MÁSTER UNIVERSITARIO EN INGENIERÍA INDUSTRIAL

TRABAJO FIN DE MÁSTER (MII)

Implementation of a Crowd Balancing Platform in Spain using Electric Vehicles and managed through a digital platform developed with Blockchain technology.

Autor: Julio Canuto García-Mina Peñaranda

Director: José Pablo Chaves Ávila

Madrid

Mes de diciembre de 2021

Declaro, bajo mi responsabilidad, que el Proyecto presentado con el título

Implementation of a Crowd Balancing Platform in Spain using Electric Vehicles and managed through a digital platform developed with Blockchain technology.

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Autorizada la entrega del proyecto

EL DIRECTOR DEL PROYECTO

Fdo.: José Pablo Chaves Ávila Fecha: 28/ 09/ 2021

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Muchas gracias.

IMPLEMENTATION OF A CROWD BALANCING PLATFORM IN SPAIN USING ELECTRIC VEHICLES AND MANAGED THROUGH A DIGITAL PLATFORM DEVELOPED WITH BLOCKCHAIN TECHNOLOGY

Autor: García-Mina Peñaranda, Julio Canuto

Director: Chaves Ávila, José Pablo

Entidad Colaboradora: ICAI - Universidad Pontificia Comillas

RESUMEN DEL PROYECTO

1. Introducción

El proyecto estudia la viabilidad del uso de una Crowd Balancing Platform en España utilizando los vehículos eléctricos como agentes principales de la plataforma, gestionada mediante tecnología Blockchain. Actualmente este proyecto es de gran interés puesto que el aumento del uso de energías renovables está dificultando el balance de la red. Este proyecto implementaría nuevos participantes del servicio de balance de una manera eficiente, disruptiva y limpia.

Se comienza poniendo en contexto el sector energético, explicando los tipos de energía, transición energética, la descarbonización y las energías renovables de manera global. A continuación, se procede a explicar de manera profunda y detallada el vehículo eléctrico debido a su importancia en el proyecto. Los temas desarrollados en este apartado son los siguientes: la historia del vehículo eléctrico, análisis de los diversos tipos de vehículos eléctricos, la situación actual y las previsiones de futuro y los cargadores de los vehículos, analizando sus funciones y su uso. Por último, se pone en contexto todo lo anterior dentro de España.

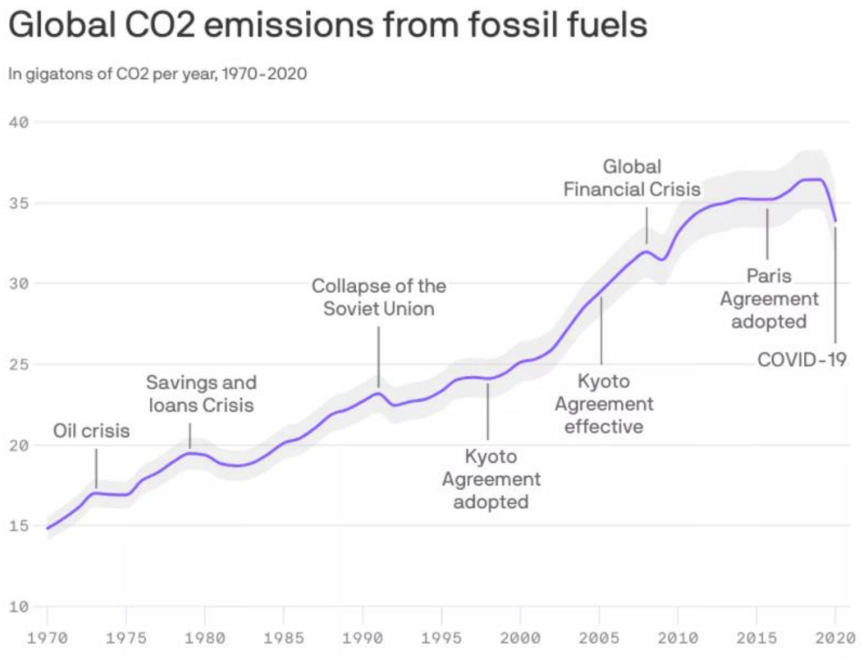


Figure 1. Global CO2 emissions from 1970 to 2020. Source: [1]

Seguidamente, se realiza un resumen del funcionamiento del balance de la red explicando los diversos tipos balance y los agentes implicados, una vez realizado se procede a poner en contexto el funcionamiento del balance en España. Para el proyecto, los agentes principales serán TSO, BSP, BRP y DSO, con este análisis se comprende el flujo de energía y que agente está implicado en cada proceso.

La tecnología en la que se basa la plataforma es el Blockchain, por lo que se ha realizado un estudio sobre su funcionamiento básico, sobre los algoritmos de consenso principales, que serán los encargados de validar las transacciones y para terminar con este apartado, se explican cuales son las principales aplicaciones que tiene el Blockchain en el sector eléctrico.

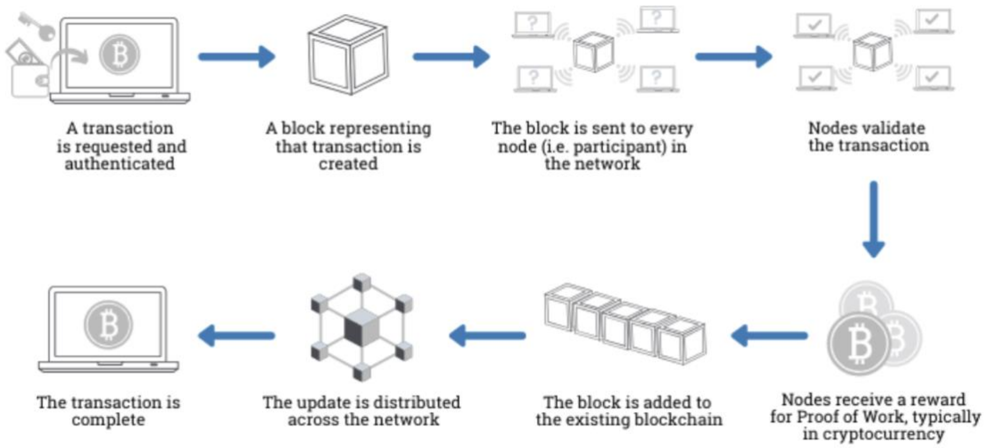
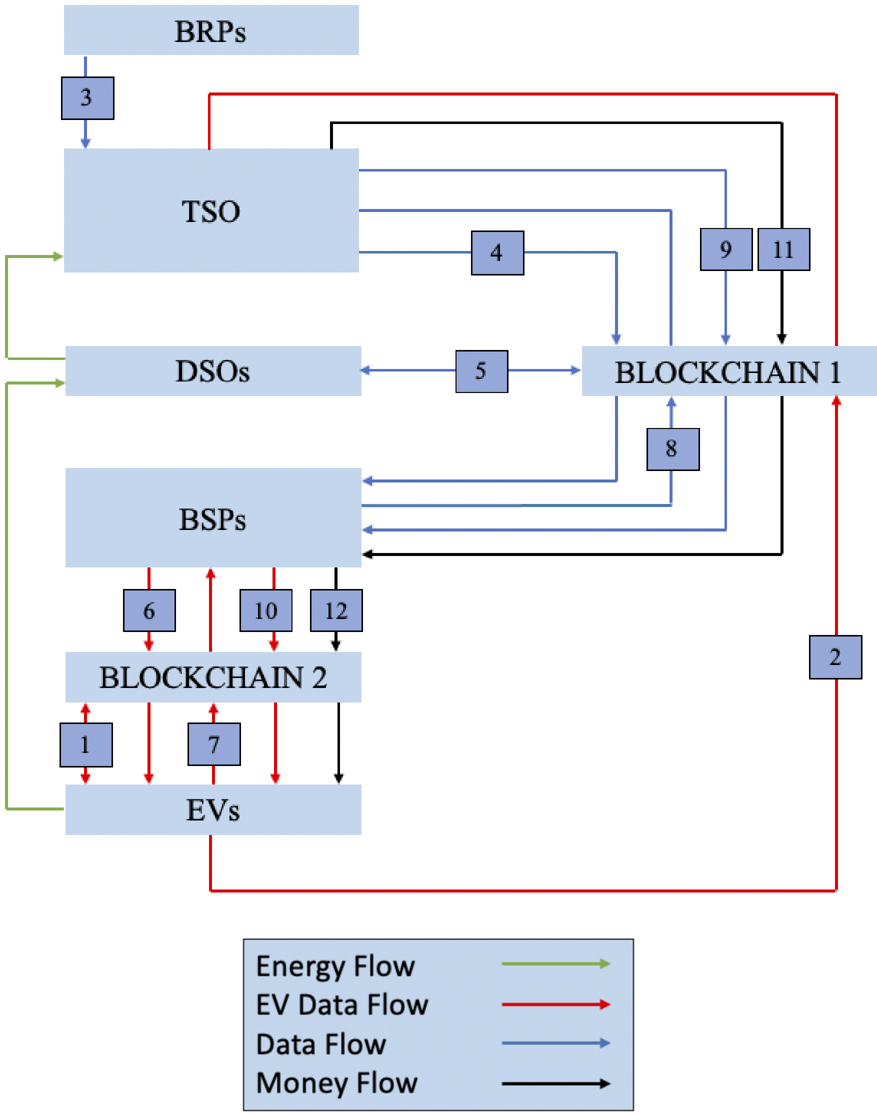


Figure 2. Schematic representation of a transaction from A to B using Blockchain technology. Source:[2]

Una vez realizado el estudio y análisis de todas las partes implicadas, se procede a investigar el estado del arte. En este caso se ha: analizado Equigy [3], una Crowd Balancing Platform desarrollada por Tennet (uno de los TSO de Alemania y Holanda) y Share and Charge [4] es un servicio de carga inteligente entre proveedores para vehículos eléctricos basado en la interfaz de puntos de carga abiertos cuyo objetivo es estandarizar este mercado emergente. Este análisis es necesario y muy fructífero puesto que se ha obtenido mucha información sobre el funcionamiento de una CBP, que se utilizará después para el desarrollo del caso de estudio y sobre la estructura de carga de los EV.

2. Metodología

A continuación, se procede a exponer la metodología de trabajo a seguir en el case study, que es la siguiente: identificación de los requisitos impuestos por ley para poder participar en el servicio de balance, identificación de las posibles aplicaciones del proyecto, establecer una relación entre los agentes, análisis de las diferentes tecnologías blockchain y realizar tablas comparativas que faciliten la elección, diagramas de flujo visuales y explicativos del proceso y un análisis final para decidir si el proyecto es viable o no.



1. EV qualification and validation to participate and contract with the BSP
2. Registration of the EVs in the Blockchain Platform and notification of it to the TSO
3. An Imbalanced is produced by the BRP
4. A bid is notified by the TSO to the the BSPs through the Blockchain
5. TSO communicates with the DSO to ask for the constraints of the grid
6. BSPs communicate through the platform to the EV to start the process
7. The whole balancing power of the EV is meassured individually
8. The BSPs communicate their total meassurements to the TSO
9. The Balancing has finished, the TSO communicates with the BSP
10. The BSPs communicate with the EV to deactivate
11. The TSO calculates the reward and pays the BSPs
12. The BSPs pay each owner of the EVs for the service (weekly, monthly)

Figure 3. Flow diagram of the Crowd-Balancing platform regarding the relation between all the parties involved: Source: Self Elaboration.

3. Conclusiones

Para concluir, se procede a exponer todas las barreras que se han encontrado a lo largo del proyecto, agrupadas en el tres grandes grupos: regulatorias, tecnológicas y económicas. Las regulatorias, incluyes aquellos puntos en los que la ley puede afectar al desarrollo del proyecto, puesto que, al hacer uso de tecnologías tan modernas, la ley varía mucho en muy poco tiempo. Las tecnológicas, incluyes las limitaciones en los vehículos eléctricos, como puede ser la falta de puntos de carga y las propias del Blockchain asociadas a su juventud. Por último las económicas, que incluyen los posibles problemas como el alto coste del desarrollo de la plataforma, o simplemente que no sea rentable ser proveedor del sistema de balance por no poder dar precios competitivos manteniendo una rentabilidad.

4. Referencias

[1] "Mounting emissions data paints bleak picture on Paris climate goals," [Online]. Available: www.axios.com.

[2] "How does a transaction gets into the Blockchain," [Online]. Available: www.euromoney.com

[3] "Crowd Balancing Platform - Blockchain Technology," [Online]. Available: www.tennet.eu.

[4] "Open Charging Network," [Online]. Available: www.shareandcharge.com.

IMPLEMENTATION OF A CROWD BALANCING PLATFORM IN SPAIN USING ELECTRIC VEHICLES AND MANAGED THROUGH A DIGITAL PLATFORM DEVELOPED WITH BLOCKCHAIN TECHNOLOGY

PROJECT SUMMARY

1. Introduction

The project studies the feasibility of using a Crowd Balancing Platform in Spain using electric vehicles as the main agents of the platform, managed through Blockchain technology. This project is currently of great interest as the increased use of renewable energies is making grid balancing difficult. This project would implement new participants of the balancing service in an efficient, disruptive and clean way.

It starts by putting the energy sector in context, explaining the types of energy, energy transition, decarbonisation and renewable energies in a global way. Then, it proceeds to explain in depth and in detail the electric vehicle due to its importance in the project. The topics developed in this section are the following: the history of the electric vehicle, analysis of the various types of electric vehicles, the current situation and future forecasts and vehicle chargers, analysing their functions and their use. Finally, all of the above is put into context in Spain.

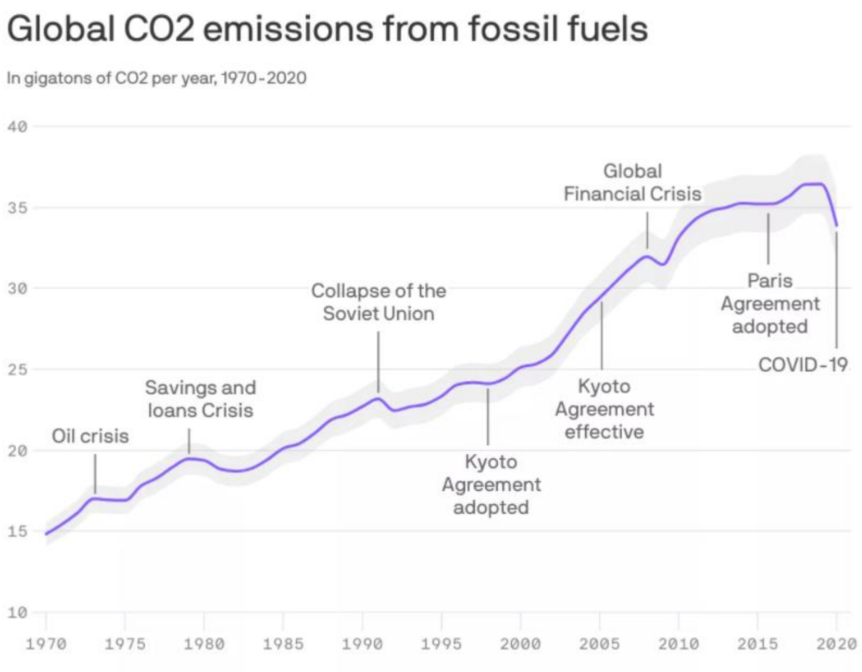


Figure 4. Global CO2 emissions from 1970 to 2020. Source: [10]

This is followed by a summary of the operation of grid balancing, explaining the different types of balancing and the agents involved, and then the operation of balancing in Spain is put into context. For the project, the main agents will be TSO, BSP, BRP and DSO, with this analysis the energy flow is understood and which agent is involved in each process.

The technology on which the platform is based is the Blockchain, so a study has been carried out on its basic operation, on the main consensus algorithms, which will be responsible for validating transactions and, to conclude this section, the main applications of the Blockchain in the electricity sector are explained.

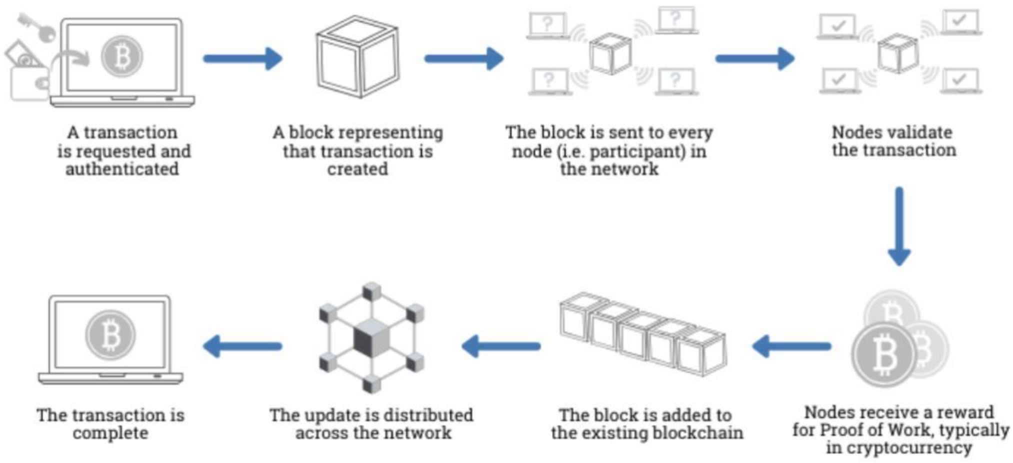


Figure 5. Schematic representation of a transaction from A to B using Blockchain technology. Source: [47]

Once the study and analysis of all the parties involved has been carried out, we proceed to investigate the state of the art. In this case, we have analysed Equigy [3], a Crowd Balancing Platform developed by Tennet (one of the TSOs in Germany and the Netherlands) and Share and Charge [4], a smart charging service between suppliers for electric vehicles based on the interface of open charging points, the aim of which is to standardise this emerging market. This analysis is necessary and very fruitful as a lot of information has been gained about the functioning of a PBC, which will be used later for the development of the case study and about the EV charging structure.

2. Methodollogy

We then proceed to explain the work methodology to be followed in the case study, which is as follows: identification of the requirements imposed by law to be able to participate in the balancing service, identification of the possible applications of the project, establishing a relationship between the agents, analysis of the different blockchain technologies and making comparative tables to facilitate the choice, visual and explanatory flowcharts of the process and a final analysis to decide whether the project is viable or not.

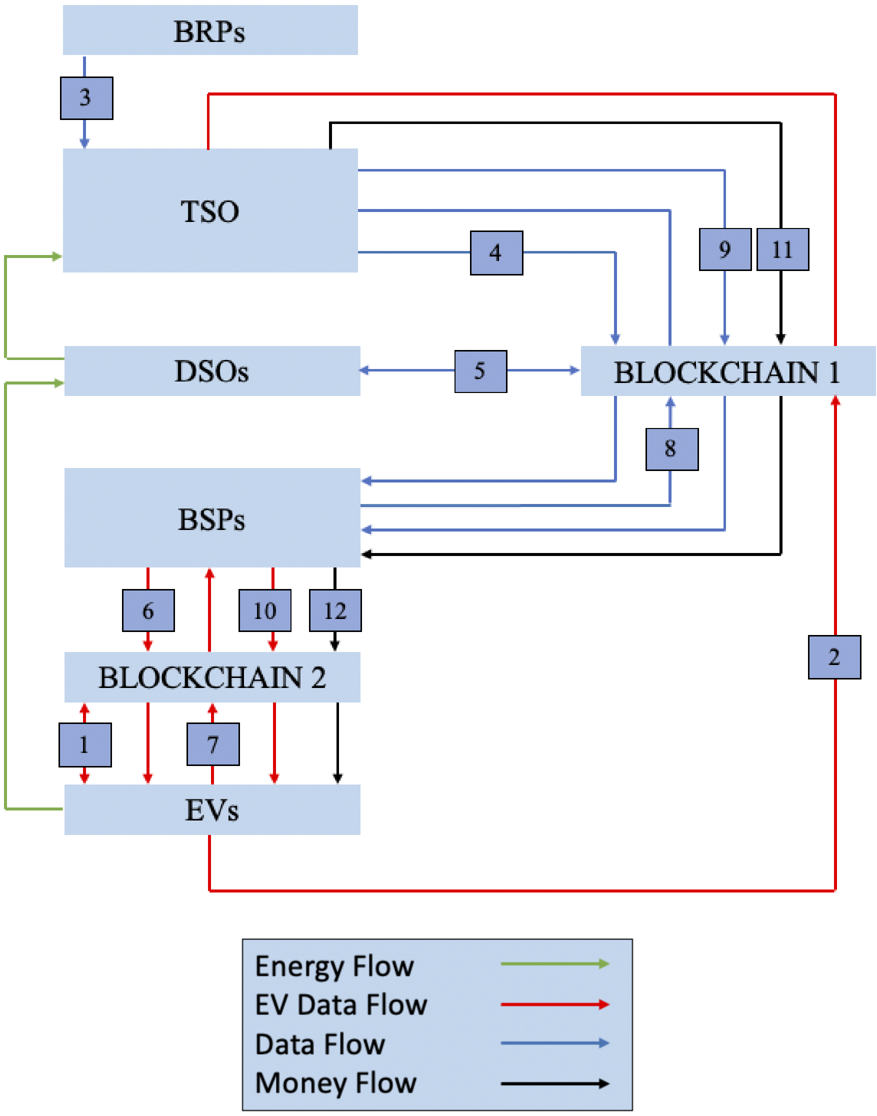


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Figure 6. Flow diagram of the Crowd-Balancing platform regarding the relation between all the parties involved: Source: Self Elaboration.

3. Conclusions

To conclude, all the barriers that have been encountered throughout the project are presented, grouped into three main groups: regulatory, technological and economic. Regulatory barriers include those points in which the law can affect the development of the project, given that, by making use of such modern technologies, the law varies a lot in a very short time. Technological, you include the limitations on electric vehicles, such as the lack of charging points and the Blockchain's own limitations associated with its youth. Finally, the economic ones, which include possible problems such as the high cost of developing the platform, or simply that it is not profitable to be a supplier of the balancing system because it cannot offer competitive prices while maintaining profitability.

4. References

[1] "Mounting emissions data paints bleak picture on Paris climate goals," [Online]. Available: www.axios.com.

[2] "How does a transaction gets into the Blockchain," [Online]. Available: www.euromoney.com

[3] "Crowd Balancing Platform - Blockchain Technology," [Online]. Available: www.tennet.eu.

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Achronyms List

aFRR: Automatic Frequency Restoration Reserve

BEV: Battery Electric Vehicle

BSP: Balance Service Provider

BRP: Balance Responsible Provider

CBP: Crowd Balancing Platform

CNMC: Comisión Nacional de los Mercados y la Competencia

DERs: Distribution Energy Reserves

DSO: Distribution System Operator

EV: Electric Vehicle

FSP: Flexible Service Provider

HEV: Hybrid Electric Vehicle

mFRR: Manual Frequency Restoration Reserve

OEM: Original Equipment Manufactures

PHEV: Plug-in Electric Vehicle

REE: Spanish Electricity Grid

RES: Renewable Energy Sources

RR: Restoration Reserve

TSO: Transmission System Operator

1. Introduction

The project will analyse the feasibility of implementing a Crowd Balancing Platform managed with blockchain technology.

To this end, a study of the technologies and agents involved will be carried out as follows:

- Analysis of the energy context.
- Analysis of electric vehicles.
- Analysis of the balance of the grid.
- Analysis of blockchain technology.

Faced with an increase in energy use and an increase in the use of renewables, the balance of the grid is becoming increasingly complicated and the fact of being able to include more participants that act in a clean way, promoting the reduction of emissions, makes the development of this project a very powerful alternative.

The objectives of the project are as follows:

- Provide a solution for the management of EV which help to mitigate the increasing difficulty of the balancing service caused by the increase of the renewable energy used.
- Provide an efficient system for the management of the charge/discharge process for the EV which is connected to the grid and contribute to the energy transition.
- Implement the platform using Blockchain technology, this platform will be in charge of the payments and the communication between the agents.

To this end, the analyses mentioned at the beginning of this section will be carried out, followed by an analysis of the state of the art, in which Equigy will be analysed, which is a Crowd Balancing Platform with Blockchain technology developed by Tennet (TSO from Germany and Holland).

This will be followed by the development of the case study and analysis of the viability of the project in the Spanish context.

Finally, an analysis will be made of the various barriers that have arisen during the development of the project.
The project will analyse the feasibility of implementing a Crowd Balancing Platform managed with blockchain technology.

2. Energy Context

2.1 Renewable Energies

Renewable energies have been used by humans since the beginning of time. Wind, solar and hydraulic energy have been the most widely used and examples of this are: sailing, windmills or water mills to grind wheat, aqueducts and certain constructions designed to make the most of solar energy.

On the other hand, for this project, we position ourselves in the 1970s. During this decade, this type of energy was proposed as an alternative to fossil fuels or traditional energies. This alternative is presented due to several factors such as the lower environmental impact, the inexhaustibility of energy sources in the future, since fossil fuels are consumed at a much higher rate than they are produced. [1]

At present, it is not presented as an alternative, but as a reality that, despite having a long way to go to improve and develop, is being implemented in our daily lives, and growing each day.

Nowadays we can differentiate between two large groups of energy:

- Non renewable: [2]
    - Fossil energy: coal, oil and its derivatives and natural gas. These energy sources were created thousands of years ago from organic matter such as plankton or forests. A rather limited source. This type of energy is currently the most widely used and its main disadvantages are high pollution and limited reserves.
    - Nuclear energy: this energy is produced from the fission of heavy radioactive atoms such as Uranium-235 or Plutonium-239. This energy source has much larger reserves. It is one of the most widespread energy sources on the planet. One of the major drawbacks is the generation of radioactive waste, which takes hundreds or thousands of years to lose its radioactivity; another drawback is that, at present, the percentage of fuel use is between 1 and 5%. It should be noted that it is the cleanest energy of all in terms of emissions during the life cycle of the project, even more so than renewable energies
- Renewable: [2]
    - Hydropower: this is based on potential energy, i.e. accumulating water at a certain height and letting it fall through turbines to produce energy. The disadvantages of this type of energy are the need to build large installations such as dams, which have a visual impact and impact on the habitat of the area.

- Solar: Solar radiation is one of the most important factors for the existence of life on the planet. This radiation is captured by devices such as photovoltaic panels or solar collectors and then transformed into electrical energy. A main disadvantages of this energy in the past was the cost of the installations but they have reduced significantly in the last decade and the lack of continuity in the source, since it can only be used during the day and if there are no clouds. [3]

- Wind: this energy harnesses the force of the wind to move the blades of windmills. The windmills' operating mechanism, consisting of gears and an electric generator, transforms the kinetic energy of the wind into electrical energy. The main disadvantages are the lack of continuity of the energy source and the visual and habitat impact of installing wind generators.

- They are also renewable energies: solar thermal, biomass, geothermal, tidal or green hydrogen.

Currently, it is estimated that non-renewable energies produce approximately 80% of total consumption, compared to 20% produced by renewable energy.

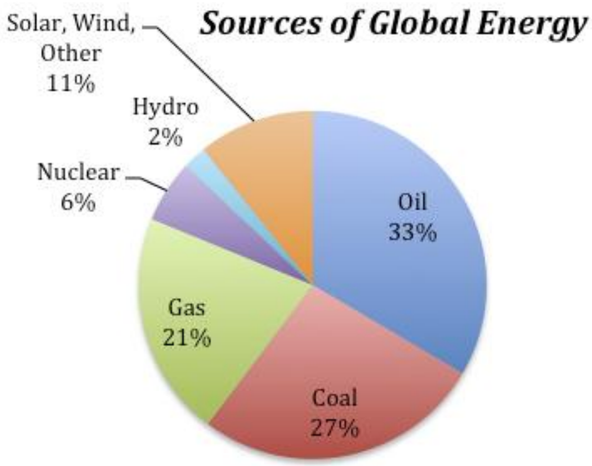


Figure 7. Percentage of production of global each energy type in 2019. Source: [4]

2.1.1 Energy Transition and Decarbonization

The energy transition is the process of changing the structure of energy systems with a long-term time horizon. Decarbonisation is the process of reducing carbon emissions, the main one being CO2 emissions.

So far, there have been two major energy transitions in our history:

- From traditional biofuels such as wood to coal, this transition took place at the end of the 19th century and represented a great revolution by improving the efficiency of the processes that involved burning the material to obtain heat. This revolution took place due to the shortage of wood produced by the high consumption of wood by the large companies of the time, which apart from being dedicated to their sector, were dedicated to the intensive felling of trees. [5] [6]

- From coal and oil to petroleum and its derivatives and natural gas, this transition took place in the middle of the 20th century, and like the previous one, it meant a great revolution in the use of fuel, improving vehicles and the efficiency of industrial processes. Engines with greater power, the existence of a liquid and gaseous fuel, and no longer only in a solid-state. This transition reduced the exhaustive whaling that had taken place in previous centuries due to the price of whale oil, among other things.

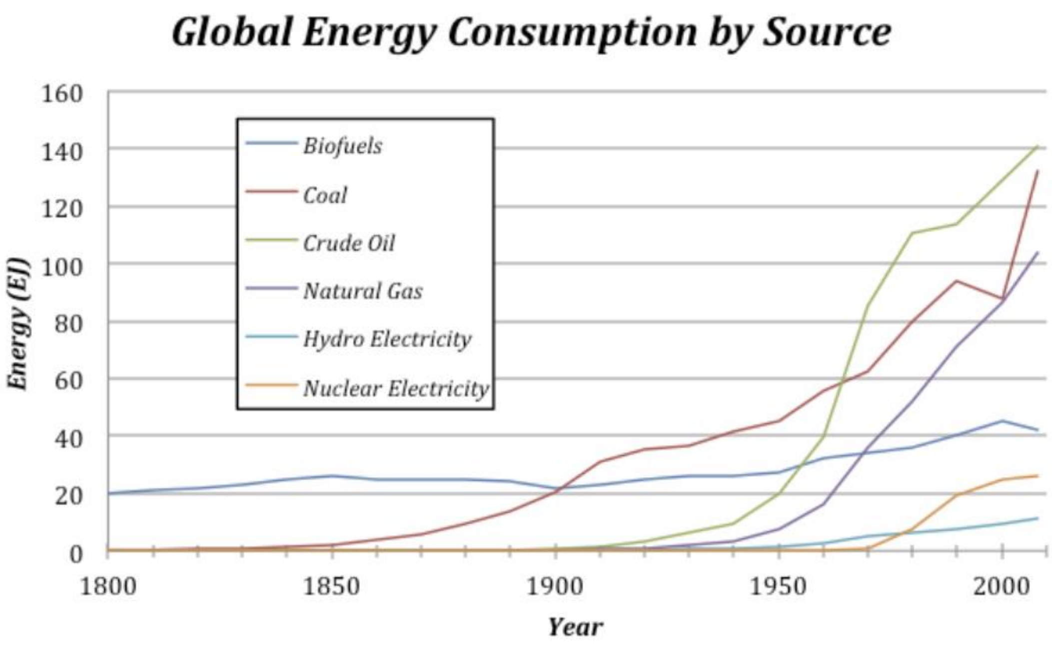


Figure 8. Graph showing the use of various energy sources over the last two centuries. Source: [4]

Currently, the energy transition sought is from non-renewable energy to renewable energy, the main motivation for this transition is the reduction of CO2 emissions, thus achieving cleaner energy in terms of environmental pollution.

One cannot talk about energy transition without mentioning the Paris Agreement, which was drafted in 2015 and entered into force in 2016. This agreement was signed by the parties that make up the UNFCCC (United Nations Framework Convention on Climate Change), to contain the increase in global temperature to below 2ºC above pre-industrial temperatures and, if possible, to limit it even further, with 1.5ºC as the target. To this end, agreements were reached to greatly increase investments in the renewable energy technology sector and decarbonisation, reducing greenhouse gases. [7]

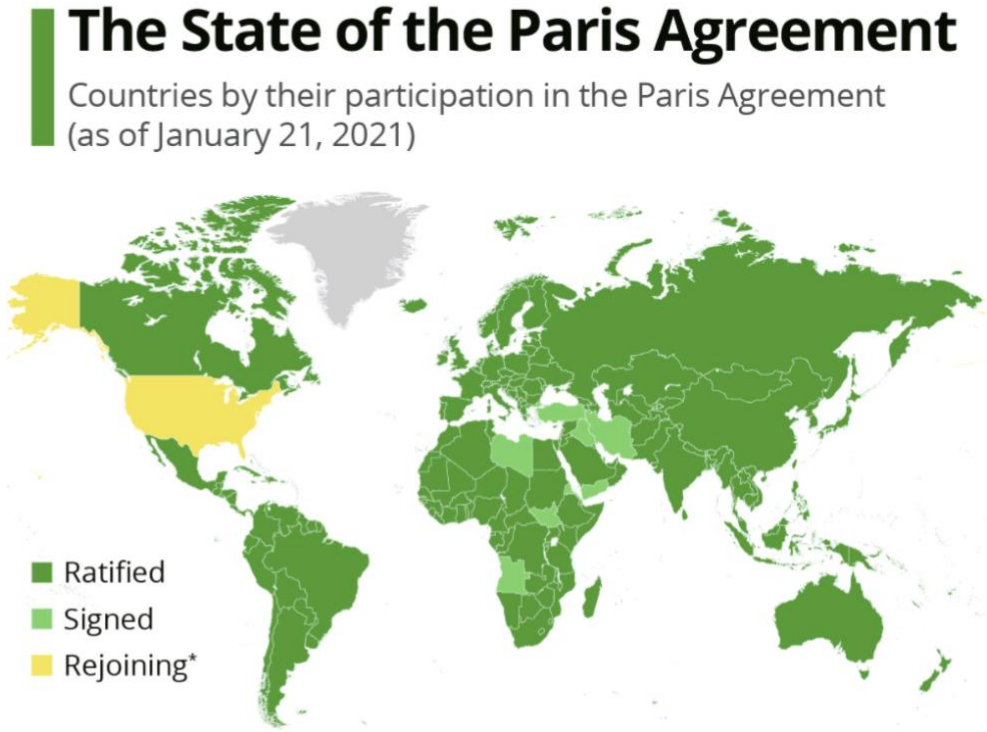


Figure 9. Parties to the Paris Agreement [8].

The implementation of this agreement requires the parties to commit to social and economic transformation. The agreement works in cycles of 5 years each cycle the measures must be more ambitious to meet the pre-set targets.

In 2020, the NDCs, which are the nationally determined contributions of each country, were presented. They present the measures to be taken to reduce greenhouse gas emissions as well as the plans to create resilience, i.e. to adapt and overcome this increase in global temperature. Another point to note is the search for transparency in the reports. The first report will be made by the different parties by 2024 in which they will present all the measures taken as well as the progress achieved during this period of time. [9]

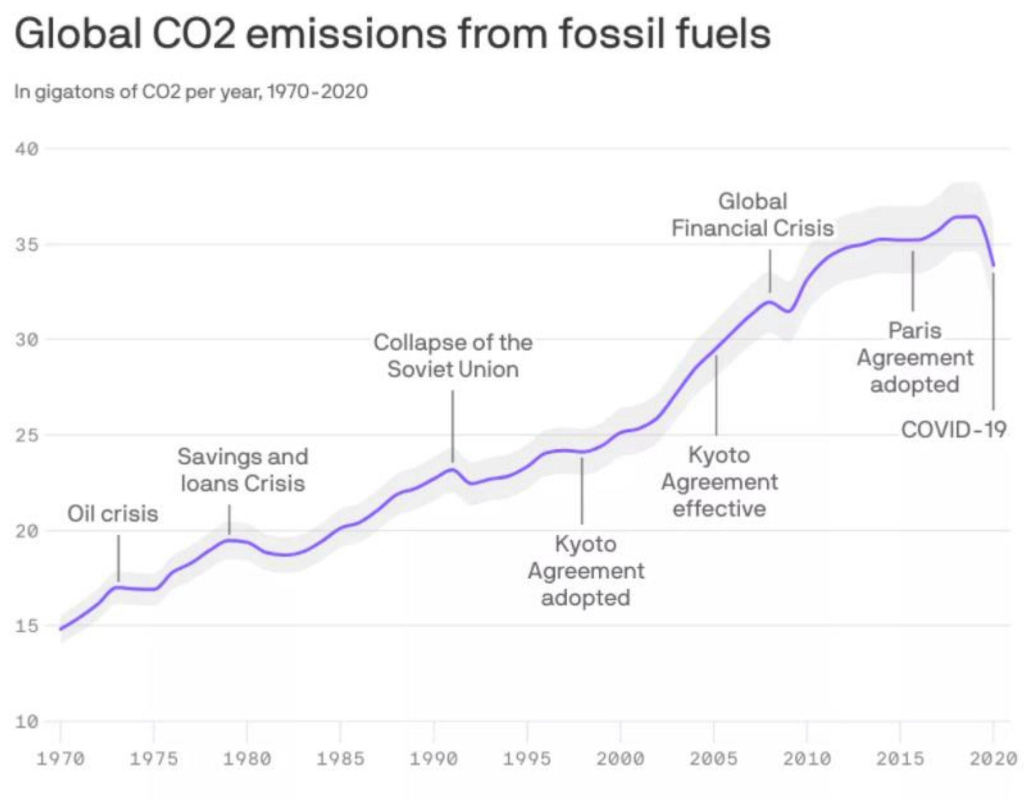


Figure 10. Global CO2 emissions from 1970 to 2020. Source: [10]

As can be seen in Figure 10, the increase in emissions slowed down its roughly linear increase since 2015. To check the effectiveness of the agreement, it will be necessary to monitor whether emissions have been reduced.

The ultimate goal is to achieve a carbon-neutral global economy by 2050. By neutral, this does not mean zero final emissions, as this is practically impossible, but rather that total emissions should be less than or equal to the planet's capacity to absorb them.

The most sensible objective is to start with the decarbonisation of the electricity sector through the use of renewable energies, which according to a study by Iberdrola, will reach between 65 and 85% of total generation by 2050.

This will be followed by electrification of the economy, the main sectors are transport, through the use of electric vehicles, and construction, with the use of electric machinery.

Lastly, there will be certain consumption that cannot be electrified, either because of economic viability or because it is not possible, and the fuels used will have to be replaced by non-carbonised fuels. This sector accounts for 16% of the EU's emissions, but this low percentage, together with the immaturity of the necessary technologies, means that this is a secondary objective.

2.1.2 Electric Vehicles

The invention of the electric vehicle predates that of the internal combustion vehicle. The first electric motor is attributed to Anyos Jedlik, who developed it in 1828. This, along with many other men who tried it in their horse-drawn carriage, led to the creation of the first EV by Thomas Davenport in 1834. It was a miniature vehicle that went round in circles. It was around this time that the electric locomotive was created. Robert Anderson designed the first EV with a non-rechargeable battery [11] [12].

A few decades later, the battery capacity was improved and made rechargeable, which was a breakthrough for EV technology.

Britain and France were at the forefront of this sector, and several fully functional electric models were produced that were highly sought after in the upper echelons of society. The first vehicle was capable of over 100km/h, nicknamed Le Jamais Contente.

The United States quickly joined this technological race, creating the first all-electric 6-passenger van, which reached a speed of 23 km/h. The vehicles were even made to have charging stations, to be clean, safe and reliable.

Despite all this, the combustion vehicle eventually triumphed. At first, they were difficult to start, unsafe, unreliable, difficult to drive, noisy and polluting. Even so, the male public chose them, leaving the EV for the female sector and high society. Therefore, as the failures of combustion vehicles were solved, they gained more and more followers. [12]

One of the most powerful points that determined the victory in the war between electric and combustion was Henry Ford's creation of the mass-production assembly line in 1908, against which the EV had little to do. Even so, an improvement by Thomas Edison in batteries in 1912 gave the EV a new boost, which ended up being forgotten due to the greater autonomy of combustion cars and the solution to their poor starting by introducing an electric starter motor. [11]

Therefore, the EV was forgotten until the 70s and 80s, when a more ecofriendly vision was taken up again due to the abuse of oil consumption and the high pollution of combustion vehicles. This, together with the Kyoto Protocol, helped two things: the improvement of efficiency and reduction of pollution by combustion vehicles and the return to research on EVs. This research led to the creation by General Motors of a model with up to 250km range and 130km/h top speed and by Ford of a model with 160km range. These vehicles fell into oblivion again due to the strength of the oil powers of the time and the economic unfeasibility of the project, being cancelled a few years later. [11]

Nowadays, and due to the incessant need to reduce emissions, the use of electric or hybrid vehicles has returned with great force and this time it seems to be here to stay once and for all, with Tesla being the leading company in this aspect, having a wide variety of EVs from supercars to affordable cars for a larger target public, demonstrating that this sector can be very profitable, thus encouraging other companies to enter it [11].

2.1.2.1. Types of Electric Vehicles

Three main types of EVs are currently recognised:

- BEVs (Battery Electric Vehicles): all the energy consumed is electric, they have no combustion engine and zero emissions. They are capable of fast charging and L2 charging (which corresponds to a level 2 charge voltage of 240V, the amperage range is between 16 and 40A) and their charge comes from the grid. These are better known as EVs [13] [14].

  An example of this type of EV would be the Tesla models such as the Tesla S with a range of 830km/h and a top speed of 320 km/h, or the Tesla Model 3 which for $50,000 offers a range of 530km and a top speed of 250 km/h. [13] [14]

- HEVs (Hybrid Electric Vehicles): Hybrids use both an electric motor and a combustion engine. The electric power is generated by regenerative braking (KERS), which recovers the energy released during braking and converts it into electrical energy that can be used to help accelerate the car. Normal hybrids cannot be charged by connecting to the grid. [13] [14]

  An example of such an EV would be the older model Toyota Prius.

- PHEVs (Plug-in Hybrid Electric Vehicles): these vehicles use both an electric motor and a combustion engine to drive the car. The main difference with HEVs is that they have a battery that allows them to travel longer distances, usually between 20 and 60 kilometres, although it can be longer, at a reduced speed, while HEVs do not usually have a range of more than 5 kilometres. On the other hand, PHEVs can be connected to the grid to recharge their batteries. If this battery runs out, the hybrid would function as an HEV. PHEVs can be charged via L2 but do not accept fast charging. [13] [14]

  An example of this type of EV would be the BMW i8 model with a range of 55km and an extendable range of 440km or the Audi A3 e tron with a range of 70km and an extendable range of 600km.

2.1.2.2. Where are we and Future Perspectives

Currently, the use of EVs is proliferating and increasing significantly every year due to the need to reduce emissions, imposed on different countries to achieve the objectives proposed in the Paris Agreement, explained above.

This sector has been greatly helped by facilitating its expansion over the last decade, thanks to supportive policies and a significant improvement in the technology associated with these vehicles.

This improvement in technology is due to the large capital investment in this sector. These improvements include an increase in battery capacity, which is currently growing at a rate of 4-5% per year, and an increase in battery charging speed. These improvements translate into an increase in EV range and speed. [15]

The expectation of improved technology and new models is changing the EV user profile from early adopters of the technology and technological avant-gardists to mass adaptation, as the price is gradually being reduced and subsidies are increasing for the purchase of EVs.

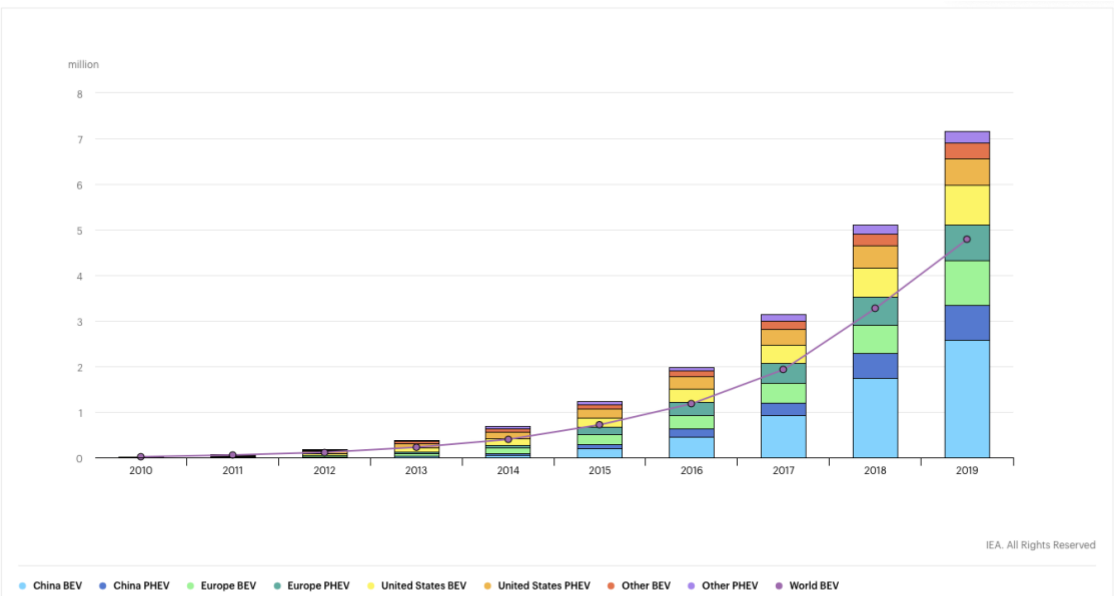


Figure 11. Global fleet of EV between 2010 and 2020. Source: [15]

As can be seen in Figure 11, the global growth of EVs has had an exponential trend over the last 10 years, with China at the forefront of this development. Between Europe, the USA and China, around 90% of the total global fleet is accounted for.

Although development has increased significantly over the last few years, this sector is still in the process of development, and the major problems currently facing this sector will be explained below.

- The cost of buying an EV compared to a conventional vehicle is higher. This price is gradually catching up as the price of batteries decreases every year.

- Lack of accessibility to nearby public charging points. As such a young market, the charging infrastructure is underdeveloped and improving this aspect is crucial for EV adoption to become a reality. [16]

- EVs generally have a shorter range than conventional cars, although some Tesla models exceed 500km, they generally do not reach 400km. Range is improving over the years and when it catches up or is exceeded, it can go from being a disadvantage to an advantage. [16]

- The charging time, the slow charging time ranges between 5 and 8h, the average charging time between 1h30 and 3h, and fast charging can take between 15 and 30 minutes, each type of charging is designed for a different situation, such as in the garage of your home for the slow, for public parking the average, and for charging points such as gas stations the fast, despite this, the times are higher than a gasoline refueling, so it is considered disadvantageous. [15]

Despite these problems, the outlook for the future is very positive, due to rapidly improving technology and infrastructure plans needed to meet the Paris Agreement objectives.

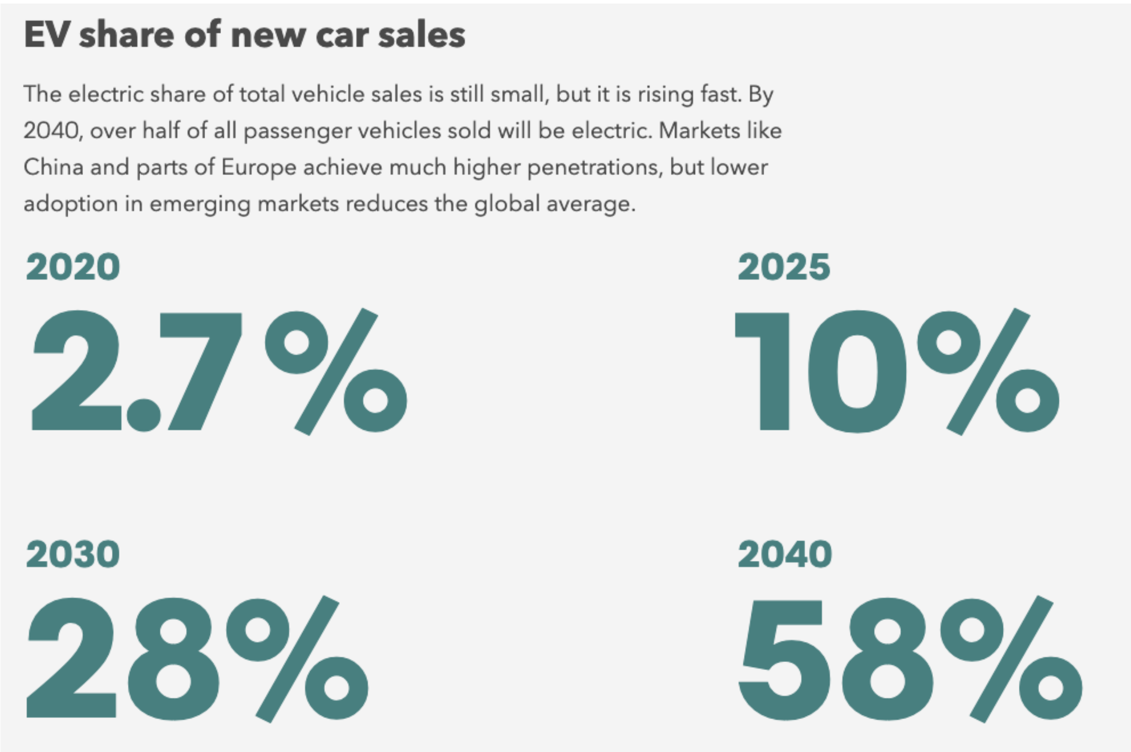


Figure 12. Percentage of EV out of the total. Source: [16]

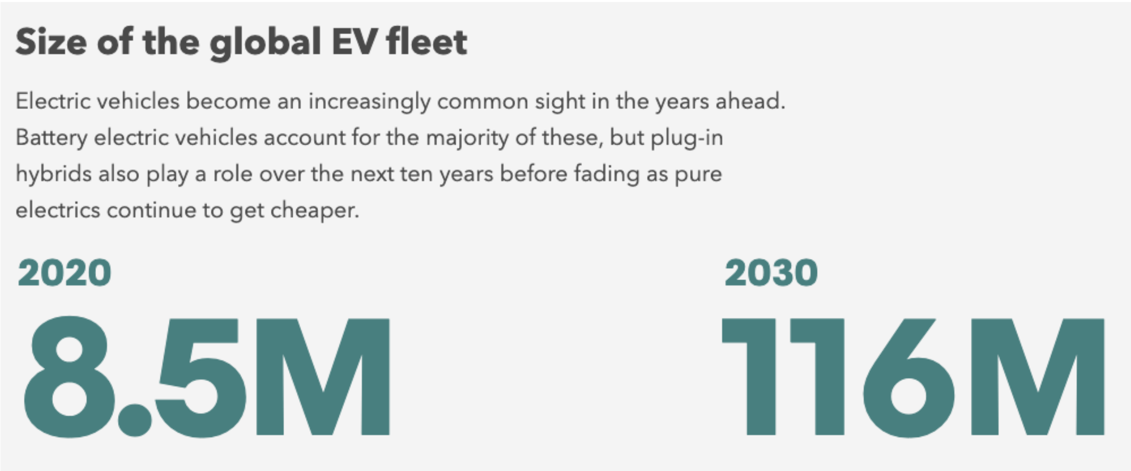


Figure 13.EV global fleet and expectancies for 2030. Source: [16]

As can be seen, the predictions propose a growth that, although very ambitious, due to the constant improvement in technology, the reduction in prices and its benefits in terms of emissions reduction, can be quite successful.

It should be noted that for this growth to be possible, the following conditions must be met:

- Develop the management and implementation of infrastructures with private charging points, such as in the garage of a house, to be able to charge without the need to access a public point and for the convenience of the user.

- Develop the infrastructure of public charging points comprehensively. There is currently a shortfall and if we want to reach 15-20 times the number of vehicles, a solid and well thought-out network of charging points should be created to avoid as far as possible long queues for charging or over-exploitation of charging points.

- Improving batteries to a high capacity that can match or exceed the range of conventional vehicles, as well as improving their efficiency and cost, to make EVs more affordable to a wider public than they are today.

- Improving the charging speed of EVs will be achieved by improving chargers and the technologies associated with transmitting power from the grid to the EV.

These are some of the points that will be followed to make these numbers a reality.

On the other hand, it is necessary to mention that this paradigm shift is not just limited to cars as one might imagine, but also includes buses, motorbikes and is already starting to develop and include electric trucks.

2.1.2.3. EV Chargers

The importance of EV chargers is vital, and their knowledge on the part of an EV user is even greater since, as will be explained, not all chargers are suitable for any type of electric vehicle and the use of these will determine the greater or lesser deterioration of the batteries.

EVs are charged by charging their batteries, which will depend on the type and model of EV chosen, each one having certain specifications indicated by the manufacturer. To begin the charging process, connect the cable first to the charging station and then to the EV, and then to finish the process in reverse order. Check that the cable is suitable for the charging point to avoid problems or accidents during the process. [17]

The charging process is determined by the following factors: [25]

- Power [kW]
- Voltage [V]
- Current [A]
- EV battery type.
- Type of plug.
- Connection wiring from charging point to EV.
- Type of charging station.
- Charging mode.

First of all, we will explain the most commonly used types of existing chargers, which are currently not standardised, so there are various models, with different sizes and charging properties. [18] [20] [21] [24] [26]

- SCHUKO domestic connector: it is compatible with existing sockets in Europe. It has two terminals and an earth connection, and can withstand currents of up to 16 A. This charger is associated with slow charging, and is a connector that can be found in household appliances.

- J1772 Type 1 or Yazaki connector: this is a Japanese connector specifically for EV charging. This connector has five terminals, two for single-phase alternating current, one for ground, one for detecting the proximity of the vehicle (thus avoiding accidents in the event of the EV moving) and the last one for control, to be able to communicate with the grid. If it is level 1, it supports up to 16 A for slow charging, and if it is level 2, it supports up to 80 A for fast charging.

- Mennekes or Type 2 connector: is a German industrial connector. This connector has seven terminals, three for phases, thus allowing three-phase AC charging, one neutral, one ground and two for vehicle communication in the same way as Type 1. There are two types of connection, for slow charging, which supports up to 16 A (in single phase) and for fast charging, which supports up to 63 A (in three phase) for fast charging.

- Combined Single Connector or CSS: German and American proposal as a possible standardised solution. There are two types:
  - CSS1 (USA). It has five terminals, for power, ground and communication with the mains. This type of connector supports both fast and slow charging.
  - CSS2 (EU) Very similar to CSS1, with the difference that this connector has seven terminals, allowing single-phase charging as well as three-phase charging.
- Scame or Type 3 connector: promoted by French manufacturers, it has five to seven terminals, depending on whether DC or AC three-phase current is required, and the rest are for ground and communication.
- CHAdeMO connector: this is a Japanese connector, designed solely for DC charging. It has ten terminals grouped into four groups, two of four terminals and two of one terminal. It admits currents of up to 200 A, thus allowing Ultra Fast Charges.
- Tesla connector: specific for non-EU Teslas, supports up to a maximum of 32 A and can charge in both single-phase and three-phase.

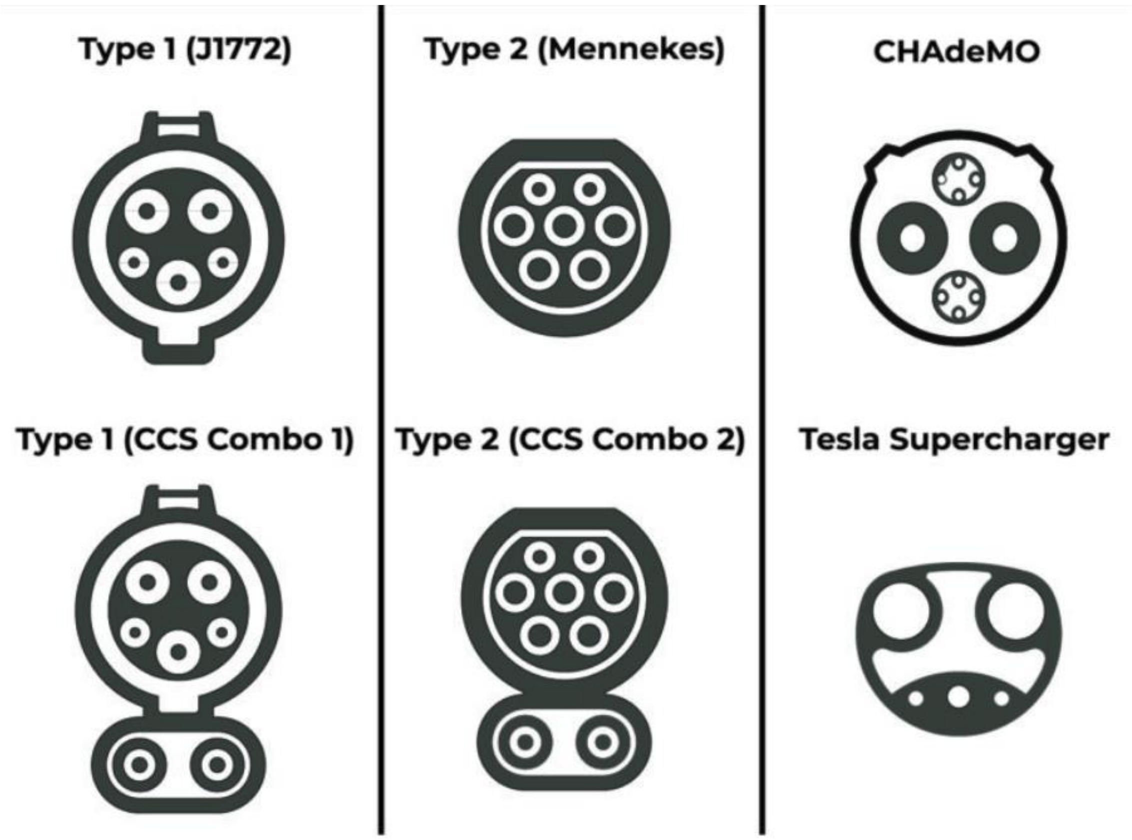


Figure 14. Main types of EV chargers. Source: [28]

Secondly, we will explain the charging modes that exist depending on the charging time: [19] [22] [27]

- Ultra-fast charging: this type of charging is still in the experimental phase, applied to vehicles equipped with supercapacitors. This type of charging is very powerful, allowing the vehicle's batteries to be fully charged in a period of 5 to 10 minutes. A normal vehicle cannot be charged in this way, as high temperatures would be reached and the batteries would be damaged.

- Fast Charge: Two types of power are available depending on the connector used:

    - Power between 43-50 kW: can charge up to 150 kilometres in about thirty minutes.
    - Power greater than 100 kW: can charge more than 300 kilometres in around thirty minutes.

  The benefits of this type of charging are: time savings and subsidised charging points.

- Semi-Fast Charging: uses a power of between 11 and 22 kW and can charge up to 150 km in one hour.
  As with fast charging, the benefits of this type of charging are: time savings and subsidised charging points.

- Normal Charging: uses a power of 7 kW, charging about 50 kilometres in one hour of charging.
  The benefits of this type of charging are electricity savings and extended battery life.

- Slow Charge: uses a power of 3.6 kW, charging about 25 kilometres in one hour of charging. This type of charging uses SCHUKO type connectors.
  The benefits of this type of charging are the same as those of normal charging, i.e. electricity savings and extended battery life.

Finally, the four charging modes currently available, depending on the type of connector and type of charging used, will be presented: [23]

- Mode 1: uses SCHUKO connectors, not necessarily designed for charging electric vehicles, they are the lowest power connectors and therefore correspond to slow charging. There is only alternating current charging and there is no communication with the vehicle. They are intended for motorbikes, bicycles, scooters and others, not recommended for charging higher power vehicles.

- Mode 2: this mode also uses SCHUKO chargers, in this case the connection between the vehicle and the network is not direct, as it is in mode 1, there is a security system that ensures the reliability of the connection, as well as the charging parameters. They admit a charging power of up to 3.7 kW, so they allow slow charging of electric vehicles. They are intended for domestic use.

- Mode 3: uses connectors designed for EV charging only, so it will use Type 1, Type 2 or Type 3 connectors. These connectors have safety functions implemented in the charging point infrastructure. These safety functions include checking grounding, correct charging operation and selection of desired charging power. This charging mode allows Normal and Semi-Fast charging, depending on the connector and the desired power selection. Charging is carried out in alternating current, either three-phase or single-phase. It is intended for domestic use.

- Mode 4: is the only one that is carried out using direct current instead of alternating current, using an AC/DC converter, supporting the highest charging powers, as well as in mode 3, the infrastructure itself contains the safety functions required for the correct operation of the process. It uses CHAdeMO or CSS2 type connectors, allowing both 50 kW and +100 kW fast charging. It is intended for charging stations outside the home. Mainly due to the high price of the station and its installation.

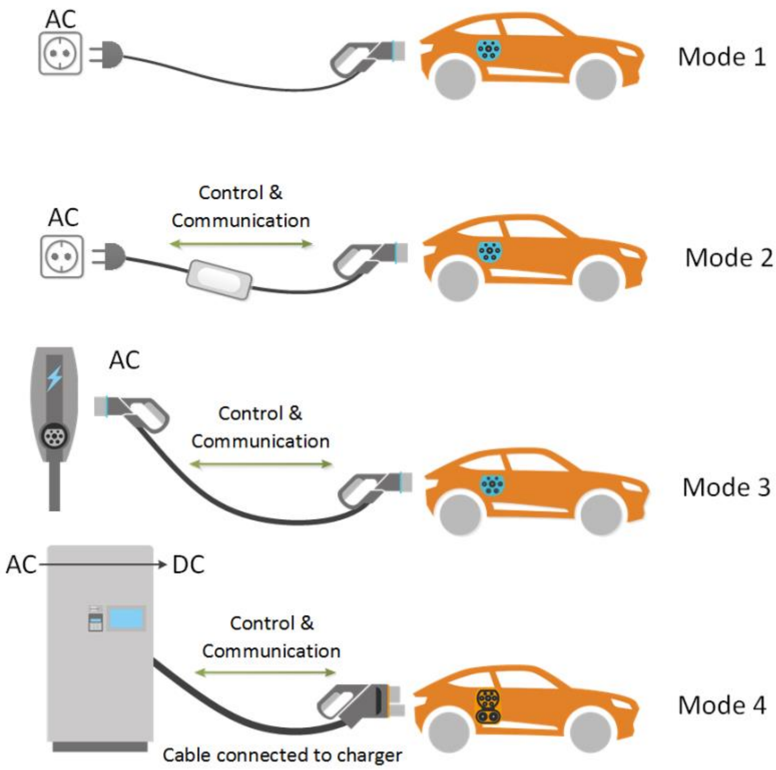


Figure 15. Four charging modes for EV. Source: [29]

2.1.3 Spanish context

2.1.3.1. Renewable Energies

The situation of renewable energies will be presented in general terms, mentioning the most important types of renewable energies used in Spain and presenting the percentage of all energy generated by renewable or non-renewable.

The main renewable energies used in Spain, due to the country's geography, are as follows, in order of highest to lowest generation [6] [30]:

- Eolic
- Hidraulic
- Solar Photovoltaic
- Solar Thermal

For the reasons explained in the section 2.1, the use of renewable energies in Spain has increased significantly over the last decade, with this year being the first year in its history in which the generation of renewable energies has exceeded that of non-renewable energies.

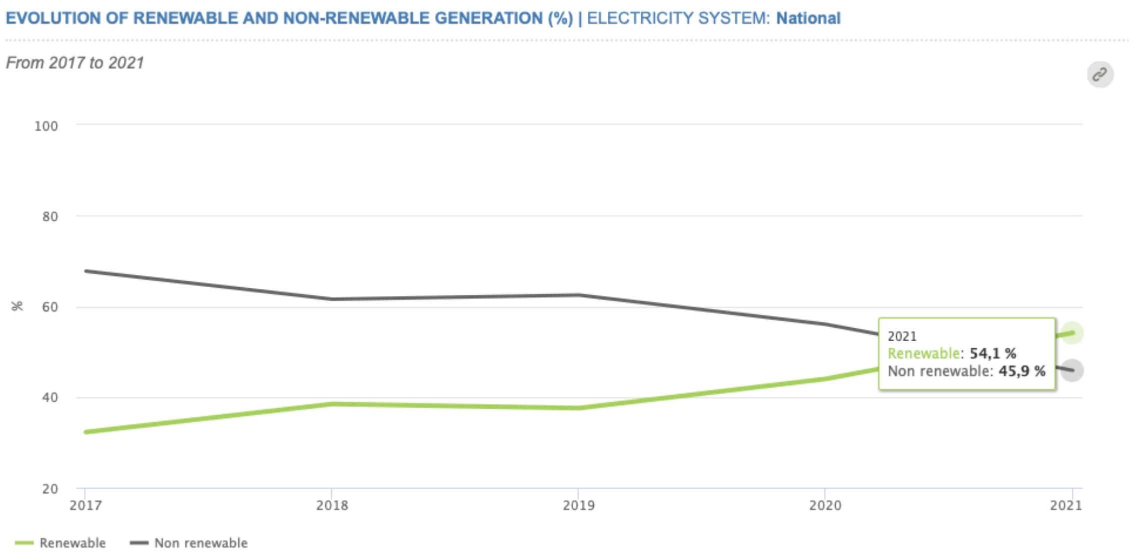


Figure 16. Percentage of generation produced by renewable and non-renewable out of total in Spain. Source: [30]

2.1.3.2. Reduction of Emissions

As shown in section 2.1.2, the main objective of the Paris Agreement is to reduce as much as we can the emission of CO_2 to the atmosphere as it is possible by 2050, to maintain the increase of the global temperature below 2ºC of the pre-industrial levels [31] [9].

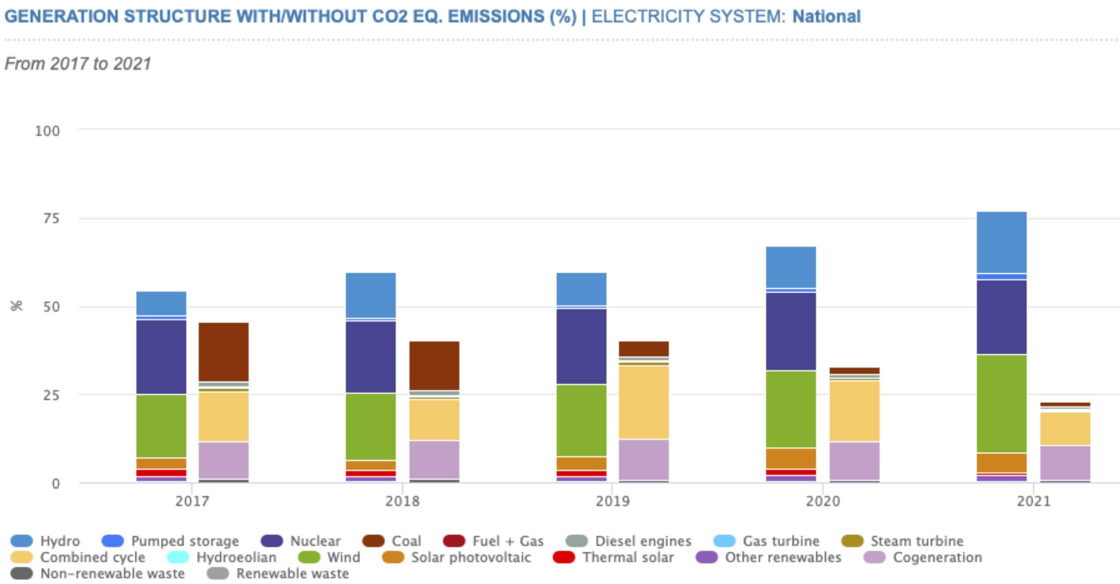


Figure 17. Generation structure differentiating with or with out CO2 emissions. Source: [31]

As can be seen in Figure 17, the situation related to the reduction of emissions in energy generation will be presented, which, as can be expected, has been improving over the last five years, reaching 75% of the energy generated in 2021, free of CO_2 emissions with respect to the total generation, which represents an increase of 50% in a period of 5 years.

This is one of the main sectors in which we have to reduce the emission but we have also to do it in transport which is also being done by the implementation of the EV, and many other sectors mentioned in 2.1.2.

The Spanish government intends to meet the targets with a long-term plan for 2050, in which it aims to reduce up to 90% of the carbon emissions measured in 1990 and to absorb the remaining 10% through carbon sinks. Thus achieving climate neutrality. [32]

2.1.3.3. Electric Vehicle Sector

Finally, the situation of EVs in Spain will be developed more extensively.

The most important general data and their evolution over the last few years will be presented graphically, followed by comments and conclusions.

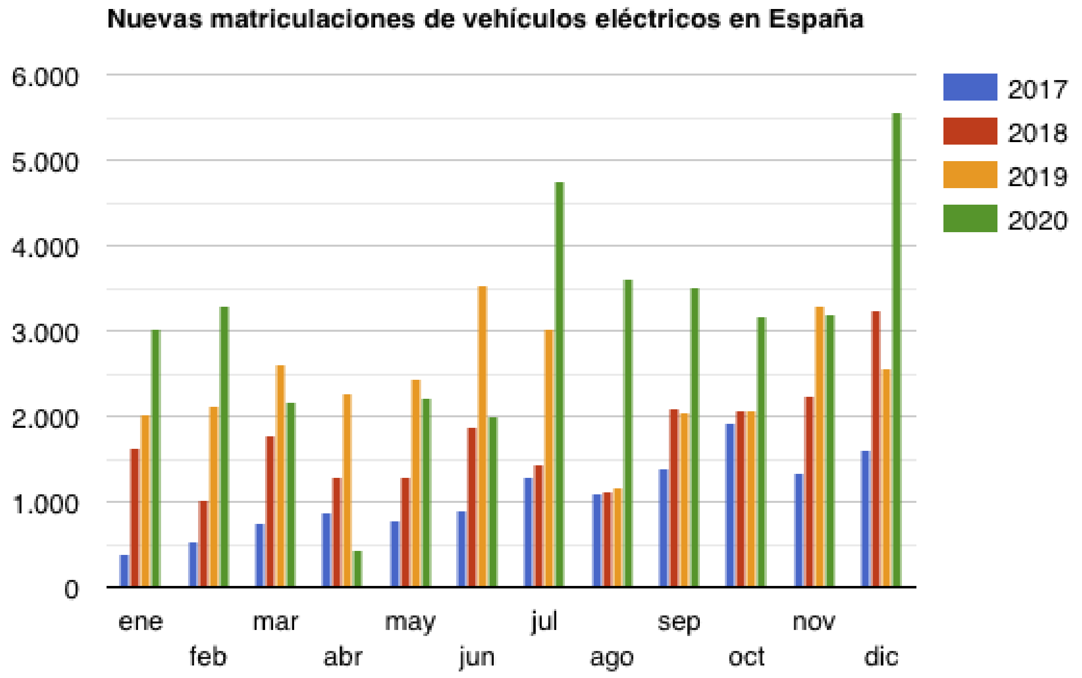


Figure 18. New EV registration by months in Spain. Source [33]

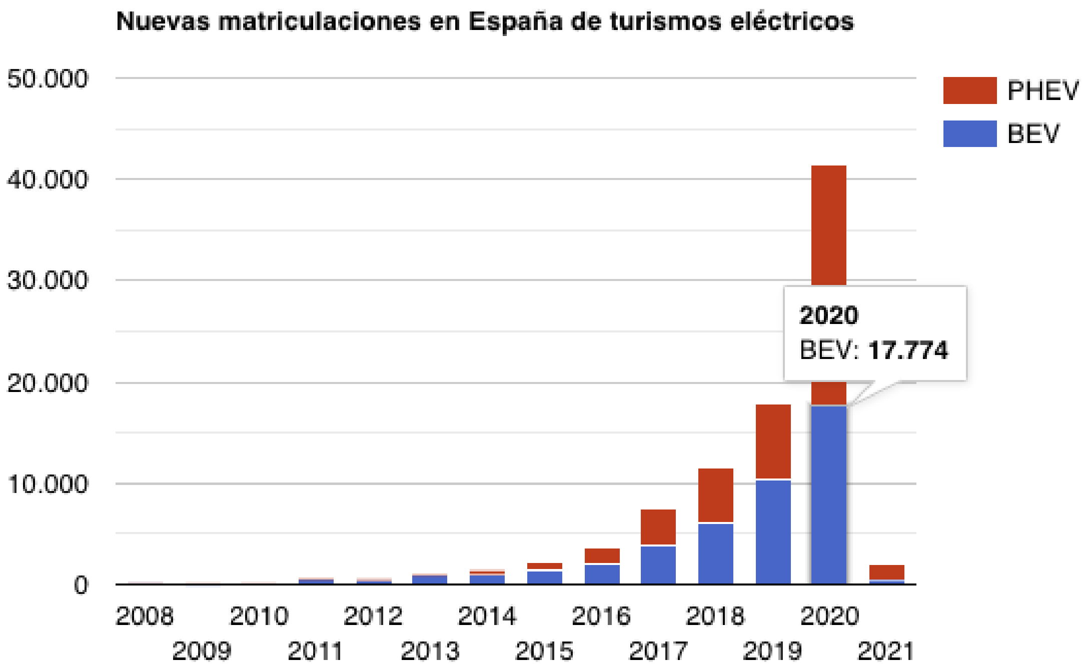


Figure 19. New yearly EV registration in Spain. Source [33]

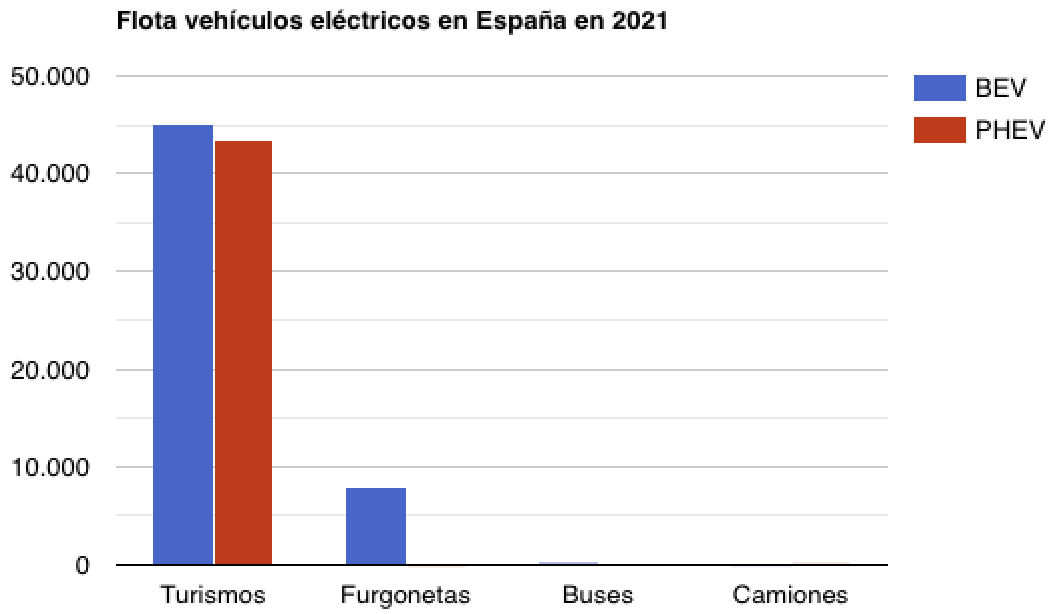


Figure 20. Spanish EV fleet in 2021. Source [33]

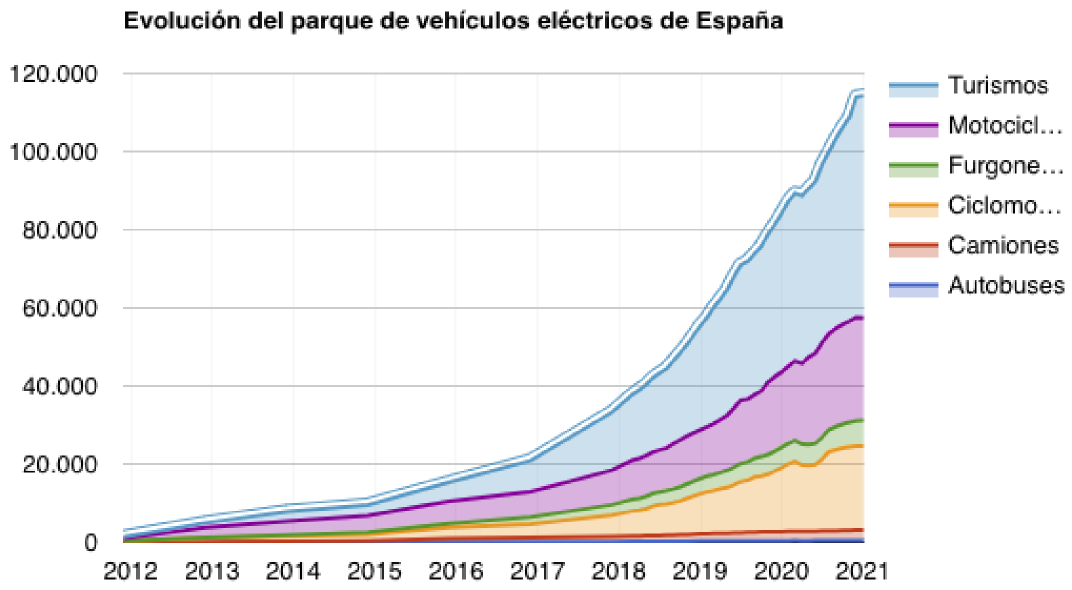


Figure 21. Evolution of the EV fleet in Spain including motorbikes and mopeds. Source [33]

According to the data obtained from the above graphs, it can be seen that the growth of EVs is exponential, and as mentioned above, it is not only limited to cars, but motorbikes have a similar fleet and are gradually being introduced in different vehicles such as vans, trucks and buses, which is a good indication of the scalability of this technology and its potential.

One of the factors that is helping to increase sales are the subsidy plans for the purchase of this type of vehicle, among which the MOVES II plan stands out. This type of initiative slightly alleviates one of the clear disadvantages of EVs compared to conventional vehicles, which is their higher cost. [33] [34]

In addition, other advantages have been promoted for EV users, such as access to areas restricted to zero-emission vehicles or exemption from parking charges in paid parking areas.

Another problem mentioned in section 2.1.3 is the lack of charging infrastructure.

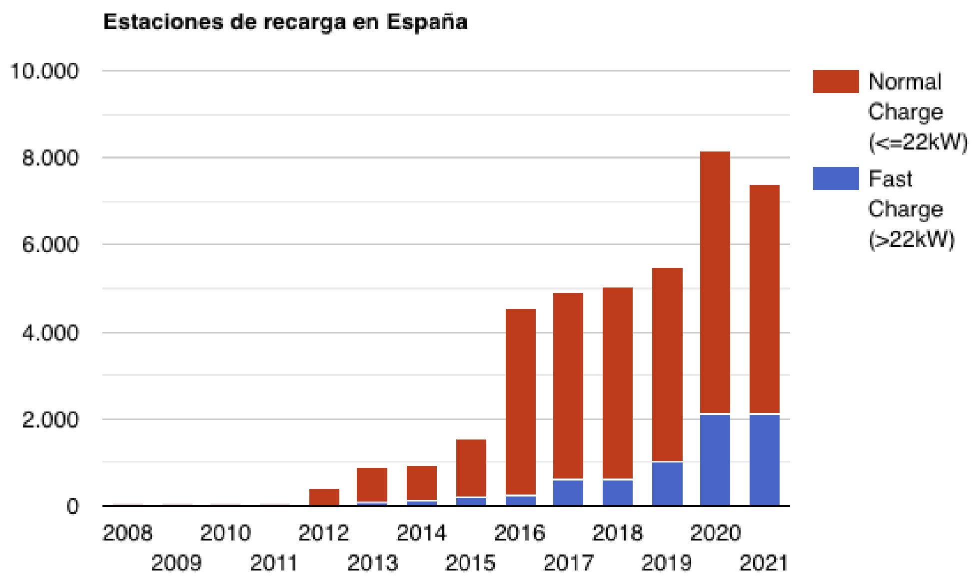


Figure 22. EV charging points in Spain. Source [33]

As can be seen in Figure 22 and compared to Figure Y, it can be concluded that this problem is serious, as there is an exponential increase in the purchase of EVs while charging points are lagging behind, at least for the time being. This may lead to a saturation of charging points, thus causing a decline in EV sales.

This aside, it is always good to compare and contrast to see if the data is as good as it seems, so a comparison of EVs and charging points in Spain versus the rest of Europe will be presented.

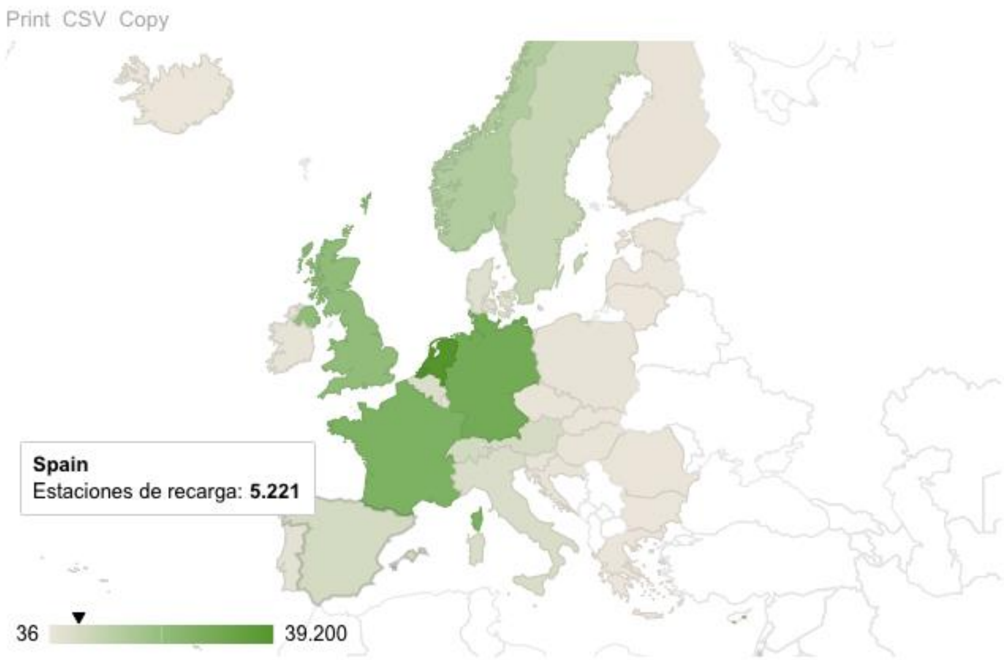


Figure 23. European map colored according to the number of EV charging points. Source [33]

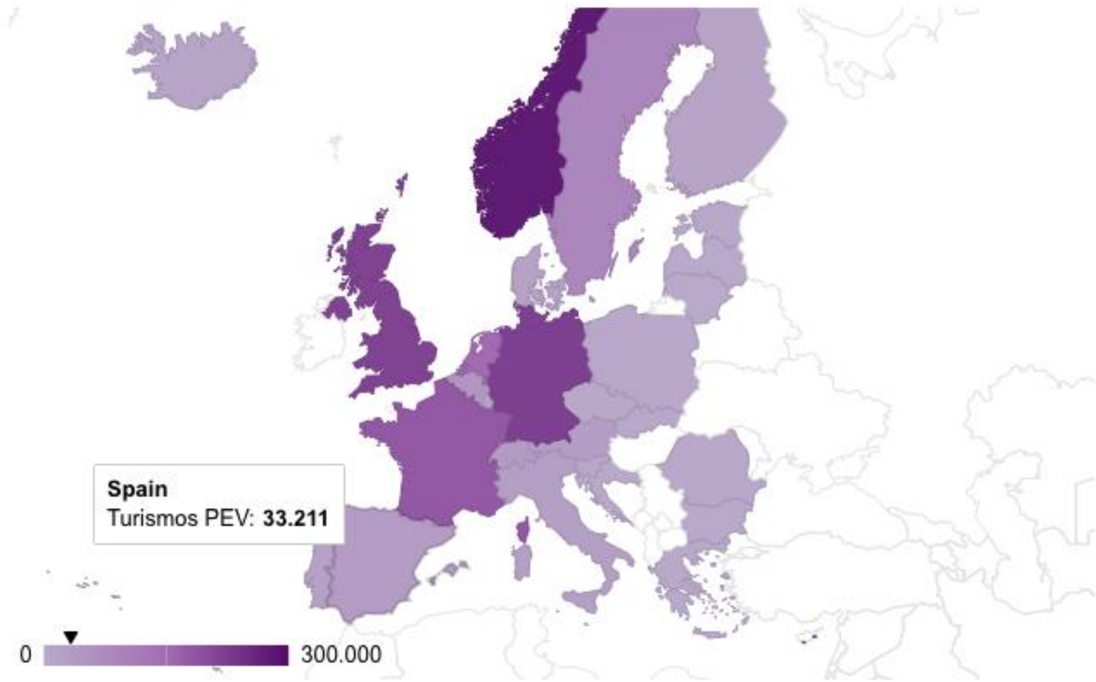


Figure 24. European map colored according to the number of EV. Source [33]

It is worth mentioning that the data in these graphs are from 2019, and that they have increased greatly, but despite this, Spain is at the bottom of the ranking in Europe, which means that the implementation of these EVs has a long way to go.

In order to comply with the Paris Agreement, predictions have been made by government agencies.

The predictions in Spain for the year 2030, according to the National Integrated Energy and Climate Plan (PNIEC), foresee a fleet of 5 million electric vehicles by that year. This represents 28% of the estimated total fleet. Meanwhile, EV manufacturers themselves estimate a maximum fleet of 2.5 million for that year, due to the lack of regulation and national cohesion policy that could facilitate EV integration.

On the other hand, according to a report by Ecodes [35] , in order to reach the target of 5 million EVs by 2030, two scenarios are proposed for the number of charging points that should be in place by that year so that it is possible to supply everyone.

Different scenarios are proposed. In the first scenario, more importance is given to slow and semi-fast charging points, while in the second, the focus is more on fast and ultra-fast charging. These two scenarios would have a demand for 289,130 and 222,901 charging points respectively. In terms of investment, scenario one requires an investment of 12,248 M EUR and scenario two of 13,231 M EUR. Scenario two requires fewer recharging points as it recharges faster but requires a higher investment due to the higher cost of manufacturing the recharging points with faster charging speeds.

2.2 Balancing of the Grid

2.2.1 Introduction

One of the big problems with electricity today is that it cannot be stored in large quantities, so for the system to work properly, generation must be matched to consumption accurately and in real-time.

The frequency of the system is closely related to the balance between generation and demand; if there is more generation than demand, the frequency increases, and if generation is less than demand, the frequency decreases. Grid balancing is used to equalise this balance. [36]

The system balancing is made up of a series of complex mechanisms, with which the frequency-power balance is managed. These mechanisms are necessary because the electricity system is very dynamic and demand varies constantly and randomly. [36]

Being the system balancing random and in real-time, this creates a challenge: to keep the values of generation and demand as close as possible at all times, so that the frequency of the grid remains as close as possible to a given value. [36]

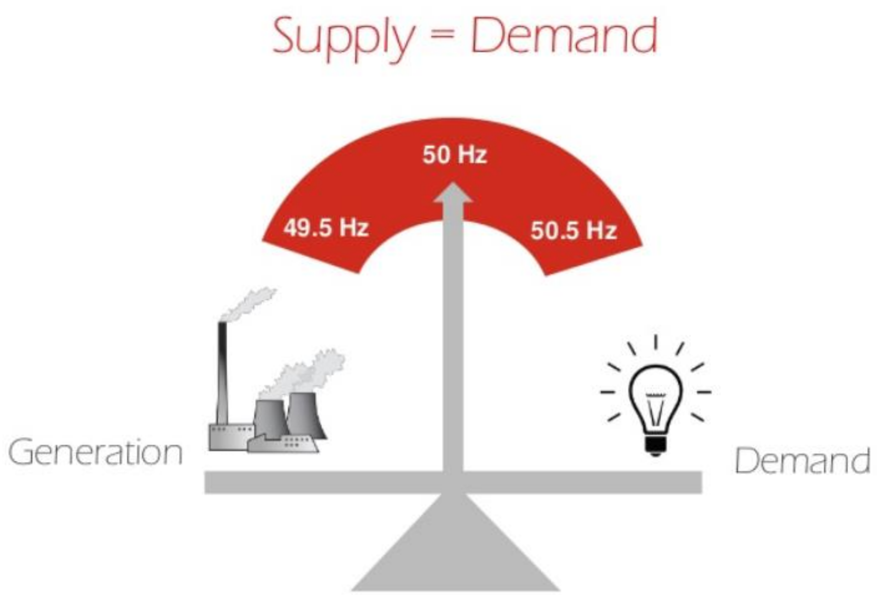


Figure 25. Ilustrative example of a balanced grid. Source: [37]

The change in demand produces an imbalance that will be corrected by the following network balancing mechanisms

- Primary Balancing: this is a frequency control carried out by the generators connected to the grid that can provide automatic frequency response. Depending on the size and capacity of the generator, they may provide more or less balancing, as this is associated with inertia. To do this, the generator measures the deviation between the real frequency and the theoretical frequency at all times and opposes it by increasing or decreasing the generation, this process must be carried out between 5 and 30 seconds after the deviation occurs. Once this time has elapsed, it switches to secondary balancing. [38] [39]

The primary balancing reserve of a generator is defined as: the power margin to be raised or lowered in which generators can modify their generated power (increase or decrease), automatically using their speed regulator, in case it is necessary due to a frequency deviation.

- Secondary balancing: this is a complementary service to frequency-power control that acts when primary balancing is ending. It is centralised, as it is the system operator who will assign the generation setpoints that have been calculated and associated with each generator. Its time horizon ranges from 20 seconds to 15 minutes after the deviation.
  The secondary balancing reserve is composed of upward and downward variations according to the current operating point of all the groups belonging to the secondary balancing of a zone. In Europe, this service corresponds to automatic frequency recovery reserve (aFRR). [38] [39]

- Tertiary balancing: this is a complementary frequency control service, the objective of which is to resolve mismatches between generation and consumption and to restore the reserve of secondary balancing previously consumed. The time horizon required is 15 minutes to 2 hours after the deviation occurs. These reserves are known as manual frequency recovery reserve (mFRR). [38] [39]

- Deviation management: is a mechanism that is used to resolve deviations foreseen hours in advance and after intraday markets close. These reserves are known in Europe as Replacement Reserves (RR). [38] [39]

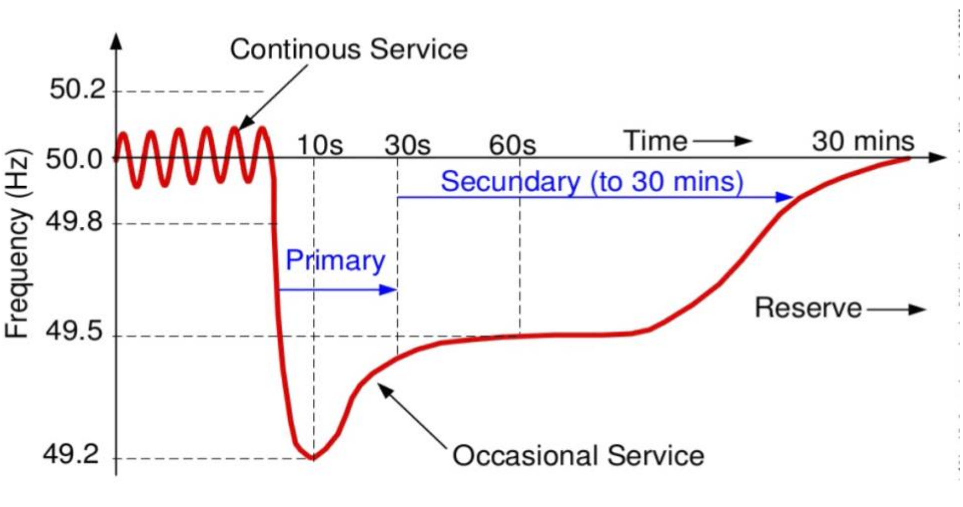


Figure 26. Example of an imbalance on the grid, and the response of the balancing services. Source: [40]

2.2.2 Balancing of the Grid in Spain

In Spain, as well as in the rest of Europe and most of the world, the frequency of the electrical system is 50 Hz. Part of the world operates at a frequency of 60 Hz, which means that the systems are not compatible unless a frequency adjustment device is used.

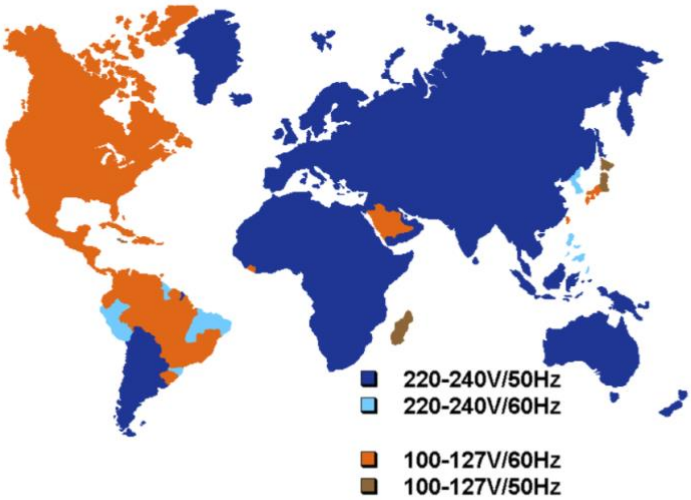


Figure 27. Map showing the different places of the world with different frequency or voltage. Source: [41]

The system operator is REE and is responsible for guaranteeing this balance between generation and consumption. [36]

To ensure optimal operation, it makes consumption forecasts and manages the generation facilities, sending them the necessary orders to resolve any deviations.

The grid balancing methods used in Spain are the same as the ones mentioned in 2.2.1, as Spain is in Europe. This services include:

- Primary balancing: this service is currently mandatory and is not remunerated, so its use will not be reflected in the customer's bill.

- Secondary balancing: the generation setpoints are managed by a central system called Peninsular Shared balancing operated by REE.

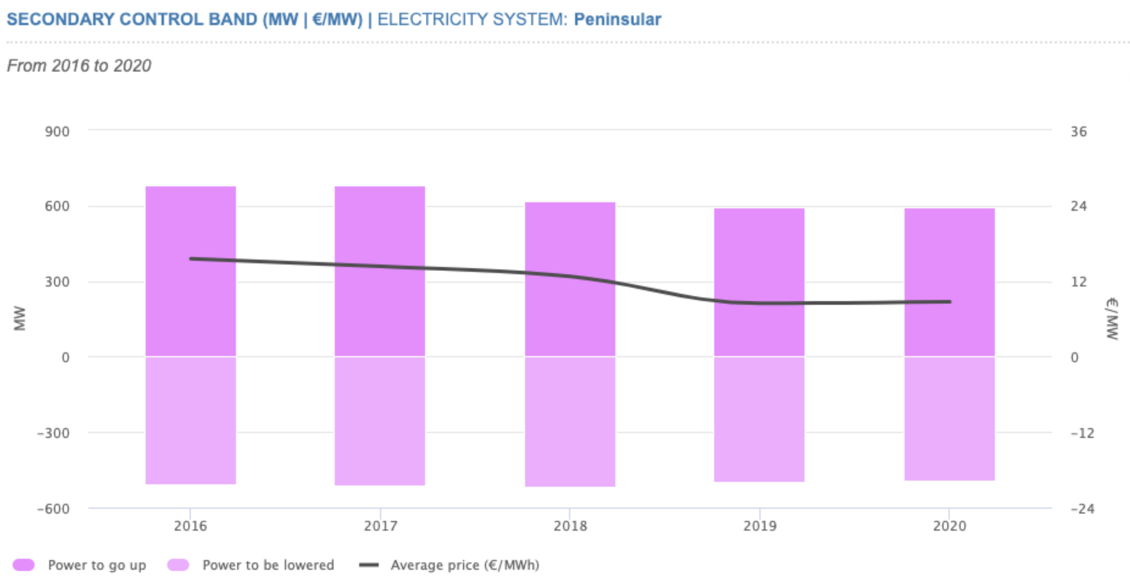


Figure 28. Example of the yearly Secondary Control Band available from 2016 to 2020 in Spain. Source: [42]

As can be seen in Figure 28, the band is relatively constant over the years both upwards and downwards since the balancing needs, although random in a single period of time, over large periods of time tend to resemble the previous time periods.

- Tertiary balancing: participation is not compulsory, but if you participate, it is compulsory to have an offer. There is also a fee for this service.

- Deviation management: same character as in the secondary and tertiary sectors, but also remuneration is obtained for its service.

It is important to mention that, except for primary balancing, the use of these services does have an impact on the consumer's price, firstly because of the need to pay for this service, and secondly because the use of this service causes generation to deviate from the programmed, thus varying its cost.

In addition to mainland balancing, REE is also responsible for non-mainland balancing in the Canary Islands, the Balearic Islands, Ceuta and Melilla.

2.3 Blockchain Technology

2.3.1 Introduction to the Technology

[43]

Throughout human history, transactions of all kinds have taken place, from food to decorative items to work tools and countless other items.

With these transactions came middlemen. Middlemen arrange for item X to pass from individual A to individual B, charging a fee for this service.

Nowadays, the number of intermediaries associated with the sale of a product is very high, which means that, on the one hand, the initial price at which the first intermediary buys it and the selling price to the public are very different due to the fees charged by each of the intermediaries involved in the transaction, which translates into a price increase for each intermediary. [44]

On the other hand, with the advent of the Internet, data traffic has increased exponentially. This personal data can be used by intermediaries to their advantage and may not be well protected and may fall into the hands of anyone who breaches its security in a cyber-attack, which is a serious problem.

For these and many other reasons, a technology is proposed with the ability to reduce intermediaries, increase security and privacy for users, reduce transaction costs and automate processes. This technology is now known as Blockchain technology.

It is a technology-based on three other technologies: [45]

- Peer to peer (P2P): refers to a peer-to-peer network that translates into peer-to-peer transactions. It is a network of computers acting as a series of nodes whose behaviour is peer-to-peer.

- Cryptography: comes from the Greek krypto meaning secret and grafo meaning word. It is the discipline of encrypting and decrypting messages using various keys and algorithms. In this case, it is used to encrypt transactions.

- Consensus algorithms: is a mechanism used to decide the correct or incorrect status of a record, the truth being whatever the algorithm indicates. validate transactions. They are used to validate or invalidate transactions sent in the chain.

2.3.2 Basic Operation of the Technology

Blockchain is a P2P technology that enables data storage, datasharing and computing between network participants. It is a digital database, in which transactions associated with an activity are recorded and which does not require intermediaries for these transactions. [46]

Blockchain is used as a decentralised database normally used as a ledger of accounts distributed among the computers that act as nodes and are responsible for verifying transactions.

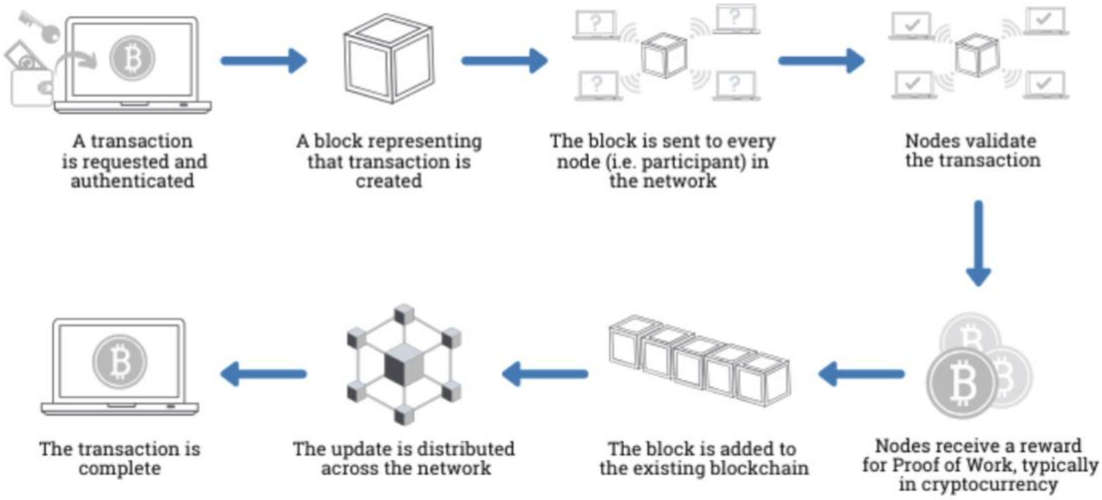


Figure 29. Schematic representation of a transaction from A to B using Blockchain technology. Source: [47]

The P2P network, as discussed in 2.3.1, is a peer-to-peer network, furthermore, neither clients nor servers are fixed, they change and nodes can alternate their status as a server to client and vice versa.

The blocks on the chain each contain one transaction packet. When a certain number of transactions is reached, they are packaged into a block, which has to be added to the chain. To do this, the block is sent to all nodes in the network for verification. Once it has been confirmed that all transactions are correct, it is added to the chain.

The blocks are connected using cryptography whose main role is to protect the information by making it secure and immutable.

To prevent fraud in the chain, each block consists of the 'fingerprint' of the previous block known as a hash, which allows alarms to be raised if there is a change in any previous block. In addition, it contains the transaction packet and its own hash, which is related to the previous one and will be used by the next block, and also includes a timestamp. [43]

As all the nodes have a record of all the previously sealed blocks, problems of information loss due to a failure or an attack are avoided.

2.3.3 Basic operation of the Consensus Algorithms

One of the pillars of the Blockchain lies in the consensus algorithms, given that so many transactions are verified by so many different nodes, a guideline is needed to ensure order and reliability in this process.

In contrast to traditional mechanisms that contain intermediaries, such as a bank, the blockchain makes it possible to eliminate these intermediaries as the users themselves verify and execute the process.

To add the block to the chain, a consensus has to be reached in which the transactions are accepted as correct, otherwise the incorrect transactions would be erased and the process would be repeated.

The type of consensus will depend on the type of blockchain network in which we find ourselves, if it is public, the consensus has to be decentralised, the incentive for participants being the rules of the game itself, which for their benefit will make these participants act honestly and truthfully, this is based on John Nash's Game Theory. [45]

In contrast to this, if the chain were private, general consensus would not be needed, but only that of the parties involved.

There are a large number of consensus algorithms, each of which has different properties, strengths and weaknesses that make them suitable for different applications.

The algorithm used to reach consensus will therefore define the performance characteristics, such as the resources needed (i.e. computational capacity), transaction speed, scalability and security.

Several consensus algorithms exist for this process, among which Proof of Work (PoW), Proof of Stake (PoS) and Proof of Authority (PoA) stand out.

2.3.3.1. Proof of Work (PoW)

Proof of work or PoW, considers the computational capacity necessary to solve a cryptographic puzzle that allows you to seal and add the block to the chain, obtaining a reward for it. The greater the computational capacity, the greater the probability of sealing the block and therefore of obtaining the reward. On the other hand, the greater the computational power, the greater the cost, and all the processes must be optimised to make it economically viable. [45]

In this consensus, the figure of the miner is necessary, they are in charge of verifying that the transactions are correct (correct order and valid transaction), sealing the block and adding it to the chain, once the process is finished, the miner obtains a reward for it, which consists of the transaction fees plus a certain amount of coins associated with that blockchain and created at that moment. [48]

PoW was the first consensus algorithm used for blockchain. Currently, it is one of the most widespread consensus algorithms, but not the best, it is one of the slowest consensus algorithms (with fewer transactions per second) and more polluting, since the electricity consumption dedicated to this process is directly related to the computational power which, as already mentioned, the greater the computational power, the greater the probability of reward and therefore the greater the electricity consumption and the greater the pollution. [49]

PoW is still useful for public networks since 51% of the network's power is needed to control it and be able to carry out an attack, which is not only costly but also counterproductive.

Currently, Bitcoin and Ethereum, among others, work with this consensus algorithm, although the Ethereum network is moving to Proof of Stake, as it is faster, cheaper and less polluting.

The miners obtain the Merkle tree of the transactions that are on the waiting list and available to add to the next block. The root hash of the tree is included in the message to be hashed and encrypted using a PoW hashcash algorithm. The miner solves the puzzle and finds the valid hash and communicates it to the other nodes, which verify it and update the blockchain. [43]

This type of consensus means that there can be two different records, both valid, and the chain with the highest PoW, i.e. the one with the most votes, will be the one that is finally valid.

From this type of event, the so-called forks arise:

- Softfork: a temporary split occurs in the chain. This type of split occurs when new rules are introduced into the chain. The chain that is not updated validates more blocks than the one that has updated the rules. This type of splitting is not entirely problematic, since the changes are made as soon as they are updated.

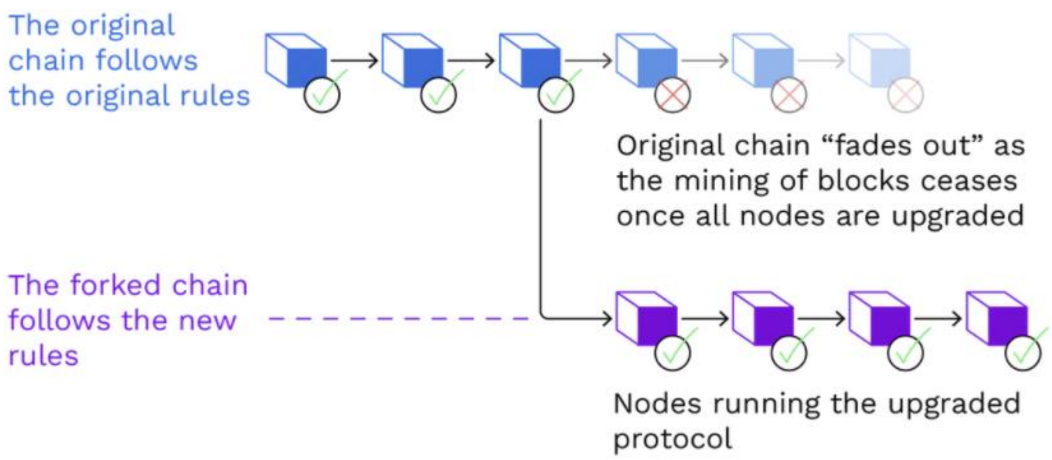


Figure 30. Schematic representation of a Softfork. Source: [50]

- Hardfork: a definitive split occurs in the chain. This type of split occurs when less restrictive rules are introduced, i.e. blocks are validated that were not validated before. This type of splitting should be avoided as it results in two fully valid blockchains.

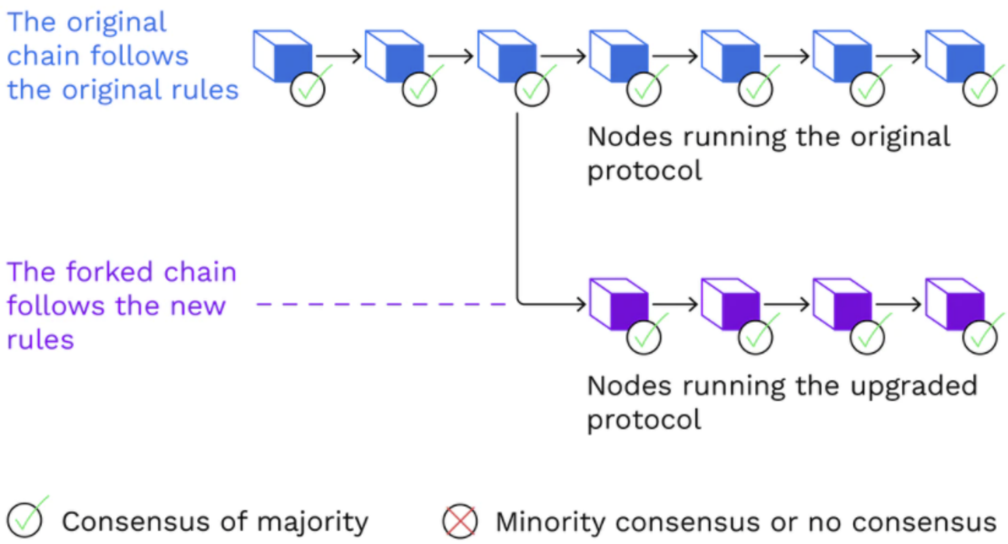


Figure 31. Schematic representation of a Hardfork. Source: [50]

2.3.3.2. Proof of Stake (PoS)

Proof of Stake, or PoS, is a consensus algorithm based on the participation of each user in the chain. Only those participants who commit their stake of tokens will be able to participate in the network consensus. The higher the stake committed, the higher the probability of being chosen to add the next block to the chain.

In this type of consensus, there is no miner as such. Even so, the participant who is chosen to add the block, and adds it correctly, will receive financial compensation, which is only the transaction fees associated with that block. [49]

To choose the participant who will seal the block, one of the following processes is followed: [43]

- Random selection of a token: from among all the tokens in the network, one is randomly selected and assigned the task of adding the block to the chain. If this participant is online, it will proceed with it, otherwise, another token will be selected and proceed in the same way with this iterative process until it is achieved.

- Selection by token age: from among all the participants, it is assigned to the one who has carried out a transaction with the coins that have not been transferred for the longest time in the entire network.

As far as security is concerned, in case a participant acts maliciously, it will lose its entire stake, which makes PoS a good consensus for non-permissioned networks.

PoS is more immature in terms of security than PoW, since it is simpler and its computational complexity is lower, which makes attacks on this type of network easier (within the difficulty). Moreover, the lower the computational complexity, the less costly it is to attack this network, being more vulnerable than PoW.

PoS still has great potential for development and its scalability is not yet fully defined and is expected to grow over the years.

2.3.3.3. Proof of Authority (PoA)

Proof of Authority, or PoA, is a consensus algorithm that relies on several authorised participants who are responsible for verifying transactions. These participants have the trust of the entire network, which is practical, useful and efficient for private blockchain networks. [45]

In this type of consensus, the value of the participant's identity prevails, so all validating nodes must be entities that can be trusted, and that will do their best to manage the network well and ensure its security. [43]

2.3.4 Applications in the Electricity Sector

Blockchain technology can be applied in practically any sector, providing, if necessary, a more effective and optimal solution than other methods, although this does not mean that it is always the best solution.

To determine whether it is viable and makes sense to apply Blockchain technology, it will be necessary to conduct a thorough analysis on the application the technology for a certain project and then compare it with other solutions, whether current solutions or other innovative solutions for the same problem, once this is done, it will be decided whether the use of blockchain technology is the best or not, it should not be forgotten that this technology is a tool, and that a tool does not serve to solve all problems. If it does not make sense to apply it, its use would be discarded and another procedure would be used.

In this case, the focus will be on the solutions that this technology can bring to the electricity sector in terms of decarbonisation, decentralisation and accessibility.

The applications in this sector are of great interest and have a very solid future projection, which is why they are being researched and developed by both institutions and industry. As a result, the number of start-ups, publications and articles is growing at a high rate over time. [43]

Blockchain technology applications in the electricity sector can be encompassed in eight major groups: [43]

- Peer to Peer energy trading: as the number of small generators installed near consumer premises is increasing, the spare energy is doing it too. The lack of regulation for these generators makes it difficult to sell the spare energy generated. The P2P solves this problem by creating a local energy market in small communities where they can buy and sell electric energy to each other.

- Wholesale markets: this markets have a lot of intermediates which ends in high transaction and operations cost meaning the cost for the end consumer will be higher. With Blockchain we can reduce this costs by reducing the number of intermediates to minimum.

- Metering, Billing and Retail markets: these processes are very inefficients as they have high administrative cost due to manual processes among other things. Blockchain technology can reduce this cost by implementing better digital processes and reduce the number of intermediaries.

- Trading of RECs, and Carbon Credits: this is a developing issue which has a high importance and potencial in the near future. The implementation of this solutions is usually very expensive and inefficient. Blockchain can help with this by bringing transparency to the emissions aspects, due to its inmutability and the easy access to the information.

- EVs: all this benefits are explained in the 2.1.2 and the 3. sections

- Enhancing Power System and Cyber Security: due to grid digitalization the number of cyber attacks is expected to grow. Thanks to the security of the Blockchain technology, can help monitoring in real time detecting any abnormality in the system. The data stored is compared among all the nodes therefore, any try on changing it will end up in a thin air try.

- Investments in RESs: there are many difficult barriers to enter in this market, such as high entry cost. However, Blockchain, can divide the asset or assets between the co-owners which will share a percentage of them, when the time to receive the revenue comes, the Blockchain network will do it automatically proportionally to the percentage owned. This can help co-financing projects and democratizing this market.

- Operation and Management of the Grid: the increasing Distribution Energy Reserves (DERs) installation is benefiting the whole grid but is also making it more complex to control it, as the DERs are intermittent and unpredictable when they are of Renewable Energy Sources (RES). As high flexibility is needed in the grid for this matter, Blockchain can provide benefits in the decentralized management of this Energy Source.

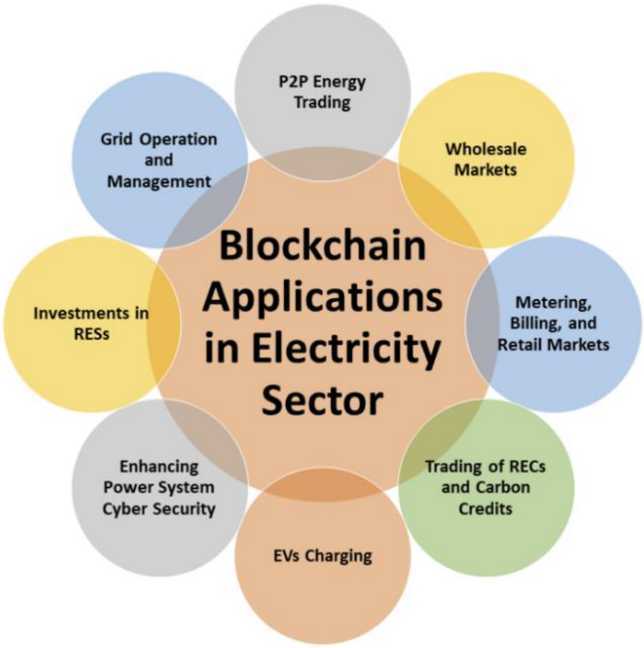


Figure 32. Illustrative scheme of the Blockchain applications in the electricity sector. Source: [43]

3. State of art of Blockchain applications to EVs charging

3.1 Share and Charge

3.1.1 Introduction

Share and Charge is a cross-provider smart charging service for EV based on Open Charge Point Interface (OCPI). [51]

The OCPI protocol support connections between EV users and the Charge Point Operators (CPO). [52]

This protocol is aiming to

- Accelerate EV growth by easing the charging structure. This is done thanks to the single communication between all the market players.

- Improve the services of mobility: optimize the user experience no matter what the border, equipment or operators are.

Briefing, OCPI aims to stardarize and simplify this emerging market.

3.1.2 OCN Services

The Open Charging Network (OCN) Service, is a back to back marketplace with solutions for the EV community focused on the charging service. [51]

The three main points of the OCN: [53]

- It is based on the OCPI 2.2 , the OCN allows to connect to the OCPI and implement the cases supported by the protocol.

- It is Open Source, all the components developed of the OCN, are done using the Apache 2.0 license. The team is in continuous development to improve the service.

- It is decentralized, meaning anyone who meets the requirements can become and OCN Node Operator. It also means that no third party is needed to complete the process. This is done using Blockchain technology.

The OCN is divided in two main networks: [54]

- Public Test Network: this network is used by the developers to test their own applications and test the new features of the OCN. Once it is tested and evaluated it can be deployed onto the Production Test Network.

- Production Test Network: this network is used for production and development of the services.

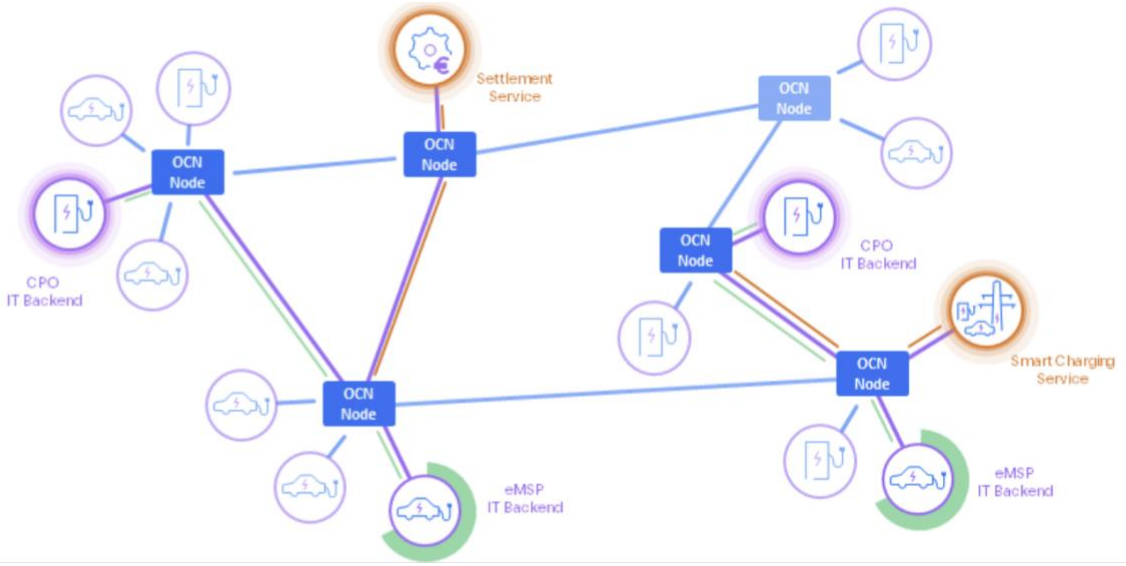


Figure 33. Scheme of the Production Test Network. Source: [54]

The main benefits of using the OCN are: [53]

- Instant Payment: lets the EV driver make instant payment through e-money, automating invoicing, payments and everything related to the charging process.

- Easy Connection: provides an easy way to connect to the OCN.

- eRoaming Contracts: by digitalizing this contracts, you reduce your cost, it finds you partners inside the OCN with who you can discuss the terms and conditions of the contract and sign the agreement.

- Certificates of Green Charging: it lets you integrate Green Certificates by making sure the EV charging user have the opportunity to charge their EV with renewable energy sources.

- Smart Charging Tool: this tool lets the grid operators analyze the charging process from different CPO in order to optimize them.

3.2 Equigy by Tennet

3.2.1 Introduction

Tennet is a leading company in the electricity sector that acts as Transmission System Operator (TSO) in the Netherlands and Germany. It covers a network of almost 24,000 km of high-voltage lines and is responsible for ensuring the continuous supply of electricity to more than 42 million users in the aforementioned countries. [55]

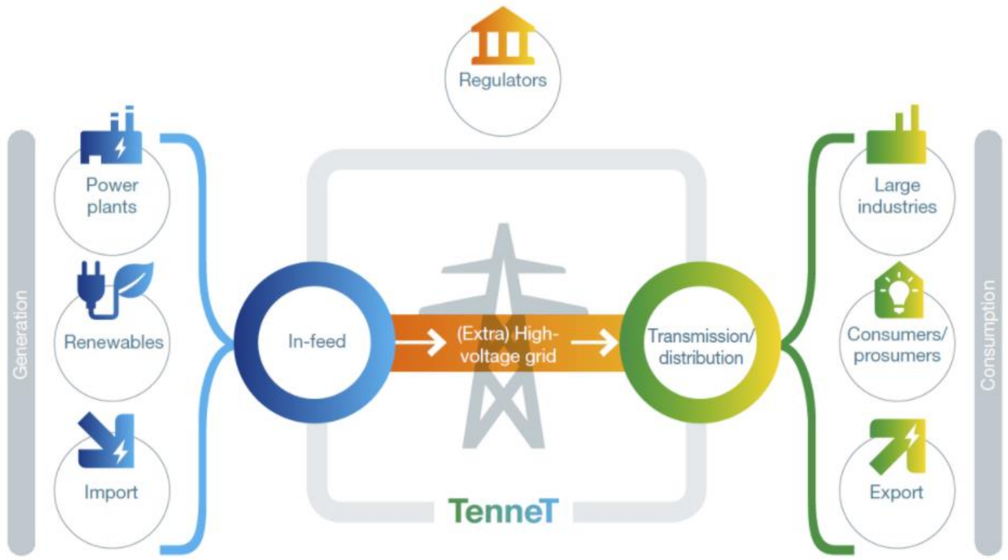


Figure 34. Illustrative diagram of the operation of Tennet. Source: [55]

Most of Tennet's activities are closely regulated by the laws in Germany and the Netherlands that deal with such matters as consumer affairs and markets. As a company of such a large size, we are talking about very strict regulation on a national level. Its business model is based on the following key points: [55]

- Ensure the continuous supply of electric energy to the end-consumers.
- Provide the electric energy transmission through the high voltage grid from point A (generation) to point B (consumption).
- Guaranty the flow of energy in both countries.
- Commit to a liquid and stable electricity market and to support the energetic transition to a cleaner and more environmentally friendly sector.

Equigy's business model would be represented as follows:

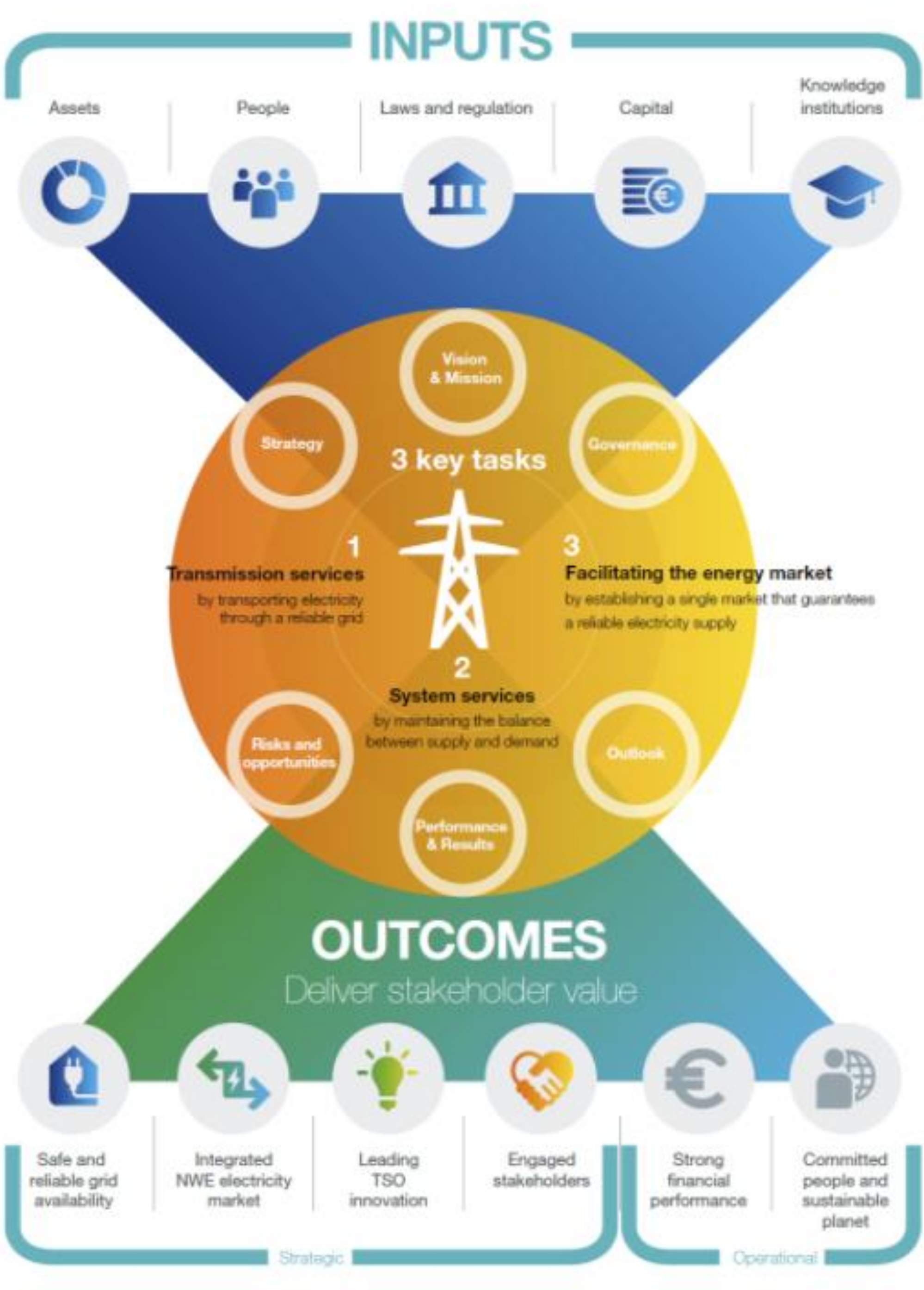


Figure 35. Illustrative diagram of Tennet´s Business Model. Source: [55]

3.2.2 Crowd Balancing Platform

A Crowd Balancing Platform (CBP) is an innovative solution in the balancing of the grid. The energy transition has involved the creation of a large number of small generators with a highly volatile production, this is creating many challenges in the balancing to the TSOs. [56]

The CBP guarantees a trust data exchange so that aggregators can participate in the market for services with small-scale flexibility sources, such as home batteries or EV, by doing this, they are turning the market consumers into market prosumers. [57]

Tennet has created an innovative and vanguardist project called Equigy, which is a Crowd Balancing Platform based on Blockchain technology [58].

This project is based on three main points:

- Challenges to the necessary energy transition: as renewable energy production is increasing so are the problems the TSO may face. The supply of renewable energy is not constant because of its dependence on the weather, therefore it has many fluctuations. To solve this, Tennet is looking for solutions to avoid expensive activations of generation by generation units.

- Storing renewable energy: it is well known that currently there is no system to store big amounts of energy, therefore the amount of energy generated must meet the demand. However, the number of private storage units for small amounts of energy, used to charge EV or to store solar energy produced by photovoltaic panels is increasing heavily, and this can be used to palliate the impact of renewable energies on the system.

- Blockchain Technology: used to store data with high security that enables a transaction between market participants. The use of this technology enables a system with high-speed transactions in a very secure environment.

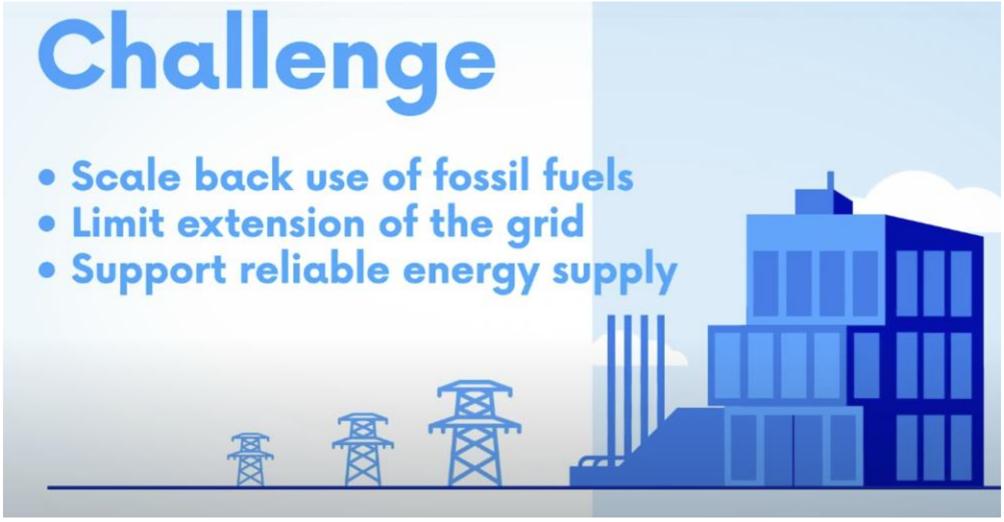


Figure 36. The challenges Equigy is to solve. Source: [59]

3.2.3 How it Works

Equigy is a crowd balancing platform that leverages EV and home battery charging to help to balance the grid, using a blockchain platform to facilitate flexible access to these decentralised loads. [59]

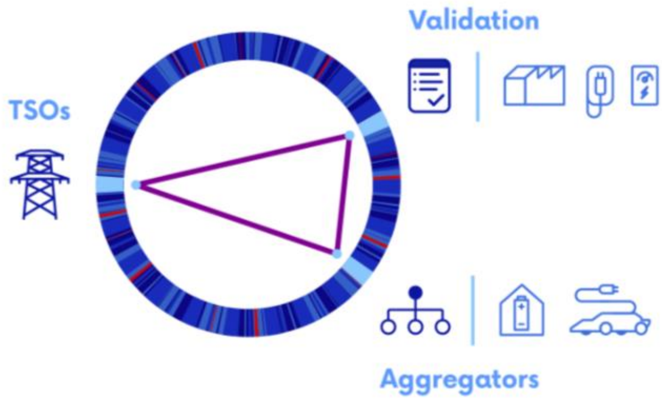


Figure 37. Illustrative diagram of the operation of Equigy. Source: [59]

Currently, to be eligible to be part of this network as an EV or battery owner, you have to meet certain requirements, which vary depending on the current regulation of this sector in each country.

The energy transition from fossil to renewable energy is creating serious problems for TSOs in ensuring the security of the energy supply. This is due to the change in the way energy is supplied. Renewable energies produce highly volatile energy flows due to their dependence on natural factors such as wind and the sun. On the other hand, total energy consumption is increasing. Therefore, increasingly fluctuations in supply and demand are expected to occur.

This has led to the need to develop solutions such as the use of EVs in grid regulation to improve grid balancing. The use of renewables is going to increase, so it is necessary to start developing solutions in this aspect in order not to slow down its growth.

To make this project possible, Equigy uses a platform with blockchain technology to record and validate all these small energy transactions from different points. In addition, it allows the TSO to monitor in a secure and immutable environment, being able to see the energy capacity available at any given moment. On the other hand, it facilitates the exchange of information between the parties, which is necessary for these transactions to take place. Thus allowing you to store or dispose of energy through aggregators or Flexible Service Providers (FSP). [59]

These transactions are validated based on data provided by OEMs (Original Equipment Manufactures) on batteries and EVs. In addition, it uses IoT devices for this purpose, such as smart meters available on devices and charging points. Thus securely including a large number of small network aggregators. [59]

These aggregators, being managed by Equigy, form a pool used by TSOs to help them manage grid balancing. The owners of these devices (EVs, batteries), can obtain an economic return by giving away or storing energy, thus helping the energy transition and grid balancing.

This cutting-edge project must be just the beginning, as mentioned above, the expectations for growth in the use of EVs are enormous. The larger the fleet, the more balancing capacity they can bring to the grid.

The main benefits of CBP for aggregators and TSOs are as follows: [60]

- Lowering the barriers for Balancing Service Providers (BSP) in terms of data exchange with the TSO and also by providing an interface which is easy to use.

- Commit to an increasingly decentralized market by the use of a blockchain platform to balance the grid.

- Improve the TSO validation methods by using data from the IoT cloud of devices, making easier collecting device measurement.

- Highly scalable to other countries TSOs and BSPs thank the technical standards and the possibility of reusing the CBP platform functionalities.

The current requirements to be part of the aFRR are: [60]

- A bid size of 1MW at least.

- Valid bid for the whole process (approximately 15 minutes).

- Ramp rate of 7 to 10% per minute.

- A reaction to the setpoint change has to have a visible change in power within the first 30 seconds.

Equigy integrates seamlessly into the current electricity system as it can be seen in the Figure 38, which shows the data flow diagram of Equigy, improving it and being a vehicle towards a more sustainable, integrated and decentralised future.

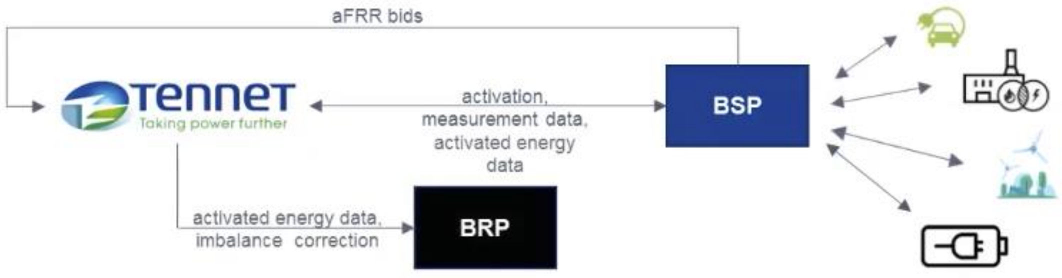


Figure 38. Equigy flow diagram of the process. Source: [60]

For the correct operation of Equigy, as the Figure 39 shows, Tennet relies on several applications for the various processes to be carried out from aFRR bids to IoT device measurements.

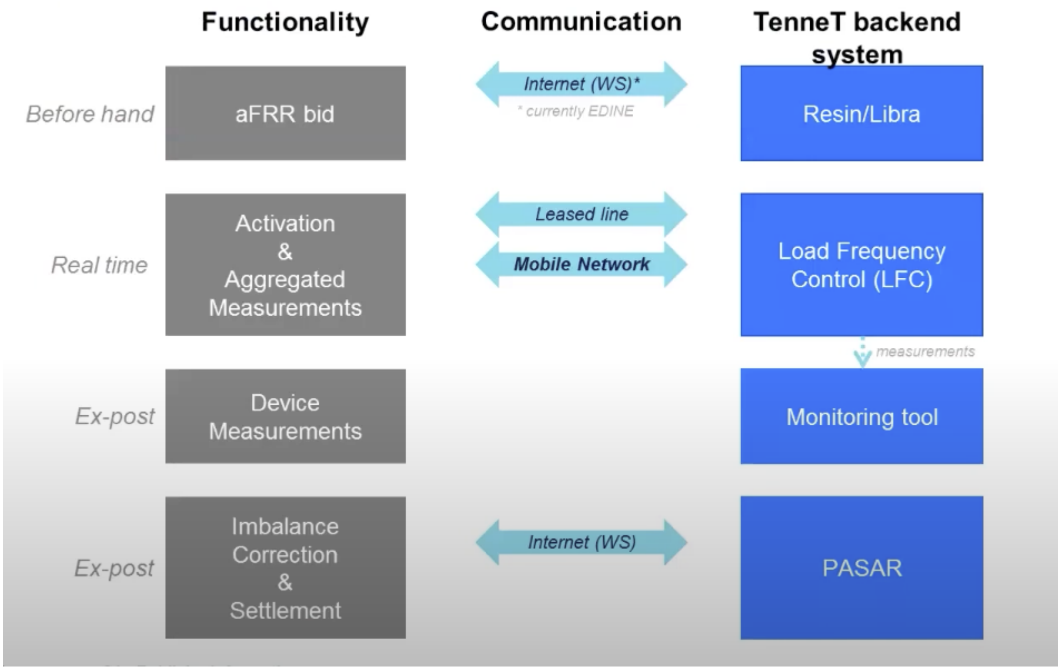


Figure 39. Illustrative diagram of the aFFR process and the data communication process. Source: [60]

As shown in Figure 40, the exchange of data in the process is very extensive and tedious (green boxes), and this data is sensitive and susceptible to attack so this data exchange will be done within the blockchain network to ensure its security of immutability.

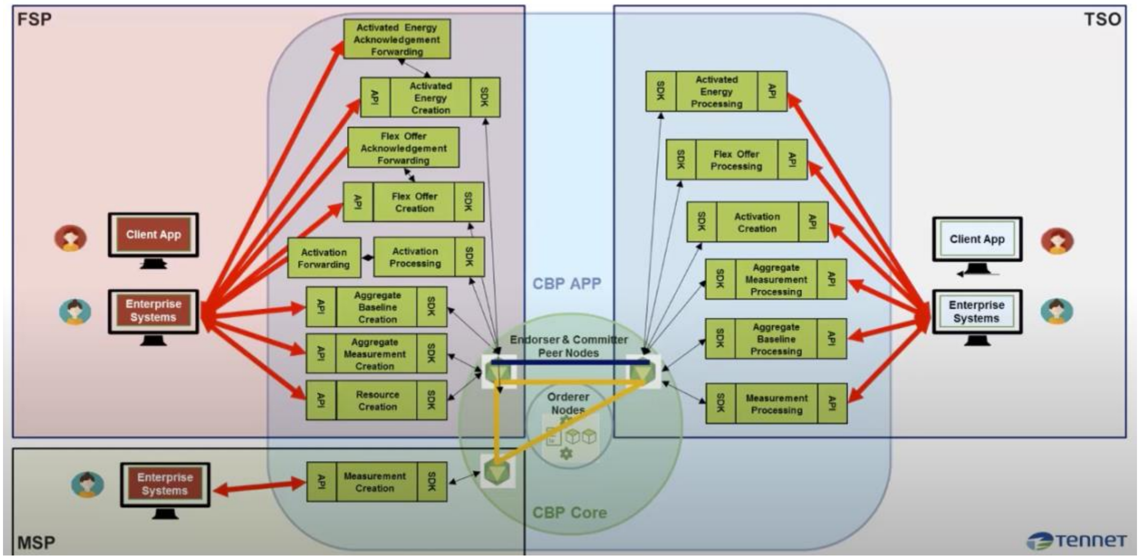


Figure 40. Interface overview of Equigy aFRR. Source: [60]

4. Methodology

The project consists of a qualitative analysis of the feasibility of developing a project similar to the Crowd balancing platform managed by Tennet (Equigy) in the Spanish context.

To this end, it will be necessary to take into account that electricity markets are different in each country, both in terms of structure and operation and in terms of regulation. Regulation is divided into two parts: regulation of the market itself internally and regulation of the operation of the grid, management of payments, etc, so a thorough analysis will have to be carried out in this aspect to establish which parts can be taken from Equigy and which parts will have to be developed differently.

On the other hand, a comparative analysis will be made between the different blockchain networks and their consensus algorithms, to deliberate which are the most suitable for this project.

For the development rof the project guidelines will be followed:

- Identification of the characteristics required by regulation to be able to actively participate in the balancing market.

- Identification of the different applications of the project: explain the different resolutions this project may have and the main applications and usage they have.

- Establish a relationship between the different agents involved in the process: it is important to establish the relationship between the different agents, as they are one of the pillars of the project, and we will try to optimise it by minimising the interaction between them. The main agents will be:

    - TSO (REE)
    - DSO
    - BSP
    - Blockchain Platform
    - Small aggregators (EV owners).

- Analysis of the various blockchain technologies, following the criteria established for the project in its different parts: due to the number of blockchain technologies available, the different technologies will have to be analysed to choose the one that best fits the project. The criteria include:

    - Resources needed (i.e. computational capacity)
    - Transaction speed
    - Scalability
    - Security

  The project has a decentralised and a centralised part. The decentralised part will focus on the payments for contributing reserves to the grid and the centralised part corresponds to the use of these reserves carried out by the TSO. The decentralised part and the centralised part have different criteria so they will have different blockchain networks.

- To make comparative tables that facilitate the choice of technology: for a better analysis of the technologies and a better visualisation, comparative tables will be made that include the criteria and that allow the necessary technology to be elucidated in each part.

- Analysing the feasibility of the project: once all of the above has been done, a brief analysis of the project will be carried out to highlight the positive points and possible barriers that the project may face. With all this, it will be decided whether the project makes sense to carry it out using Blockchain technology or whether it is not necessary.

5. Case Study

5.1 Analysis of the Regulation of the Grid Balancing

In Spain, the National Markets and Competition Commission (CNMC) establishes the methodology to be applied in the electricity market with regard to system balancing services in the *Real Decreto-Ley 1/2019*. [61]

This methodology will be approached from two main points of view:

- Economic: improve the economic efficiency, regarding all the different markets inside the electricity sector, to incentivize competition, which benefits directly to the consumer.

- Non-Discriminatory Market: ease the accessibility to a great number of participants, to participate you just have to meet the requirements for any given process.

These three points are intended to encourage network users to participate in these balancing services.

On the other hand, the CNMC in the *Boletín Oficial del Estado la Circular 3/2019 artículo 5 y artículo 19,* establishes the methodologies to regulate the functioning of the electricity market and the administration of the system operation, establishing that the TSO will be in charge of managing the proposals for the correct development of the European regulation and in charge of the management of the balancing services provided by the BSPs, to achieve a balance between generation and demand, thus ensuring a correct electricity supply. In addition, the TSO will be in charge of ensuring that the activated balancing energy, the energy exchanged with other operators and the deviations are correctly settled with the different parties. [61]

In this case study the main focus will be on regulation and conditions relating to aFRR and RR.

5.1.1 Secondary Regulation or aFRR

The aFRR regulation focuses on four main points: [62]

- Diary assignation of aFRR bandwidth (reserves).

- Assure that the service supply is going to meet the requirements.

- Measurement and control of the service supplied.

- Economic settlement criteria for the service.

The aFRR involves four agents:

- TSO: manager of the aFRR.
- BSP: provides the balancing service to the TSO.
- BRP: agent who produces the imbalance, and the one who has to pay to restore it.
- MP: a market participant who is involved in the electric market, can sell, consume or generate energy, can also participate in the balance of the grid or storing energy. Having also the role of BRP.

This balancing service works with prior assignment of an aFRR capacity band and has an automatic activation process of aFRR energy in real-time depending on the regulation zone and is managed by the RCP (Peninsular Shared Regulation system). This system acts as the master regulator and due to the importance of this process, there is a duplication of this system, in case there is any failure in the master. [62]

A regulation zone is defined as a grouping of regulation units that can react appropriately to a regulation order received in real-time and with the capacity to be evaluated.

The regulation band is established by the TSO through allocation mechanisms that are based on the day-ahead market. [62]

The technical requirements of the regulatory areas are as follows: [63]

- Minimum of 200 MW enabled to participate in the aFRR market.
- Each regulation zone is formed by more than one unit which actively participates in the aFRR market and also by non-active participants of the aFFR service all of them under the control of an agent which is the ownership of the regulation zone

In addition, the technical requirements of the units are as follows: [63]

- The supply capacity of at least 1 MW.
- Being integrated into the control center accredited by the system operator, responsible for the regulation area.
- Meet the communication requirements including:
    - Structural information.
    - Real-time measurements.
- Pass the specific challenges to participate in the aFRR which can be seen in the Procedimientos de Operación 9.

To become an aFRR participant, an application has to be sent to REE and the necessary tests have to be carried out.

5.1.2 Reserve Restoration

The balancing energy from Reserve Restoration product involves the following actors:

- TSO: manager of the aFRR.
- BSP: provides the balancing service to the TSO.
- BRP: agent who produces the imbalance, and the one who has to pay to restore it.

The activation of these energies is done through the European platform dedicated to RR, as they are cross-border products and managed by the TSO of each country.

The RR offers received by the TSO from the authorised BSPs are made available to the European platform. The BSPs will receive instructions from the TSO in terms of activation of this energy. [64]

The technical requirements for participation in this balancing service are as follows: [63]

- Supply capacity of at least 1 MW.
- Being integrated into the control center accredited by the system operator, responsible for the regulation area.
- Meet the communication requirements including:
  - Structural information.
  - Real time measurements.
- Pass the specific challenges to participate in the aFRR which can be seen in the Procedimientos de Operación 9.

To an aFRR participant, an application has to be sent to REE and the necessary tests have to be carried out.

5.2 Identification of the Applications

Several parts will be necessary for the realisation of the project:

- Analysis of EV's current data and its ability to provide a balancing service to the grid, firstly by meeting the technical conditions necessary to participate and secondly by passing the necessary tests imposed by the TSO when applying to become a BSP.

- A pilot project: it will be a simple project that fulfils the necessary functions to carry out this service in a small area of the peninsula. The chosen area will be the Community of Madrid as it is the city with the most EVs and the most charging points available.

- Final project: once the pilot project has been successfully tested, the final project, which is much more complex and much more scalable, will be implemented, initially at the national level.

The analysis of the actual data of the EV was done in section 2.1.3.3 and according to the data provided there, the EV fleet in Spain currently totals approximately 88,000 and we will classify public access charging stations into two main groups:

- Low power: chargers with a power of less than 22 kW.
- High power: chargers with a power of more than 22 kW.

There are currently around 5,000 low-power charging points and 2,000 high-power charging points in Spain, with an average of three connectors, bringing the total number of connectors to 21,000.

As explained in section 2.1.3.3 which describes in detail all the types of electric chargers, to give an idea of the calculations, an average charging time of 10 kW for low-power chargers and an average of 50 kW for high-power chargers.

Low power chargers take on average around 6 hours to fully charge the vehicle while high power chargers take around 1 hour on average.

To make the necessary predictions to estimate the feasibility of the project, a prediction will be made in an unfavourable scenario. For this purpose, the following case is presented:

- Only 1% of EVs are charged at any one time, which would leave around 1000 EVs, or approximately 5% of all total charging points.

- Taking this into account, and putting an average load at 22 kW would leave us with an instantaneous consumption of around 22 MW, which exceeds the established minimum of 1 MW to be able to apply for participation in the balancing service.

- In Madrid there are 2,400 connectors, which represents a percentage of more than 10% of all connectors in Spain, following the line of the previous calculations, this means an instantaneous consumption of more than 2 MW, in the most unfavourable case, which is still above the minimum established per area to apply for participation in the balancing service. [65]

This leads to the conclusion that a pilot project could be carried out in Madrid to analyse the feasibility of the project.

5.3 Analysis and Comparison of the Different Blockchain Technologies

The operation of the platform will be divided into two distinct parts, as we have two types of transactions and associated information.

The first, energy need transactions dedicated to the grid balancing service managed by the TSO and the associated payments to be made to the BSP.

The second, transactions between the BSP and the EVs that will include monetary transactions, dedicated to the payment of EV owners for their service and registration, activation and deactivation of EVs in the balancing service.

Both networks will be interlinked with each other.

As these two groups of transactions have very different technical needs, it has been decided to have two blockchain networks, one for each type of transaction.

- The first blockchain network will be dedicated to managing the information associated with the energy transitions necessary for the balancing service and payment to the BSPs by the TSO. The TSO, DSO, BSP and EV will be involved and this network will have the following requirements:

    - High Transaction Speed or Latency: the notifications must be sent almost immediately to start providing the balancing service.

    - High Security: must be secure to not be corrupted or hacked and send fake information that may slow the balancing process.

    - Public permissioned or Private, if possible: the TSO is the one in charge of sending the notifications to the DSOs and the BSPs

- The second blockchain network will be dedicated to communication between BSPs and EVs. This network will manage the availability of EVs for the balancing service and the payment of the BSPs to the EVs for participating. This second network has the following technical requirements:

    - Medium / Low Transaction Speed or Latency: the main transactions are, availability of the EV, and payments for the service which can be made weekly or monthly.

    - High Security: high sensitive information regarding the EV and the owners' personal information such as the location of the EV or the house of the owner, monetary transactions and all the information involved in that process.

    - Private if possible: all the EVs available can participate in this service if they can pass the requirements needed.

Although they have different technical aspects, there are parts in which they have points in common, such as the following requirements:

- Handle with a high number of users and information associated with them and to the transactions.
- Low transaction cost, as there will be a big amount of them each day.
- Smart contracts: this will be necessary for the payments and to activate or deactivate the balancing service.

PARAMETERS	Ethereum	Energy Web Chain	Hyperledger
Governance	Ethereum Developers	Energy Web Foundation	Linux Foundation
Purpose	General Applications	Energy Applications	General Applications
Cryptocurrency Associated	Ether	Energy Web Tokens	Not necessary
Network	Public	Public	Private
Consensus Alg.	PoW, soon it will change to PoS	PoA	PFBT
Latency	Medium (10 transactions per second)	Medium (30 transaction per second)	High (3.000-20.000 transactions per second)
Transaction Fees	High	Low	Zero if private or permissioned
Smart Contracts	Yes	Yes	Yes
Electricity Projects Already Developed	Power Ledger and Grid+	Electron and EW Origin	Tennet and Energy Blockchain Labs

Figure 41. Comparative overview of the three blockchain which may be suitable options for the project. Source: Self Elaboration.

After explaining the different types of blockchain networks, we proceed to explain the selection of the networks that will form the platform.

Firstly, no network with a pure PoW consensus algorithm is included (Ethereum has been included due to its incoming change to PoS), as this type of consensus algorithm has a very high energy consumption and one of the objectives of this project is to reduce consumption and emissions, which would be an obvious contradiction.

On the other hand, Ethereum has a high cost per transaction, so for the moment it would also be discarded since another of the objectives of this project is to make it economically viable, in addition to the cost per transaction, the development of the platform with the future PoS algorithm would also be more expensive and less efficient, despite this, in Ethereum private networks can be written on the public Ethereum network with other consensus algorithms, but due to the high cost of this platform compared to the others, we will not focus on the last two options:

- Hyperledger: the first blockchain network, explained in this section, will be developed with Hyperledger Fabric, and will be a private permissioned network managed by the TSO, with the TSO acting as the validating node. Hyperledger has been chosen because it allows a large number of transactions per second, which will be necessary for the TSO to communicate network imbalances to the different BSPs at any given moment. Another reason why it has been chosen is because it allows a private network to be managed.

- Energy Web Chain: EWC is very similar to Ethereum in terms of development platform, which will allow a private layer to be written on top of the main public network. The second network, largely dedicated to communication between BSPs and EVs, will in turn be a permissive private network, and to access the network, the requirements established by law will have to be met. Once inside, unlike the first, there will be a more decentralised character in which BSPs will be able to act as validating nodes of the network.

Due to the need to keep certain information private, such as bank details or the TSO's own data, while some of the information has to be public, such as bids or the power that an EV can provide to the balance service, both networks perfectly match the attributes of a private permissioned network, which is why this type of network has been chosen for the two blockchains.

This type of network requires designated validator nodes, which in our case will be the TSO for Blockchain 1, and the BSPs for Blockchain 2. These Blockchains will be in charge not only of validating the network, but also of moderating it and introducing various necessary changes, whether for regulatory or innovation purposes.

Another benefit of this type of network is its ability to keep information private to the majority of the network, leaving access only to some nodes that have special permissions, which is a great advantage when it comes to being audited or reviewing transactions.

The consensus algorithm which is going to be used in both of the Private Permissioned Blockchain it is going to be Proof of Authority (PoA) [66], and the reason are explained below.

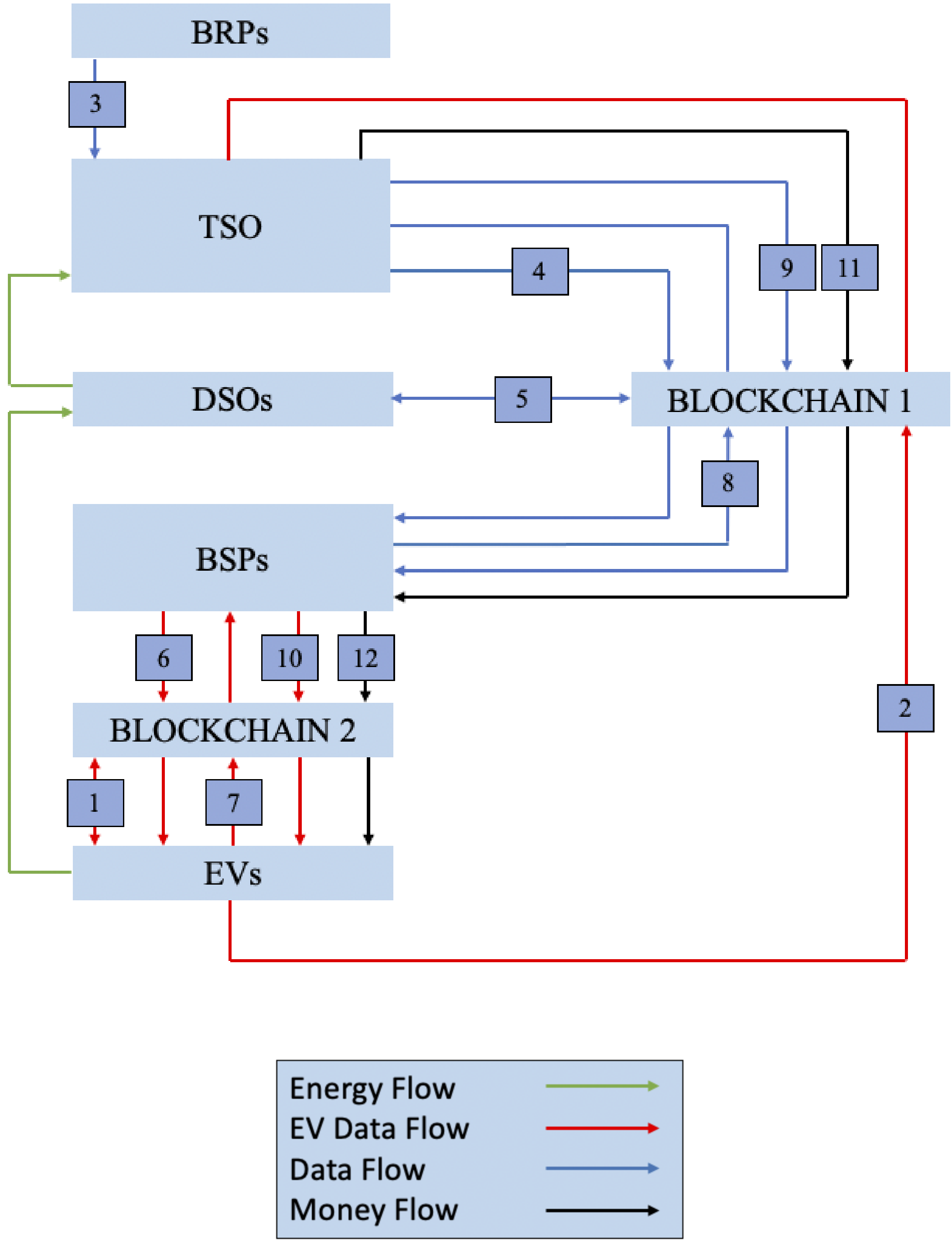
Advantages	**Explanation**
Closed Ecosystem	The participant should not worry about the security of the data because they are procteted from the outside
Protection to Attacks	All the integrants are know, therefore it does not make sense to make an attack because it will be very easy to track the attacker
Privacy	The high sensitive information will be private to the vast majority of the net, only being available to the full nodes, which will use it to improve the net.
Efficient	Using PoA, will end up in a cheaper developed platform whit a higher transaction speed
Low Transaction Cost	As it is going to be a private blockchain, the transaction cost it is nearly zero because the nodes are not going to get lucrative for it
Rewrite the Rules	If necessary, changes can be applied in order to improve the net, it is very easy to do and it will not rewrite the previous blocks

Figure 42. Overview of the advantages of using a private permisioned blockchain using PoA as consensus. Source: Self Elaboration

5.4 Interaction Between the Main Parties Involved

In this section, the interactions between the various agents involved in the process will be explained graphically.

The agents involved in the process are the following: TSO, DSOs, BRPs, BSPs, EVs, Blockchain 1, Blockchain 2. Their relationship will be explain in the *Figure 43*, which is comformed by a flow diagram of the energy, data, EV data and money and an explanation of each step.



1. EV qualification and validation to participate and contract with the BSP
2. Registration of the EVs in the Blockchain Platform and notification of it to the TSO
3. An Imbalanced is produced by the BRP
4. A bid is notified by the TSO to the the BSPs through the Blockchain
5. TSO communicates with the DSO to ask for the constraints of the grid
6. BSPs communicate through the platform to the EV to start the process
7. The whole balancing power of the EV is meassured individually
8. The BSPs communicate their total meassurements to the TSO
9. The Balancing has finished, the TSO communicates with the BSP
10. The BSPs communicate with the EV to deactivate
11. The TSO calculates the reward and pays the BSPs
12. The BSPs pay each owner of the EVs for the service (weekly, monthly)

Figure 43. Flow diagram of the Crowd-Balancing platform regarding the relation between all the parties involved: Source: Self Elaboration.

5.5 Considerations of the proposed application

Based on the analysis in section 5, the following conclusions can be drawn:

- The project adds value to the system as it increases the number of participants in the balancing market and allows energy storage in EVs.

- It meets the regulation requirements to participate in the balancing market as a low percentage of EVs participate.

- The project can be potentially used for aFRR and for RR which increases the potential revenue and support provided.

- A smaller pilot project needs to be carried out first to verify the proposal.

- The platform structure will consist of two blockchain networks, both using PoA as the consensus algorithm.

- It makes sense to use blockchain technology as it requires high encryption security for transactions, transaction validation nodes to avoid fraud, a medium/high transaction rate supported by this network and smart contracts for e.g. payments to electric vehicle owners. The Platform will include to Blockchain network one developed with Hyperledger and the other one developed with Energy Web Chain, the reasons are explained in the 5.3 section.

6. Identified potential barriers

The proposed project has potential barriers of different nature: technological, regulatory and economic. These barriers are described below.

6.1.1 Technological

6.1.1.1. Blockchain

As blockchain is a technology in the process of development, it has many areas in which to improve and certain aspects that may pose a barrier to the development of a project as large as the one described above.

The main barriers that the project may face are:

- High computational power consumptions requirements, because of the validation process.

- The scalability, is one of the main problems to be solved on blockchain, as it is difficult to develop an application with a high number of users and a high number of transactions per second.

- For high data storage, the platform should store many data from the different agents to do the process correctly.

- Non-user friendly interface and lack of developers, as it is in an early stage of development. Blockchain does not have as many developers as other programming interfaces may have.

6.1.1.2. Electric Vehicles

Electric vehicles, despite their exponentially increasing market integration, have still some disadvantages compared to conventional vehicles. These include the following:

- Less autonomy than conventional vehicles.

- Less number of charging points than the number of gas stations.

- High charging time compared to refuel.

- High number of different types of chargers.

Besides, the EVs need to be equipped with energy boxes capable of measure energy used for balancing services and automatically activate the provision of such services. These energy boxes need to communicate with the Blockchain platform.

6.1.2 Regulation

6.1.2.1. Blockchain

For similar reasons to those mentioned in the idenfifed technological barriers, being a developing technology, its regulation is unclear and very dynamic, i.e. it varies over time.

No law regulates this technology in a general way; its regulation will vary depending on the use that is made of the technology.

In the case of this project, which includes a large amount of sensitive data such as bank details and personal data, regulation will be strict and may cause problems when it is implemented.

6.1.2.2. Electric Vehicles and the grid implementation

The use of small devices with charging and discharging capacity, such as electric vehicles or home batteries, to participate in the balance of the grid is very recent and has been little explored for the moment.

For this reason, the regulations concerning this issue are not entirely clear and it can be very cumbersome to find up-to-date information, and like the blockchain, they are dynamic and can change several times a year.

This can jeopardise the development of the project, since, if the conditions change in the middle of the project, it can ruin everything that has been developed so far.

6.1.3 Economics

The economic barrier in relation to this project will be particularly relevant for several reasons.

The main reason is the development of the blockchain platform and its implementation, due to the combination of these factors: the lack of developers, the high cost of implementation and the dimensions of the project mean that the initial investment is high, apart from the initial investment, smaller investments will have to be made from time to time to optimise the platform and maintain it.

Another economic barrier concerns electric vehicles, and the main thing that the project will have to deal with:

- High cost in comparison with conventional vehicles.
- Installation of new charging points.
    - Private: involves the potential customer of EV.
    - Public: involves the State, in this case Spain.

Finally, another economic barrier that the project will face, although the most obvious, is the economic viability of the project itself.

This is to explain that the market in which we are going to try to enter is a market with high competition that uses already developed and optimised technologies, which can make it difficult to obtain continued economic profitability if the project is not developed correctly, if there are no subsidies or if the numbers are not in line and it is more expensive to develop it than the potential benefits. Therefore, a cost-benefit analysis is needed to be developed considering the potential revenues and the costs of the system.

Despite being an innovative and necessary idea, it is still a business and it will be difficult, if not impossible, to get investors if the project is not profitable.

7. Conclusions

The reduction of emissions in the electricity market is one of the biggest challenges in this sector today.

There are very ambitious medium-term objectives explained throughout the project. On the other hand, the growing integration of renewable energies creates the need to design new ideas to facilitate grid balancing, which is so difficult for these energies, due to their lack of constancy associated with dependence on weather conditions.

This is why this project is being developed, which proposes to take advantage of the EV charging process by using them as balancing agents, thus providing greater response capacity in the event of an imbalance. This will incentivise the use of EVs compared to conventional ones and reduce emissions in this sector, as you can make your EV profitable when you are not using it and you can be part of the decarbonisation of the electricity sector.

This project is based on a digital platform that is based on two Blockchain networks, the first to manage the information involved in energy flows necessary to help balance the grid and the second is dedicated to the communication of the BSPs with the EVs.

This separation is made because the needs of each network are different and therefore their parameters will also be different.

The two selected Blockchains are both private permissioned Blockchains. The first one is developed using Hyperledger Fabric and the second one using Energy Web Chain (EWC). Although both are private permissioned, the second one will have a more decentralised character associated with EVs.

The consensus algorithm integrated in both networks is Proof of Authority (PoA), due to the fact that the validation of transactions needs to be carried out by a reduced number of nodes and assigned by the agents involved in the process, since the information processed is sensitive and this avoids information leaks.

To reach this point, various types of Blockchain and consensus algorithms have been analysed. By means of the analysis and comparative tables, the aforementioned have been chosen as they are the ones that best adapt to the needs of the project.

A proposal has been developed in which the relationships between the various agents involved in the process are explained by means of energy, data and money flow diagrams.

Throughout the project and due to the size of the electricity market and the novelty of the technologies under development that are to be introduced in this proposal, certain barriers have arisen: technological, economic and regulatory barriers that the project will have to face.

For each barrier detected, the corresponding solution has been proposed which, in our opinion, was the most suitable.

Finally, it should be said that this project if implemented can potentially adds value, as it increases the number of participant in the balancing market by allowing energy storage in the EV batteries in a very ecofriendly way and creates a possible side hustle to the EV owners.

8. Future Outlines

This project can be used as a basis for further research and development on the implementation of Crowd Balancing Platforms (CBP), because it is a very new and little exploited project, it opens up a wide range of possibilities to continue in this line.

The main directions to pursue proposed by the author are the following:

- Development of the blockchain platform and programming it or a pilot project of the same with the data set out of this project as a guide.

- Development and research of new elements that can serve as participants in the balance of the network for example home batteries, how they work and how they can help together with the EV or just by themselves.

- A detailed economic study of the possible project, regarding all the costs the project may incur and the main revenue streams to analyse the profitability of it.

- Study and development of a CBP in another country taking into account the change in regulations and the way the electricity market is operated.

- Study and investigation of possible improvements to EV batteries to take into account their use as a participant in grid balancing.

- Adaptation and development of the present project for implementation at the European level and analysis of the possible barriers that the project would face and their possible solutions.

- Analyse in greater depth the regulations associated with the project and propose a solution for each of them.

- Communication between DSO and TSO, and a proposal on how it can be improved to maximise the efficiency of the energy transmission and reducing the costs associated with them.

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10. Appendix

10.1 Alignment with the Sustainable Development Goals (SDGs)

Due to the very nature of this project, which consists of optimising resources and achieving an efficient solution to facilitate the implementation of renewable energies, with the instability that this entails for the grid. Therefore, of the 17 SDGs, the ones that most closely align with this project are the following:

- Affordable and non-polluting energy (7): it favours the use of renewable energies by implementing a solution that will allow a better balancing of the grid, using Electric Vehicles, which are much less polluting than conventional ones.

- Sustainable cities and communities (12): this objective is achieved through the use of electric vehicles, which are less polluting and favour the use of renewable energies.

- Climate action (13): the implementation of this project helps to fulfil the energy transition and emissions reduction plans as it favours the use of Electric Vehicles through economic reward (reward for participating in the balancing of the grid) and environmental sustainability (favouring the inclusion of renewable energies by helping to balance the grid).

- Partnership to achieve the targets (17): through the use of Electric Vehicles and facilitating the use of renewable energy on a medium/large scale will contribute to meeting the objectives of the PNIEC 2030 and Climate Neutral Europe by 2050.