine business models for V2G to articulate the advantages and disadvantages compared to smart charging.

The list covers specific aspects of different fields, that could be synthesized including:

- Standards and protocols
- Regulation
- Economic support
- Charger localization
- Research and technology

All these aspects could be provided as recommendations to the European Commission, policy makers and regulators. The list indeed represents a very important starting point for the content of Section 4.

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3.3. Working Group “Policy and Regulation”

The third and last instrument adopted to identify the recommendations presented in Section 4 is the Policy and Regulation Working Group (WG), created within the FLOW consortium with a “cross-WP” approach. Despite being organized and managed by WP5, the WG was open to all FLOW participants, with the aim to gather the most important outcomes of all the Work Packages and to catch knowledge from all the experts involved in the project.

The WG was launched in autumn 2025 and was intended as a space to carry out the last step of the activity, i.e. the final identification of key messages to bring to the attention of relevant stakeholders, in the field of “Policy and Regulation”. Starting from the results of the Questionnaire and the inputs coming from the V2X Cluster, the WG defined the final set of recommendations and the most effective way of presenting them.

The outcomes of the WG activities are therefore the core part of the next Section 4.

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4. Key Recommendations on new policies and regulation to boost VGI

The concepts of smart charging and vehicle-to-grid, together with the idea of leveraging EVs to provide flexibility to energy systems, are well known and deeply studied in the last 10-15 years. The same can be affirmed for their potential benefits. Despite that, the diffusion of these charging schemes is still very limited and far from representing a commercial and widely adopted solution. In order to fill this gap between the opportunity and the actual deployment, it is crucial to identify the aspects that are still unsolved and to suggest the most effective solutions. One of the scopes of this document is exactly to propose a set of recommendations that could contribute to foster the adoption of innovative charging schemes throughout Europe, with a specific focus on new policies and regulation.

This Section includes a description of the approach decided by the WG Policy and Regulation to effectively identify and present the recommendations, followed by the recommendations themselves and by some final remarks.

4.1. Recommendations identification and presentation: concept and approach

The most common way to develop a set of recommendations is the identification of the most critical aspects (through different instruments, like the ones presented in Section 3) and then the synthesis of proposals and suggestions to solve them. The outcome is typically a list of 10-20 recommendations, quite similar to the one presented in Section 3.2 derived from V2X Cluster discussion.

The discussion within the Policy and Regulation WG invited to adopt a partially different approach, not just compiling a list of recommendations, but trying to map them into specific use cases, providing a vision that will help a progressive diffusion of EV-based flexibility, by clearly differentiating the services and their present needs.

From the point of view of the WG, providing just a list of recommendations would generate two risks:

- Communicate the wrong message that all flexibility services are unfeasible today and they will stay that way until many or all the recommendations are addressed.
- Reduce the added value of the message sent to the relevant stakeholders, as the pure content of most recommendation would be probably already known (and partially taken care of) by policy makers and regulators, that receive similar inputs from many actors.

The approach used to develop the “use case mapped” recommendations was the following:

- Identify the most relevant use cases for the implementation of VGI and innovative charging schemes
- Analyse for each of them the user objectives, the system benefits, the present needs and the possible solutions
- Select from the possible solutions the one that can be supported by policy makers and regulators.

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The idea behind this is that, in the next few years, several different ways of managing EV flexibility will coexist. Relevant benefits for the energy systems would come not only from the inclusion of EVs in flexibility markets, but also from the commonly called “Behind-the-Meter” services that, despite being driven by the final user interests, present implicit advantages for the whole system.

4.2. Use cases for EV flexibility

4.2.1. Use cases selection

Fifteen use cases have been selected as relevant to take advantage of EVs flexibility. Their classification is made according to three characteristics:

- The charging location, that strongly influences the charging patterns and the vehicle availability during a typical day.
- The participation or non-participation in flexibility market mechanisms.
- The adoption of unidirectional or bidirectional (V2X) charging schemes.

Four charging locations have been considered:

- Workplace: parking lots of companies (or similar organizations) where employees can charge their vehicles during working hours (typically during daytime).
- Park & Ride: parking lots in the proximity of mobility hubs at the entrance of big cities, where commuters leave their cars for several hours (typically during daytime).
- Home: private parking spaces located at home places. For this case, a sub-segmentation has been proposed, differentiating the use case of users that are mostly out of home (traditional workers) from the case of users that are mostly at home (remote workers, retired people, housewives, househusbands, …). It is interesting to notice that, despite the common perception, the second group can be bigger than the first.
- Long stay parking lots: parking premises where cars remain parked for days, for example in proximity of airports.

En-route and destination charger have not been included in this phase, as their typical usage is less suitable for power modulation. Please consider that this does not mean that flexibility options could not be applied to these locations.

With regards to participation in flexibility markets, a distinction similar to the “Behind-the-Meter” Vs “Front-of-the-Meter” services have been considered. The first group could also be described as “user based”, “off-market” or “implicit” services and includes the management of the charging process aimed at maximising the benefits for the final user through local optimization. As already mentioned, it must be underlined that while looking for the highest advantages for the final user, important benefits for the energy system could also take place “implicitly”. The second group could be defined as “market based” or “aggregator based” and includes all the services that are directly offered to flexibility markets for TSOs and, where existing, for DSOs.

The last distinction is quite clear and depends on the availability of bidirectional chargers. It deserves mentioning that bidirectional schemes could be adopted here both for “off-market” services (Vehicle-to-Home, V2H or Vehicle-to-Building, V2B) and for “market based” services (V2G).

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Table 4-1 reports a scheme of the identified use cases, divided for location and market participation. It has to be noted that the 15 use cases are not the full and exact combination of all the above-described parameters, as some combinations are considered less relevant in terms of flexibility potential. For example, off-market smart unidirectional charging at households for people staying mostly at home during the day, doesn't provide many advantages and is therefore omitted here. Similarly, bidirectional charging in workplaces would make more sense for grid services than for V2B local solutions, as cars would be mostly present during daytime but absent during morning and evening peak hours, limiting the advantages in terms of energy arbitrage. As already mentioned before, these choices, made for this specific activity, don't mean that flexibility could not be applied to other use cases.

Table 4-1. Relevant use cases to take advantage of EV flexibility

Use Case Type	Location	Use Case Description
Off-market	Workplace	UC1: Uncontrolled, day charging
		UC2: Smart, unidirectional charging
	Park & Ride	UC3: Uncontrolled, day charging
		UC4: Smart, unidirectional charging
	Home	UC5: Smart, unidirectional charging (not @home users)
		UC6: V2H for @home users
Market-based	Workplace	UC7: V1G for grid services
		UC8: V2G for grid services
	Park & Ride	UC9: V1G for grid services
		UC10: V2G for grid services
	Home	UC11: V1G for grid services (not @home users)
		UC12: V2G for grid services (not @home users)
		UC13: V1G for grid services (@home users)
		UC14: V2G for grid services (@home users)
	Long stay parking lots	UC15: V2G for grid services

4.2.2. Use cases characterization

The selected use cases have been analysed and characterized in terms of 4 elements:

- User objective
- System benefit
- Present needs
- Possible solutions

In the rest of this section, a short description and a synthetic characterization of all the 15 use cases (UC) is presented. For the sake of simplicity, use cases that present quite similar characteristics are analysed and presented together.

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4.2.2.1. Off-market use cases

UC1: Workplace – Uncontrolled charging

Short description
UC1 considers the “simple” shifting of EV charging from households to workplaces. This typically implies a time-shift of the power absorption from evening/night hours to daytime, that can be intended as a first kind of flexibility allowed by EVs. UC1 considers only this shifting, leaving the rest of the charging process “uncontrolled”.

User Objectives
- Save money and have easy access to charging with workplace infrastructure

System benefits
- Reduce distribution grid overloads during evening peak hours
- Reduce the energy demand during peak hours, consequently reducing energy market price (less need for energy generated by expensive plants in peak hours)
- Exploit a small part of PV generation in the morning

What is needed?
- Support charger installation at workplaces
- Guarantee that EV charging at workplace is cheaper than domestic/en-route charging

Possible solutions
- Fiscal/economic incentives for companies that install charging stations
- Bundle solutions “EV+charger” proposed by leasing/long-term rental companies[2]
- Tariff schemes that establish low prices during daytime (even Static Time-of-Use tariffs would work for this UC)
- Economic support from the company to its employees to reduce charging costs (e.g. certain amount of discounted/paid kWh included as company benefit)

UC2: Workplace – Smart, unidirectional charging

Short description
UC2 considers the shifting of EV charging from households to workplaces, like UC1, and the adoption of smart, unidirectional charging algorithms for local economic optimization. These will typically tend to concentrate the charging process during high renewable generation (both in-situ or not) in the central hours of the day.

User Objectives
- Save money (even more than in UC1) and have easy access to charging thanks to workplace infrastructure
- Lower the environmental impact of their mobility by using renewable energy

[2] This could be applied for company cars offered as a fringe benefit to their employees

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System benefits

- Reduce distribution grid overloads during evening peak hours (vehicles return home charged)
- Reduce the energy demand during peak hours, consequently reducing energy market price (less need for energy generated by expensive plants in peak hours)
- Maximise the use of PV generation, reducing curtailments due to overgeneration (with both environmental and economic benefits)

What is needed?

- Support charger installation at workplaces
- Guarantee that controlling the charging process will produce economic benefits for users
- Smart charging algorithms (simple versions for local optimization already exist but not as off-the-shelf products) to monitor and control a pool of charging stations
- Harmonized input data for algorithms
- User information, user training, user friendly tools/apps

Possible solutions

- Fiscal/economic incentives for companies that install charging stations with smart charging capabilities
- Bundle solutions “EV + smart charger” proposed by leasing/long-term rental companies
- Tariff schemes that establish low prices during daytime (Static Time-of-Use tariffs, or tariffs following Day-ahead Energy Price would be needed for this UC (e.g., 15-min or hourly))
- Economic support from the company to its employees to reduce charging costs (e.g. certain amount of discounted/paid kWh included as company benefit)
- Harmonization and common implementation of communication protocols (ISO 15118 and OCPP)

UC3: Park & Ride – Uncontrolled charging and UC4: Park & Ride – Smart, unidirectional charging

Short description

UC3 and UC4 consider a situation very similar to UC1 and UC2. Park & Ride facilities can indeed be seen as a “workplace” parking lot for commuters that reach big cities by car and then shift to public transport. UC3 considers uncontrolled charging in these facilities, while UC4 adds the application of smart charging algorithms. User Objectives, System benefits and Present needs are practically coincident with UC1 and UC2, while the possible solutions could slightly differ as the charging infrastructure owner won’t be the company employing the EV driver.

User Objectives

- See UC1 and UC2

System benefits

- See UC1 and UC2

What is needed?

- See UC1 and UC2

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Possible solutions

- Public funding for local Public Administrations (PAs) to install (smart) charging infrastructure in Park & Ride facilities
- Local laws to encourage the installation of (smart) charging infrastructure in all new/renovated Park & Ride facilities
- Tariff schemes that establish low prices during daytime (see UC1 and UC2)
- Tariff schemes that feature discounts for companies managing Park & Ride facilities
- Harmonization and common implementation of communication protocols (ISO 15118 and OCPP)

UC5: Home – Smart, unidirectional charging for not@home users

Short description

UC5 considers the adoption of smart charging for domestic charging and for EV drivers that go out during the day. In this case, smart charging algorithms would tend to avoid charging during evening peak-hours and postpone it until a more suitable time that night or in the morning.

User Objectives

- Save money, both on energy cost and on the costs of the contracted power

System benefits

- Reduce distribution grid overloads during evening peak hours
- Reduce the energy demand during peak hours, consequently reducing energy market price (less need for energy generated by expensive plants in peak hours)

What is needed?

- Smart charging algorithms (simple versions for local optimization already exist but not as off-the-shelf products) for a low number of charging devices (typically just one), potentially integrated into a home EMS
- Guarantee that controlling the charging process will produce economic benefits for users
- User information, user training, user friendly tools/apps

Possible solutions

- Static Time-of-Use tariffs with low prices during nighttime
- Static Time-of-Use tariffs, or tariffs following Day-ahead Energy Price
- Harmonize communication standards with home EMS
- Harmonization and common implementation of communication protocols (ISO 15118 and OCPP)
- Promote and simplify users' engagement through information and specifically designed apps.

UC6: Home – V2H for @home users

Short description

UC6 considers the engagement of EVs that are mostly parked at home in V2H schemes. In particular, an "energy arbitrage" concept could be applied in this case, with vehicles that are charged during low prices hours (typically daytime during high renewable generation) and are discharged during peak

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hours to power the house, limiting the purchase of energy in high prices moments. The same principle can be applied if the home is directly equipped with a PV system. UC6 considers EV owners with low usage and long connection times of the cars, so the economic advantage for owners would be not just on charging costs, but on the overall electricity bill.

User Objectives

- Save money on the electricity bill thanks to a rarely used vehicle (acts like a large home battery).
- Lower the environmental impact of mobility and domestic consumption by concentrating consumption when renewable energy is available

System benefits

- Reduce distribution grid overloads during evening peak hours, not only by not charging the car, but also using EV energy for powering other domestic loads.
- Reduce the energy demand during peak hours (again with the double effect of not charging and of reducing grid absorption for other loads).
- Maximise the use of PV generation, reducing curtailments due to overgeneration (with both environmental and economic benefits)

What is needed?

- Cost competitive bidirectional charging devices and vehicles.
- Smart charging algorithms for local level optimization of a low number of charging devices (typically just one), that include bidirectional flows and potentially integrated into a home EMS.
- User information, user training, user friendly tools/apps

Possible solutions

- Static Time-of-Use tariffs with distinct pricing periods
- Static Time-of-Use tariffs, or tariffs following Day-ahead Energy Price
- Harmonize and avoid different implementations for Communication protocols trying to overcome closed EV+EVSE setups. This would increase competition and result in cheaper devices.
- Create a supportive environment for AC bidirectional charging (e.g. harmonize grid standards so to help manufacturers to standardize products and lower prices)
- Harmonize communication standards with home EMS
- Promote and simplify users' engagement through information and specifically designed apps.

4.2.2.2. Market-based use cases

Unlike Off-market (behind-the-meter) use cases, that can be quite different depending on the location and the user, Market-based use cases have many aspects that don't vary with the place or the kind of fleet involved. For this reason, in the following part of this section they will be characterized in an aggregated manner.

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UC7-15: Ancillary services provision with V1G or V2G schemes

Short description

All the Market-based use cases (from UC7 to UC15) consider the provision of grid services by an aggregation of EVs managed by a Balance Service Provider (BSP, often referred to as "aggregator"). The BSP calculates the flexibility margins of the group of EVs and offers services in flexibility markets, both local (satisfying DSOs needs) and regional (satisfying TSO needs). In these cases, the EV owner delegates the charging management and the economic optimization to the BSP. V1G and V2G schemes differ, in these use cases, mainly for the amount of flexibility that can be offered by the BSP. Similarly, if the vehicle is connected to the charging station during daytime, nighttime or the entire day (e.g. in UC17), it has impact on the amount of flexibility offered and on the time slot of the offers.

User Objectives

- Earn money (or save money on the electricity bill) by allowing the BSP to manage the charging process of its vehicle and offer services in flexibility markets.

System benefits

- Obtain ancillary services from cheap and diffused resources, reducing the activation of traditional flexibility by Gas-Turbines and other fossil-based power plants.
- Reduce the need to install stationary storage systems expressly to provide flexibility, leveraging an already available resource.

What is needed?

- Smart or bidirectional charging stations in the locations related to these use cases
- Charging stations management systems that allow remote monitoring and control by BSPs, with simple and universal messages (i.e., interoperable)
- Forecasting tools, real-time data and techniques to evaluate aggregated flexibility margins and the consequent market offers
- Smart charging algorithms to identify the optimal set-point of each charging station (optionally managed centrally by the BSP or in a decentralized way by charging stations owners).
- Clear and simpler market rules for aggregated resources
- Clear rules and architectures on the interaction between local and regional markets and between DSOs and TSOs
- Services remuneration that can generate a positive business case for BSPs and EV owners
- Solutions to double taxation issues for bidirectional use cases
- User information and user training and education, in particular on battery degradation issues.

Possible solutions

- Fiscal/economic incentives to install smart/bidirectional chargers
- Harmonize and avoid different implementations for communication protocols, in order to allow chargers control and data collection.
- Create a supportive environment for AC bidirectional charging from a grid perspective (e.g. harmonize grid standards)
- Update regulation to eliminate double taxation issues (only in specific EU states)

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- Simplify market rules for BSPs, e.g. modifying entry limits, duration and symmetry of flexibility offers and making the ancillary service market bidding closer to the real time (to reduce BSPs uncertainty)
- Promote and simplify users' engagement through information and specifically designed apps.
- Increase scientific consensus and consumers' awareness on battery degradation due to bidirectional charging.
- Explore limitations of EV warranties and work with OEMs and battery manufacturers to relax limitations or implement more dynamic warranties.
- Promote research activities and pilot projects on TSO-DSO interaction and on the coexistence of local and global flexibility markets.

4.3. Recommendations to boost EV flexibility provision

The characterization of the use cases in terms of needs and possible solutions provides at the same time an overview of many innovations and changes that need to be deployed, and a clear representation of the specific situation of different use cases, in terms of complexity and readiness.

Off-market use cases can be mostly launched with simpler interventions with respect to market-based ones and the expected benefits are not negligible for the EV owner nor for the energy system.

Starting with the fact that all the "possible solutions" described in the use cases characterization could themselves represent a recommendation for policy makers, regulators and other stakeholders, it is useful to summarize a shorter list of final and more general recommendations.

1. **Support installation of smart chargers in locations where EVs can charge during daytime, especially workplaces and Park & Ride facilities.** Potential instruments are fiscal and economic incentives as well as legal obligations for new/renovated facilities.

2. **Adopt tariff schemes that clearly imply:**
    - **Very low prices during low demand and high renewable generation hours**
    - **Low prices during off-peak hours**
    - **High prices during peak hours**

    This could be done both with static Time-of-Use tariffs or, better, with dynamic tariffs. It is strongly suggested to remove old Time-of-Use tariffs that still feature higher prices during daytime.

3. **Push for harmonization and common implementation of communication protocols, trying to overcome closed EV+EVSE setups both for smart and bidirectional charging.** A powerful instrument could be the official introduction of a "certificate" for interoperability.

4. **Simplify flexibility market rules for BSPs aggregating EVs and distributed resources.** This could be done by modifying entry limits, duration and symmetry of flexibility offers and, more importantly, by making the market bidding closer to the real time, reducing BSPs uncertainty.

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5. **Update European and National regulation to eliminate double taxation in V2G schemes and allow seamless AC bidirectional charging throughout Europe**. Potential specific solutions would be to equalize EV batteries and stationary storage in terms of taxation and to harmonize grid codes of different countries.

6. **Increase user awareness on the opportunities provided by flexibility schemes for EV charging**. This would require a joint effort by many actors. Among others: car manufacturers, car dealers, e-mobility service providers, utilities, scientific community. Specifically designed tools, like smartphone apps, could help in promoting the engagement and simplifying the participation of final users.

7. **Promote research activities and pilot projects on still open aspects.** This includes, for example, developing smart/bidirectional chargers that consider battery degradation as part of the optimization, as well as clarifying the most effective architectures and interactions between local and regional flexibility markets and between DSOs and TSOs.

To conclude this section, recommendations are mapped to the above-described use cases. This helps in identifying which set of actions are needed to enable the use cases and which use cases are closer to actual implementation. The mapping result is reported in Table 4-2.

Table 4-2. Correlation between use cases and recommendation

Use case	Recommendation						
UC1: Workplace, Uncontrolled, day charging	1	2					
UC2: Workplace, Smart, unidirectional charging	1	2	3			6	
UC3: Park & Ride, Uncontrolled, day charging	1	2					
UC4: Park & Ride, Smart, unidirectional charging	1	2	3			6	
UC5: Home, Smart, unidirectional charging for not@home users		2	3			6	
UC6: Home, V2H for @home users		2	3		5	6	7
UC7: Workplace, V1G for grid services	1		3	4		6	7
UC8: Workplace, V2G for grid services	1		3	4	5	6	7
UC9: Park & Ride, V1G for grid services	1		3	4		6	7
UC10: Park & Ride, V2G for grid services	1		3	4	5	6	7
UC11: Home, V1G for grid services (not@home users)			3	4		6	7
UC12: Home, V2G for grid services (not@home users)			3	4	5	6	7
UC13: Home, V1G for grid services (@home users)			3	4		6	7
UC14: Home, V2G for grid services (@home users)			3	4	5	6	7
UC15: Long stay parking lots, V2G for grid services	1		3	4	5	6	7

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5. Conclusions

The deliverable summarized the most relevant activities and results of Task 5.4 of the FLOW project, investigating the role of electric vehicles as flexible assets within future power systems, with a specific focus on the regulatory and policy dimensions and the interventions required to unlock effective Vehicle-Grid Integration.

The first part of the activities was focused on modelling the effect of different charging strategies on the energy market, using as a test-case an Italian 2030 energy scenario. The developed modelling framework is based on a zonal electricity market simulator developed by RSE and an EV charging simulator tool made available by IEA. Four different charging strategies proposed within the IEA tool, to optimize charging costs and reduce grid stress, were simulated with the market model. The results demonstrated that EV charging strategies can significantly influence energy market outcomes, electricity prices and system costs, even when EV demand represents a relatively modest share of total electricity consumption. Unmanaged charging was shown to exacerbate peak demand and price volatility, particularly during evening peak hours, while smart charging strategies consistently reduced system stress and user costs by shifting demand towards off-peak periods. The integration of the market model with the charging simulator proved to work successfully and this will represent the basis for further developments and applications of the modelling framework. Being able to analyse the impact of different charging strategies could indeed represent a valuable support for guiding policy and regulatory decisions.

In the second part of the deliverable, the process and the instruments put in place to identify a set of key recommendations on new policies and regulation to boost VGI was presented. A rich background for the discussion was obtained through a questionnaire, circulated first within the FLOW consortium and then within other expert groups. The results pointed out that flexibility provision through EVs is considered a real and effective solution to manage future energy systems, with both behind-the-meter and grid/frequency related market services. Dynamic tariffs and bidirectional charging will be two key elements to foster EV flexibility provision, while an update of ancillary service market rules and the emergence of new flexibility markets and flexibility instruments could also be beneficial. The V2X Cluster and the related documentation represented other useful means to collect expert opinions on barriers and suggestions, while the final discussion on the recommendations and the way of presenting them happened in a specifically launched “Policy and Regulation Working Group”, gathering FLOW experts.

The outcome of the activities and of the deliverable itself is a set of 7 recommendations, targeted mostly to policy makers and regulators:

1. Support installation of smart chargers in locations where EVs can charge during daytime, especially workplaces and Park & Ride facilities.
2. Adopt tariff schemes that clearly imply very low prices during low demand and high renewable generation hours, low prices during off-peak hours and high prices during peak hours
3. Push for harmonization and common implementation of communication protocols, trying to overcome closed EV+EVSE setups both for smart and bidirectional charging.
4. Simplify flexibility market rules for BSPs aggregating EVs and distributed resources.

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5. Update European and National regulation to eliminate double taxation in V2G schemes and allow seamless AC bidirectional charging throughout Europe.
6. Increase user awareness on the opportunities provided by flexibility schemes for EV charging.
7. Promote research activities and pilot projects on still open aspects.

As thoroughly described in Section 4, the final recommendations were mapped into 15 specific use cases, that were previously described and characterized. This approach provides a more complete and concrete vision, that will help a progressive diffusion of EV-based flexibility, by clearly differentiating the services and their present needs.

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References

IEA. (2023). *Electric Vehicle Charging and Grid Integration Tool*. Retrieved from https://www.iea.org/data-and-statistics/data-tools/electric-vehicle-charging-and-grid-integration-tool

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