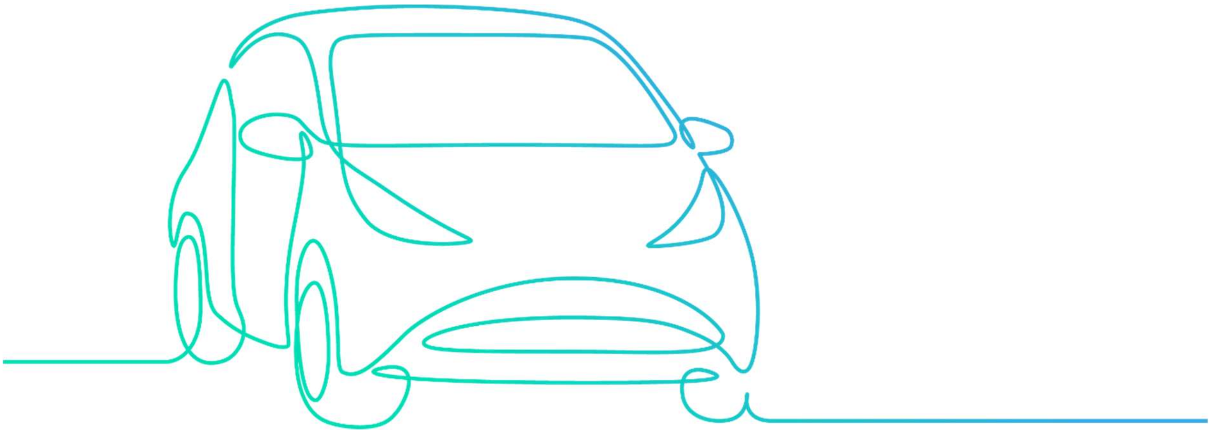

Analysis of the electricity markets and its potential for integrating V2G

D3.1

APRIL 2022

Deliverable

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SUMMARY

Review of key elements of the Day-Ahead, Intraday Continuous, and Intraday Electricity Auctions markets' potential for V2G integration and participation of the EV owners and aggregators. Potential in similar EU markets.

This deliverable is the result of the collaboration of the V2Market project members during the firsts tasks of the Work Package 3: *Analysis of the electricity markets and its potential for integrating V2G.* The main objective of the D3.1 is to procure a global vision of the current situation of the electric vehicle integration in Spain and Europe and assess what opportunities are available for vehicle-to-grid in the electricity markets. Also, the deliverable analyses barriers and legal aspects that must be modified to allow the introduction of V2M into the market.

First, this document introduces the Vehicle-to-X concept including Vehicle-to-Grid (V2G), Vehicle-to-Home (V2H) or Vehicle-to-Building (V2B), analysing what are the benefits that these technologies offer to final users. The grid operation and the electricity market will also benefit from the introduction of V2G in the electricity market.

Second, the deliverable 3.1 is a review of the actual trends, policies and legal barriers related to the EV, necessary infrastructure and V2G integration. Further, it will inspect the current state of the EV technology (EVs elements, bidirectional charging, infrastructure, cost trends, etc.) in the Metropolitan Area of Barcelona (AMB), Spain, and in other European states.

The document also introduces the electricity market in Spain and Europe, explaining how the wholesales markets work and what will be the incoming changes for the Day-Ahead Electricity Market (SDAC), Intraday Continuous Market (SDIC) and Intraday Auctions (IDAs). An analysis of the potential that the SDAC, SIDC and Intraday Auctions markets offers for the V2G flexibility services is included in the document. In order to understand this opportunity, the document explores the expected trends on the demand and price signal patterns for the next years under a scenario of high energy renewable penetration, along with an increasing EV demand, identifying the main figures that will be involved in the new EV business model (EV owners, aggregators, etc.).

Work Package 3 tasks involved in this deliverable:

- Analysis of key market conditions (T3.1).

- Analysis of the SDAC, Intraday Auctions Market and SIDC markets' potential for V2G integration (T3.2).

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TABLE OF ACRONYMUS

Acronym	Description
4MMC	4M Market Coupling
ACER	Agency for the Cooperation of Energy Regulators
BEV	Battery Electric Vehicle
BRP	Balancing Responsible Party
CACM	Capacity Allocation and Congestion Management
CAN	Controller Area Network
CCS	Combined charging system
CNMC	Spanish National Regulatory Authority
CMM	Capacity Management Module
CPO	Charging Point Operators
DER	Distributed Energy Resource
DA	Day Ahead Market
ENTSO-E	European Network of Transmission System Operators for Electricity
EC	European Commission
EGD	European Green Deal
EMSP	eMobility Service Provider
EUPHEMIA	Pan-European Hybrid Electricity Market Integration Algorithm
ESL	Spanish Electricity Sector Law
EV	Electric vehicle
EVSE	Electric Vehicle Supply Equipment
FCEV	Fuel Cell Electric Vehicle
GHG	Green House Gases
GOT	Gate Opening Time
GCT	Gate Closure Time
HEV	Hybrid Electric Vehicle
IDAs	Intraday Auctions
IM	Intraday Market
LTS	Local Trade System
MIBEL	Iberian Electricity Market
MRC	Multi-Regional Coupling

Acronym	Description
NECP	National Energy and Climate Plan
NEMO	Nominated Electricity Market Operator
NWE	North-Western Europe
OCPP	Open Charge Point Protocol
OSG	Official State Gazette
OMIE	Omi Polo - Español
PCR	Price Coupling Regions
PLC	Power Line Communication
PHEV	Plug-in Hybrid Electric Vehicle
PX	Power Exchange
REE	Red Eléctrica de España
REN	Rede Electrica Nacional
RES	Renewable Energy Resources
ROW	Rest of World
SDAC	Single Day Ahead Coupling
SDIC	Single Intraday Coupling
SM	Shipping Module
SOB	Shared Order Book
TSO	Transmission System Operator
XBID	Cross-border Intraday Coupling
UVARs	Urban Vehicle Access Regulation Schemes
V2B	Vehicle-to-Building
V2G	Vehicle-to-Grid
V2H	Vehicle-to-Home
V2X	Vehicle-to-Everything

1/ Background

General overview of the EV policies in the EU and Spain.

The global electric vehicle fleet expanded significantly over the last decade reaching 5% global car sales in 2020 [1], supported by new climate and decarbonization policies. Environmental and sustainability targets are being introduced in many countries to reduce air pollution to contribute to energy diversification and greenhouse gas emissions reduction. The success of policy actions for EV depends in large part on the EV technology evolution and the acceptance by society. With the growth and adoption of electromobility new EV vehicle technologies have appeared: Vehicle-to-Grid, Vehicle-to-Home and Vehicle-to-Building are some of the new options that users have available in the market. With these innovative technologies, users can reinject the energy stored in their EV batteries into the grid through their participation in the electricity markets, obtaining an income from it.

EUROPEAN DECARBONIZATION OBJECTIVES

In December 2019, the European Commission adopted the European Green Deal (EGD)[1], a set of proposals to make the EU's climate, energy, transport, and taxation policies fit for reducing carbon emissions.

In September 2020, the Commission adopted its proposal for a European Climate Law. On April 21, 2021, the Council and European Parliament reached a provisional political agreement on the European Climate Law[2]. All 27 EU Member States committed to turning the EU into the first climate neutral continent by 2050. To get there, it is necessary to reduce emissions by at least a 55% by 2030 compared to 1990 levels, according to the Commission's proposal COM/2020/562, September 2020. It is an ambitious challenge that will create new opportunities for innovation and investment.

The European long-term vision is based on a flexible, decentralized energy system where citizens will have an important role in the energy transition.

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[1] Communication from The Commission to The European Parliament, The European Council, The Council, The European Economic and Social Committee and The Committee of The Regions The European Green Deal. EUR-Lex - 52019DC0640 - EN - EUR-Lex (europa.eu)

[2] Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 establishing the framework for achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999 ('European Climate Law').
https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32021R1119

The 2030 target is in line with the Paris Agreement goal of keeping global temperature rise well below 2°C and continuing efforts to limit it to 1.5°C.

V2GRID & RENEWABLE ENERGY

Renewable energy sources make the power generation more volatile. An electrical system based in renewable energies as main generation sources needs storage and flexibility to cover that volatility, requiring new ways to balance and store energy. Electric vehicles are an efficient solution to store energy that can also provide flexibility to the electrical system. V2G solutions can improve the utilization of renewable energy and help mitigating grid constraints [2].
The number of EV on roads will grow rapidly, and a substantial energy storage capacity deployed in the next years will have wheels on it. EVs through V2G technology can be part of the solution to the stress that the electricity grid will have to face because of the mismatch between renewable generation and electricity demand [3].

TRANSPORT CARBON EMISSIONS & RENEWABLE ENERGY INTEGRATION

Transport is one of the sectors where greenhouse gas (GHG) emissions have been on the rise. GHG emissions from road transport, account for almost 20% of total EU GHG emissions and have increased considerably since 1990[3]. Also, congestion and traffic affect the air quality, leading to an increasing number of cities introducing low or zero-emission areas, limiting the entry of internal combustion engine vehicles [4].

55%	**50%**	**0**
reduction of emissions from cars by 2030	reduction of emissions from vans by 2030	emissions from new cars by 2035

[3] COM/2021/556 final Proposal for A Regulation of The European Parliament and of the Council amending Regulation (EU) 2019/631 as regards strengthening the CO2 emission performance standards for new passenger cars and new light commercial vehicles in line with the Union's increased climate ambition. EUR-Lex - 52021PC0556 - EN - EUR-Lex (europa.eu)

Low and zero emission areas

There is an increasing number of low or zero emission areas where most polluting vehicles are regulated. In zero emission areas, only electric vehicles and hydrogen fuel cell vehicles are allowed in.

In Europe, the majority (73%) of the more that 500 UVARs concern low (and zero) emission zones.

In Spain, all municipalities with a population higher than 50.000 inhabitants will have to adapt their mobility framework with the establishment of low emission areas before 2023[4].

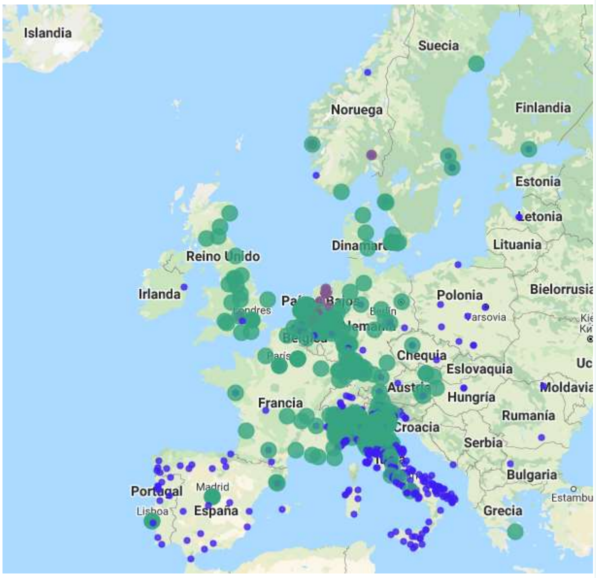

Table 1 - Low and zero emission areas across Europe.

The European Green Deal has an objective of a 90% reduction in GHG from transport, in order for the EU to become a climate-neutral economy by 2050, while also working towards a zero-pollution ambition.

The transport sector is going through a relevant structural transformation, including changes in digital and clean technologies. The shift from internal combustion engines towards low-emission or zero-emission technologies is especially relevant. Although the share of low and zero emission vehicles is growing rapidly, the total numbers are still behind the decarbonization objectives established in the EU.

[4] Law 7/2021, of May 20, of Climate Change and Energy Transition. [Disposition 8447 del BOE núm. 121 de 2021]

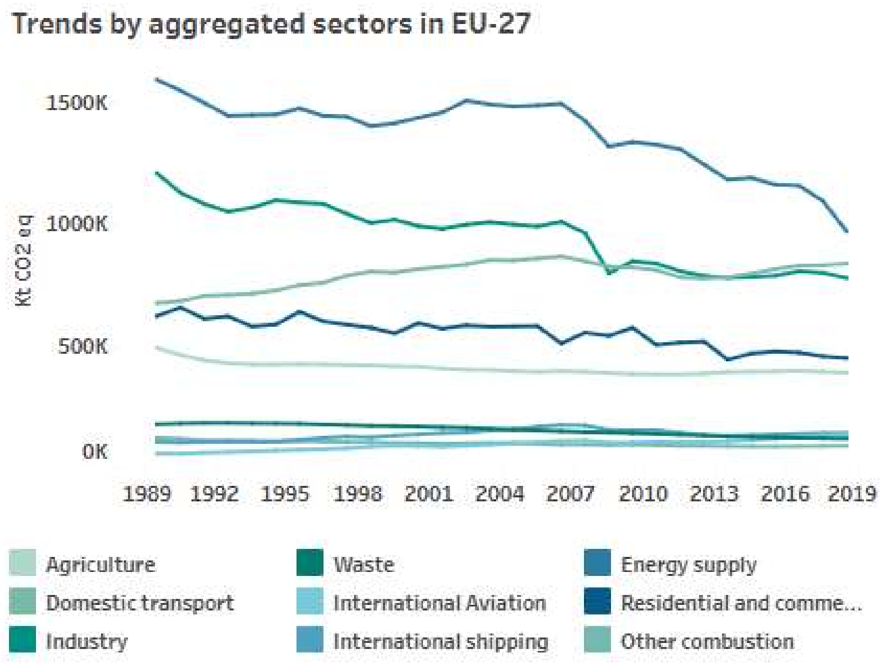

Figure 1 - EU Greenhouse gases. Trends by aggregated sector in EU-27. Source: EEA *[5]*

The EC has three specific objectives in terms of reducing transport emissions[5]:

- Contribute to 2030 and 2050 objectives by **reducing CO2 emissions** from cars and light commercial vehicles. Early action is needed to ensure that the necessary emission reductions for 2050 are achieved, in consideration of the long lead time needed for changes, especially for the fleet renewal.
- **Benefits for consumers and citizens**: not only in terms of air quality, but also for having more affordable zero-emission vehicle models due to an increasing number of sustainable vehicle models in the market.
- Stimulate **innovation in zero-emission technologies,** boosting zero-emission technologies and charging infrastructure.

To reduce greenhouse gas emissions, electric vehicle adoption has been discussed worldwide. Incentivizing the electrification of the transport sector contributes also to the renewable energy objective. The Commission presented Europe's new 2030 climate targets in the proposal for amending the Renewable Energy Directive[6], on 14th July 21. The proposal establishes a new

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[5] COM (2021) 556: Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL amending Regulation (EU) 2019/631 as regards strengthening the CO2 emission performance standards for new passenger cars and new light commercial vehicles in line with the Union's increased climate ambition. EUR-Lex - 2021_197 - EN - EUR-Lex (europa.eu)

[6] COM (2021) 577 Proposal for a Directive of The European Parliament and of The Council amending Directive (EU) 2018/2001 of the European Parliament and of the Council, Regulation (EU) 2018/1999 of The European Parliament and Directive 98/70/EC.

binding renewable energy target in the EU for 2030 of at least a 40% in the EU's overall energy mix by 2030, up from the 32% previous target. The proposal is now with the European Parliament and the Council. EVs' emissions depend on the grid supply mix, to achieve true decarbonization of transport via electrification, the electricity used to charge EVs must be from green sources.

In 2019, electric vehicles in operation globally avoided the consumption of almost 0,6 million barrels of oil products per day and the supplied energy to those electric vehicle fleets emitted the equivalent to 50 Mt CO2, half the amount that internal combustion engine vehicles would have emitted [1].

THE TRANSPORT SECTOR IN SPAIN

In Spain, mobility and transport sector represent 25% of the total GHG emitted. The road transport represents almost 95% of the transport emissions, while the contribution of other kind of transport is much smaller. Since 2016, domestic transport represents the highest source of GHG emissions in Spain and the second in the EU-27 only after energy supply.

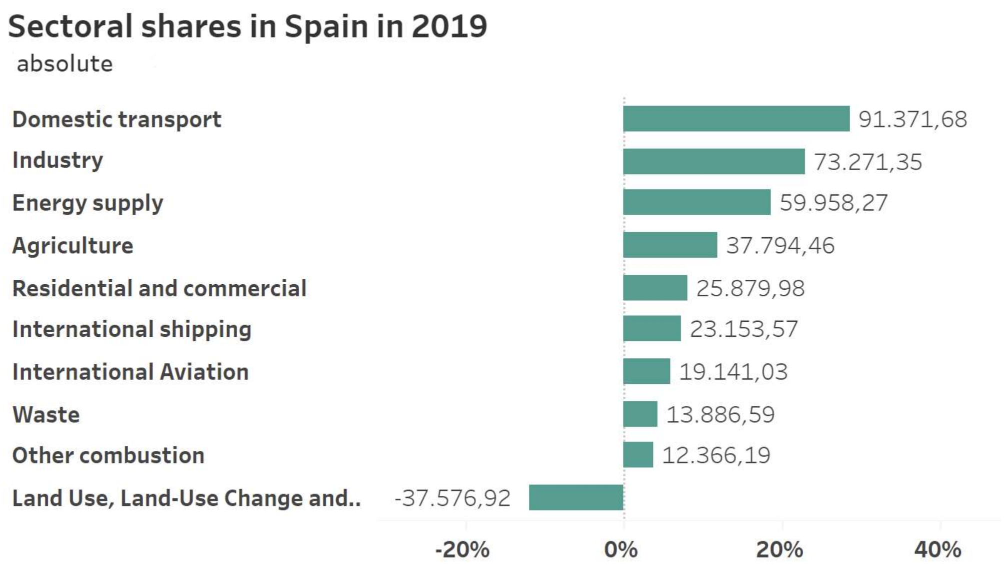

Figure 2 - Sectoral GHG emitted during 2019 in Spain [5].

The proposed legislation (Fit for 55) targets to cut EU greenhouse emissions from cars by 55% and vans by 50% by 2030 and also proposes to cut emissions from cars and vans by 2035. In Spain the Climate Change and Ecological Transition Law[7] states in terms of mobility that

[7] Law 7/2021, of May 20, of Climate Change and Energy Transition. OEG num. 121 de 2021

different measures will be adopted to achieve a vehicle fleet free of direct emissions by 2050. All the necessary measures will be adopted in accordance with the EU regulations, so that domestic cars and light commercial vehicles, might gradually reduce their emissions, so that no later than 2040 would vehicles be of 0g CO2/km[8] in accordance with the established by European Community regulators.

V2GRID AND ELECTRICITY MARKETS

The participation of V2G vehicles in electricity markets has been gaining importance among researchers and market participants. V2G is a technology that can help final users generate value. The electrification of the transport sector represents a challenge and electricity markets are an opportunity for EV users to have an extra revenue or income for participating in them.

A first concern about vehicle charging is that this could increase the load on the grid, especially in peak moments, but shifting the vehicle charging to other periods may also bring benefits to the power system.

V2G creates new business models and additional revenue opportunities by sharing a key underutilized resource: EV batteries. All this storage capacity could be aggregated, and act as a market participant in wholesale energy markets and in local and flexibility electricity markets.

The electricity price varies over the day in the wholesale electricity market. This opens an opportunity of arbitrage for V2G owners to participate in electricity markets, charging the batteries of their cars in moments of low prices and selling the energy when it is required because of demand peaks, or in moments with a higher electricity price. If EVs react to market price signals and thereby shift their behaviour, they will be able to reduce the overall cost of the electricity consumed.

Variable/smart charging and V2G have lasting value to the electricity system, both in terms of local flexibility in distribution grids and energy arbitrage as price spreads and volatility increases with the use of renewable energies.

Vehicle-to-grid will compete with a range of technologies to increase system flexibility, especially stationary battery storage, secondary batteries, flexible gas systems and smart charging.

[8] Article 14.2 of the Law 7/2021, of May 20, of Climate Change and Energy Transition. OSG núm. 121 de 2021

2/ V2G Concept

What is V2G and what are the V2X technologies?

2.1 V2X Technologies

Vehicle-to-Everything (V2X) and Vehicle-to-Grid (V2G)

V2X (Vehicle-to-Everything), is a technology that allows EV owners to manage the energy stored in the EV battery, charging and discharging it by putting back the energy to the grid or to a building from the battery of the car. The battery can be charged and discharged based on different signals such as electricity price. This technology can help to avoid constraints in the distribution grid, providing a value energy service to the network or also giving electricity supply to homes or buildings in moments that the electricity price is high. V2X includes different technologies depending on whether the user wants to use the electricity stored in the EV battery. This new concept can also increase and improve the EV batteries use for financial and non-financial benefits of their users as well as for the whole community and the electricity system.

Figure 3 - V2X charging technology, V2Market.

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V2G charging technology

	Charging technology
V1G **Unidirectional charging**  	This technology is **unidirectional charging.** It is the simplest way of implementing EV technology. Users can check when prices are low to charge their EV. This price signals are accessible to the public though different websites and apps. There are specific EV apps or systems which indicate to the final user when is the best moment for charging. It is also possible to automate the charger control response according to price signals. However, it is necessary to have implemented a control and communication system. The main advantage of this technology is the minimized cost of charging if the system dynamically reacts to price signals.
V2G **Vehicle-to-Grid**  	**V2G** is a bidirectional charging technology that uses the energy storage of EV to provide a service to the grid solving for example possible constraints on the distribution grid. This technology has the potential to participate in electricity markets providing the final user an extra income and helping at the same time to the overall system with their energy flexibility. This technology requires an appropriate model of charger, an auditable service render and a communication platform to control the V2G system. In order to give a reliable response to the grid, aggregation of multiple EV or fleets is required.
V2B **Vehicle-to-Building** **V2H** **Vehicle-to-Home**  	**V2B** is a bidirectional charging technology where the discharged energy from the car gives service to a building. **V2H** is a bidirectional charging technology where the discharged energy from the car gives service to a home. V2B and V2H can be combined with the V2G technology to also give service to the grid even if the vehicle is connected to a building or a home. V2H and V2B can generate value to the final user by reducing the electricity bill cost and by maximizing the self-consumption when combined with a solar installation.

Table 2 - V2G, V2H and V2B concepts.

In general terms, the Vehicle-to-Everything V2X concept is the technology where EVs can provide electricity to different electrical systems from the vehicles' energy to fulfil the necessities of a certain service.

V2G is an innovative service that is in touch with the final use of electricity domain but also with the transport domain where the end user is at the centre of both. The benefits that this technology can provide to users and organizations encourage the development of these technologies and infrastructure. One of the main advantages that V2G or V2B offer to the final user is the opportunity to reduce their energy bill and the protection against price spikes, offering them an efficient charging solution. V2G technology also helps the independence, affordability, trust on service providers, environmental concerns, and participation in energy communities or with self-consumption.

2.2 Benefits of the V2X technology

V2X and in more in particular V2G and V2B are technologies that offer a huge range of benefits to active consumers and EV owners but also to the electrical system and the society. Electric vehicles are one of the most important new elements in the power system. By balancing energy variations of production and demand, V2G technologies will help scaling up renewable energy resources and, due to that EV drivers will literally drive the energy transition. V2G and smart charging technologies open a new opportunity for active customers to participate in the electricity market with low effort and in an effective way. New business models will emerge in the coming years for consumers and business regarding smart charging and V2G technologies. Some of the advantages that V2G offer to final users are:

- **Reduction of the final electricity bill** by adapting users' behaviour thanks to the flexibility of the energy in their EV batteries. For that, users must react to clear electricity price signals provided by the electricity market. Discharging their battery to the grid in peak price moments can also help all consumers by offering more supply and **lowering** this way the final **electricity price at peak time**. Researchers found that participation in V2G services for the grid would result in a significant **decrease of charging costs** [6].
- Efficient and **smart charging,** as part of the V2G technology, allows final users to always have their vehicles ready to go with enough capacity for their day-to-day. One of the main concerns is the user's mobility needs to be satisfied at all circumstances.
- V2G is a technology that offers **protection against electricity prices spikes.** Final users will be able to react to energy prices and modify their consumption to save energy

in moments of high demand prices and consume it in periods with lower electricity cost for them.

- Electric vehicles are also an opportunity for increasing **self-consumption** when combined with renewables generation technologies, i.e., users that have an EV car and a photovoltaic installation on their rooftop can use the energy generated by their solar panels to charge their vehicle increasing in this way their percentage of self-consumption. This energy could also be discharged later in hours when no solar production is available.
- V2G technology **provides a source of income** and helps to reduce the operational cost of vehicles and fleets and the investment cost in new vehicles. Through their participation in electricity markets EV users will see an income for the energy they provide to the electrical system. Users will have a clear incentive to participate in the electricity market. V2G users can get market price arbitrage revenue because of the variation of the energy cost with time. The amount of revenue available depends on the variation between the price at which the battery was charged versus the market price when the battery was discharged.
- Vehicle-to-grid lowers the cost of running electric vehicles by generating extra savings through a combination of behind-the-meter **reductions in grid charges** and savings in energy cost.
- V2G systems have **easy controls over the vehicle´s state of charge**. Final users need to know exactly the availability of the charge that their vehicle has. Final users need to have the total control over their car independently of the V2G service that are providing to the grid. The most common monitoring tool for users are apps developed by their technology and energy providers.

Figure 4 - Benefits that V2G/V2B can have for final consumers. Source: V2Market own elaboration.

V2G offers several opportunities and advantages, and not only for final EV users. When electricity consumption increases, it can put a strain on the grid, creating overloads. V2G charging solutions can help the power grid in many ways:

- V2G can provide a **solution to grid congestions** due to overloads or other type of stress moments in the network.
- EV and V2G technologies **support the uptake of renewable energies** on the electricity system. V2G increases the positive impact that EV have in reducing carbon emissions by supporting the uptake of renewable sources to the network.
- With V2G, EVs can discharge their batteries into the grid during consumption peaks and charge them during periods with an excess of renewable generation.
- Electric vehicle charge-discharge management could **delay or avoid** transmission and distribution power investments **such as transformers and power lines**. This reduces the network charges for all customers.
- EVs and V2G can reduce the emissions of the transportation sector when fueled with an electricity mix mostly made up of renewable energy.

3/ Electric vehicle technologies and infrastructure

Bidirectional charging, the base for vehicle-to-grid technology.

The EV market is a growing one with 12 million passenger EVs currently on the market representing 1% of the global fleet with predictions to grow to 54 million units and more than 1 million commercial EVs comprised of buses, trucks, and delivery vans, by 2025. On the road globally, there are more than 260 million electric mopeds, three-wheelers, scooters, and motorcycles [7].
With better performing new EVs coming on the market that have higher battery range, with battery prices dropping and policy pressure toward 'Net Zero' raising at a global level, the predictions regarding the growth of the EV market are more than positive.
Last year registered the most significant increase of EV acquisition in the last 5 years. This is due to the increased policy push and support, the battery increased performance and lower cost of the battery, investments into infrastructure (also due to public incentives), fast charging and bidirectional charging, rising commitments, and developments from automakers and at the same time the growing comfort of consumers with EV's [8]. At the same time the market has experienced an increase on the adoption of electric trucks and vans, not as sharp as of passenger EV, but still notable.

3.1 Electric vehicle and charging technologies

Global vision of electric vehicle technologies.

The typical EV is known as a battery powered electric vehicle or BEV. Then under the EV umbrella one also finds the hybrid versions such as the classic hybrid electric vehicle (HEV) and the plug-in hybrid electric vehicle (PHEV):

- **Battery Electric Vehicle** (BEV) also called All-Electric Vehicle (AEV) run solely on battery power and can be charged via EV chargers.
- **Plug-in Hybrid Electric Vehicle** (PHEV) builds on the concept of the standard hybrid vehicle as it has an internal combustion engine (ICE) and a battery-powered

electric motor. PHEV batteries can be charged using a charging equipment. There are two types of PHEVs: extended range electric vehicles (EREVs), or series plug-in hybrids and parallel or blended PHEVs [9].

- **Hybrid Electric Vehicle** (HEVs) run on battery power with assistance from internal combustion engines, as such it combines an electric motor that uses the energy stored in a battery with an internal combustion engine. A specific feature of this type of vehicle is that it charges its battery via regenerative braking.

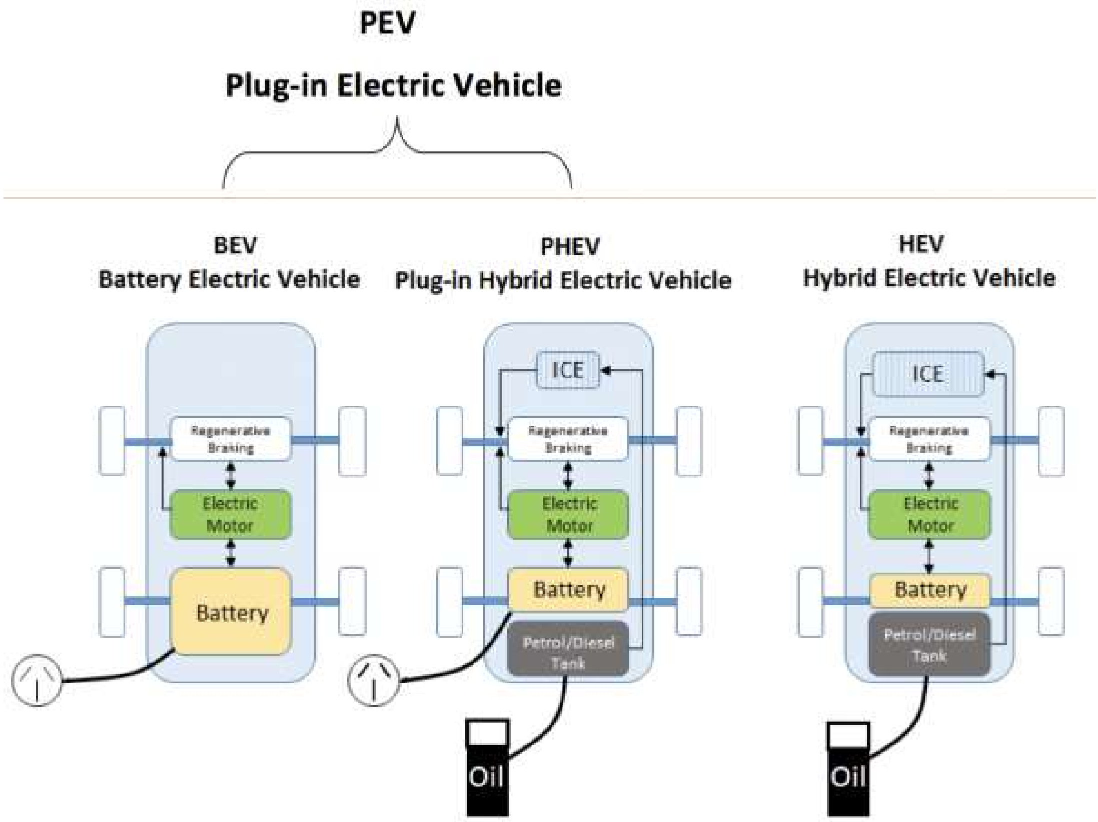

Figure 5 - Electric vehicle types: Battery Electric Vehicle, Plug-in Hybrid Electric Vehicle and Hybrid Electric Vehicle. [10] [11]

V2G technology can be adopted in battery electric vehicles (BEV) or plug-in hybrid vehicles (PHEV).

In 2020 in European countries, BEV registrations accounted for 54% of electric car registrations, continuing to exceed those of plug-in in hybrid electric vehicles (PHEVs). The share of BEVs was particularly high in the Netherlands (82% of all electric car registrations), Norway (73%), United Kingdom (62%) and France (60%) [1].

BIDIRECTIONAL CHARGING

Bidirectional EV charging allows the energy to flow in two ways: from the grid towards the EV (whilst the car is charging) and from the EV to the grid, either to a house or building (V2H/V2B), or directly to the grid (V2G). Clearly this development in the charging infrastructure, and the fact that it is becoming more affordable and more efficient, is opening multiple opportunity funnels for the consumers, and it has a positive impact on the adoption of EVs by consumers. This was confirmed by a study performed by Wallbox [8], finding that 75% of the respondents confirmed that bidirectional charging is having a major impact and true potential to facilitate the energy transition towards a green model. The first bidirectional charger for home users was launched in 2021 by Wallbox.

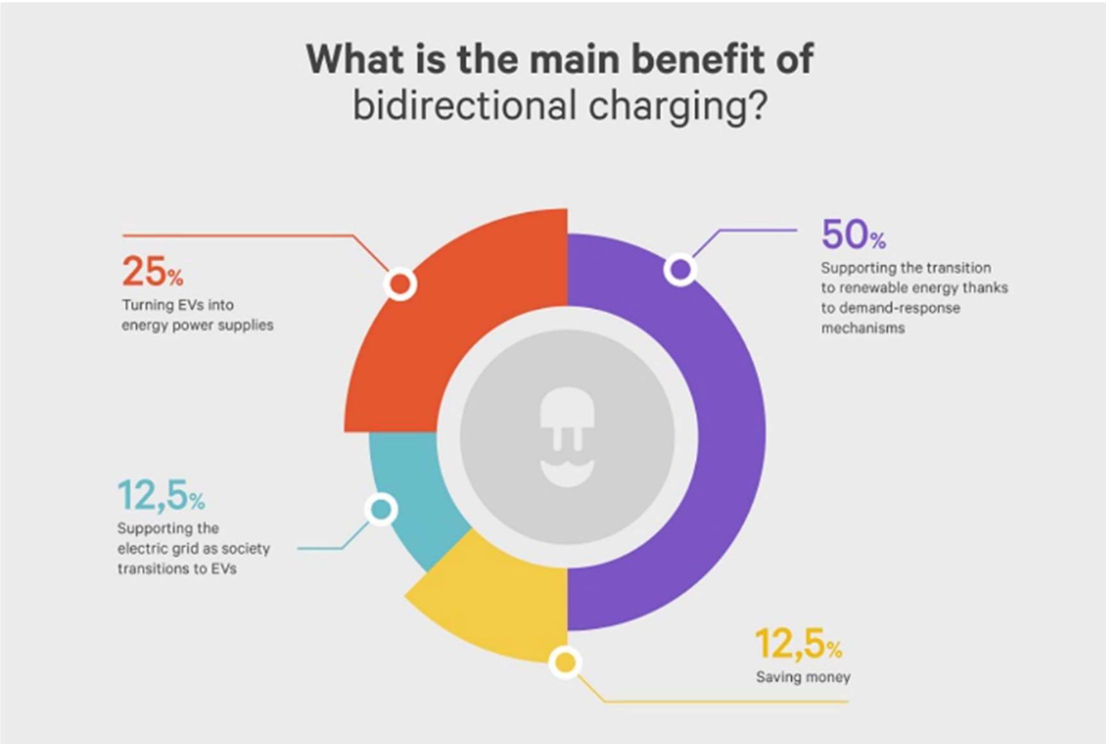

Figure 6 - Benefits that user see for bidirectional charging EV technologies [8].

The sharp increase of EVs predicted for the next years means an important increase in energy consumption which puts enormous pressure on the grid. Bidirectional chargers can support and solve this problem by using the EV batteries as storage and as grid balancing tools throughout periods of peak demand and low renewable energy supply. These mechanisms positively impact the use of renewables by maximizing them, cuts out polluting energy supply and avoids high investments in grid upgrades which would be necessary to increase their energy capacity [8].

The bidirectional chargers are transforming a simple EV into a source of energy supply for grid and market operators, and, at the same time, they can become a source of different cash flows for the end consumer by selling energy back to the grid through the electricity markets. V2G has the potential of becoming an essential tool for managing peak energy demand for distribution system operators (DSO).

V2G allows existing EV batteries the capability of a modern grid-connected battery, but additional equipment is also required if it is compared with normal EV plugs. It is necessary to implement other equipment such as bidirectional inverters to convert the DC current into AC or bidirectional measure counters. The vehicle and battery must be compatible also with bidirectional charging and prepared in terms of communication protocol for V2G technology. In the section the standardization of the communication protocol will be studied.

CHARGERS CHARACTERIZATION

Nowadays, the most common classification for EV chargers is according to the level or charger speed and power. There are three commercially widespread levels:

- **Level 1** (up to 3.7kW), normal or conventional plugs, refer to devices installed in households in single-phase, there are not specialized for EV charging. This type of charging simply connects to a standard outlet. It is a type of connection that is usually common for charging motorcycles or small cars. With this type of charging the full recharge of the battery varies between 8 to 12 hours and 1 to 2 days depending on the capacity of the battery.
- **Level 2** (up to 22kW) exploit AC current while Level 3 can be either AC or DC for two-phase or three-phase supply voltage. For level 2 chargers it is common to have a wall box. This level of connection requires the existence of electric vehicle supply equipment. This type of charging infrastructure is used for a faster charger than a level 1 connection and is use in homes and in public points where users have their car for a period between 4 to 8 hours.
- **Level 3** chargers are referred to as fast-chargers and ultra-fast, and the power outputs range from up to 43.5kW for AC 3-phase technology and up to 400kW for DC. Level 3 chargers are used in public places where the objective is to spend the least time possible, as in the middle of a long travel. For this, their power must be very high. DC fast charger can reach charging levels up to 80% of the battery in 30 minutes.

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	Normal plugs LEVEL 1	Slow chargers LEVEL 2	Fast chargers LEVEL 3	
Power	<3.7 kW	>3.7 kW and < 22 kW	> 22 kW and < 43.5 kW	<400 kW Ultra-Fast Charging
Current	AC	AC	AC	DC

Table 3 - EV chargers' classification according to the level or charger speed and power.

Fast and ultra-fast charging are significantly faster than regular charging stations or charging points, taking between 15 to 45 minutes to charge most passenger electric vehicles up to 80%. In Europe only one in nine public charging points is a fast charger [12] .

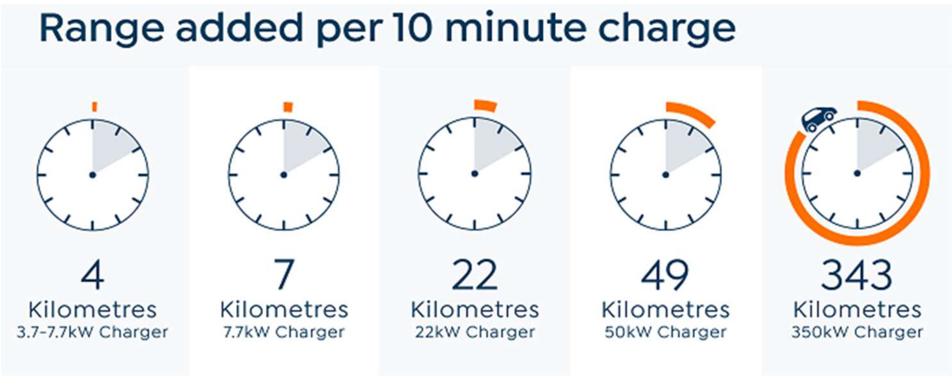

Figure 7 - Range added per 10-minute charge of an EV according to the charger capacity [11].

Another of the characteristics that differentiate charges is the **type of socket** and connector used for charging. Types of sockets and connectors vary depending on the country, but European standards follow Type 2 IEC 62196-2 and Type 2 IEC 62196-3, also called Combined Charging System Combo 2.

The reality is that there are several charging standards and plug options, depending on the country, manufacturer, or region. Standards are constantly changing and there is a necessity of standardization and harmonization of these technology standards. The most common DC fast charger plugs in the global market are the CHAdeMO, charge de move (accepted by IEC 62196-3 and IECC61851-23) and initially proposed by five Japanese companies, the Tesla supercharger and the Guobiao (recommended-standard 20234) that is proposed by the Standardization Administration of China (SAC).

Chargers can have different types of sockets; and also incorporate or not additional types. Additionally, there are adapters that allow a vehicle to be connected to a recharging point with a different connection system.

The mode of the charger in terms of **communication protocol** is another necessary characteristic. Different chargers host different types of communication protocols and rely on different physical connections. While AC slow-chargers are not prepared for communicating information, it is possible to regulate the charging speed of AC fast-chargers, but still require external controls for communication.

On the other hand, DC fast-charging combined charging system (CCS) is coupled with power line communication (PLC), while CHAdeMO, Tesla and Guobiao use a controller area network (CAN). PLC and CAN protocols allow for smart charging strategies such as V2G. CCS is an international standard used in Europe for charging electric vehicles that uses a single connector for various charging modes, both alternating current and direct current.

One of the main barriers is the necessary standardization of the equipment and communication protocols. As EVs move from one place to other, using different plugs and connectors, a standardization process in terms of communication protocols, infrastructure, and sockets is needed. The lack of standardization could limit the deployment of V2G services. Products should be interoperable, regardless the supplier or manufacturer and allow cross-industry interactions.

The lack of a standardized protocols makes V2G adoption more difficult. Each manufacturer has its own adaptation of the OCPP protocol, the communication protocol of the recharging points, this results in considerable increased implementation costs and more difficulty in the uptake of V2G.

3.2 Overview of EV and infrastructure costs

In the past decade, electric vehicles have gone from a rare and expensive transportation option to a more common and affordable option. The cost of electric vehicle components such as the battery – one of the most expensive components of EV- has fallen due to technology innovation and a higher demand of these technological components. New battery manufactures have appeared and, in the last year, EV sales set new records, particularly in countries with policies that support zero emission policies in transportation. This speeding growth means it is necessary to provide more places to charge EVs. The objective of the EU is to build enough public fast-charging stations to meet demand and enable a real transport transition to EV.

It is an important factor to enable EV and V2G technology to build out the charging network with the right number and distribution of charging stations, ensuring they are properly maintained and functioning. Reliability of charging stations, specifically on highways and destination charging are as important as large coverage. Final users need to have the assurance that they can find a working charging station when they need it. V2G has at its basis a range of enabling technologies and infrastructures (vehicles, chargers, controls, and communications).

CHARGING INFRASTRUCTURE COST AND EVOLUTION

Charging infrastructure's cost is affected not only by expenditure on the technology (the charging station itself). Many other factors contribute to the final overall cost and must be considered when forecasting and assessing future costs:

1. **Installation costs**: include working hours of skilled staff, grid updates (lines, transformer upgrades…) and vary whether the charging station is located at an existing gas-station (where electrical connection is already available) or in a new location.
2. **Land costs**: in literature those are recognized to be quite an important parameter, especially sizing, and allocating parking lots for EVs. Physical location and proximity to a parking area is a key factor for the final user [13]. Land costs can be highly variable and location-specific [14].
3. **Operation and Maintenance cost:** general maintenance for charging infrastructure includes storing charging cables securely, checking parts periodically, and keeping the equipment clean. Chargers may need intermittent repairs as well [15].

V2G hardware prices are dropping, as demand increases, but still, it needs to arrive to approximately the same price as smart charging solutions to be valuable. V2G offers a longer-term value to the end customers in addition to the normal charging of their vehicle. The chart below is from V2Britian in 2019 [16] and it shows price forecasts for V2G hardware, the ink circle indicates the current price range. Prices are dropping faster than projected but still vary depending on power ratings for example for V2G from 7kW to 150kW.

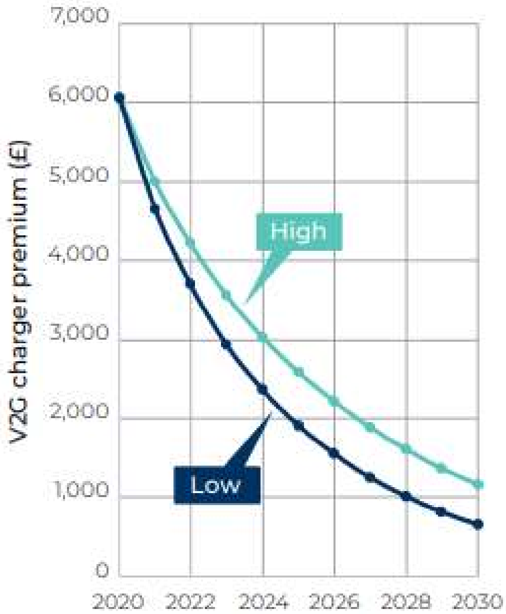

Figure 8 - projected V2G charger premium price [16].

In the coming years the price of charging stations will go down driven by customer demand, wider offer of compatible vehicles, opening of markets and increase of manufacturing capabilities.

EV EVOLUTION AND COST FORECAST

Passenger EV sales are predicted to increase constantly in the next few years, from 3.1 million registered in 2020 to 14 million in 2025 globally [7]. This would represent a 16% of passenger EVs to be sold by 2025. However, in some countries such as Germany, the share is expected to be a lot higher, up to roughly 40% by 2025, and in China it would reach 25% (largest market in the world). This growing trend is primarily due to policy regulation i.e. Europe's vehicle CO2 regulations [7].

In terms of heavier vehicles, at a global level there are currently 600.000 electric buses on the road, which represents roughly a 39% of new sales and a 16% of the global fleet. China is the biggest player on the electric busses sales in 2020 with more than 74.000 units sold (98% of the global fleet) [7].

In terms of biggest short-term opportunity, the e-buses and the two and three wheelers are the most promising e-mobility ones in emerging economies.

Electrification is also being developed on the heavier vehicles segment. In urban duty cycles, battery electric trucks of any size become the cheapest option for several use cases in the 2020s. That is due to a combination of factors, including rapidly declining battery costs, modest driving ranges, and the relatively large efficiency penalty of diesel trucks in urban traffic, which tend to consist of congested and recurring start-stop operation.

The cost of electric vehicles is mainly influenced by:

- **Battery Price.**
- **Raw material** availability and demand (metal i.e. cobalt, lithium and nickel).
- **Supply chain** (last year the supply chain issue that started in China within the chip industry influenced timelines of delivery and prices).
- **Emissions and CO2 price** for the commercial players i.e. transport and distribution companies, delivery companies.
- **Access to charging infrastructure** due to utilization rates, maintenance costs, the grid state, infrastructure investments needed to support these chargers i.e. public incentives or private investments and overall economics.
- **V2G, V2M and V2H developments.**
- **Electricity demand and supply.**

Batteries are one of the EV structural elements that represent the highest costs and is also a key element in terms of performance limitations. Batteries are characterised by different parameters, being the most important energy density, power, efficiency and degradation. All these battery parameters have been improved in the last decade resulting in a 17% increase annually of the autonomy of an EV in the last decade [8].

According to the BNEF's yearly survey on battery prices, the average cost of EV storage systems declined by 13% between 2019 and 2020, and lithium-ion battery packs [17], the most common in the EV industry, which were above $1.200/kWh in 2010, have fallen by 89% in real terms to $132/kWh in 2021 [17]. The cost of an average battery pack is expected to go below $100/kWh on a volume-weighted average basis by 2024, with a cumulative demand of 2 TWh for that year [18]. The decrease in price will be due to the introduction of new techniques and a higher demand of electric vehicles and battery systems for household. Some big EV manufacturers have publicly announced targets of $80/kWh [18].

Battery improvements and new developments will have a massive positive impact in the growth of EV uptake for instance in the view of John Goodenough (co-inventor of the lithium-ion battery) and Seth Leitman (from The Green Living Guy), the next big step will be the solid-state batteries. According to them sooner or later solid-state batteries will become the future and it is possible than within the next 10 years. That would mean that EVs will have an autonomy of 900 plus miles in only one charge [8].

With the increase in EV demand EV batteries demand also rose quickly with shipments that increased by 45% in 2020 compared to 2019 and manufacturers have announced plans totalling 2,539 GWh of annual capacity due by 2025 [8].

The cost of an average battery pack is predicted to decrease due to the introduction of new techniques and new cell chemistries i.e., the use of new materials such as manganese, however high levels of investment will be needed to keep this trend [7]. Batteries will also improve their performance having higher energy densities and longer cycle life.

The supply for raw materials, such as manganese from currently known reserves, is predicted to be sufficient to meet demand up to 2050. However, to assure the balance for the other metals needed such as lithium, nickel and cobalt a strategy will be needed that will require that all the stakeholders i.e., governments, auto producers, cell manufactures and recycling facilities to collaborate. The EV battery recycling process can also help EV owners to obtain revenues back due to the sale of it to a third party [19].

4/ Analysis of the charging infrastructure in Spain and Europe

An intense work in installing new charging points must be done in the next years

The deployment of charging infrastructure, in line with the EV uptake, is a crucial enabler to allow e-mobility to be an alternative to conventional transport. This deployment is supported by environmental and transport policies that are in line with transport electrification and have the objective of reducing emissions to the atmosphere and making electric vehicle charging as easy as filling a combustion vehicle tank.
The next section describes regulation and policy for charging infrastructure as well as an assessment of the status of the charging infrastructure in Barcelona Metropolitan Area, Spain and in Europe in general.

4.1. Applicable regulation for charging infrastructure: regulation & permitting

CHARGING INFRASTRUCTURE IN THE EU AND SPAIN

Development of charging infrastructure in the EU

According to EU regulation, each Member State is responsible for designing and carrying out its policy for alternative fuel infrastructure under the general framework set by EU legislation. However, given that alternative fuels infrastructure is a trans-national challenge, it will be essential that EU legislation sets the tools to ensure common standards for interoperability and coordination between Member States in the deployment and monitorization of progress by Member States.
It has been noted that the deployment of EVs and charging infrastructure fall within the market failure described as “chicken-and-egg” problem, whereby investments in one are held back by the uncertainty of the development of the other, thereby slowing down the development of the market as a whole. Therefore, it is more important for there to be clear guidelines at a European level steering investments to green mobility.

Indeed, the Directive 2014/94/EU on the deployment of alternative fuels infrastructure, together with the European Green Deal, sets the framework for the desired greenhouse gas reduction from transport, aimed at 90% by 2050 compared to 1990, and requirements for the transition to alternative fuels. More recently, the Commission presented the “Fit for 55 Package”, a set of policies with the objective of achieving a reduction of net greenhouse gas emissions by at least 55% by 2030, compared to 1990 levels. The way to achieve this target is by limiting net emissions from new vehicles. The new European targets propose that by 2030, emissions from new cars must be reduced by 55 % compared to 1990 levels. Similarly, the European Commission has proposed a complete phase-out of ICE (internal combustion engine) vehicles by 2035. This means that by 2035 all new cars on the European market must be zero-emission vehicles. This will be accompanied by a Proposal for a regulation on the deployment of alternative infrastructure, which will repeal Directive 2014/94/EU[9].

It is also relevant to mention the article 39 of Regulation (EU) No 1315/2013 on the development of trans-European transport network, which establishes the availability of alternative clean fuels as a requirement for the 50.000 km of roads which are identified as the “core” network by 2030. However, despite this European legislation, a Special Report by the European Court of Auditors from 2021[10] found that “there are no clear and coherent EU-wide charging infrastructure targets” and that “travel across the EU is still complicated by the absence of minimum requirements for harmonised payment systems and user information.” Art. 4.8 of Directive 2014/94/EU stipulates that operators must be allowed to provide charging services directly (on a contractual basis with the customer) or indirectly (though a hub), on behalf of other providers. This necessarily requires roaming technology between different actors to allow users to charge using a single identification or payment method. Also, charging stations must be able to communicate to all EVs.

Development of charging infrastructure in Spain

At present, the public recharging service of electric vehicles in Spain is liberalized and it is the private companies, together with consumers (since the enactment of Royal Decree-Law 15/2018), who are responsible for rolling out the public recharging service according to demand and interests of the sector. According to ANFAC (the Spanish Association of Automobile and Truck Manufacturers), Spain is currently at the bottom 3 in Europe for electromobility,

[9] Directive 2014/94/EU on the Deployment of Alternative Fuels Infrastructure. [DIRECTIVE 2014/94/EU (europa.eu)]

[10] Infrastructure for charging electric vehicles: more charging stations but uneven deployment makes travel across the EU complicated:

considering the level of penetration of the electric vehicle and its public access charging infrastructure.

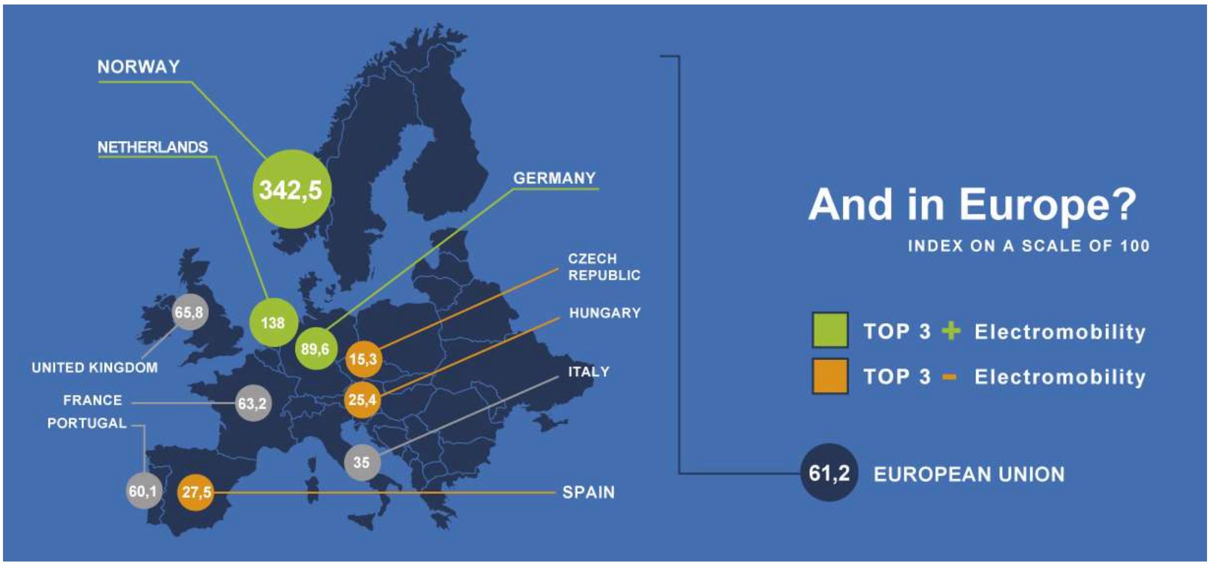

Figure 9 - The ANFAC index measures the level of penetration of electrified vehicles and their public access charging infrastructure. Barometer 4rt trimester 2021, ANFAC [20].

Regarding the evolution in the deployment of recharging infrastructure, ANFAC estimates that in 2025 there will be 110.000 - 120.000 charging points, which seems quite in line with the estimations of the PNIEC, according to which there should be 500.000 charging points in 2030 (taking a ratio of 1 charging point for every 10 vehicles and an estimation of 5.000.000 EVs).

To help with the deployment of the charging infrastructure, currently, the Spanish government has in place the Moves III plan, which offers subsidies for the purchase of EVs and deployment of charging infrastructure both for public and private use. The total budget is 400 million euros, which can be increased if fully allocated. In the case of charging infrastructure, the subsidized amount ranges from 30% for private companies and public entities with economic activity to 70% in the case of individuals, freelancers, condominiums, etc. All the following types of charging infrastructure are covered: private use in the residential sector, pre-installations in a housing condominium, public use in the non-residential sector (such as, public car parks, hotels, shopping centres, universities, hospitals, industrial estates, sports centres, etc.), private and public use in parking areas of private and public companies, public use on public roads and highways. Very relevant to this project, EV charging management systems will also be eligible, as well as telecommunications, internet, 3G, 4G or similar systems that guarantee intelligent vehicle charging that minimizes the need for an increase in contracted electrical power.

The regulation that lays down the minimum endowments for recharging points in newly built buildings and parking lots is contained in Royal Decree 1053/2014, as follows:

a. In car parks or collective parking lots of condominiums the main infrastructure must be carried out through communal areas, so that it is possible to carry out derivations to the recharging stations located in parking spaces.
b. In car parks or parking lots of private, cooperative or company fleets, or municipal vehicle depots and permanent public parking lots, the necessary facilities to supply one recharging station for every 40 spaces must be guaranteed.

Royal Decree Law 29/2021[11], on the other hand, lays down the minimum endowments for recharging infrastructure on roads. Specifically, it sets obligations for gas stations to install recharging infrastructure of 50 kW or 150 kW on direct current, depending on their volume of operations, within 14 months from the entry into force, which was December 22nd 2021. It also establishes that all recharging points accessible to the public must provide the possibility of punctual recharging to users of electric vehicles, without the need for a contract with the electricity supplier of that point.
The Spanish Government approved in 2021 the Energy Storage Strategy[12], key to guarantee security of supply and lower energy prices for the future years. The objective is "enabling the use of the fleet of electric vehicles as an energy storage resource, for which it will be necessary to design and update network codes, evaluate market incentives, and support policies to allow the load shaping. The application of storage systems on board electric vehicles will offer another series of services, through smart charging and vehicle to grid technologies (mobility to grid and mobility to home […]. Promote citizen participation in the intelligent management of the electrical system through the electric vehicle it is one of the keys to the effective use of this energy storage resource. To do this, Spain will work on establishing norms and standards in electric vehicle charging systems so that consumers can participate in the intelligent management of the electricity system and take advantage of tariffs on the loading of vehicles and the vehicle to grid" [21].

[11] Royal Decree-Law 29/2021, of 21 December, adopting urgent measures in the energy field to promote electric mobility, self-consumption and the deployment of renewable energies (Official State Gazette núm. 305, de 22/12/2021)

[12] "Estrategia Almacenamiento Energético", Spain 2021.(miteco.gob.es)

RECHARGING SERVICES

Article 48 of the Electricity Sector Law[13] (hereinafter, "ESL") reads as follows: "the main function of the energy recharging service will be the delivery of energy for free or for a fee through vehicle charging services and storage batteries in conditions that allow charging efficiently and at a minimum cost for the user and for the electrical system.".

The energy recharging services may be provided by any consumer and must comply with the requirements established by the Government regulations.

The provision of recharging services in one or several locations may be carried out directly or through a third party, in an aggregate manner by a holder or by several holders through interoperability agreements."

Royal Decree 184/2022[14] establishes the requirements for the provision of recharging services for electric vehicles at public access charge points. The preamble of the Royal Decree states that the necessary recharging infrastructure deployment means not only promoting and strengthening the provision of recharging points in all existing areas (residential, urban and interurban...) of the national territory, but also requires setting and consolidating the bases for the management of activity models linked to the provision of the EV recharging service.

Royal Decree 184/2022 covers charge points on the roads as well as those in private or public car parks, shopping centres, etc, as long as they are accessible to the public. There are two main figures:

- The **Charging Point Operator** (CPO) is the holder of the exploitation rights of electric vehicle recharging infrastructure, and is constituted as the consumer of electrical energy, in accordance with the provisions of article 6 ESL. However, the consumer may assign or transfer, in whole or in part, the rights to operate the electric vehicle recharging point infrastructure to third parties, who will assume the rights and obligations of the recharging point operator set out in RD 184/2022.
- The **eMobility Service Provider** (EMSP) participates, as a third party, in the provision of energy recharging services, without being the owner of an infrastructure of electric vehicle recharging points or its exploitation rights. The EMSP acts as a link between the charging users and the CPO through interoperability agreements.

We started this section mentioning that the deployment of charging infrastructure is liberalized. Unfortunately, as we have seen, the provision of electric mobility services is not liberalized.

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[13] Ley 24/2013, del Sector Eléctrico (Official State Gazette núm. 310, de 27/12/2013)

[14] Royal Decree 184/2022 which regulates the activity of providing energy recharging services for electric vehicles (Official State Gazette núm. 67, de 19 de marzo de 2022)

Indeed, the obligation of the recharging point operator (CPO) is only to allow recharging to all EV users, without the obligation for the user of having a contract with the supplier or the recharging point operator (what is termed in the regulation as "punctual recharging"). It is established that when CPOs give access to EMSP to their charge points through interoperability agreements, they must do so under non-discriminatory conditions. However, it is not mandatory for the CPO to make its recharging points available to the EMSP, which is a very clear barrier to competition.

Furthermore, the figure of the EMSP does not include at all the attributions of a flexibility service aggregator, nor are energy exchanges in the direction from vehicle to grid envisaged or regulated. In addition, as the law is drafted, the EMSP is expressly excluded from ownership of both the electrical infrastructure of recharging points and its exploitation rights.

PERMITING

From the permitting point of view, RDL 29/2021[15] has exempted the installation of charging infrastructure from obtaining a construction permit from the city council, which could take up to 6 months, and substituted it for a simple communication, meaning that once the technical documentation is submitted to the Council, the petitioner may directly carry out the installation.

From an industrial security perspective, ITC-BT-52[16] regulates the requirements that qualified installers must follow when installing a charging point. ITC-BT-52 is applicable to all kinds of charging infrastructure, whether public or private. It also lays down the different kinds of connection diagrams applicable depending on the distribution panel of the building.

Currently, the Ministry of Industry, Trade and Tourism of Spain is undergoing a process for reviewing the Electrical Low Voltage Regulation and its technical instructions, including ITC-BT-52. The public consultation period ended in March 2021. It would be expected and desirable that such modifications contemplate the inclusion of the terms of V2G and V2B and set the requirements for bidirectional chargers.

[15] Royal Decree-Law 29/2021 by which urgent measures are adopted in the energy field to promote electric mobility, self-consumption, and the deployment of renewable energies. This RDL modifies art. 48 of ESL relating to energy recharge services (Official State Gazette 305, de 22/12/2021)

[16] Royal Decree 1053/2014 which passes a new Complementary Technical Instruction, ITC-BT-52 "Facilities for special purposes. Infrastructure for recharging electric vehicles" (Official State Gazette num. 316 31/12/2014)

Regarding connection to the grid, the fifth final provision of RD-law 6/2022[17] modifies Royal Decree 1955/2000[18] to introduce stand-alone storage facilities, adding a section 4 to its article 115 with the following wording:

"*In relation to the need and processing of administrative authorizations, the storage facilities that are directly or indirectly connected to transmission and distribution networks alone or hybridized will have the same treatment than power generation facilities*".

REGULATION

The applicable regulation in Europe and Spain regarding recharging infrastructure is the following:

Regulation	Description
Directive 94/2014 on the deployment of alternative fuels infrastructure	Sets a common framework of measures for the deployment of an infrastructure of alternative fuels with the aim of achieving long-term oil substitution in transport.
Regulation (EU) No 1315/2013 of the European Parliament and of the Council of 11 December 2013 on Union guidelines for the development of the trans-European transport network	Sets the guidelines for the creation of a Trans-European transport network with the aim of promoting the growth and cohesion of member states. This transport network is based on the principals of efficiency and sustainability, aiming to achieve a significant reduction in CO_2 emissions.
Royal Decree 639/2016 establishing a framework of measures for the implementation of an infrastructure for alternative fuels	This Royal Decree transposes into Spanish legislation the provisions of Directive 94/2014. However, this regulation falls very short in ambition, providing no specific commitments and only some very general guidelines regarding infrastructure for alternative fuels, including recharging points for electric vehicles and refuelling points for natural gas and hydrogen.

Table 4 - Regulation in Europe and Spain regarding recharging infrastructure, April 2022.

[17] Royal Decree-Law 6/2022, of March 29, by which urgent measures are adopted within the framework of the National Plan to respond to the economic and social consequences of the war in Ukraine (Official State Gazette nº 76 30/03/2022).

[18] Royal Decree 1955/2000, of December 1, which regulates the activities of transport, distribution, marketing, supply, and authorization procedures for electrical energy installations. (Official State Gazette nº 310, 27/12/2000).

Regulation	Description
Royal Decree 1053/2014 passes a new Complementary Technical Instruction, ITC-BT-52 "Facilities for special purposes. Infrastructure for recharging electric vehicles"	This Technical Instruction regulates from the electrical point of view the connection of the infrastructure for the recharge of electric vehicles.
Royal Decree 647/2011 which regulates the load manager activity of the system for the performance of energy recharge services	This Royal Decree has been practically all repealed by Royal Decree-Law 15/2018, which eliminated the load manager figure and thus liberalised the provision of recharge services. Still in force are the additional and final dispositions which regulate tolls.
Royal Decree 15/2018 of urgent measures for the energy transition and the protection of consumers	Repeals most of RD 647/2011 and simplifies the regulation on energy recharge services.
Royal Decree Law 24/2021 for the transposition of EU Directives. Directive 2019/1161, on the promotion of clean and energy-efficient road transport vehicles is transposed	It transposes Directive 2019/1161 into Spanish legislation. This regulation establishes emission thresholds for the public sector when purchasing road transport vehicles which are set at 0 g CO_2 /km from January 1^{st} 2026.
Royal Decree-Law 29/2021 by which urgent measures are adopted in the energy field to promote electric mobility, self-consumption and the deployment of renewable energies	This Royal Decree-Law modifies art. 48 of ESL defining the scope of the energy recharging service. Also, it simplifies the requirements and duration for obtaining authorisations for installing recharge infrastructure on roads and in municipalities.

Table 4 - Regulation in Europe and Spain regarding recharging infrastructure, April 2022

Regulation	Description
Royal Decree 184/2022 which regulates the activity of providing energy recharging services for electric vehicles	This regulation develops article 48 of the ESL by setting the requirements for the provision of energy recharging services for electric vehicles. It introduces for the first time in Spanish regulation the figures of Charging Point Operators and eMobility Service Provider.

Table 5 - Regulation in Europe and Spain regarding recharging infrastructure, April 2022

4.2 Analysis of the charging station infrastructure for EV and V2G in Europe.

Fast charging infrastructure is being gradually deployed in Europe, at the same time the EV technology is growing in relative share above the total amount of vehicles. There is a need of modern charging infrastructure to respond to electric vehicles with higher power requirements (vans, buses, tracks…). Thanks to the technological progress in fast charging, charging times are being reduced and more users decide to acquire an EV as they facilitate longer journeys. During 2020, despite the COVID pandemic situation, publicly slow and fast chargers increased to 1,3 million [1].
In Europe the fast-charging technology is becoming more popular in publicly accessible places and are introduced in the market with a higher rate than slow charging. In terms of slow chargers, Europe counts with 250.000 chargers.

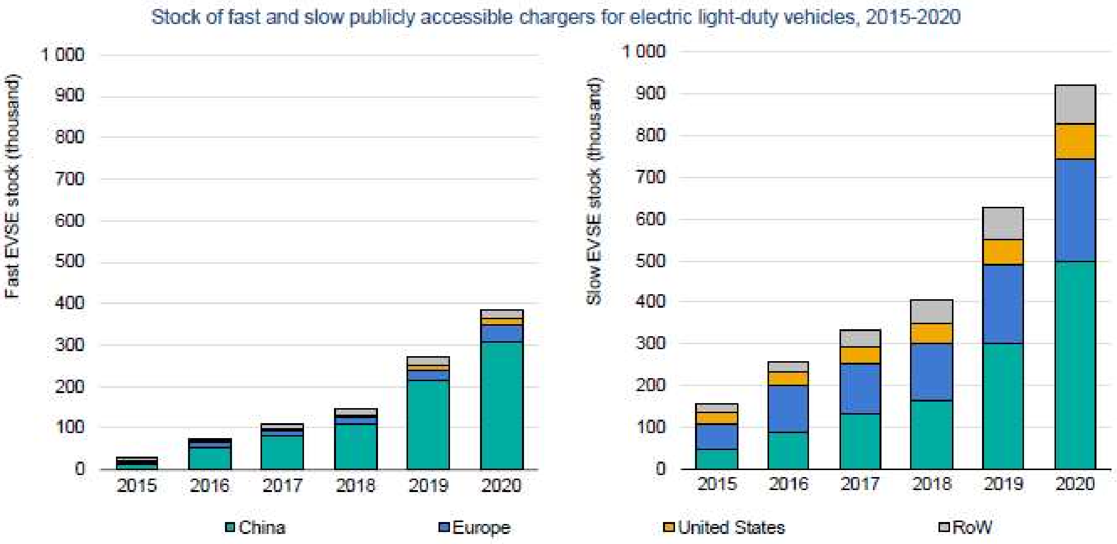

Figure 10 - Stock of chargers for electric vehicles, 2015-2020 [1]

In 2014, the Alternative Fuel Infrastructure Directive[19] regulating the EVSE in the European Union, set that the appropriate average number of recharging points should be equivalent to at least one recharging point per 10 EVs by 2020, also taking into consideration the type of cars, charging technology and available private recharging points. Only The Netherlands, Italy and France reached a ratio equal or higher than 1/10 [1].

By the end of 2019, 76% of the public charging infrastructure network in Europe 26 was concentrated in five countries (The Netherlands, Germany, France, the United Kingdom, and Norway), while only the 45% of the European population are inhabitants of these five countries [22].

[19]Directive 2014/94/EU on the Deployment of Alternative Fuels Infrastructure. [DIRECTIVE 2014/94/EU (europa.eu)]

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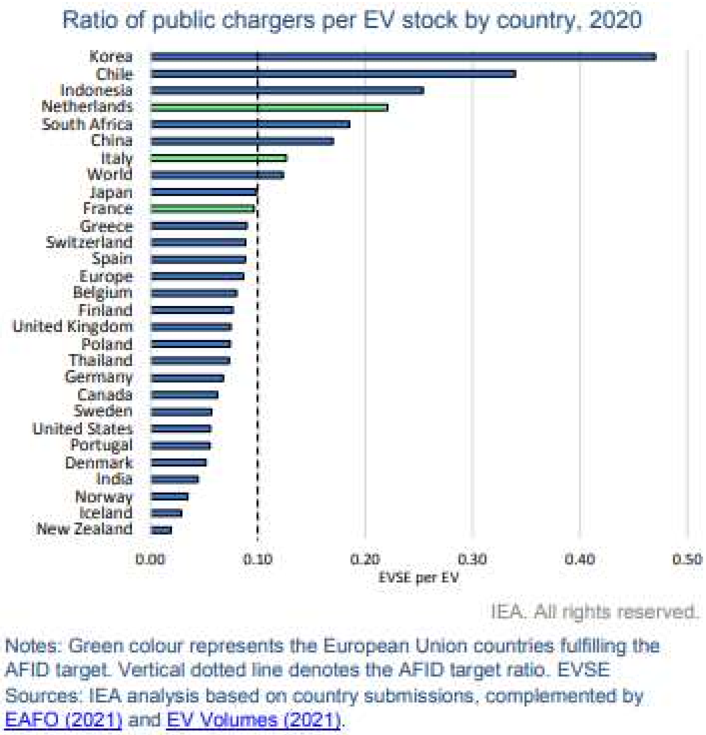


Figure 11 - Ratio of public chargers per EV stock by country, 2020 [23]

Countries with a low ratio of public charging points are those who have the highest EV penetration: Norway (0.03), Iceland (0.03) and Denmark (0.05). In these countries it is common to have a charging point at home, with a high proportion of fast-charging infrastructure.
EV sales have increased during the last decade. In 2020, the share of electric cars registered in EU-27, Iceland, Norway and the UK reached the 10% of the market. In 2021 this share increased from the 10% of the previous year to 17%, with a peak of the 26% in December [24].

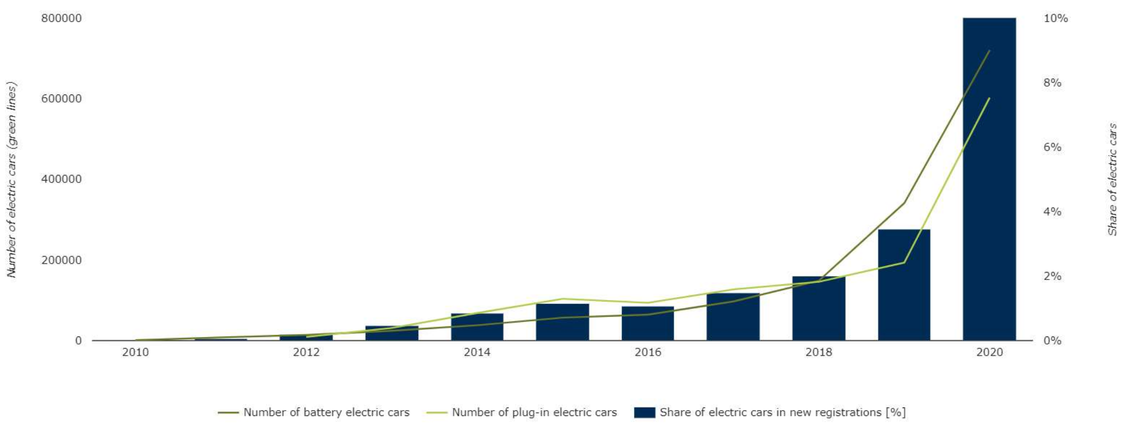


Figure 12 - Electric cars registered in the EU-27, Iceland, Norway, and the United Kingdom [25]

4.3 Analysis of the charging station infrastructure for EV and V2G in Barcelona and Spain.

Spain is the fifth largest passenger car market in Europe only behind Germany, Italy, France and UK. However, the growth of electric cars in Spain has been slower than in other European countries. The Integrated National Energy and Climate Plan 2021 – 2030 (PNIEC) includes measures to achieve a total fleet of 5 million electric vehicles and 500.000 chargers for 2030. Spain also introduced a target of 100% new EV sales by 2040 according to the Law on Climate Change and Energy Transition[20].

The National Government, through State Secretariat for Energy, works in a European project on identification and placement of recharging points that will be available along 2022. According to estimations of the sector (Spanish Association of Car and Trucks Manufacturers –ANFAC- based on Electromaps data), at the end of 2021 there were 13.411 available charging points for public use (5.726 of them, placed on roads and the other 7.685 in urban areas).

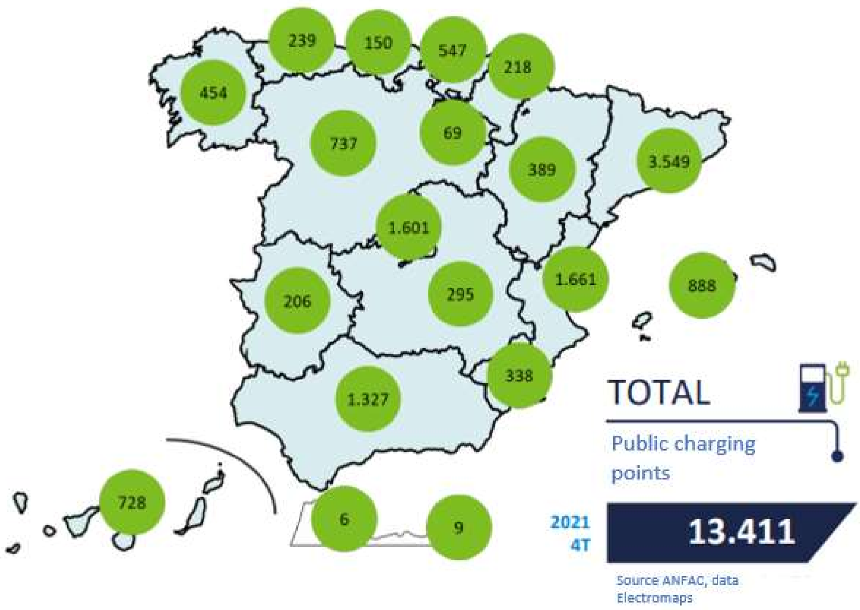


Figure 13 - ANFAC, Public recharging infrastructure in Spain (T4, 2021) [20]

20 Law 7/2021, of May 20, of Climate Change and Energy Transition. [OSG num. 121 de 2021]

The objective of the Recovery, Transformation and Resilience plan (PRTR) in Spain is in the range of 80.000-100.000 public recharging points by the end of 2023.

During 2021, 42 new recharging points of at least 250 kW were installed in Spain. The 92 public access charging points that currently exist are 350 kW and 400 kW and are spread over 33 stations. Canary Islands, Cantabria, Rioja, Ceuta and Melilla do not have any high-power public access charging point. 95% of high-speed public access charging points responds to projects of vehicle manufacturers [20].

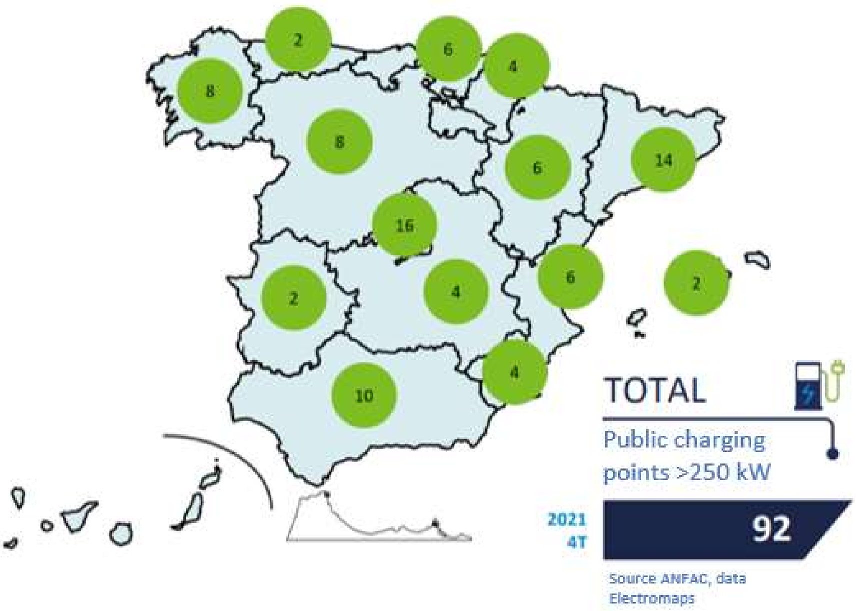


Figure 14 -ANFAC, Public recharging infrastructure > 250 kW in Spain (T4, 2021) [20]

The uptake of the electric passenger car market in Spain is not uniform across the country. The EV market is rapidly growing in the Barcelona Metropolitan Area (AMB) reaching a total sold amount of nearly 11.070 cars during 2021. The EV is now on the citizens agenda, after the prohibition to enter in the Barcelona metropolitan area with fossil fuel cars that were sold before 2006 [26]. This measure, combined with population awareness of climate change and economic incentives (MOVES plan) to buy zero emission cars is booming the amount of EV being sold in the region.

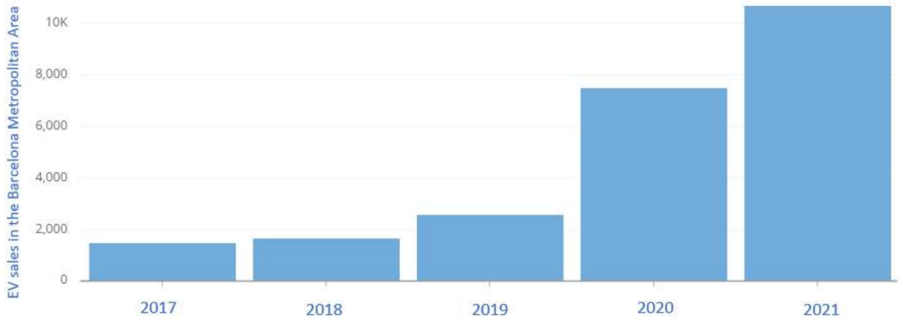


Figure 15 - Number of electric vehicles sales in the Barcelona Metropolitan Area [27].

The next map shows that electric passenger vehicles share was highest in the Madrid Metropolitan Area and Barcelona Metropolitan Area. The uptake in metropolitan areas is higher than in non-metropolitan areas. The metropolitan areas of Barcelona, Alicante and Las Palmas had a 125% more of new electric vehicles registrations during 2019 compared with the national average [22].

Figure 16 - Passenger battery and plug-in hybrid electric vehicle sales share in 2019 [22].

A research study published by ICCT that estimate the number of chargers needed for 2025 and 2030 shows that intense work in installing new charging must be done in the next years. The publication contemplates two scenarios: one with a 50% of electric car share in 2030 and a second one that elevates this ratio to a 70%.

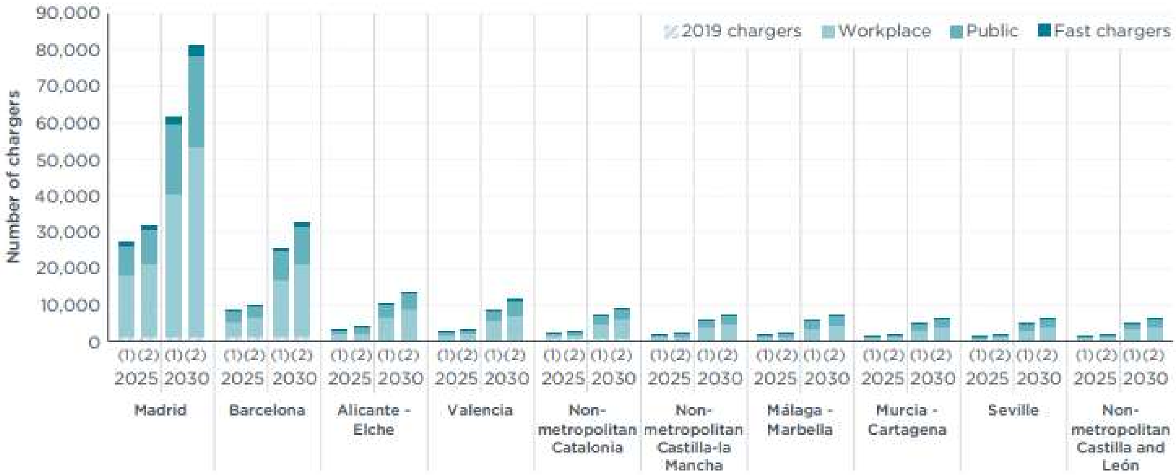


Figure 17 - Chargers existing in 2019 versus chargers needed by 2025 and 2030 for selected metropolitan and non-metropolitan areas [22].

According to the Table 6, in 2019 Barcelona had only about a 16% to 19% of the 2025 charging needs for 2025 and 5% to 6% of the charging facilities needs for 2030. It is expected that in non-metropolitan areas the ratio of chargers per vehicle will be lower due to home charging. On the opposite point, the number of workplace chargers is expected to increase due to the higher demand for charging at work [22].

In the Barcelona Metropolitan Area there are a total of 214 public charging stations divided in the following municipalities and power, according to the data of the Generalitat of Catalunya [27]:

Charging level	Number of charging stations
Badalona	6
50 kW	1
Not specified	5
Barberà del Vallès	2
11 kW	1
50 kW	1
Barcelona	177
11 kW	2
22 kW	8
50 kW	19
7.5 kW	7
Not specified	141

Table 6 - Total EV Charging facilities in Transparencia de Catalunya data base *[28].*

Charging level	Number of charging stations
Castellbisbal	1
Not specified	1
Castelldefels	2
Not specified	2
Cornellà de Llobregat	2
50 kW	1
Not specified	1
El Prat de Llobregat	2
50 kW	1
Not specified	1
Esplugues de Llobregat	1
Not specified	1
Gavà	3
50 kW	1
Not specified	2
L'Hospitalet de Llobregat	3
50 kW	1
Not specified	2
Molins de Rei	1
22 kW	1
Montcada i Reixac	1
50 kW	1
Pallejà	1
50 kW	1
Ripollet	1
Not specified	1
Sant Adrià de Besòs	1
Not specified	1
Sant Cugat del Vallès	7
Not specified	3
120 kW	1
22 kW	1
50 kW	2

Table 6 - Total EV Charging facilities in Transparencia de Catalunya data base [28].

Charging level	Number of charging stations
Sant Joan Despí	1
50 kW	1
Santa Coloma de Gramenet	1
Not specified	1
Viladecans	1
Not specified	1
Total general	**214**

Table 6 - Total EV Charging facilities in Transparencia de Catalunya data base *[28].*

Most of the charging stations are located in the city of Barcelona, not being its power specified. Approximately 5 % of these stations belong to hotels, 27% to underground public car parks, 10% to shopping centres, 2% to taxi charging stations and the 55% are located on the streets. The most interesting charging stations for this project would be those allocated in shopping centres where users can spend between 1 and 3 hours and underground public car parks where users can spend from 1 hour up to days because some public car parks also provide residential parking.

The presented numbers do not include residential charging points due to lack of data. The estimation data is that each EV user has their own charging station.

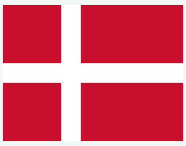
At the moment, there is only one public charging station with V2G technology operational, although AMB is currently installing 16 more in the following locations:

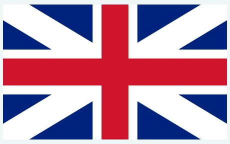
Municipality	Public building associated	N charging stations (V2G)	Power (kW)	Status
Molins de Rei	Local sports center	1	10 kW	Already Operational
Sant Just Desvern	Local Police Station	1	7,4 kW	Operational in 2022
Sant Cugat del Vallès	City Hall	13	7,4 kW	Operational in 2022
Esplugues de Llobregat	Local maintenance repair shop	2	11 kW	Operational in 2022

Table 7 - AMB public charging stations. Source: AMB.

4.4 EVs and V2G in other European countries

It is interesting to mention the different strategies that are being deployed to boost the deployment of EV infrastructure and V2G in other neighbour countries.

	EVs AND V2G IN OTHER EUROPEAN COUNTRIES
DENMARK 	By 2021 there are 31,886 of EVs in the Danish market [29]. There are around 500 DC chargers, spread along the highways [30]. Some private companies are offering V2G chargers at both AC and DC. There is no government roll out of smart charging stations planned, all installations are done by market parties. However, there are public incentives that support the roll out of infrastructure. For example, public incentives: there is a subsidy scheme of 49.9 mio. DKK for the roll out of charging infrastructure in highways, cities, and rural areas. The scheme is administrated by the Danish Road Directorate.
THE NETHERLANDS 	In The Netherlands there are over 49.000 regular public & semi-public AC charging points, more than 1.100 fast chargers, and probably over 120.000 private chargers, mostly in homes. Most of these EV chargers are also capable of smart charging. Many of the operators are already implementing various levels of vehicle-to-grid integrations, using open protocols such as OCPP, OSCP and using ISO15118 V2G technologies. With the growing demand for fully electric cars in the Netherlands, the development of charging stations is inherent to this trend. A steady progress has been made to develop an infrastructure to support the so-called plug-in EVs. In 2011 the volume of these charging stations amounted to a total of 1.826, in 2019 it significantly increased to approximately 41.000. In the same fashion, the EV charger density by country displays that the Netherlands top the ranking with roughly 19 EV stations per 100 kilometers of paved road in 2017. Categorizing the number of charging stations by type, both regular public as well as semi-public charging stations saw a steady increase between 2010 and 2019. Regular public chargers are available 24/7 and increased from 400 stations in 2010 to 21,049 as of February 2019. Semi-public charging

	points are interoperable (reported as accessible by their owners) and can be found at shopping malls, office buildings, parking garages etc. This type of charging station grew from 0 in 2010 to 17.059 in 2019 [31].
UNITED KINGDOM 	In the UK as of the end of December 2021 there were more than 740.000 plug-in vehicles with approx. 395.000 BEVs and 350.000 PHEVs registered. Last year saw the biggest annual increase in number of registrations, with more than 305.000 EVs registered showing a growth of 74% in 2020. The total number of locations which have a public charging point installed is 18.073, the number of devices at those locations is 28.666 and the total number of connectors within these devices is 48.396. The total number of locations which have a rapid (incl. ultra-rapid) public charging point installed is 3.248, the number of rapid devices at those locations is 5.165 and the total number of rapid connectors within these devices is 11.649. There has been strong growth in the number of rapid chargers in the UK from just over 30 CHAdeMO connectors in 2011 to over 9.000 rapid connectors across CHAdeMO, CCS, Tesla and Type 2 Rapid chargers by the end of 2020 [32].

**Notice that statistics on private charging points and especially on V2G are usually not available.*

Table 8 - deployment of EV infrastructure and V2G in other European countries.

4.5 Tolls and charges for EV tariffs in Spain

Access tolls and electricity charges are unique throughout the national territory and are collected from consumers by suppliers and paid to the distributors and the transmission system operator. Tolls are regulated prices intended to recover the costs of transmission and distribution networks and are determined by the National Regulation Agency (hereinafter, NRA) (in Spain, the CNMC). Charges are the regulated prices that serve to cover the rest of the regulated costs, such as the financing of the remuneration schemes for financing renewable generation or the extra cost of energy production in non-peninsular territories and are determined by the Ministry for Transition Ecology and the Demographic Challenge of Spain.

Both tolls and charges are applied on the contracted power of the supply point (expressed in €/kW) as well as on the consumption of energy (expressed in €/kWh), and therefore have a fixed part and a variable part.

The applicable regulation in Spain regarding tolls and charges is the following:

- Regarding electricity tolls, the CNMC passed Circular 3/2020[21], which establishes the methodology for calculating electricity transmission and distribution tolls. Resolution of December 16, 2021, of the National Commission of Markets and Competition, establishes the values of the access tolls to the electricity transmission and distribution networks applicable from January 1, 2022.
- On the other hand, the Ministry for the Ecological Transition approved Royal Decree 148/2021[22], of March 9, which establishes the methodology for calculating charges for the electricity system, establishing a new methodology for charges and tolls that has been in force since June 1, 2021. Order TED/1484/2021[23], establishes the prices of the electricity system charges applicable from January 1, 2022, and establishes various regulated costs of the electricity system for the year 2022.

Careful design of EV tolls and charges is crucial to achieve the right incentives for the development of EVs. Thus, developing business models and EV supply contract terms will be very important for the deployment of EVs, specifically, how final consumers receive price signals and how these are offered to them by suppliers can significantly impact their preference for EVs. For example, the fact that Circular 3/2020[24] eliminated the injection charge is very relevant for EV battery owners wishing to participate actively in the market.

In this section we will look at the design of the tolls and charges in Spain. It must be noted that we are talking here only about tolls and charges, not about the final energy price for the consumer, which could be the regulated tariff (PVPC) for consumers with a contracted capacity

[21] Circular 3/2020 of January 15, of the CNMC, which establishes the methodology for calculating electricity transmission and distribution tolls. (Official State Gazette num. 21, 24/01/2020)
[22] RD 148/ 2021, of March 9, which establishes the methodology for calculating charges for the electricity system. (Official State Gazette num. 66, 18/03/21)

[23] Order TED/1484/2021 establishes the prices of the electricity system charges applicable from January 1, 2022 and establishes various regulated costs of the electricity system for the year 2022. (Official State Gazette num. 313, 30/12/21)

[24] Circular 3/2020 of January 15, of the CNMC, which establishes the methodology for calculating electricity transmission and distribution tolls. https://www.boe.es/eli/es/cir/2020/01/15/3

under 10 kW, or any from the free market. Therefore, a consumer with a flat rate for example, will have the same energy price for all 3 periods, however, charges and tolls for energy will be applied considering the kWh consumed in each period (P1, P2 or P3)[25].

Tariffs in low voltage are separated by contracted power of the supply point. There are two tariffs, 2.0 TD, which is for ≤ 15 kW, and tariff 3.0 TD which is for > 15 kW < 451 kW.

Residential consumers 2.0TD (≤ 15 kW) have two contracted powers in two periods (P1 and P2), being P1, the peak demand period more expensive than P2, the valley demand period. Below is a graphic representation of the Peak and Valley power periods. Peak is from 8am to 00 hours, whereas Valley is from 00 to 8am, as well as all hours of the weekend and holidays.

Figure 18 - Peak and Valley power periods, CNMC.

For energy, consumers have three periods (P1, P2 and P3), where P1 is more expensive (peak), P2 is medium (flat) and P3 is the cheapest period (valley). Below is a graphic representation of the distribution of the three periods. Peak: from 10am to 2pm and from 6pm to 10pm on weekdays, Flat: from 8am to 10am, from 2pm to 6pm and from 10pm to 00 on weekdays. Valley: from 00 to 8am and all hours on weekends and holidays.

[25] Precio Voluntario para el Pequeño Consumidor (PVPC) is regulated in the Royal Decree 216/2014, de 28 de marzo, por el que se establece la metodología de cálculo de los precios voluntarios para el pequeño consumidor de energía eléctrica y su régimen jurídico de contratación (Official State Gazette nº 77, 29/03/2014)

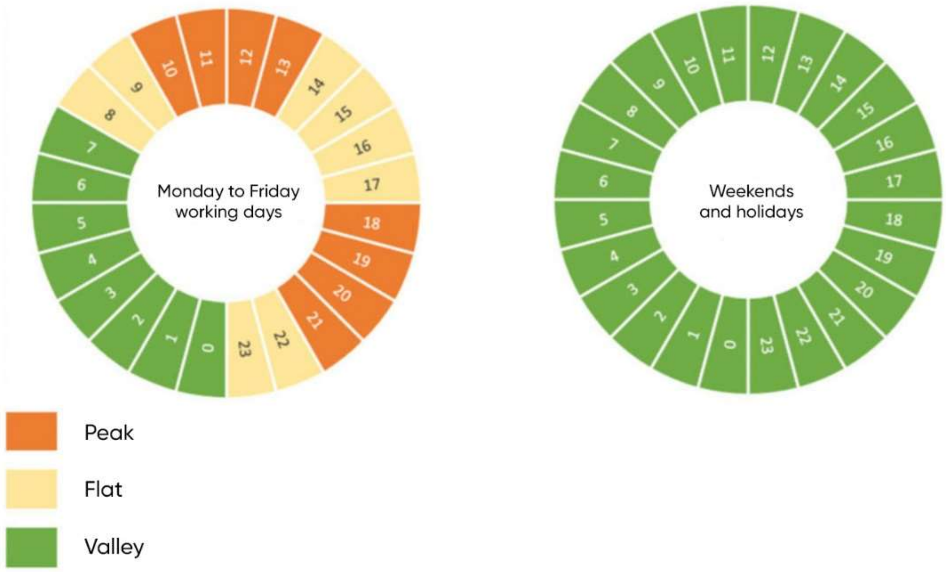


Figure 19 - Peak and Valley energy periods, CNMC.

Higher-volume consumers 3.0TD (>15kW < 451 kW) have six periods for power and six periods for energy (although only three on a certain day will apply), following a similar logic to residential consumers.

Finally, there are industrial consumers 6.0TD (> 450 kW) who also have six periods for contracted capacity and six periods for energy, where P1 is most expensive and P6 is the cheapest. Depending on the voltage required by the consumer, the toll or tariff will be different, as can be seen in the chart below.

According to the time periods explained above, the price of the tolls and charges for power and energy are shown below.

POWER

€/kW YEAR						
TARIFF	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**
2.0TD	4,970533	0,319666				
3.0TD	6,176299	3,090846	2,245571	2,245571	2,245571	1,029383
6.1TD	6,411267	3,208540	2,331370	2,331370	2,331370	1,068544
6.2TD	3,764914	1,884462	1,369060	1,369060	1,369060	0,627486
6.3TD	3,014497	1,508533	1,096011	1,096011	1,096011	0,502416
6.4TD	1,474591	0,737911	0,536215	0,536215	0,536215	0,245765

Table 9 - Power charges applicable from January 1st 2022, Official State Gazette

ENERGY

€/kWh						
TARIFF	P1	P2	P3	P4	P5	P6
2.0TD	0,072969	0,014594	0,003648			
3.0TD	0,040678	0,030119	0,016271	0,008136	0,005215	0,003254
6.1TD	0,022119	0,016384	0,008848	0,004424	0,002836	0,001770
6.2TD	0,010378	0,007687	0,004151	0,002076	0,001331	0,000830
6.3TD	0,008507	0,006302	0,003403	0,001701	0,001091	0,000681
6.4TD	0,003232	0,002394	0,001293	0,000646	0,004140	0,000259

Table 10 - Energy charges applicable from January 1st 2022, Official State Gazette

POWER

€/kW YEAR						
TARIFF	P1	P2	P3	P4	P5	P6
2.0TD	22,988256	0,938890				
3.0TD	10,493920	9,152492	3,688512	2,802739	1,122833	1,122833
6.1TD	18,320805	18,320805	9,988571	7,565889	0,502550	0,502550
6.2TD	13,592890	13,592890	6,648956	6,048771	0,418446	0,418446
6.3TD	10,021051	10,021051	5,543157	3,240960	0,638147	0,638147
6.4TD	10,314368	7,894062	3,797235	2,795290	0,528120	0,528120

Table 11 - Power tolls applicable from January 1st 2022, Official State Gazette

ENERGY

€/kWh						
TARIFF	P1	P2	P3	P4	P5	P6
2.0TD	0,027787	0,019146	0,000703			
3.0TD	0,017752	0,014567	0,007955	0,005361	0,000321	0,000321
6.1TD	0,017364	0,014247	0,008124	0,005428	0,000315	0,000315
6.2TD	0,009168	0,007529	0,004228	0,002954	0,000174	0,000174
6.3TD	0,007774	0,006515	0,003917	0,001880	0,000235	0,000235
6.4TD	0,007046	0,005743	0,003063	0,002433	0,000156	0,000156

Table 12 - Energy tolls applicable from January 1st 2022, Official State Gazette

Temporarily until 2025, there are specific tolls and charges for recharging points for electric vehicles which are of public access with contracted power greater than 15 kW as set by the second additional disposition of Circular 3/2020:

- Toll 3.0 TDVE toll (tariff segment 2VE of charges) for low voltage supply points (<1kV) and contracted power greater than 15 kW.
- Toll 6.1 TDVE (tariff segment 3VE of charges) for high voltage supply points and contracted power greater than 15 kW.

POWER CHARGES (€/kW YEAR)						
TARIFF SEGMENT	P1	P2	P3	P4	P5	P6
2 VE	0	0	0	0	0	0
ENERGY CHARGES (€/kWh)						
TARIFF SEGMENT	P1	P2	P3	P4	P5	P6
2 VE	0,086454	0,064013	0,034581	0,017292	0,011084	0,006916

Table 13 - Tolls and charges for recharging points for electric vehicles for low voltage, Order TED/1484/2021, Official State Gazette.

The main conclusions are:

- All consumers have to pay tolls and charges with hourly discrimination in terms of contracted capacity and energy.
- This means the price of tolls and charges will be different according to the period of consumption (peak/valley/flat)
- The power-based tolls and charges incentivise consumers to shift consumption, such as EV recharging, away from the hours of their individual peak demand, to keep their contracted capacity as low as possible.
- EV charge is promoted through tariff definition both at home and for public access charge points during low demand hours. The fact that night hours are cheaper in terms of energy and power tolls and charges incentivise recharging of the electric vehicle during valley periods.
- However, there is a concern about the fact that power-based tariffs may not be reflective of system costs, as two consumers with the same contracted power will pay the same in terms of power tolls and charges, regardless of how much they consume and when, even though they impose very different burdens on the grid.
- Cost-effective demand response, shifting demand from peak times to cheaper times, is not incentivised. This barrier was identified in the report by the commission of experts of energy transition.
- Tariffs must evolve towards smart tariff models, where charges and tolls reflect the real cost of opportunity of the electricity market prices, with higher rates when the grid is more saturated and low ones the rest of the time.
- All in all, the design of the tariffs is very complicated and could result in low effectiveness if consumers are not able to understand how to adapt to the signals.

5/ Electricity Markets

V2Grid is a technology that enables EV owners to charge and discharge their batteries according to electricity price signals to give their flexibility to the electrical system. The increasing number of electric vehicles and the V2G technology create an important relationship between mobility and the electricity system that may integrate EV batteries as additional and important flexibility resources as Distributed Energy Resources (DERs). To reach that full integration between mobility and the grid, electricity markets will have an important role in the task of coupling both sectors. Many actors related with e-mobility and the electricity market will be involved in the integration of the V2G innovative technology into markets (i.e., final users, aggregators, energy retailers, grip operators, market operators, software providers, charging providers, fleet managers, manufacturers).

Introduction to wholesale electricity markets in Spain

The Spanish electricity market began in 1998 with the liberalization of the electricity sector in Spain (Law 54/1997[26]). Since 2007, it was integrated with the Portuguese electricity market shaping the Iberian Electricity Market (MIBEL), born as a result of the collaboration between both countries in order to increase the integration of the electrical system. MIBEL promotes a framework that guarantees the access to the electricity market to all interested parties under equal conditions of transparency and objectivity.

The electricity pool is a wholesale market where large consumers and producers meet to buy and sell electricity. These companies then sell the energy to end consumers, such as small consumers, households, or other companies. This is the retail market.

The wholesale electricity market in Spain and Portugal is managed by an independent operator, OMI Polo – Español (OMIE). OMIE is the Nominated Electricity Market Operator (NEMO) and participates actively in connecting wholesale electricity markets in Europe, along with the rest of NEMOs designated in each of the countries.

Nowadays the wholesale spot market in the Iberian Peninsula is based on a day ahead market, and on intraday markets (intraday auctions and continuous intraday). The Day-Ahead market and Intraday Continuous and Auctions markets represented over the 92% of the total energy negotiated in Spain during 2020.

[26] Law 54/1997 of the Electric Sector https://www.boe.es/eli/es/l/1997/11/27/54/dof/spa/pdf

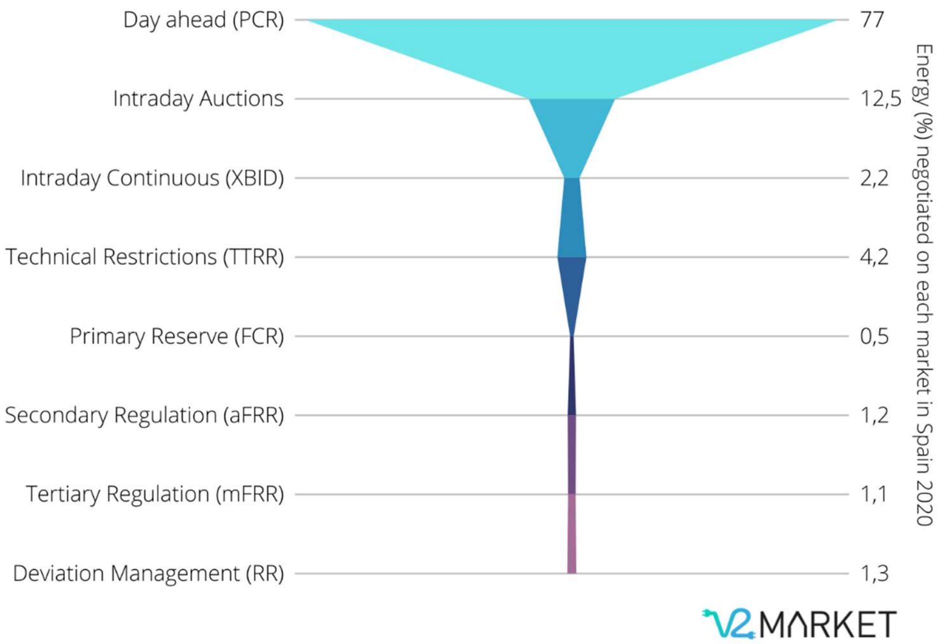


Figure 20 - Energy (%) negotiated on the wholesale markets and ancillary services in Spain (2020). Elaborated based on OMIE and REE data.

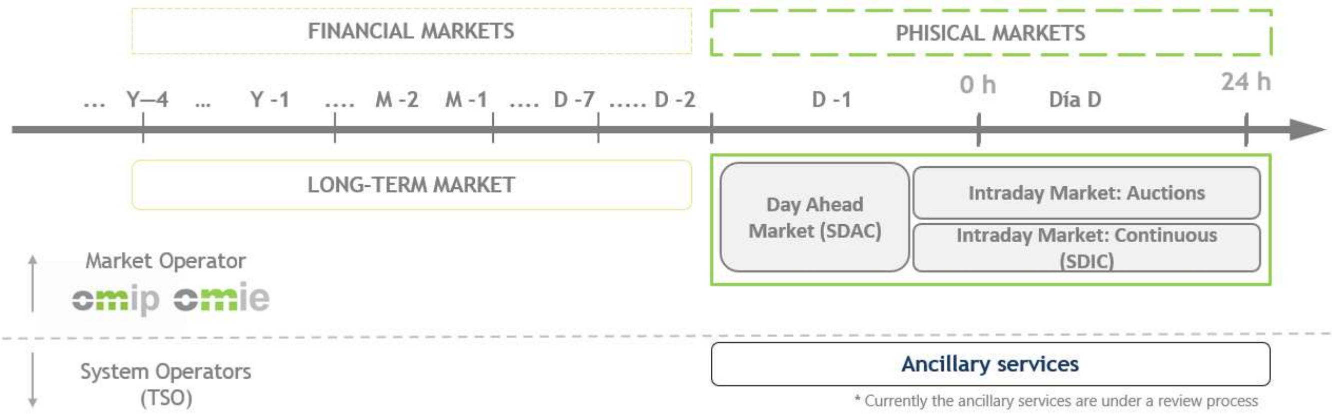


Figure 21 - Electricity market scheme in Spain.

The entities that are responsible of guaranteeing the appropriate balance between supply and demand and the correct electrical system operation are Red Eléctrica de España in Spain (REE) and Rede Eléctrica Nacional in Portugal (REN). They are responsible for managing ancillary services markets, that allow adjustment of production schedules, resulting from the trading on the day ahead market, intraday market and bilateral contracts, for the resolution of technical constraints of the system and the management of deviations.

	Status	Markets	Operator
Day ahead and intraday markets	On production	- Day Ahead Market (Europe) - Intraday Auction Market (Spain and Portugal) - Intraday Continuous Market (Europe)	OMIE
Local flexibility markets	In development	- Long term flexibility auctions - Short term flexibility auctions - Continuous flexibility trading	The first approach to cover the needs of distribution networks through the participation of DERs was IREMEL project.
Ancillary services	On production	- Technical Restrictions (RRTT) - Primary Reserve – Frequency Containment Reserve. - Secondary Regulation – Automatic Frequency Restoration Reserve (aFRR) - Tertiary Regulation – manual Frequency Restoration Reserve (mFRR) - Deviation management - Replacement Reserve (RR)	REE
Balancing Capacity Markets	In development	- Capacity markets.	REE

Table 14 - Summary of the current status of the electricity markets in Spain.

RENEWABLE ENERGY IN THE ELECTRICITY MARKET

During 2021, the total amount of energy negotiated in the MIBEL region on the day-ahead and intraday markets was 275,2 TWh, 5% more than the traded energy in 2020. Of those 275,2 TWh, 230,4 TWh were negotiated on the day-ahead market and 44,8 TWh on the intraday markets.

Figure 22 - Traded energy in each of the spot markets during 2021 in the MIBE region. The energy negotiated is calculated as the sum of acquisitions and net exports for each area. The light-coloured columns indicate values of the series for the same period from 2020. Source: OMIE.

Renewable technologies produced 46.6% of all electricity in Spain during 2021. The share of green production in 2021 was 9,9% higher than in 2020. Solar photovoltaic is the technology with the highest increase on its production with a 37.7% compared to 2020 (8.2% of the total energy) [33]. Wind power is already the main source of electricity generation in Spain.
During 2021 the renewable power capacity has increased by more than 2.800 MW, reaching a share of 55.6% of the overall total installed power capacity. Since 2018, the installed MW of solar photovoltaic has almost tripled.

5.1 Day-Ahead Electricity Market

Day-Ahead Coupling, a European market.

The Single Day-Ahead Coupling (SDAC) also known as Day Ahead Electricity Market (DA) has as goal create a single pan European cross-regional day ahead electricity market, improving the overall efficiency by promoting competition, liquidity, and being more efficient using generation resources across Europe. SDAC allows energy cross-border transmission by allocating available grid capacity as a result of coupling wholesale markets in different areas [34].

INTRODUCTION AND INVOLVED INSTITUTIONS

NEMOs and TSOs are the promoters of the SDAC system that is under the CACM framework[27]. This framework implements cross-European transactions through implicit auctions to deliver electricity the following day. The SDAC relies on the Price Coupling of Regions (PCR) solution, that integrates different markets into one coupled market with a European scope, only restricted by electricity network constraints.

PCR is a project of European Power Exchanges to harmonise the European electricity markets described by CACM Regulation 1222/2015. Since 2014 it is coupled with the rest of Europe, and it is a key part of the European Internal Energy Market [35].

The PCR project is based on three main principles:

- **One single algorithm**: a common algorithm named Euphemia is the one that is used to calculate every day electricity prices for all the member states of PCR.
- **Robust operation**: there are different protocols and procedures to follow under different scenarios to obtain a valid solution from the algorithm.
- **Individual accountability**: each PX carries out the clearing for selling and takeover bids based on the least expensive offer until equalling demand in each scheduling period [36].

The integrated European electricity market is beneficial due to the increased liquidity, transparency, efficiency, and social welfare. The design of this system guarantees the overall welfare and optimal use of electricity network constraints.

In February 2014 PCR was launched in two different operation areas: North-Western Europe (NWE) and South-Western Europe (SWE). In May 2014 those areas reached a full coupling creating the Multi-Regional Coupling (MRC) region.

In November 2014 the 4MMC countries where live (Czech Republic, Hungary, Romania and Slovakia) with the same PCR solution but they were not coupled with the MRC region until June 2021.

[27] COMMISSION REGULATION (EU) 1222/2015 of 24 July 2015 establishing a guideline on capacity allocation and congestion management. EUR-Lex - 32015R1222 - EN - EUR-Lex (europa.eu)

Figure 23 - SDAC project members map [34].

PRC is used to couple the following countries:

PCR Coupling Countries	Austria, Belgium, Bulgaria, Czech Republic, Croatia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Italy, Latvia, Lithuania, Luxembourg, The Netherlands, Norway, Poland, Portugal, Republic of Ireland, Romania, Slovakia, Slovenia, Spain, Sweden and UK (Northern Ireland).

Table 15 - Countries that are in the Price Coupling of Regions system for the Day-Ahead market *[34].*

TSOs and NEMOs involved in the Price Coupling of Regions project:

TSOs	0Hertz Transmission, ADMIE, Amprion, APG, AST, ČEPS, Creos, EirGrid, Elering, ELES, ELIA, Energinet, ESO, Fingrid, HOPS, Litgrid, MAVIR, PSE, REE, REN, RTE, SEPS, SONI, Statnett, Svenska Kraftnät, TenneT DE, TenneT NL, Terna, Transelectrica, and TransnetBW.
NEMOs	CROPEX, EPEX, EXAA, GME, HEnEx, HUPX, IBEX, Nasdaq, Nord Pool, OKTE, OMIE, OPCOM, OTE, SEMOpx, South Pool and TGE.

Table 16 - TSOs and NEMOs that participate in the Price Coupling of Regions project *[34].*

The DA market handles electricity transactions for the next day through the submission of sale and purchase offers by each of the market participants. Offers are sent every day before 12:00

CET, when the market session starts. In these daily market sessions electricity prices and electricity flows are set for all across Europe.

Market participants in Spain and Portugal submitting buying and selling offers will present their bids to the DA through OMIE's platforms, which is the only NEMO for the Iberia Region [37].

The market session starts at 9:00 CET with the verification of the Price Matcher and Broker (PMB), all the communications and the algorithm configuration for each of the NEMOs. At 10:30 CET available capacities on the interconnectors and in the grid are sent to the PMB in the Network Data file and are received by each Operational NEMO. This file contains all the information related with cross border capacities that each of the TSOs send to the NEMOs and that will allow or not the electricity flow between different areas or countries. The information is validated and processed, and these capacities will be considered during the matching process.

OFFERS SUBMISSION

All market participants can submit their offers for the DA market until 12:00, when the matching process starts. Bid and Ask offers can be made considering the hourly base of the market, thus each market participant introduce the quantity of energy and price limit that they would like to buy/sell energy hourly. For each hour it is allowed to introduce between 1 and 25 tranches of quantity and energy-price. In case of sales, the bid price increases with the tranche number; in the case of purchase, the bid price decreases with the tranche number. Only one offer submission is allowed for each production/demand unit.

Bid and Ask offers submission

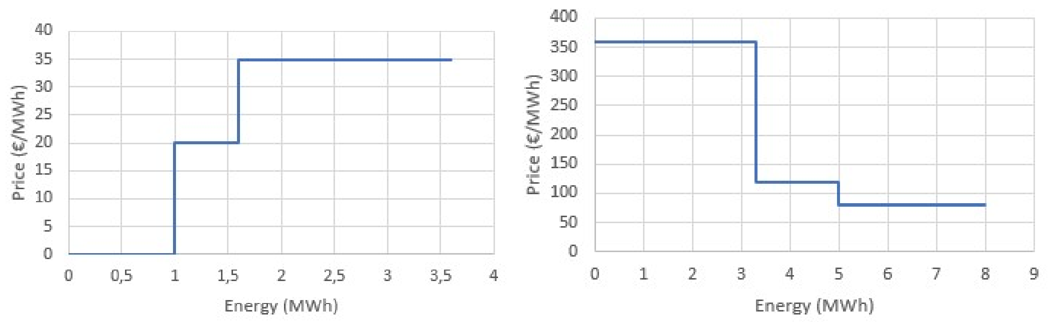


Figure 24 – Examples of ask (left) and bid (right) offers for the Day-Ahead market.

Electricity sale bids submitted to the DA market may be simple or include complex conditions. Simple orders incorporate price and amount of energy indicated for each hour and production unit. Complex orders are those that indicate complex sale terms and conditions that must be complied with during the matching process to finally match the offer. There are different complex conditions, each bidding could have other kind of complex orders or block orders. Complex orders in Spain and Portugal [37]:

- **Minimum income condition**: if the offer does not obtain an income higher than the income declared, the hole offer is withdrawn. The minimum income condition has a fix component (€) and a variable component (€/MWh) that is proportional to the energy matched.
- **Load gradient:** enables the maximum difference between the energy in one hour and the energy in the following hour of one production unit. Load gradient condition allows to avoid sudden changes in production units from one hour to other than later cannot be performed from a technical view.
- **Scheduled stop:** production units that have been withdrawn from the matching step because they fail to comply the minimum income condition to carry out a schedule stop of their units. The stop of the production units has to be carried out within the three first hours. A scheduled stop complex order allows production bidders to avoid stops in their schedules from one hour of the previous day to zero in the first hour of the following day by accepting in the matching process the slot of first three hours as simple bids but energy offered in bids must drop in each of these three hours.

The SDAC system is prepared for working with different type of restrictions like complex orders, blocks orders, flexible hourly orders, or PUN orders.

In July 2021 Day-Ahead and Intraday Electricity Market Operating Rules were updated to harmonize the technical limits to European matching limit. The maximum bid price was updated to +3.000 €/MWh from +180,30 €/MWh and the minimum price to -500€/MWh from 0 €/MWh. In April 2022 the maximum price was updated to +4.000€/MWh[28].

[28]Resolution of May 6, 2021 of the CNMC of the National Markets Commission and Competition, which approves the rules of operation of the daily and intraday electric energy markets for its adaptation of the bid limits to European matching limits https://www.boe.es/boe/dias/2021/05/20/pdfs/BOE-A-2021-8362.pdf

Day Ahead product details	
Granularity	0,1 MWh
Minimum quantity to bid	0,1 MWh
Maximum quantity to bid	No constraint
Price tick	0,01 €/MWh
Maximum bid price	+4.000 €/MWh
Minimum bid price	-500 €/MWh

Table 17 - Granularity, minimum and maxim quantity, and price limits in the Day-Ahead Electricity Market. Source: OMIE

MATCHING PROCESS

The auction process starts every day at 12:00 CET after all market operators validate all the bids received, following the marginalist model use for the SDAC market. NEMOs are synchronized and send all their orders, anonymised first, to the rest of NEMOs in the Order Data file. Submitted offers are matched with other orders in the pan-European market coupling session. The Pan-European Hybrid Electricity Market Integration Algorithm (EUPHEMIA) is the European matching algorithm that runs in all NEMOs IT systems and that calculates the electricity price and energy flow for each of the hours of the following day and for each bidding zone. The objective of Euphemia is to optimise the overall welfare which consists in maximizing the consumer surplus (difference between the price of the matched purchase bid and the marginal price resulted), the producer surplus (difference between the marginal price and the price of the matched sale bid) and the congestion rent across regions.

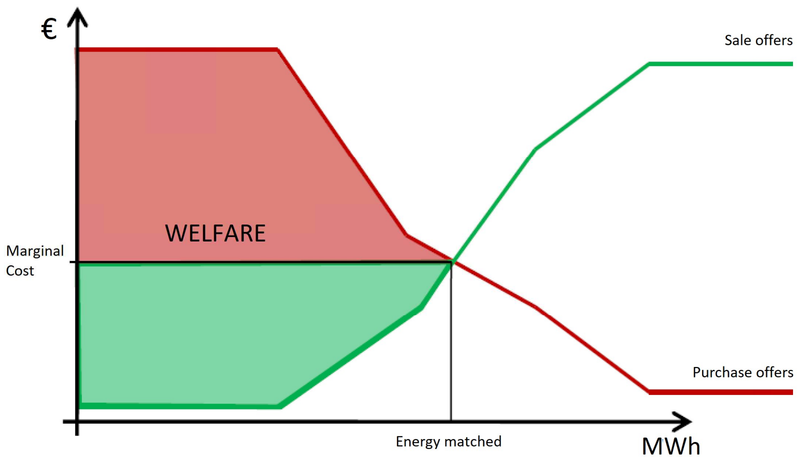


Figure 25 - Matching point for demand and supply in the Day-Ahead market. Source: OMIE.

Before the auction TSOs communicate to NEMOs the available capacity in all the interconnectors between different bidding zones. If there is enough available capacity between two different bidding zones the final price resulting from the auction will be the same in both areas.

EUPHEMIA considers stepwise aggregated curves. Bid and ask offers are ordered according to economic merit. The result are two curves, one for each type of offer. For the processing of both curves, the Euphemia algorithm performs the matching process with the accuracy of price and energy values. The accuracy for Spain and Portugal is two decimals for price (€/MWh) and one decimal point for energy (MWh). The price and volume of energy at a specific hour is fixed by the intersection of supply and demand.

Once the matching process is completed, market operators proceed to allocate the matched and unmatched blocks in each production area [37].

After validation and review of the daily auction, results are published around 12:45 CET or later. Individual results are reported to each market participant. These auction results represent the most efficient solution to the complex problem of matching supply and demand from an economic point of view [38].

Day Ahead Market (DA), Single Day-Ahead Coupling (SDAC)	
Pricing	Marginal Pricing
Algorithm	EUPHEMIA calculates day-ahead electricity prices across Europe and allocates cross border transmission capacity on a day-ahead basis.
Frequency	Daily auctions
Bidding period	Without gate opening time (GOT) and closing time at 12:00 CET on the day before the energy delivery
Product	Energy (MWh) in hourly base for the 24 hours of the next day. • Granularity: hourly. In next year will be changed to 15 minutes according to European market regulation. • Minimum Quantity to bid: 0,1 MWh. • Maximum Quantity to bid: No constraint. • Price Tick: 0,01 €/MWh. • Minimum bid price: - 500 €/MWh • Maximum bid price: 4.000 €/MWh.[29]

Table 18 - Table – Pricing, algorithm, frequency, bidding period and product details of the Day-Ahead market. Source: OMIE.

[29] This new maximum price has been adopted in April 2022 according to the Harmonised maximum and minimum clearing prices for single day-ahead coupling in accordance with Article 41(1) of Commission Regulation (EU) 2015/1222 of 24 July 2015 establishing a guideline on capacity allocation and congestion management (CACM Regulation). Before May 10, 2021, the maximum limit was +3.000€/MWh. SDAC Communication note (nemo-committee.eu)

FINAL RESULTS

After the DA market, the TSOs performs a validation from the technical point of view to ensure that the previous results are technically feasible in the electrical network. All these checks and small variations that the TSO applies to the previous schedules are sent back to OMIE in the PVDD (Programa Viable Diario Definitivo).
OMIE also carries out the clearing for selling and takeover bids based on the least expensive offer until equalling demand in each scheduling period.

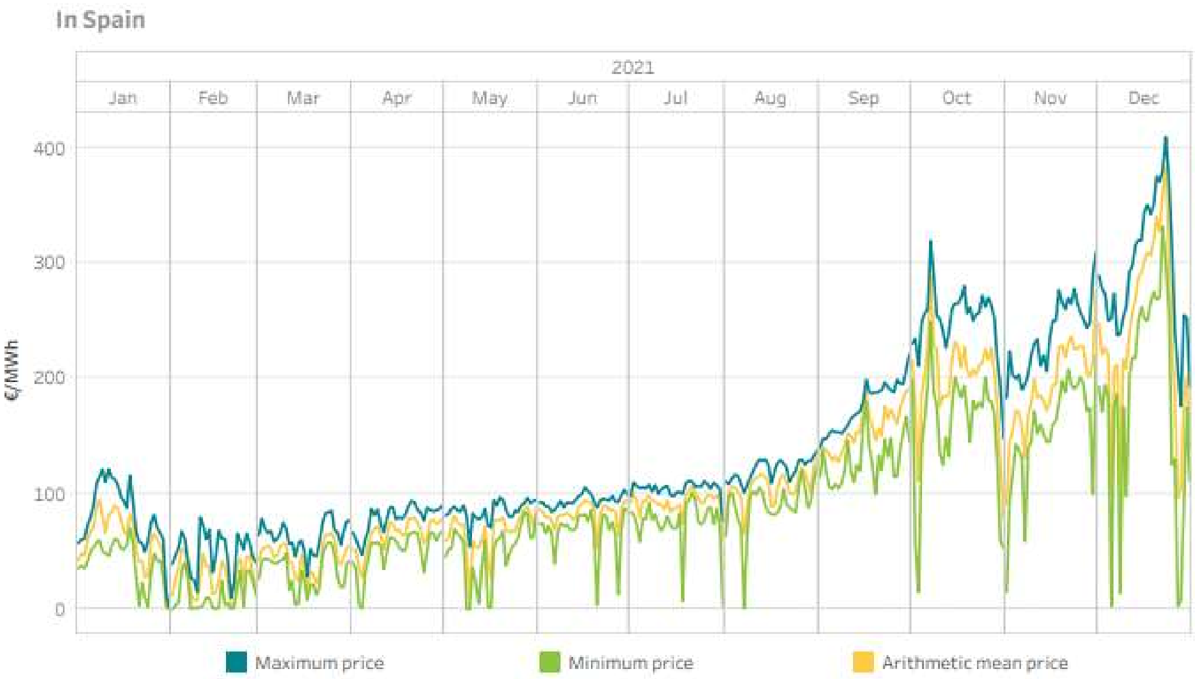


Figure 26 - Minimum, maximum and arithmetic mean prices on the day-ahead market in Spain. Source: OMIE [39].

5.2 Intraday Electricity Markets

Intraday Auctions Market and Intraday Continuous Market

Intraday wholesale electricity markets allow market participants to adjust their outcome schedule of the day-ahead market, according to their real needs, closer to the energy delivery time. Intraday trading in Spain and Portugal is structured in six auction sessions, with an Iberian scope, and a continuous cross-border European market. These auctions and continuous trading are activated after the day-ahead market and after the system operator has made the necessary adjustments.

Figure 27 - Electricity market chronogram in MIBEL region. Source: OMIE

INTRADAY AUCTIONS MARKET

Intraday auctions are structured into six sessions with different time horizons for each of the sessions. Intraday auctions trading manages only Spain and Portugal and the free capacity in the next interconnectors:

- Spain-Portugal.
- Spain-Morocco.
- Spain-Andorra.

As well as in the day ahead market, intraday auctions are also based in marginal pricing and the market coupling model for the borders that it manages. There is a particular condition that must be fulfilled to participate in intraday auctions: market participants need to submit a valid offer to the day-ahead market according to market rules [40]. Intraday auctions aim to attend the adjustment necessities of the PDVD (Programa Diario Viable Definitivo) resulting from the Day-Ahead auction.

Each of the intraday auctions have an auction time of 50 minutes. During the trading period, market participants submit their purchase and sale bids, that are validated by OMIE according to the market rules [40].

	1st Session	2nd Session	3rd Session	4th Session	5th Session	6th Session
Auction Opening Time	14:00	17:00	21:00	01:00	04:00	09:00
Matching Process	15:00	17:50	21:50	01:50	04:50	09:50
Auction Closing Time	15:00	17:50	21:50	01:50	04:50	09:50
Results Publication (PIBCA)	15:07	17:57	21:57	01:57	04:57	09:57
TSOs Publication (PHF)	16:20	18:20	22:20	02:20	05:20	10:20
Schedule Horizon (Timing periods included in the horizon)	24 hours (1-24 D+1)	28 hours (21-24 D and 1-24 D+1)	24 hours (1-24 D+1)	20 hours (5-24 D+1)	17 hours (8-24 D+1)	12 hours (13-24 D+1)

Table 19 - Schedule of Intraday auctions in MIBEL region. Source OMIE.

Market participants can submit multiple offers for the same production or purchase unit with different conditions for each one. Bids can be simple or include complex conditions, some of them are the same as in the DA market:

- **Load gradient condition and minimum income:** the same as those described in the DA market.
- **Full acceptance in the matching of the first tranche of the bid of sale or acquisition:** if the first tranche is not full matched, the offer is withdrawn.
- **Complete acceptance in each hour in the matching of the first section of the bid of sale or acquisition:** if the first tranche is not fully accepted in an hour, all tranches offered in that hour are withdrawn but not the remaining tranches for the rest of the hours on the horizon.
- **Minimum number of consecutive hours with full acceptance of the first tranche:** if in the matching horizon there are hours with energy allocated that do not meet the specified condition (N consecutive hours with complete acceptance of the first tranche), the entire offer is withdrawn.
- **Maximum energy condition:** if the offer is matched, it will be for a value equal to or less than the declared limit of the unit. Only one bid per bid unit may be submitted if it incorporates the maximum energy condition.

The maximum number of tranches for each hour in an intraday auction bid is five.

OMIE as market operator performs the matching process, adjusting supply and demand according to the simple and complex orders submitted to the auction. Algorithm interactions are necessary to obtain a valid result that fulfils all the complex conditions of the bids matched.
In case of internal congestion within the Iberian region (interconnectors between the Spanish and Portuguese electrical systems) the previously described process is repeated, generating a market splitting between both market areas, and obtaining a different price in each zone of the Iberian Market.

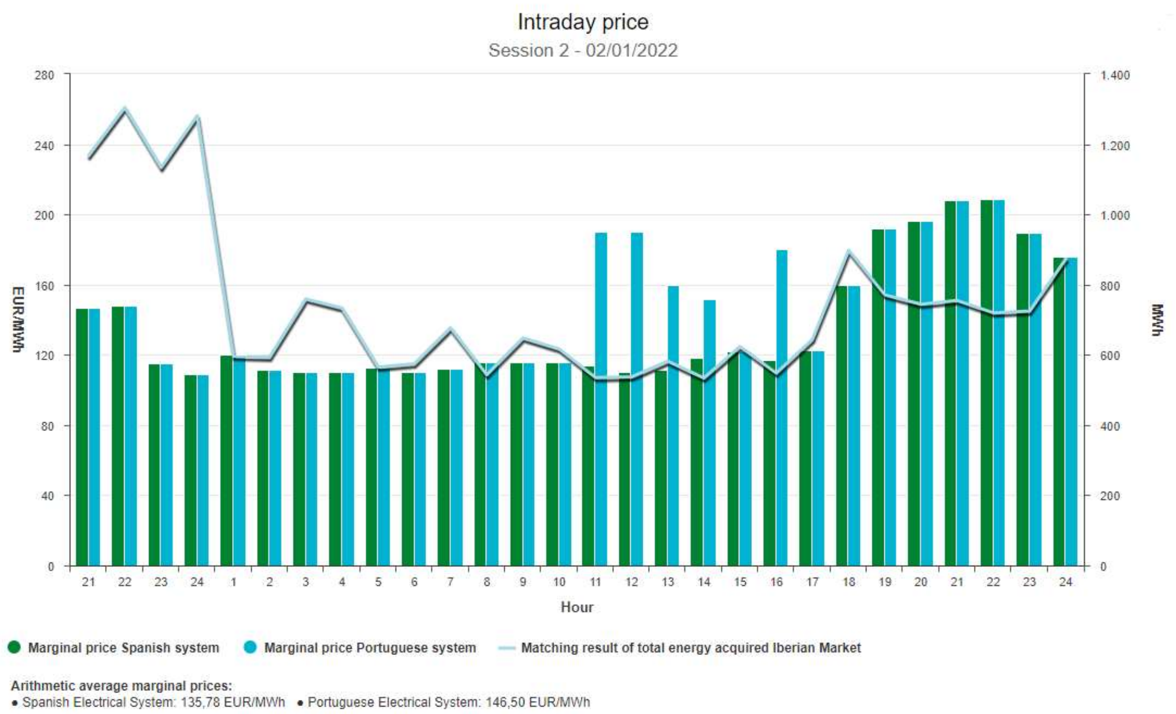


Figure 28 - Market splitting situation in the second session of the Intraday Auction market (02/01/2022) between the Spanish price and the Portuguese. Source: OMIE [41].

At the end of each of the intraday auction sessions, OMIE publishes, to market participants and TSOs, the incremental results for each of the production or bid units (PIBCI). All the schedule information in the PIBCI file allows TSOs to update and send back to OMIE the final program schedule of the session (PHF).

Intraday Auction Details	
Pricing	Marginal Pricing
Frequency	6 Daily auctions
Bidding period	50 minutes for each session, except the first one that is 1 hour.

Product	Energy (MWh) in hourly base. • Granularity: hourly. • Minimum Quantity to bid: 0,1 MWh. • Maximum Quantity to bid: No constraint. • Price Tick: 0,01 €/MWh. • Minimum bid price: - 9.999 €/MWh • Maximum bid price: +9.999 €/MWh.

Table 20 - Pricing, frequency, bidding period and product details of the Intraday Auction Market in MIBEL. Source: OMIE.

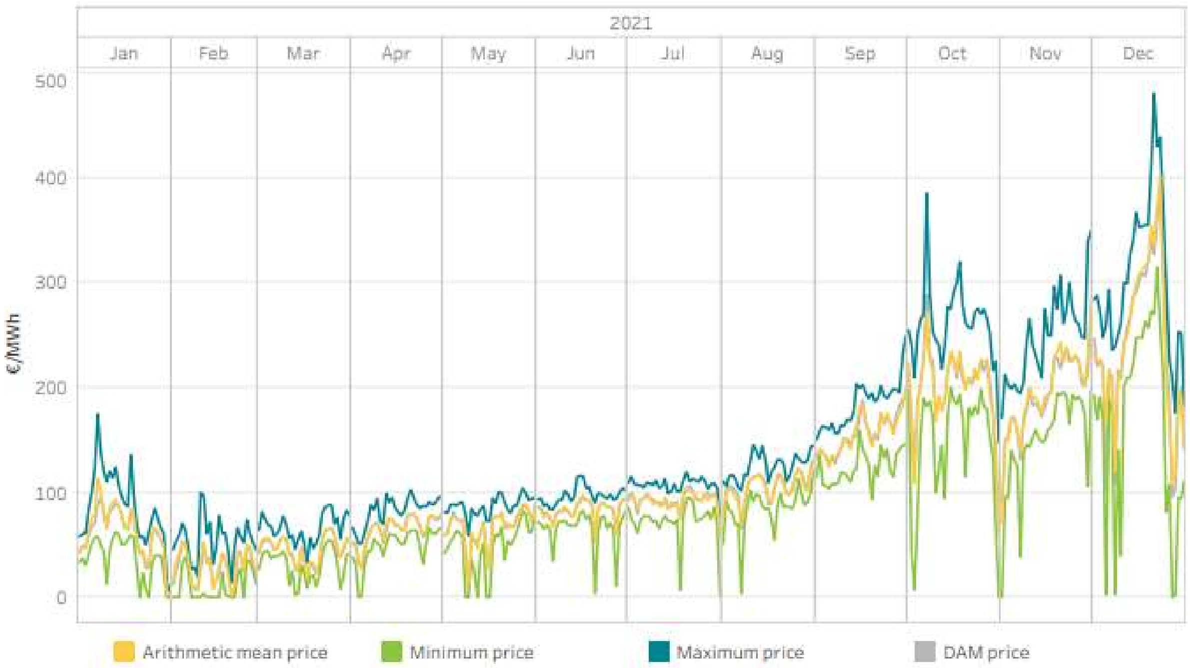


Figure 29 - Minimum, maximum and arithmetic mean prices on the intraday auction market in Spain. Source: OMIE [39]

FUTURE OF THE INTRADAY MARKET IN EUROPE – IDAs

On January 2019 ACER (Agency for the Cooperation of Energy Regulators) decided to establish a single methodology for pricing intraday cross-zonal capacity based on intraday European auctions (IDAs) that shall be part of the single intraday coupling system. This ACER decision is in line with CACM Regulation 2015/1222 of July 2015[30]. On January 30, 2021 ACER launched a common proposal with the objective of creating implicit intraday auction trading sessions for simultaneously matching orders from different bidding zones and allocating the available intraday cross-zonal capacity at the bidding zone borders by applying a market coupling mechanism. IDAs[31] will be using the marginal pricing principle. As starting point, the proposal is to introduce three intraday auctions:

- 15.00 CET day-ahead.
- 22.00 CET day-ahead.
- 10.00 CET within-day.

Cross-zonal capacity will not be allocated at the same time for IDAs and continuous trading, due to this condition, SIDC trading shall be temporally suspended and during that period all the capacity will be allocated trough IDAs. With the objective of increasing RES shares, auctions will have a granularity of 15-minutes time [42].

Intraday European Auction Details (IDAs)	
Pricing	Marginal Pricing
Frequency	3 IDAs
Algorithm	Similar to Euphemia.
Bidding period	• **Opening auction** (15.00 CET) to ensure that remaining transmission capacity form the day-ahead market is allocated in an intraday auction (D-1), i.e., from the first auction MTU starting at 00:00 until the end of the delivery day D, with a deadline for bid submission at 15:00 market time D-1. • **Evening auction** (22.00 CET) to allocate transmission capacity that would result from the capacity recalculation (D-1), i.e., from the first auction MTU

[30] COMMISSION REGULATION (EU) 1222/2015 of 24 July 2015 establishing a guideline on capacity allocation and congestion management. EUR-Lex - 32015R1222 - EN - EUR-Lex (europa.eu)

[31] ACER Decision on the Methodology for pricing intraday cross-zonal capacity of January 2019. (europa.eu)

	starting at 00:00 until the end of the delivery day D, with a deadline for bid. ○ submission at 22:00 market time D-1. • **Morning auction** (10.00 CET) shall be held on the delivery day D, i.e., from the first auction MTU starting at 12:00 until the end of the delivery day D, with a deadline for bid submission at 10:00 market time D.
Product	Volume of energy (MWh) with a granularity of 15-minutes.

Table 21 - Pricing, frequency, bidding period and product details of the European Intraday Auction Market (IDAs).

NEMOs and TSOs are working together in the implementation of IDAs in several working groups of the design phase.

INTRADAY CONTINUOUS MARKET

The objective of the Intraday Continuous Market also known as Single Intraday Coupling (SIDC) is to establish a common cross border implicit continuous intraday trading solution across Europe, where all the cross-border capacities are allocated as defined in the CACM Regulation 2015/1222 of July 2015.
In the same way as in the intraday auction market, the intraday continuous market gives the opportunity to participants to change their energy schedule balance according to their real needs after the day-ahead market.

Figure 30 - Energy and average price of the negotiated energy in the intraday auction market. Source: OMIE [39]

SIDC allows market participants to manage their energy imbalances until one hour before the delivery time of the energy. Due to that, it has become a useful tool for energy producers and consumers, especially for renewable generation because of the more challenging needs of balance according to their intermittent production. Balancing their schedules in the SDIC market is favourable for market participants and for the energy system, decreasing the need for reserves and their cost, also ensuring the stability of the electrical grid form the security point of view and thus increasing the efficiency of the system.

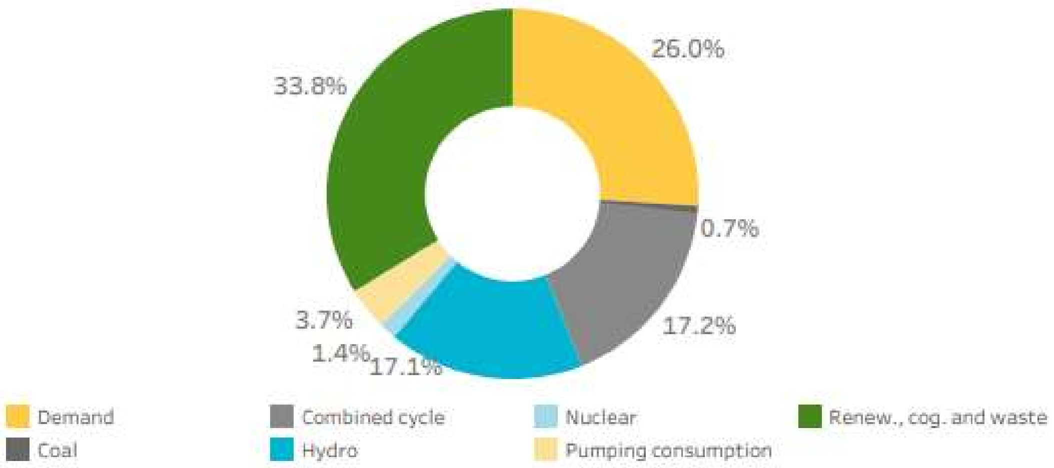


Figure 31 - Technologies in the intraday continuous program (Programa Intradiario Básico de Casación Incremental Continuo, PIBCIC) in MIBEL area during 2021. Source: OMIE [39].

In this market, market participants can negotiate up to 15 mins (depending on the bidding area, it could be one hour) before the moment of delivery of energy.

The base principles of the SDIC project are a continuous implicit allocation and reliable pricing, reflecting congestions and based on actual orders.

The continuous intraday market is a European market that allows the negotiation between market participants in different bidding zones if the interconnection capacity between both areas, and the interzonal ones, allow the energy flow. This fact of being integrated across Europe enables agents to access a market with increasing liquidity.

A group of NEMOs, including OMIE, launched in June 2018 the SDIC first go-live with the XBID solution (Cross Border Intraday) and it involved 15 countries: Austria, Belgium, Denmark, Estonia, Finland, France, Latvia, Lithuania, Luxembourg, Norway, The Netherlands, Portugal, Spain and Sweden. The second go-live, in November 2019, added to the XBID system another 7 countries: Bulgaria, Croatia, Czech-Republic, Hungary, Poland, Romania and Slovenia. In 2022 Italy started to trade in SDIC. It is expected that Greece and Slovakia will join the trading on the Cross Border Intraday Project by the end of the year.

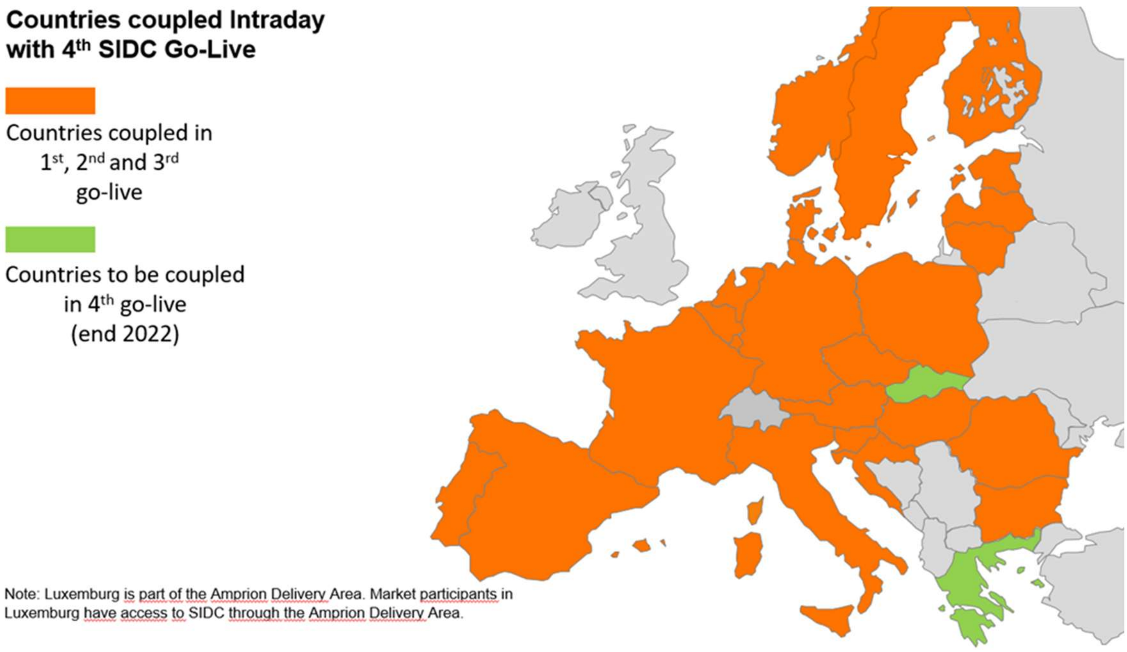


Figure 32 - Map of countries that are part of the SDIC system. Source: All NEMO Committee [43]

The European Intraday Continuous Platform is based on a common IT system that is the core of the project. Market operators across Europe are connected to the central system and send and receive all the necessary information. The common IT system has a Shared Order Book (SOB) module, a Capacity Management Module (CMM) and a Shipping Module (SM). The first one allows NEMOs to submit orders and manage all the information about the market (orders, bidding area, delivery area, status of the market…), CMM allow TSOs to share intraday cross-border capacities and the SM manages the reception of all the data from the SOB after a trade is matched to establish the responsible counterparty for making the correct settlement for interzonal trades.

ORDER SUBMISSION:

Bids to SDIC are sent by market participants through a Local Trading Solution (LTS) that each of the NEMOs have developed adapted to their necessities. Agents in Spain and Portugal use OMIE's LTS.

The LTS system is the link between market participants and the common XBID IT system. It sends all the market participant orders, after validating them, to the Shared Order Book (SOB) and receives all the information related to the matched and unmatched offers. Orders that are competitive enough are matched immediately recording a trade. Orders could be from the same bidding zone or from other European bidding zones if there is available cross-border capacity between them. Each bid may be for a specific contract, contain an energy quantity and price and for a specific unit or portfolio unit.

The LTS is a platform where market participants can see all the available offers at that moment and that have been submitted by other market participants. Although they do not know to whom each offer belongs, they can see prices and quantities offered at each moment and the references of the last matched, maximum, and minimum price.

Negotiation of one or several contracts of the SDIC will be carried out in different periods called "Rounds". Rounds are a group of different trading periods. Each of the rounds open when the immediately previous round is closed, and it is associated with the end of the negotiation for a contract in the European Continuous Trading Platform.

ROUNDS "D" AND "D+1"																																			
DAY	OPENING	CLOSING	ROUND																																SESSION
D-1	14:00	15:00	17	17	18	19	20	21	22	23	24																								MI1 14:00-15:00 (1-24)
D-1	15:00	15:10	18	18	19	20	21	22	23	24																									
D-1	15:10	16:00	18	18	19	20	21	22	23	24	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
D-1	16:00	17:00	19	19	20	21	22	23	24	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24		
D-1	17:00	17:50	20	20	21	22	23	24	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24			
D-1	17:50	18:00	20	20																															MI2 17:00-17:50 (21-24, 1-24)
D-1	18:00	19:00	21	21	22	23	24	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24				
D-1	19:00	20:00	22	22	23	24	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24					
D-1	20:00	21:00	23	23	24	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24						
D-1	21:00	21:50	24	24	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24							
D-1	21:50	22:00	24	24																															MI3 21:00-21:50 (1-24)
D-1	22:00	23:00	1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24								
D-1	23:00	0:00	2	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24									
D	0:00	1:00	3	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24										
D	1:00	1:50	4	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24											
D	1:50	2:00	4	4																															MI4 1:00-1:50 (5-24)
D	2:00	3:00	5	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24												
D	3:00	4:00	6	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24													
D	4:00	4:50	7	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24														
D	4:50	5:00	7	7																															MI5 4:00-4:50 (8-24)
D	5:00	6:00	8	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24															
D	6:00	7:00	9	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24																
D	7:00	8:00	10	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24																	
D	8:00	9:00	11	11	12	13	14	15	16	17	18	19	20	21	22	23	24																		
D	9:00	9:50	12	12	13	14	15	16	17	18	19	20	21	22	23	24																			
D	9:00	10:00	12	12																															MI6 9:00-9:50 (13-24)
D	10:00	11:00	13	13	14	15	16	17	18	19	20	21	22	23	24																				
D	11:00	12:00	14	14	15	16	17	18	19	20	21	22	23	24																					
D	12:00	13:00	15	15	16	17	18	19	20	21	22	23	24																						
D	13:00	14:00	16	16	17	18	19	20	21	22	23	24																							

Figure 33 - Intraday auctions and intraday continuous rounds and periods negotiation timings. Source: OMIE [44]

SDIC it is based on a pay as bid method. A purchase order is matched if the price is higher than any of the sale orders in the order book. A sell order is matched if the price is lower than any of the buying offers. If there is a match, a trade between the buying part and the seller part is settle. Currently in Spain and Portugal only hourly products can be traded. In other bidding zones other products can be traded.

XBID products	
	- **Hourly products:** there are 24 trading contracts, one for each hour of the day. - **Half-hourly:** support trading in 48 contracts. 30-minutes products are tradable across the borders: FR-DE, FR-BE and BE-NL.

XBID products	- **Quarter-hourly products:** 96 power contracts are managed each day for each period of 15 minutes of the day. 15-min products are tradable across borders BE-NL, NL-DE, AT-DE, AT-HU, AT-SI and HU-RO.

Table 22 - Summary of the different products that are possible to trade in the SIDC and borders that admit 30-min/15-min trading *[43]*.

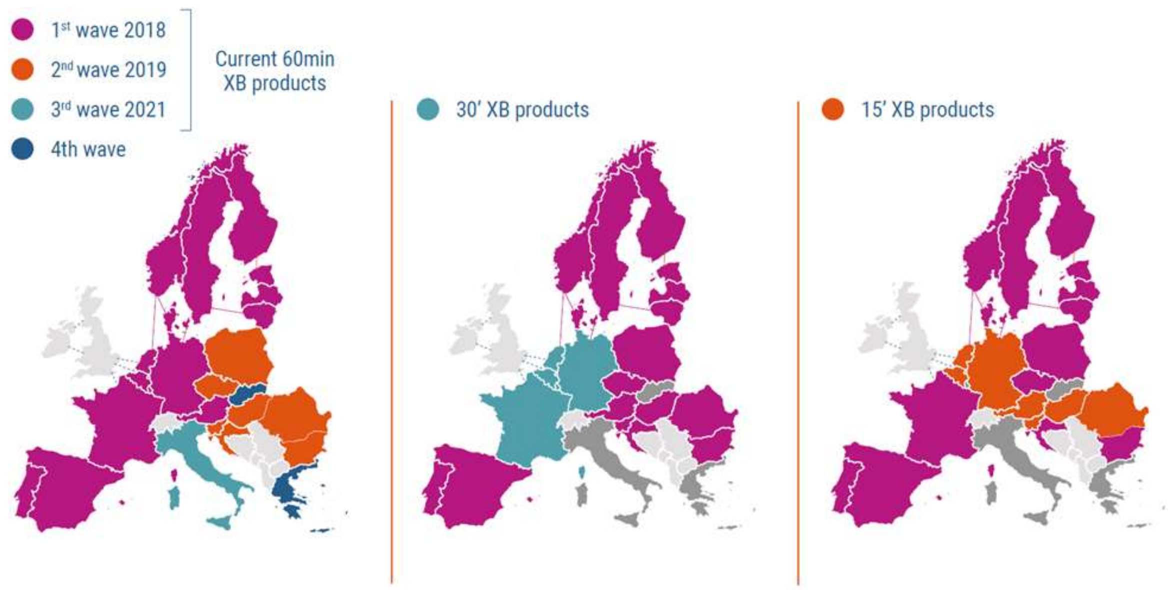


Figure 34 - European SIDC product map. On it are detailed those countries where 1 hour/30-min/15-min trading is activated. Source: All NEMO Committee [43].

ACER decided in 2018 that the Gate Opening Time (GOT) for trading should be harmonized for the hole Europe at 15.00 h (CET) and that the intraday cross-zonal Gate Closure Time (GCT) should be 60 minutes before the energy delivery.
Orders must go through some system validations. If an order does not meet the acceptance criteria, the order is rejected. Furthermore, the economic value of the order may not exceed the guarantees deposited by market participant in OMIE. The price and energy quantity must be within the limits declared in the Market Rules.

Intraday Continuous Market	
Pricing	Pay as bid
Frequency	24/7
Bidding period	60 min / 30 min / 15 min depending on the product available for each of the bidding areas. GOT: 15:00 D-1 GCT: h-1
Product	Energy (MWh): • Granularity: 1 hour/30-min/15-min • Minimum Quantity to bid: 0,1 MWh. • Maximum Quantity to bid: No constraint. • Price Tick: 0,01 €/MWh. • Minimum bid price: - 9.999 €/MWh • Maximum bid price: +9.999 €/MWh.

Table 23 - Pricing, frequency, bidding period and product details of the Intraday Continuous Market. Source: OMIE.

All orders must include energy quantity, price, production/consumption unit. Different validity conditions can be submitted to SDIC market, according with different trading possibilities:

- **None (NON):** is the default type. The order can be matched totally or partially. The not matched volume will remain in the Order Book.
- **Immediate or Cancel (IOC):** the order may be matched immediately totally or partially. If it is partially matched the unmatched volume will be cancelled.
- **Fill or Kill (FOK):** the order may be matched immediately for the total amount of energy submitted or cancelled if not. This type of order will never keep active in the Order Book. It is not possible to cancel or modify them.
- **All or Nothing (AON):** matching may only affect the full volume.
- **Iceberg (IBO):** only a part of the total volume of the order will be visible in the Order Book. The total volume of the offer will only be shown to the market participant who sent the bid. When the visible volume is totally matched a new slide of the total offer will be shown in the LTS and will receive a new order number.
- **Iceberg with price increase:** iceberg order with an additional parameter, the price incremental. In this case when a new slide of the offer is shown, the price of the new offer will be calculated as the price of the previous one plus the incremental price.

In addition to the previous order conditions, two more conditions may also apply:

- **Good-for-Session (GFS):** orders with this restriction will be valid until the closing time of the contract to which they were assigned. This is the default option.
- **Good-till-Date (GTD):** orders will be valid until a certain time established by the market participant during the creation of the order. This moment will be prior to the closing of the trading of the contract.

Market participants can submit a basket of several orders, also known as basket order, that may be associated to different trading contracts. Submitting a basket order will involve the simultaneous processing of all the offers included in the basket order.
At the end of each round, OMIE publishes the incremental and accumulated results for each of the production/consumption units and sends them to TSOs. After their validation they send back the Final Continuous Time Programs (PHFC) and update the values of the capacities of the interconnections.

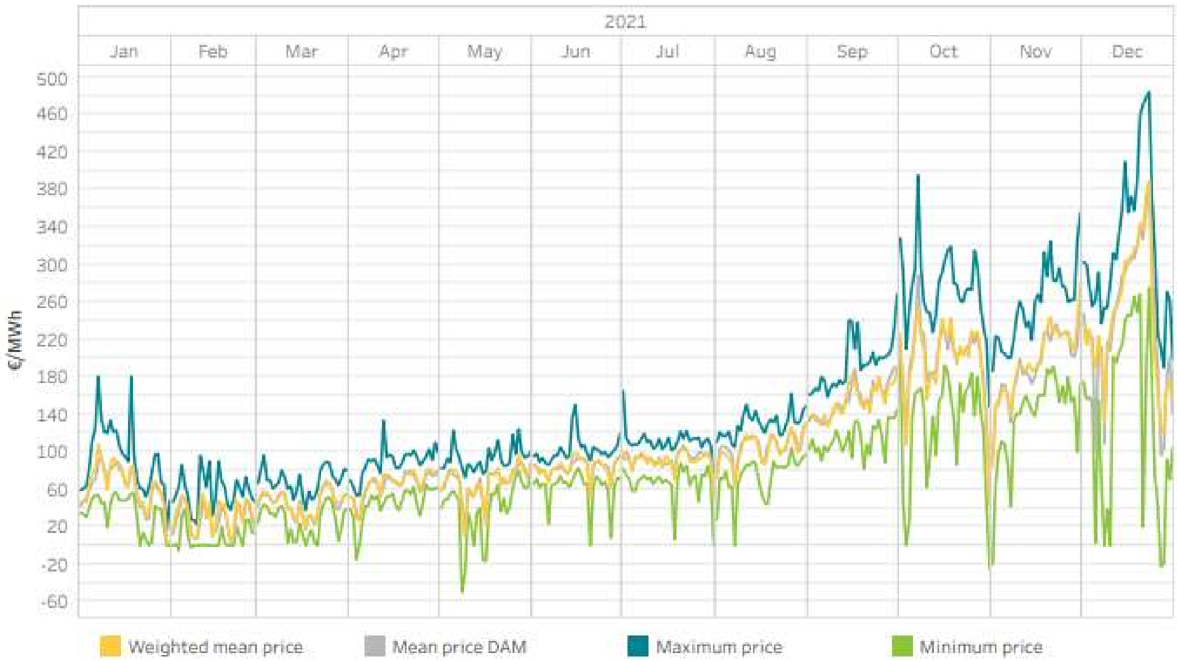


Figure 35 - Minimum, maximum, and arithmetic mean prices on the intraday continuous market in Spain. Source: OMIE [39]

6/ Ancillary Services and Balancing Markets

Introduction to TSO balancing mechanisms

In the Iberia region REE and REN are the entities involved in the regulation and balance of the electrical system, they manage all the balance mechanisms and ancillary services through which production and consumption schedules are adjusted after the negotiation in the DA market and in the intraday markets. All these mechanisms include the resolution of technical constraints, the management of deviations and the allocation of complementary services.
Balancing the energy system means to make all necessary actions and processes through which the TSOs ensure in a continuous manner that the frequency of the system is maintained within a stable range, thus ensuring the electricity delivery[32].
In Spain, the required actions for balancing the electrical system are based on a market mechanism in which market participants can introduce their offers and participate in the balancing of the system. Only the resolution of technical constraints is not activated through a market mechanism, the aim of the constraint resolution process is to limit or modify the production schedules so that technical constraint problems can be resolved.
The integration of balanced energy markets should facilitate the efficiency of intraday markets to provide market participants the option to adjust their schedules as close to real-time as possible. Only the imbalance remaining after the end of the intraday market should be balanced by the TSO with the balanced market.

SOLUTION OF TECHNICAL CONSTRAINTS

The objective is to solve technical constraints after the daily and intraday market sessions by limiting or modifying production schedules. Is a mandatory service that involves the analysis of the production units schedule and international exchange programs.
The technical constraints identified during real-time operation by curtailing, or if deemed necessary, modifying the power generation schedules of the programming units [45].

[32] Regulation (EU) 2017/2195 establishing a guideline on electricity balancing. COMMISSION REGULATION (EU) 2017/ 2195 - of 23 November 2017 - establishing a guideline on electricity balancing (europa.eu)

SECONDARY REGULATION

It is an optional power-frequency regulation service with an action horizon range between 20 seconds to 15 minutes of imbalance. The correction of deviations is automatically activated when a power-frequency deviation occurs in the system with respect the anticipated power exchange schedule of the Spanish Control Block. The objective is to maintain the target frequency of the system [46].

The secondary regulation service is carried out thought regulation zones and programming units that have the capacity to regulate their schedule according to an automatic signal received from the TSO.

The System Operator publishes every day at 14:45 h power requirements to go up and down according to their necessities and for each or the D+1 trading periods. Only qualified programming units can participate in the market and send their offers. Offers are matched according to an economic merit criterion and ensuring the security and stability limits stablished by the OS. The matching process is based in marginal pricing.

The retribution that the matched market participants receive has two components: availability (regulation band in €/MW) and activation (energy in €/MWh).

Secondary regulation is the equivalent to automatic Frequency Restoration Reserves (aFRR) in European nomenclature. It is expected that during 2024 Q2, Spain will integrate secondary

Figure 36 - Members and observers of the PICASSO project [53].

regulation in the European Platform for the International Coordination of Automated Frequency Restoration and Stable System Operation (PICASSO) platform[33].

In October 2020, Spain joined the European platform IGCC to compensate secondary regulation energy needs in real time. This integration minimizes the activation needs for the entire European control block that is interconnected.

TERTIARY REGULATION

Tertiary regulation is an active power balancing service that helps to maintain a constant equilibrium between supply and demand. This service is manually activated, and qualified units may respond to the system needs in a time equal to or less than 15 minutes and that they can maintain the service for at least two consecutive hours.

Tertiary regulation is based on a market mechanism where market participants have to submit their bids, for each of their production units, with the maximum variation of active generation that their production units can perform within 15 minutes. Retribution is paid at marginal price, through an allocation process 15 minutes before the scheduled period.

Tertiary regulation is the equivalent to manual Frequency Restoration Reserves (mFRR) in European nomenclature. It is expected that during 2023 Q3, Spain will integrate secondary regulation in the European Manually Activate Reserves Initiative (MARI) platform.

Figure 37 - Members and observers of the MARI project [47].

[33] Regulation (EU) 2017/2195 establishing a guideline on electricity balancing. [COMMISSION REGULATION (EU) 2017/ 2195 - of 23 November 2017 - establishing a guideline on electricity balancing (europa.eu)]

REPLACEMENT RESERVES (RR)

Replacement reserves is a balancing service of active power with the aim of correcting imbalances between generation and demand and also to restore the level of secondary and tertiary reserve. This service is manually activated, and qualified units may respond to the system needs in a time equal to or less than 30 minutes. This service is activated and managed through the LIBRA - Trans European Replacement Reserves Exchange (TERRE). Market participants send their offers to the TSO and after a validation process these offers are sent to the European LIBRA platform also with the information of the interconnectors and all the local requirements from the TSO.

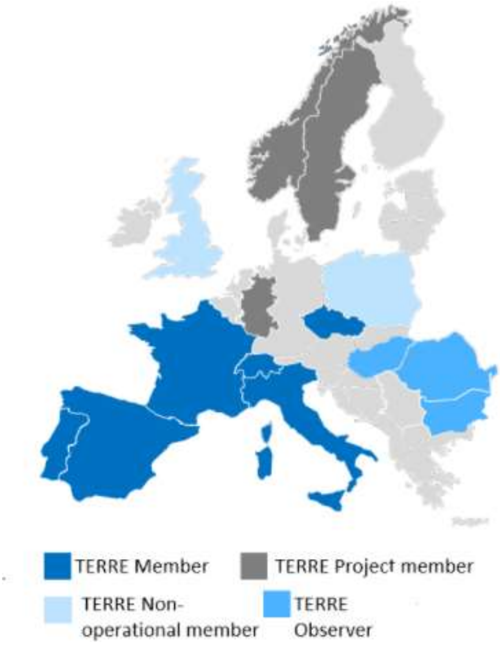


Figure 38 - Members and observers of the TERRE project. [48]

The European system optimizes the solution at local and European level and allocates all the necessary activations managing also international interconnectors.

CAPACITY MARKETS

Capacity markets in Spain are under development. In May 2021 the Spanish government launched a public consultation[34] for the creation of capacity markets in the electrical system. The capacity market will create long-term price signals. The System Operator will contract firm

[34] Public consultation related to the implementation of capacity mechanisms in the electrical system. (energia.gob.es)

power according to the electrical system needs, power that installations can supply to the grid in peak demand moments.

Capacity markets will be auctions based on a pay-as-bid mechanism where consumers, generation (including also self-consumption facilities), or storage facilities may participate. The first analysis [35]contemplates two modalities for these auctions:

- Auctions with a service horizon provision of five years.
- Adjustment auctions with a service horizon provision of twelve months, to solve possible needs not covered by the main capacity auction.

7/ Participation of V2G in wholesale electricity markets.

Understanding the potential of V2G when participating in day-ahead, intraday and intraday auctions in Spain

Understanding the effect of the integration of this electric fleet on the system is key to assess the potential of having control over the charging and discharging of electric vehicles, as proposed by V2G models.

This section will assess the participation of V2G in the global energy markets and the participation of V2G in Vehicle-to-Home and Vehicle-to-Building schemes. V2G is a very good candidate for flexibility markets and ancillary services. However, these flexibility markets will be covered in a different derivable, D3.2.

Finally, we will present the status and future developments in terms of regulation in Spain and Europe.

7.1 Future demand evolution in Spain

ELECTRIC VEHICLE DEPLOYMENT

One of the main changes in the transport and electricity system will be the adoption of electric vehicles. Spain plans to have 5M electric vehicles on the road by 2030 (3M cars and 2M

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[35] Analysis of the Impact for a Capacity Market in the Spanish Electrical System
https://energia.gob.es/_layouts/15/HttpHandlerParticipacionPublicaAnexos.ashx?k=24975

motorcycles, vans and buses) [49]. All these vehicles will use the electrical grid to be charged, which will have an impact on the electricity demand curve. Unlike with conventional vehicles, most EV charging is done at home or at work, instead of using public infrastructure. It is estimated that there will be close to 10 home charging points per every public charging point. A study published by the ICCT (International Council of Clean Transportation) forecasts that 69% of EV owners will have access to charge their EV at home in 2030, meaning 3.45M residential charging points in Spain [22]. Regarding public charging infrastructure the Spanish Association of vehicle manufacturers ANFAC foresees to achieve 360.000 public charging points in 2030 [20].

The deployment of electric vehicles will shift the residential demand curve and may generate potential risks to grid congestion caused by peak hours due to EV charging. According to the research by the ICCT 57% of the total energy for EVs charging will take place at home in 2030. Followed by 24% of the energy from public infrastructure (including fast chargers) and 20% of the energy from work chargers.

Uncoordinated charging demands of EVs increase the load during peak hours, which in turn has a negative impact on the stability of power grids due to its sizable rating. Typically, an EV draws approximately 7 kW power from the grid, which is significantly higher than the peak demand of most of the residential households. Moreover, EV owners tend to charge their EVs after returning from work, which is also usually the time of peak demand in the grid, thereby coinciding with the power drawn from EV and household peaks. This scenario leads to a significant increase in system peak demand and threatens the stability of the power grid.

Since a great share of EV charging points will be at home in 2030 and will not have smart charging features following actual market trends, the charging periods will highly depend on working schedules from owners and on the adaptability from customers to EV electricity tariffs. As mentioned before, 57% of the total energy for EV vehicle charging will happen at home in 2030.

When talking about non-scheduled charging we must mention that drivers can manually decide the best time to charge their vehicles. This would mean that the EV owner would not charge their vehicle when they arrive home from work but will wait to valley hours when prices are low to charge their vehicle.

MASSIVE INTEGRATION OF RENEWABLES

The Spanish Energy and Climate Plan 2021-2030, sets as its main objectives the decarbonization of the economy and the integration of renewable generation sources, demand response, storage, and flexibility, as well as the development of self-consumption and distributed generation. All these initiatives will have a direct impact on the electricity market and in the electricity price. According to the national plan for the year 2030 42% of the energy must be renewable, to reduce greenhouse gas emissions to the required level.

The largest increase in installed power technology corresponds to solar PV generation, from 15 GW of installed power capacity in 2021 to 37 GW forecasted for 2030 [49], which is equivalent to x2.5 compared to 2021. This change is one of the main reasons that will cause the hourly price curve of the electricity pool to undergo a major transformation over the next years. The electricity price during the central hours of the day will be reduced due to the increased presence of photovoltaic generation.

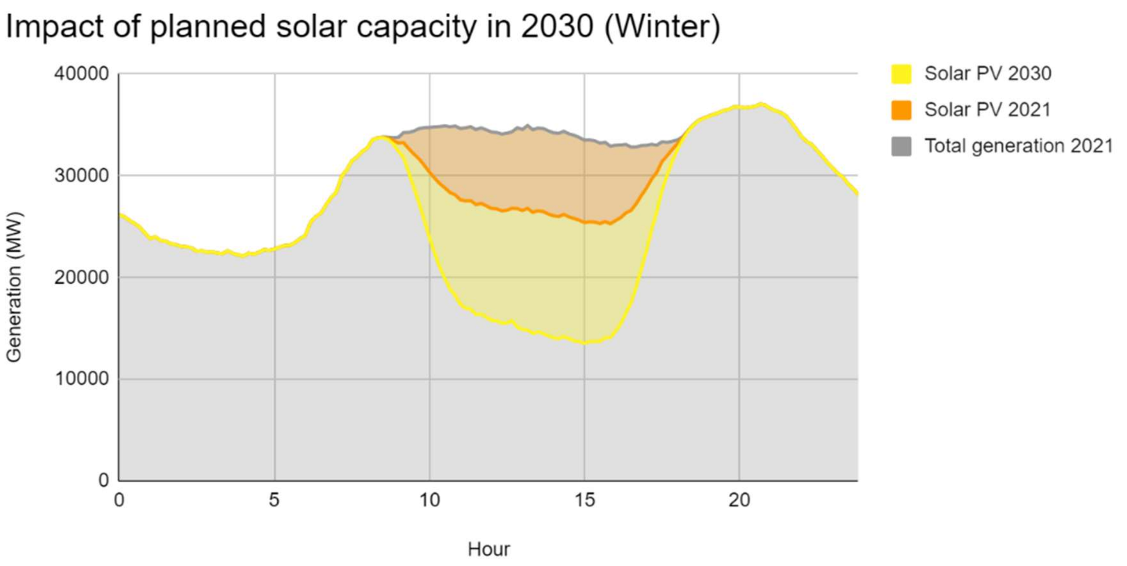
The increasing penetration of PV technology will cause other technologies not to participate in the mix in the central hours of the day. The entry into production of conventional generation plants is conditioned by the production of non-manageable renewable technologies. The thermal gap is the proportion of demand that this type of renewable technology is not capable to cover and therefore must be generated by conventional technologies. As more renewable capacity is incorporated, the thermal gap will be smaller and therefore it is foreseeable that the number of hours in which renewable technologies set the marginal price will increase and the resulting price from the matching process will be lower.

Solar generation begins to decline in the afternoon when electricity demand begins to increase. This means that the necessary increase or ramp of conventional production in the afternoon and evening hours will be much more accentuated. This leads to the fact that, if there is no flexibility available such as storage, demand-response or bidirectional EV the rest of conventional technologies, must quickly enter in the mix generating electricity during those hours, causing prices to rise at those periods of the day and generating a large price difference between the central hours of the day and peak price hours. However, this scenario can be avoided thanks to the change in consumers behaviour, the introduction of the bidirectional electric vehicle, the adoption of demand response strategies and the incorporation of storage systems.

We can see in Figure 3939 the generation mix on June 29 2021 (Summer) and on January 7 2022 (Winter). In Spain there was 15 GW of solar capacity installed in 2021. The National Integrated Energy and Climate Plan foresees a total installed capacity in the electricity sector of 37 GW solar photovoltaic. That figure also shows the impact of the solar generation on June 29 2021 (Summer) if 37 GW solar photovoltaic were already implemented. The figure shows what generation would look like on a day with the same demand/production circumstances as in the previous year.

We are not considering the improvement on solar energy efficiency, nor changes in demand and the integration of other types of renewables and storage. We must mention that the adoption of energy storage and hydrogen production will help dispatch energy generated from solar to other periods of the day. However, the National Integrated Energy and Climate Plan only foresees a total of 6GW of storage (3.5 GW of pumped storage and 2.5 GW of batteries) for 2030.

The impact of the planned solar PV generation capacity by 2030 on Winter and Summer scenarios in Spain



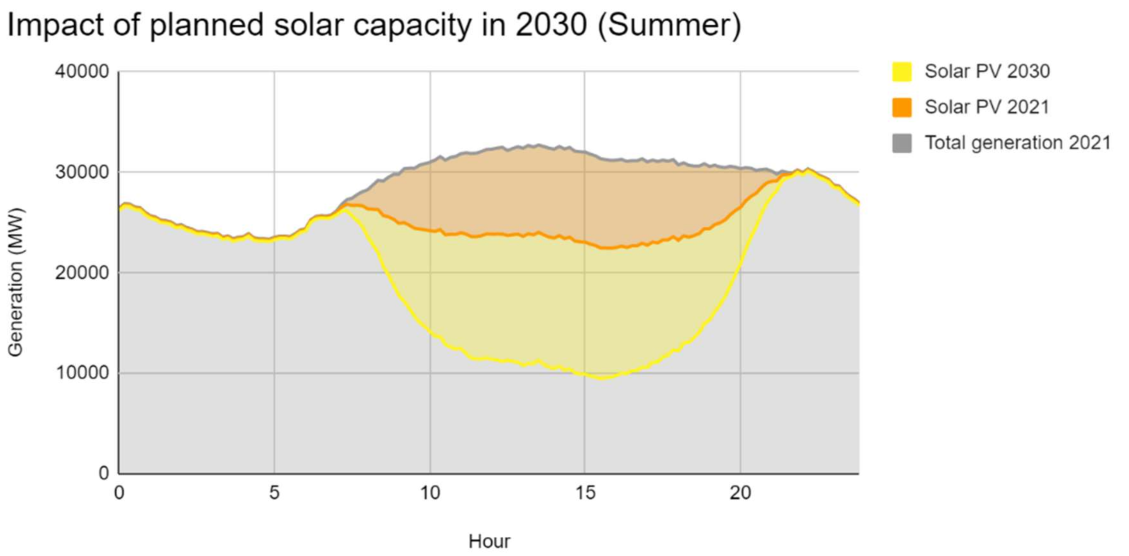


Figure 39 - The impact of the planned solar capacity by 2030 in a winter and a summer scenario. Internal data from Holaluz.

This demand behaviour is called the 'Duck Curve'. This popular curve, developed for the first time by the California Independent System Operator (CAISO) predicted in 2013 the behaviour of the Californian electricity system in a scenario of high penetration of photovoltaic solar energy for the future years. In California, this has caused the pool price to fall in central hours of the day. This effect means that conventional generation is displaced to other hours of the day where solar production is not sufficient or non-existent, relegating these technologies mainly to peak demand hours.

TRENDS ON PRICING

On Figure 40 there is a recent example of this behaviour in the day-ahead Spanish electricity market on the day April 7th 2022. During central hours of the day, the day-ahead price felt to 7 €/MWh. It is remarkable that in the hours previous to solar generation and after solar generation reach the highest prices of the day (252 €/MWh).

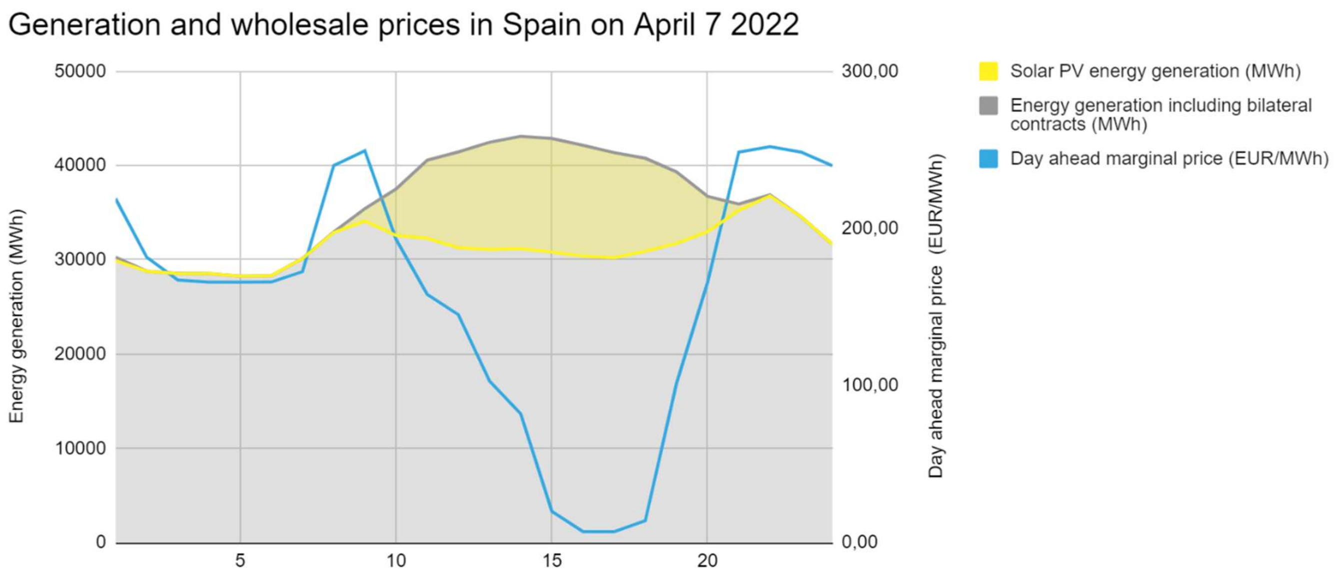


Figure 40 - Generation and day-ahead prices in Spain on April 7 2022. Data source: OMIE.

We can expect hours of high solar generation to be extremely cheap in the wholesale market, even possibly reaching negative prices during those hours in that period. This will mean that current hourly-based tariff will need to change to adapt to this new scenario. The mid period of the day will be the one promoted for consumption like, for example, EV charging or industrial high consumption activities.

7.2 Market opportunity for V2G in the global markets

As mentioned before, this working package assess the potential participation of V2G in the day-ahead market, the intraday markets, and the intraday auction, even though V2G is a very good candidate for flexibility electricity services.

The electrification of the energy system and the integration of renewables will pose challenges for the management of electricity networks and generation. The paradigm of baseload and peaking generation opens a window to new players, able to offer reliable and fast generation to contribute to security and quality of supply.

The opportunity for EVs in the electricity market is easy to understand if we consider the example of the generation power curve in Spain on January 7 2022 (Winter) of Figure 41, where it is possible to differentiate generation from non-solar sources into 3 main operational areas: flat hours, valley hours and large ramps and peak hours.

- **Flat hours** will be still covered by baseload generation and renewables.
- **Valley hours** will reach really low prices and could be even negative at very specific moments with high renewable capacity in the next years. This will be the period promoted for consumption.
- **Large ramps and peak hours** are being covered though gas peaking plants which have high costs and emit CO2. When gas peaking plants are in operation, they usually set the price on the spot market, leading to high-cost hours.

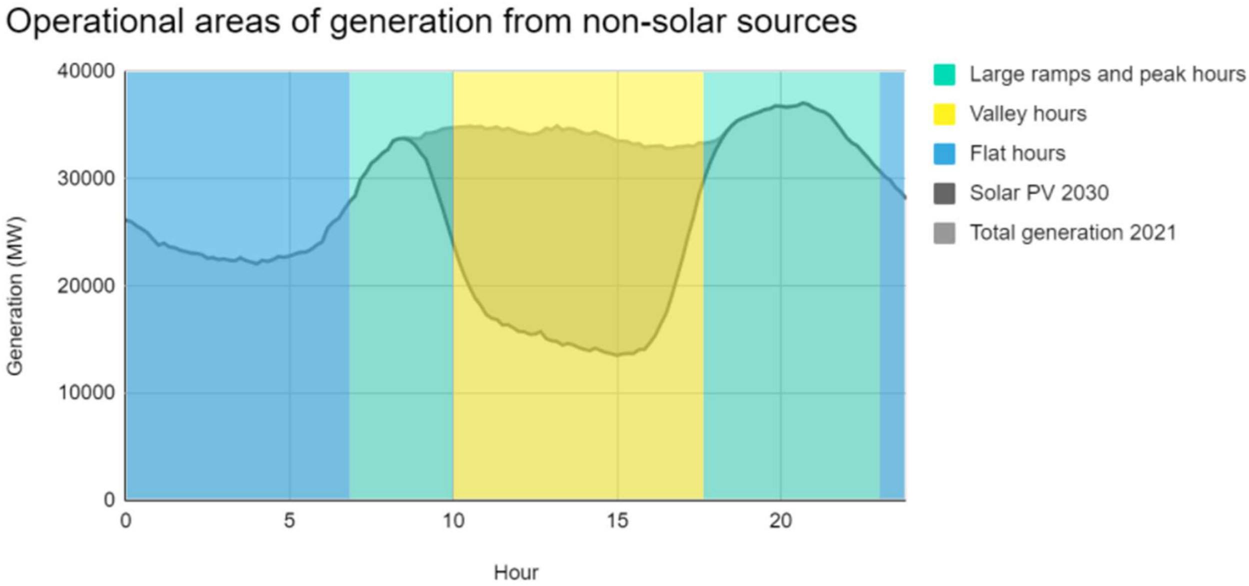


Figure 41 - Operational areas of generation from non-solar sources. Generation data from OMIE.

V2G has the possibility to offer flexible generation capacities and put into operation its fleets with low marginal costs. V2G can be fully charged during valley low-cost hours and then be discharged during the evening peak to cover the demand.

Over time, the technology components of V2G will decrease in price as well as they gain scale (such as batteries and EVs), while gas-fuelled plants will face increasing financial and regulatory risk, largely due to fuel prices and carbon emissions. V2G, as DERs in general, therefore represent the cheaper and cleaner alternative to meeting demand peaks.

V2G could participate in the global energy markets as any other electricity generation installation through the aggregation of assets performed by aggregators. Aggregators gather multiple players to enable them to reach the required size to enter some markets, mutualize costs to enter the market and perform a global optimization of their asset.

To provide generation services in the market, aggregators must meet a set of technical and regulatory criteria. The criteria for the participation in the different global markets can be checked in chapter 5 of this document. When assessing the business case for the global market we will focus on the following criteria:

- **Aggregated capacity**: Minimum bidding of 0,1 MWh enables de participation of aggregated resources. A V2G aggregated fleet could reach the minimum bidding size by aggregating less than 50 electric vehicles.
- **Service duration**: Hourly granularity until 15-minutes granularity is in operation. Shorter service timers represent an advantage for V2G, since it has the possibility to charge/discharge for short periods if possible.

- **Time to activation**: The operation on the intraday market is as minimum confirmed 1 hour in advance the moment of the energy delivery/consumption, which would be enough time to activate available V2G capacity.

At the moment it is not possible for V2G to participate in wholesale electricity markets. It is necessary to modify regulation related to electricity storage to include storage facilities and V2G services in the market scheme. The participation of storage in the electricity markets is reduced to pumped hydro storage and storage associated with solar power.

Roles in electricity markets

The participation of V2G in the electricity market depends on a range of different actors that need to coordinate efficiently to deliver quality services to the grid. When participating in an electricity market it is necessary to aggregate enough capacity to deliver service and to be able to compete with large scale installations.
The most relevant actors in V2G participating in electricity markets are:

- **Aggregator:** An aggregator is a user that can operate many distributed energy resources (DERs) together, creating a sizeable capacity like a conventional generator to participate and manage their energy in electricity markets. V2G EVs can be aggregated in fleets or with other type of DERs. Due to the condition of minimum traded energy in the wholesale markets this figure that will act as intermediary entity between vehicle owners and electricity markets submitting blocks of offers to buy or sell energy to the market. The aggregator will be able to manage V2G capacities according to the consent periods agreed with the vehicle owner.
- **V2G users:** Final users are the owners or users of the electric vehicle. They will be a key piece in the interaction in the electricity markets, because a better management of their energy flows can reduce overall electricity costs.
  It is important to contemplate that EV owners will be motivated to participate in wholesale electricity markets only if aggregators guarantee enough flexibility and final users do not suffer loss of freedom due to empty or low battery.
- **EV fleet operators:** EV fleet operators aggregate a large number of EVs and require less contract management overhead on a per-vehicle basis. Vehicle-to-grid (V2G) integration investments in fleets achieve a speedier return than investments in individually owned passenger EVs. Additionally, fleets of larger commercial vehicles, including buses, often have regimented drive schedules that can make forecasting and scheduling easier.

- **Electricity retailers (suppliers):** Energy retailers provide energy users with options for purchasing energy in wholesale markets. They provide and sell electricity to final users, that pay in their bill the cost of the electricity and charges and tolls. Energy retailers are a part involved in the development of V2G technology as they may be service providers and at the same time customers.
- **Market operators:** Responsible of the operation of the electricity market, ensuring that all their markets are transparent and fair for all the participants, including V2G users. They give access to market platform to all the agents and guarantee the correct functioning of the systems, matching demand, and supply. The electricity market is in the centre of all the actors. Market operators are also in charge of nomination, receiving the bids, guarantees and carrying out the clearing and settlement processes.
- **Software providers:** They are an important key to provide data services to final users, connecting the electricity market with V2G and EV users, giving them useful and understandable information, which allow them to make their own decisions. This role may be also provided by the aggregator or the energy retailer.

BUSINESS MODEL FOR AGGREGATORS

The aggregator acts as an intermediary between multiple DERs and the electricity market. Aggregators gather multiple players to enable them to reach the required size to enter some markets, mutualize costs to enter the market and perform a global optimization of their asset. The aggregation platform can include a range of DERs systems such as rooftop solar photovoltaics, stationary batteries, and the loads and batteries embedded in electric vehicles and supporting infrastructure. The larger and more available the fleet of assets, the more valuable the aggregation pool becomes.

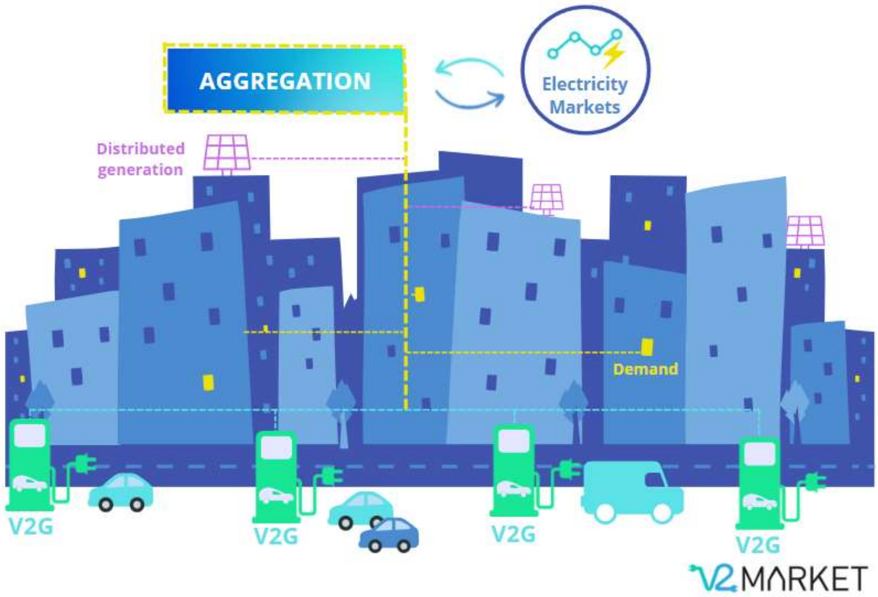


Figure 42 - How the aggregator interacts with V2G and electricity markets. V2Market.

Aggregators take care of the forecasting and bidding of the renewable generation and perform day-ahead scheduling of V2G operation for each EV, to estimate the D-1 day electricity capacity participating in the Day-Ahead market, while meeting EVs owner availability schedule. If it is necessary, aggregators' final schedules may be modified in the intraday, continuous or auction markets to adapt to their real needs and generation possibilities. The aggregator distributes the revenue that is delivered to it from the market to vehicle owners that have been connected to that aggregator's V2G charger network during the V2G operation.

A simplified V2G aggregation architecture is composed of EVs, bidirectional charging stations, communication structure (hardware and software), the aggregator platform and the electricity market platform provided by the market operator. Both EVs and charging stations have to be V2G-compatible to participate in electricity markets since they have to coordinate their operation with the aggregation platform. Aggregators have to aggregate a large group of EVs to provide electricity service to the power grid. Examples of systems reported in the literature include 500, 1000 and 1500 EVs. However, in Spain the minimum bidding on the Day-ahead and intraday markets is 0,1 MWh, which allows the participation of smaller fleets.

Aggregators, based on the received information make a decision to a set of EVs charging/discharging command. These decisions are based on the electricity market price €/kWh announced by the market operator. In this model, there is only one aggregation entity managing the EVs through different charging stations.

7.3 Market opportunity for V2B and Energy communities

V2B (Vehicle to Building) and V2H (Vehicle to Home)

V2B (Vehicle to Building) and V2H (Vehicle to Home) support building and home energy use, respectively. They can provide a cost reduction associated with a reduction of the electricity bill, taking advantage of the energy stored in the batteries, charged at cheaper periods to inject it into the network during peak hours, where electricity price is higher, reducing the building's peak energy demand and associated cost and, in this mode, the EV and its battery transfer energy consumption from the most expensive hours to the cheapest ones.

Practically all households and a large part of consumers have a low-voltage (electric power less than 15 kW) access tariff or access toll named 2.0 TD. As explained in chapter 4.5, this tariff has 3 energy consumption billing periods:

- **The peak period**: with the highest price, from 10am to 2pm and from 6pm to 10pm from Monday to Friday non-holiday.
- **The flat period**: a less expensive price from 8am to 10am, from 2pm to 6pm and from 10am to 12pm.
- **The valley period**: with a reduced price includes the night hours (from midnight to 8 a.m.) and all hours of Saturday and Sunday and national holidays.

V2B and V2H combined with self-consumption allows consumers to use the energy generated in their solar panels to charge their vehicle and discharge the battery later in hours where no solar production is available, maximizing their self-consumption.

We present a real case in the residential sector of a system with a photovoltaic installation and a second life Li-ion battery manufactured by the Spanish company BeePlanet Factory. This use case can be one of the most similar to V2B in residential since it involves an electric car battery as if it was an electric vehicle. The residential on grid installation has a 5,6 kWp PV rooftop solar and a 8 kWh 2nd life storage solution. In this example the battery is available 24 hours every day of the week, which would not be the case for most of the V2G owners. The total daily consumption of the household is 19,78 kWh, while only 0,07 kWh comes from the grid.

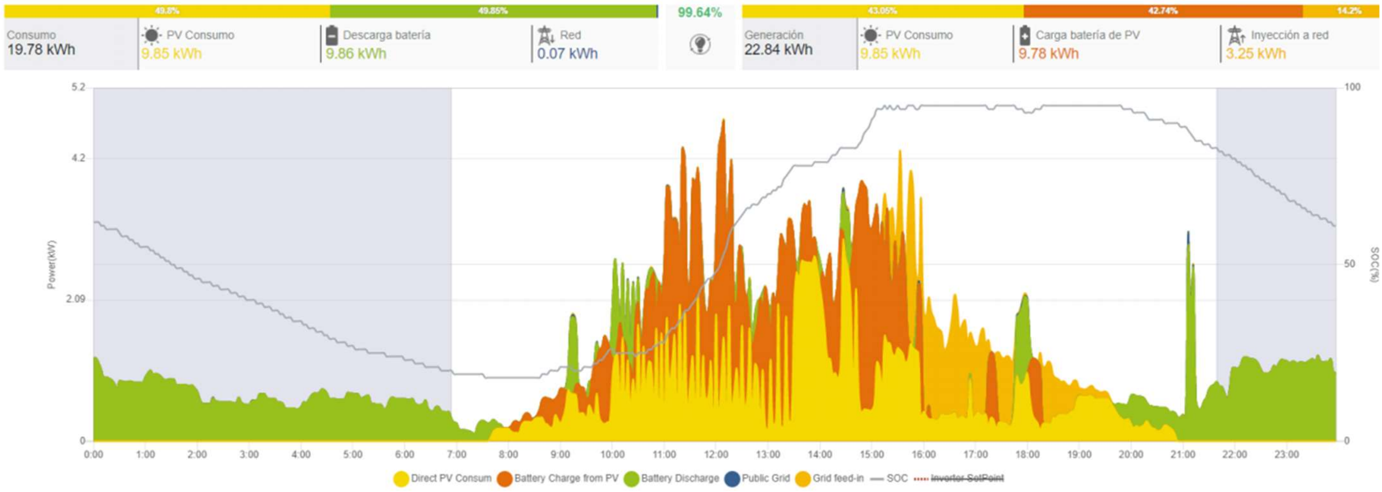


Figure 43 - Sources of consumption from a residential with rooftop solar PV and a second-hand electric vehicle from Beeplanet battery [50].

Nowadays, under the current regulatory framework, V2B and V2H are the only possible V2G business model in Spain. However, they are limited to behind-the-meter operation, so they can only provide electricity bills reduction and not a source of income.

Energy communities

V2G may be a useful technology for energy communities. Energy communities are legal entities that can carry out they all kinds of activities within the electricity sector, such as, generation, distribution, supply, EV charging or aggregation within their community. The communities are made up of individuals, small businesses, companies, municipalities, and cooperatives, among others. The renewable sources can be under co-ownership or owned by one of the members.
The members may consume the energy generated within the community directly and this way the energy community can maximize and share cost reduction on their electricity bill. V2G on local communities can store energy from the community's renewable sources at high production hours and then give it back during high price hours. More about energy communities will be discussed in deliverable 3.2.

7.4 Regulatory context: participation in the Spanish electricity market

Due to the current minimum size bid needed to participate in the electricity markets (0,1 MWh) and to the necessity of aggregation of several EVs or fleets to give to the system a V2G service it is necessary to aggregate the demand or supply of multiple vehicles. This aggregation will be a useful tool for aggregating different type of resources in order to make robust operations in the markets. It is especially interesting for those facilities that may have variations in their demand or energy generation due to their intermittent generation or consumption, for example: rooftop photovoltaic, wind power generation, EVs and V2G fleets, etc.

Participation in the market through the aggregator in Spain and learnings from Portugal

The Directive 2019/944 states "*All customer groups (industrial, commercial and households) should have access to the electricity markets to trade their flexibility and self-generated electricity.*" Clearly for EV batteries, which have a small capacity, this participation in the markets will require the intermediation of the aggregator.

The aggregator's role is to manage multiple distributed resources, such as rooftop solar panels or EV batteries, as if they were one single asset, with the use of technology and software. Essentially, this aggregated volume can carry out two roles. On the one hand, it can participate in the organized electricity markets, purchasing electricity when the price is low and injecting electricity when the price is high, thus obtaining a gain on the difference in market price. On the other hand, it can participate giving flexibility to the market helping the overall efficiency of the system and providing stability to the electricity system in exchange for an economic compensation.

Unfortunately, the European provisions contained in the Directive 2019/944 which should have been transposed into national legislation by 31 December 2020, have not yet been introduced in the Spanish regulation, except for the definition as a subject of the electricity sector of the independent aggregators. An independent aggregator according to Directive 2019/944 means "*a market participant engaged in aggregation who is not affiliated to the customer's supplier*".

In Spain the definition of independent aggregator has been incorporated into the Electricity Sector Law, in art. 6.1 i), and has been defined as a subject who can carry out activities related to energy supply. Art. 49 ESL on the other hand, incorporates provisions for independent aggregators dealing with demand management, specifically stating that "Consumers and owners of storage facilities, either directly or through independent suppliers or aggregators, may participate, where appropriate, in the services included in the production or demand management market in accordance with what is determined by regulation.". Thus, the role of the aggregator could be carried out by the electricity supplier or a third party independent from the supplier, such as a battery manufacturer or an energy community.

For the full development of this role as independent aggregator many factors will be key, as Regulation 2017/2195 envisages when it sets a set of technical, operational and market rules to regulate the functioning of the electricity balance markets, based on guaranteeing adequate competition and fair conditions for market participants.

Storage and aggregation require a full regulatory treatment in order to provide a framework which answers the complex energetic and legal challenges posed by the introduction of these subjects. As these challenges remain unsolved so far in Spain, we believe it is useful to look, if only briefly, at the regulation recently passed in Portugal. Decree-Law nº 15/2022 was passed on January 14th, 2022, establishing the organization and operation of the National Electric System, transposing Directive 2019/944 and Directive 2018/2001 on the promotion of the use of energy from renewable sources.

The Portuguese legislator includes storage and aggregation in the chapter on activities of the National Electric System, which seems a much more comprehensive approach than the Spanish one where, as we have seen, these figures are only contemplated from the perspective of recognising them as subjects or market participants by the Spanish Electricity Sector Law. In the first place, the process for registration as an aggregator -valid for the whole of the National territory- is defined in detail in article 145 and electricity suppliers are expressly exempted from having to carry out the registration process and only must notify the Directorate General for Energy and Geology.

Also, aggregators are admitted as members of the organized market, as long as they comply with the necessary requirements set in the regulations and by the market operator.

In the second place, the aggregator is given the same rights and duties as electricity suppliers as well as some specific ones, as follows:

a) Trading electricity through organized markets or through bilateral agreements with other market agents, as long as the aggregator meets the requirements for access to these markets.

b) Aggregate and represent electricity producers in the market that are not covered by guaranteed remuneration schemes or other subsidized remuneration support schemes.

c) Have access to networks and interconnections, under the legally established terms, for delivery of electricity to the respective customers.

d) Freely contract the purchase of electricity with the producers it aggregates.

In the third place, the Portuguese legislator sets a clear connection between self-consumption and aggregation. The Decree Law, understands that the aggregator can aggregate producers, customers, storage facility holders or self-consumers. Specifically, when defining the duties of the self-consumer, it states that the self-consumer must allow and facilitate access the self-consumption production unit (UPAC) to the technical staff of the aggregator and of the network operator, in the scope and for the exercise of the respective attributions, competences, or contractual rights.

Finally, the aggregator of last resort is regulated and defined as that which has the obligation to purchase additional electricity from renewable energy producers and self-consumers who inject surplus energy in the public service power grid (RESP), as well as in the purchase of electricity from producers benefiting from guaranteed remuneration schemes or other subsidized remuneration support schemes.

As was pointed out earlier, in Spain the regulations which currently refer to aggregators, are strictly referred to balancing services and wholesale electricity markets.

- Aggregators participating in balancing services: Resolution of December 10, 2020, of the National Commission of Markets and Competition, passing the adaptation of the system's operating procedures to the conditions related to the balance approved by Resolution of December 11, 2019[36].
- Aggregators participating in wholesale electricity markets: Circular 3/2019, of November 20, of the National Commission of Markets and Competition, which establishes the methodologies that regulate the operation of the wholesale electricity market and the management of the operation of the system[37].

[36] Resolution of December 10, 2020, of the National Commission of Markets and Competition, passing the adaptation of the system's operating procedures to the conditions related to the balance approved by Resolution of December 11, 2019 (Official State Gazette, num. 335, 24/12/2020)

[37] Circular 3/2019, of November 20, of the National Commission of Markets and Competition, which establishes the methodologies that regulate the operation of the wholesale electricity market and the management of the operation of the system (Official State Gazette num. 289, 02/12/2019)

The following chapters will cover the potential participation of aggregators in the different markets and the criteria to be met.

DAY-AHEAD AND INTRADAY MARKETS

Regarding day-ahead and intraday markets, article 7 of Regulation 2019/943 on the internal market for electricity establishes the obligation that they are "*organised in such a way as to ensure that all market participants are able to access the market individually or through aggregation*" without discrimination. In Spain, decentralized resources can participate in the wholesale markets both indirectly (via supplier or representative) and directly as a direct consumer with a minimum offer of 0.1 MWh in a single type of participation (as a buyer or as a generator). However, other than pumping storage, currently there is no provision for stand-alone storage participation, which is the category that corresponds to V2G, but this type of storage is starting to be considered in the electricity system.

Currently, the participation of storage in the electricity markets is reduced to pumped hydro storage and storage associated with solar power. Stand-alone storage, that is not pumping storage, needs further proposals and cannot participate in wholesale electricity markets yet. The same happens to V2G services that are in essence, dynamic storage. It would be necessary to integrate these systems into the electricity market: storage and V2G facilities should have two bidding units, one for purchase and other for selling. Thus, these facilities should be able to have a net consumption balance or a net selling balance schedule after their negotiation into the electricity markets. At the moment, for example, a consumer cannot have a final schedule that is against the nature of the unit. In the case of consumers, the bidding unit associated with them is a purchase unit.

Thus, at present it is not allowed, from a regulatory point of view, to operate V2G in wholesale electricity markets, as it has the same regulatory barriers as conventional stand-alone storage systems. However, the electricity markets have the tools and the structure ready to incorporate all these new resources as soon as the regulation and agreements admit them.

Finally, article 8 of the Regulation determines that market participants should be able to trade energy in time intervals at least as short as 15 minutes in both day-ahead and intraday markets, unless NRAs have granted derogations or exemptions (derogation may be granted only until 31 December 2024). In Spain, nowadays, the granularity is 1 hour.

BALANCING SERVICES

Article 19 of Circular 3/2019 establishes that the System Operator will be responsible for managing the balancing services markets provided by the providers of these services to guarantee the proper balance between generation and demand, and security and the quality of the electricity supply. Also, according to this same article, the System Operator will be responsible for the liquidation to suppliers of the activated volumes of balancing energy, the liquidation of energy exchanges with other operators, as well as the liquidation of deviations to each liquidation subject responsible for the balancing. All this, according to the provisions of Regulation (EU) 2017/2195 of the Commission, of November 23, 2017, which establishes a guideline on the electrical balance.

Accordingly, the National Commission for Markets and Competition (hereinafter, "CNMC" from its in Spanish acronym) passed Resolution of December 11, 2019, which approves the conditions related to the balance for balance service providers and the liquidation subjects responsible for the balance in the Spanish peninsula electricity system. This resolution allows the participation of the demand and storage systems in the balance services, establishing the conditions for the aggregation of these facilities and for their authorization to participate in the different balancing services. Specifically, it contemplates the aggregation of demand facilities, storage facilities and electricity generation facilities, to offer balancing services to the system, as well as allowing owners of demand facilities, third parties and owners of power generation facilities, as well as owners of storage units, to be balancing service providers.

For the provision of balance services, the corresponding authorization from the System Operator must be previously obtained, proving its technical and operational capacity to provide the service.

The adaptation of the system operator's procedures has materialized in Resolution of December 10, 2020, of the National Commission of Markets and Competition. This Resolution contemplates that each programming unit providing balancing services must have a minimum offer capacity of 1 MW.

REDISPATCHING

Redispatching, that is, the shift in electricity production, must be open to all generation technologies as well as storage and demand response, according to Regulation 2019/943. In Spain, the TSO performs a market based redispatch.

The participation of all installations or groups of installations that have a physical unit with a specific electrical location may participate in redispatching in Spain, according to Resolution of

January 13th, 2022[38], of the CNMC. This includes storage facilities not associated with generation or demand facilities, which will have a differentiated programming unit for deliveries and power outlets. Similarly, Operational Procedure 3.1[39] of the System Operator does not exclude or limit types of batteries, it regulates storage in general terms. The only distinction made is whether the storage is associated with a generation or demand unit. If it is not, it must have its own programming unit for the system. Therefore, EV batteries could participate as stand-alone storage in redispatching.

No specific remuneration is foreseen for participation in the automatic power reduction process, nor for the availability for activation, although the redispatch that is necessary when applying the reduction, will be remunerated at the price of the submitted offer.

Thus, a single programming unit will be created for BRP and a participant in the market for the delivery of energy from the set of storage facilities associated with generation or demand facilities. Additionally, a single programming unit will be set up by BRP and participant in the market for the energy intake of the set of installations of storage not associated with generation or demand facilities, as would be the case for EV batteries.

Regarding time granularity, a 15-minute period is established for assignments and redispatches corresponding to system adjustment services (technical restrictions, band of secondary regulation, reserve substitution balance energies, tertiary regulation and energy of secondary regulation). Although redispatches for technical restrictions must present the same value until quarterly-hour products are introduced in the energy markets.

CAPACITY MECHANISMS

The capacity mechanisms, according to the Article 20 of Internal Market Regulation, will be focused on solving a problem of coverage of the demand, which persists after applying previous alternative measures.

There is currently a capacity mechanism Proposal under consultation. The proposed capacity mechanism consists of a centralized system where the TSO contracts the firm power required, in other words, the power that an installation may offer at peak times, for two time-horizons: 5 years and 1 year. This firm power would be contracted through competitive bidding procedures managed by the system operator through *pay-as-bid* tenders. Capacity providers in tenders will

[38] Resolution of the CNMC whereby a new operating procedure 3.11 is approved and operating procedure 3.2 is modified to develop an automatic power reduction system. (Official State Gazette num. 21, 25/01/2022).

[39] Operating procedure 3.1: Resolution 17th March, 2022 of the CNMC (Official State Gazette nº 75, 29/03/2022).

offer to the system their committed capacity expressed in MW and the corresponding offered price in €/MW. Then, they must maintain an availability equal to or greater than the firm power assigned, offering said power, and the variation of energy associated with it, through their effective participation in the daily, intraday and balance markets, in situations of system stress which are communicated by the system operator.

On paper, the participants in these tenders may be consumers, generation, or storage facilities, including self-consumption facilities, provided they meet the established requirements. However, depending on how the system operator designs the framework, storage could *de facto* be excluded from capacity mechanism participation.

For instance, if a user has a photovoltaic installation with a battery, it could participate in the capacity market if the TSO designed the service in advance with a minimum of 6h and a supply of 2h. Thus, if not required for service, the battery could be used in other markets or save the energy for another time. However, if the TSO defined schema requires the capability request with 30 minutes in advance, a part of the battery should always be charged and could not monetize its energy in other ways, depending exclusively on the payment of the capacity market and limiting its participation or excluding it directly.

Unfortunately, the proposed capacity market only requires firm capacity, ignoring the provision of flexibility services that would allow mitigating the other great challenge of operation of an electrical system with a high penetration of renewables, energy discharges.

7.5 Legal barriers and considerations for EV to enter the electricity market in Spain

This chapter has presented the analysis of the regulatory framework for aggregators participating in electricity markets in Spain, referring to the documents of the European Union and domestic legislation. Potential barriers that could hinder the implementation of V2G technology have been identified, such as:

1. Interoperability of the infrastructure: there is a clear need for the development of interoperability standards for communication and control between the different distributed resources (for example, between the different brands of electric vehicles, as well as the charging stations and systems). In addition to the need for interoperability,

complementary measures related to the infrastructure of charging and control systems and facilitating cross-border travel of electric vehicles (e-roaming) will also be required for the development of a V2G business model. This point has been identified in the storage strategy by the Ministry of Ecological Transition.

2. Attributes for EMSP and CPO: also, regarding EV charging regulation, the fact that the figure of the EMSP does not include at all the attributions of a flexibility services aggregator, nor are energy exchanges in the direction from vehicle to grid envisaged or regulated, is a barrier for V2G. In addition, as the law is drafted, the EMSP is expressly excluded from ownership of both the electrical infrastructure of recharging points and its exploitation rights.

   Another possible barrier to the implementation of V2G services is the definition of the CPO, making it the effective energy consumer. This introduces complexities in the management of possible V2M services provided through vehicles whose ownership is different from that of the charging point. Speculating, even if an agreement were established whereby the recharging point operator assigned the status of energy consumer (or in this case, “prosumer”) to the owner of the vehicle, would that limit the vehicle's access to V2M services in the operator's network, thus limiting the potential of V2M?

3 Representation in TSO markets: regarding rules for participation in the markets, currently, if the market participant is a representative on behalf of another (direct representation), it must act with the programming unit of the owner of the production or storage facility. On the other hand, if the market participant is a representative in its own name (indirect representation) of installations with an installed capacity greater than 1 MW or groups of installations whose sum of installed capacities exceeds 1 MW, it may act with its programming unit or with the programming unit of the owner of the production or storage facility.

For EV battery aggregation it will be necessary to regulate for the possibility of the aggregator to participate with its own operative unit, regardless of the type of representation. One solution is to dissociate ownership (property right) from administrative ownership (operational right) of the EV battery as happens for self-consumption installations since Royal Decree 244/2019, so as that EV owners may allocate administrative ownership of the battery to aggregators.

4 Regulation for storage in wholesale electricity markets: it is necessary to review the regulation and Market Rules (market rules do not specify the type of technology, maybe will be no necessary to make new changes) in order to allow the participation of V2G and storage services into the wholesale electricity markets (day-ahead market and intraday markets). Stand-alone storage, that is not pumping storage, needs further proposals and

being able to buy and sell energy from the market, taking advantage of the liquidity of wholesale electricity markets. If for example the market establish the same conditions as pumping hydro storage for EV storage, this technology will have two units (one for sale and another for purchase) and the minimum traded energy will be 0.1 MWh. It is necessary to adapt wholesale markets and balancing services to include storage technology in all the markets.

5 Minimum bidding capacity: it would be very interesting to study the possibility of setting lower quantity minimums to participate in wholesale electricity markets for V2G services for trading in the day-ahead and intraday markets, in which small-sized products should facilitate the integration of V2G services.

6 Regulation on flexibility services for DERS: furthermore, there is a need for a definition of the rights and obligations with respect to storage, (for the purposes of this work, distributed storage though EV batteries) of regulated figures, namely, the DSO and TSO, as well as non-regulated figures, such as independent aggregators or energy communities, in relation to their participation in the market. In line with article 32 of Directive 2019/944 the Spanish regulatory framework needs to encourage the use of flexibility in distribution networks, as well as defining the requirements and obligations adapted to distributed storage assets, including assets behind the meter, such as storage and generation by active customers or prosumers, electric vehicles, or related with demand management. This framework should contemplate the possibility that storage systems provide several services simultaneously.

7 Update of technical codes: from the technical perspective, ITC-BT 52 is the technical instruction that regulates the connection of the infrastructure for the recharge of electric vehicles. This instruction needs to be revised in light of V2G and V2B technological developments in order to define minimum standards for deployment of recharging facilities which are capable of bidirectional energy flows.

8 Promotion of V2G: finally, from a business model perspective from the aggregator's point of view there will be many different issues to take into account when dealing with the value proposition for EV users. From who will bear the deterioration of the battery life due to charge/discharge for participation in the market, to how the benefits of such participation will be delivered to the end customer. For example, under the current VAT regulation in Spain, receiving recurrent income, regardless of its amount, entails the obligation of registration with the tax authority and making quarterly VAT liquidations. This administrative burden could easily draw away the interest of a residential EV owner to participate in V2M, especially if the returns from such participation are not very high.

8/ Conclusions

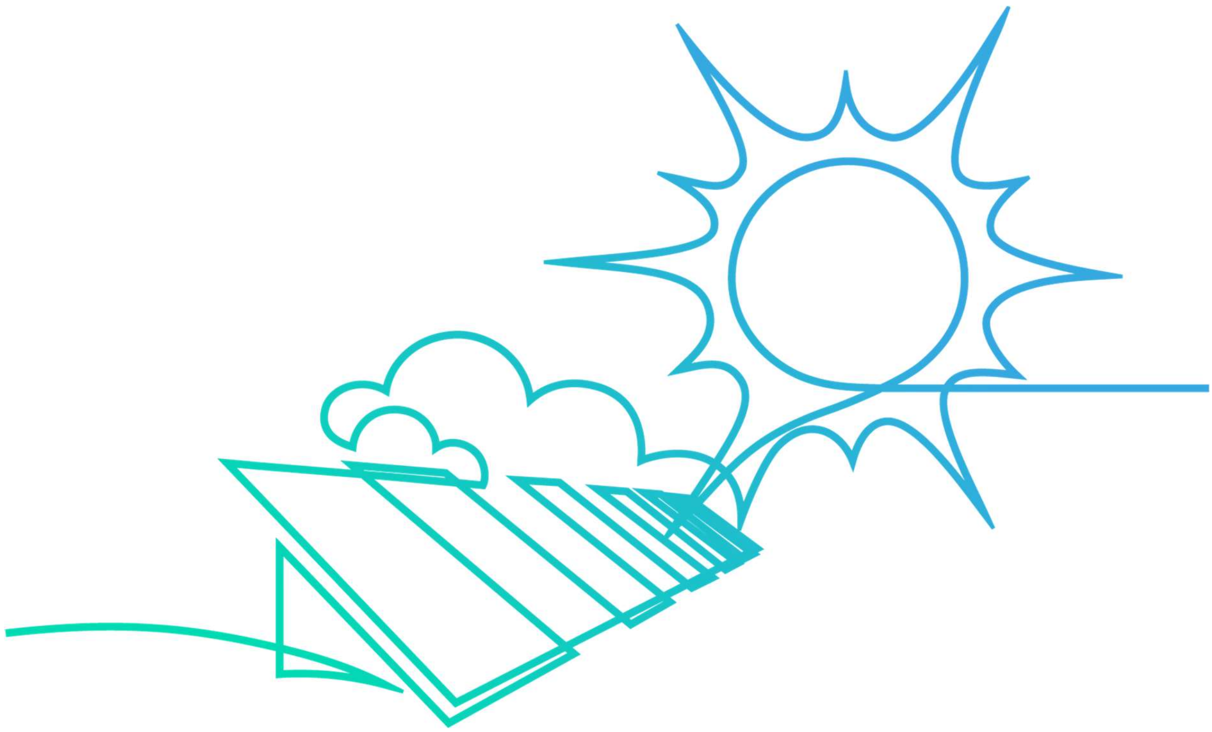
- **V2G technology will enable scaling up renewable energy resources integration** into the electricity market and, due to that EV drivers will literally drive the energy transition.
- Due to the **participation of V2G technology in the electricity market,** EV owners can perceive some revenues for their energy that can help to reduce the operational cost of vehicles and fleets and the investment cost in new vehicles. Users will have a clear incentive to participate in the electricity market. V2G offers the possibility to charge their batteries during valley low-cost hours and then be discharged during the evening peak to cover the demand.
- **Bidirectional EVs are also an opportunity for increasing self-consumption** by means of **V2B or V2H**. Consumers can use the energy generated in their solar panels to charge their vehicles and use the stored energy in hours where no solar production is available. Nowadays, under the current regulatory framework, V2B and V2H are the only possible V2G business model in Spain. They are limited to behind-the-meter operation, so they can only provide electricity bill reduction and not a source of income.
- **V2G can be a solution for grid congestions or grid stress moments.** With V2G, EVs can discharge their batteries into the grid during power spikes and charge them during periods with high renewable production rates.
- Although EV and EV infrastructures are expected to be massively deployed on a global scale in the coming years **there is a lack of standardization of socket, connectors, and communication protocol for chargers**.
- The adoption of V2G will have to lead with the **high cost of V2G hardware prices, even though, costs are dropping as demand increases**. Battery costs are the main manufacturing costs and are highly dependent on raw materials supply. It is expected that the increasing demand of EV will help to decrease costs and develop innovative technologies.
- **The rate of charging points per electric vehicles across Europe needs to be increased** to ensure that the infrastructure is ready to face the number of EVs in

roads for the next years. There is a slow deployment of the public electric vehicle infrastructure in Spain, when compared to other European countries.

- Spain plans to have 5M electric vehicles on the road by 2030 (3M cars and 2M motorcycles, vans and buses). In order to secure the investment on V2G it is mandatory to **set promotion policies and reduce the regulatory risk**.
- **Energy markets should evolve to harness all the benefit of distributed resources** and to involve final customers as active players.
- Spain presents one of the highest rates of smart meter deployment in the EU (99%) and already offer dynamic electricity price tariffs linked to wholesale market prices, therefore offering price signals to costumers. This is an essential point to promote customers' acceptance. However, **tariffs must evolve towards smart tariff models, where charges and tolls reflect the real cost of opportunity of the electricity market prices**, with higher rates when the grid is more saturated and low ones the rest of the time.
- Due to the increase in renewable energy capacity in the coming years based on the PNIEC forecasts that **it is necessary to have enough flexibility integrated in the wholesale electricity market** to provide electricity in peak-price moments when the renewable production cannot generate enough energy due to their variability.
- The granularity of the Spanish day-ahead and intraday markets' products is still 1 hour. Nevertheless, by 2023 Spain will reduce the settlement period to 15 minutes. **One of the main advantages of V2G is the quick activation** and the possibility to charge/discharge for short periods. In a scenario of shorter settlement periods aggregated V2G would offer higher rates of flexibility.
- In Spain, decentralized resources can participate in the wholesale electricity markets with a minimum offer of 0.1 MWh, facilitating the participation of aggregated resources. However, **V2G is considered a storage facility** (but different than pumping storage) and there is no provision yet for their participation in the electricity market currently. V2G technologies are starting to be considered, but there is not a specific road map for the inclusion of V2G. Storage and V2G need to be able to have a net consumption balance or a net selling balance schedule after their negotiation on the electricity market. As mentioned before, the changes to allow all types of storage sources, and of course V2G, to participate in the market are not too difficult to implement. It is probable that more sooner than later, these storage sources could be integrated into the electricity market.
- **The aggregator figure is contemplated by the national law but there is not a proper regulatory framework.** The independent aggregator is not fully regulated

yet, details of contract, roles and responsibilities are still missing. Currently, the regulation only referrers to the participation of aggregators in balancing services and wholesale electricity markets. However, the interaction between electricity suppliers and aggregators is not yet regulated. The actions of an independent aggregator may cause an imbalance in a supplier's portfolio.

- **Storage, including V2G, requires a full regulatory treatment in order to provide a framework** which answers the complex energetic and legal challenges posed by the introduction of these subjects.



Figures

Tables

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