UNIVERSIDAD PONTIFICIA COMILLAS

**ESCUELA TÉCNICA SUPERIOR DE INGENIERÍA (ICAI)**

OFFICIAL MASTER'S DEGREE IN THE ELECTRIC POWER INDUSTRY

Master's Thesis

# REGULATION CHALLENGES FOR BATTERIES AND COST-EFFECTIVENESS ANALYSIS

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**Co-Supervisor:**

**Madrid, 28th June 2018**

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# I. Summary

In the near future scenario of decarbonization, electrification of the economy and increase in urban population, the provision of flexibility will be key for the evolution of the power sector functioning. Lowering prices in energy storage solutions and the evolution of communication technologies are opening new business opportunities for the power sector industry. There is a need for both private and public stakeholders to understand the energy storage options, the possible opportunities they can offer and the main challenges they have to face.

This report will try to provide answers on (i) the state of the art, a comparison of storage technologies, the services they can provide, the business models that can be built and the main regulatory challenges they have to face; (ii) how to analyze a regulatory framework to identify aspects that facilitate the development of energy storage and how to apply it to leading markets such as USA, the EU, Germany, UK, California and New York State; and (iii) present a cost-effectiveness analysis with real parameters of an hypothetical battery connected to a windfarm in Spain.

The results present how energy storage performance in the electricity sector can be analyzed in based on three key aspects: (i) speed of discharge, (ii) energy capacity and (iii) round-trip efficiency. From a technical point of view, Li-Ion batteries, show very good performance thanks to their modularity, high energy density (~200Wh/l), fast response (<1sec) and efficiencies of 95%, being able to provide balance services for the network, firm capacity and arbitrage opportunities for the integration of renewable energy, and small-size services to end consumer. Pushed by the research in the electronics sector and the growth on the electric vehicle industry, Li-Ion batteries are expected to reduce their costs by 50% in the next ten years and increase their energy densities up to 10 times from current values.

Main regulatory barriers for energy storage can be classified in three groups: (i) the existence of a clear definition in the regulation, so it can be treated in a non-discriminatory way and subject to appropriate fees and benefits, (ii) the adaptation of wholesale, reserve and balancing markets to shorter settlement periods, integrating the constraints such as state of charge and rewarding its fast speed response capability, and (iii) the public support of the industry by creating financing programs, research, reference standards and targets. The USA is leading regulatory measures to integrate storage in their markets with the recently approved FERC Order 841 and with the specific targets and financing programs the States are developing. The EU is seeking full integration of storage technologies in power markets through the approval of the “Clean Energy for All Europeans” Package, with Germany and the UK leading the path either benefiting storage with incentives for renewables, creating specifically tailored products or including them in capacity auctions. The remuneration of FCR has been key for the utility level battery development in these regions.

Finally, the cost-effectiveness case developed for Sierra Moncayo in Spain shows that under current operation hypothesis, the installation would not be profitable. Nevertheless, the exercise shows the need of stacking revenues from different sources is necessary to justify large storage investments, the lack of attractiveness in secondary regulation participation, the constraints the state of charge impose and the still need of financing support for new projects.

# II. Table of Contents

# III. Introduction

In the last few years, many studies addressing energy storage technologies have been released by the power sector industry and the main public stakeholders. There is a need in the sector to understand the challenges that the upcoming power sector scenario is bringing and what opportunities can storage technologies provide. The diversity of storage technologies and the large number of possible services they can provide to the power sector make it difficult to understand and to correctly assess regulation approaches and cost-effectiveness judgements.

This report will have the following objectives:

- Gather existing information on storage technologies in a comprehensive way and clarify the business opportunities that can be built with them.
- Identify main regulatory barriers to the development of energy storage technologies and create a methodology to assess how countries are supporting them.
- Understand the functioning of markets leading storage deployment and identify the reasons for its success.
- Simulate the functioning of a battery and develop a cost-effectiveness analysis with real information of the industry, assessing the profitability of a particular business case.

The report will be structured in three sections:

- Section A: analyzing state of the art, and identifying main opportunities and challenges.
- Section B: assessing regulatory frameworks and analyzing leader markets for storage.
- Section C: developing a cost-effectiveness analysis of a real business-case for a battery connected to a wind farm power plant.

At the end of the report, global conclusions will be presented.

# IV. Section A: The situation of batteries in the power sector

# 1 Summary of Section A.

The energy sector is experiencing a deep transformation pushed by the global de-carbonization initiative, the electrification of the economy and the increase in urban population. This trend is bringing with it challenges related with the increase in not firm renewable sources and the business opportunities that new communication technologies offer. In this environment, the flexibility that storage technologies could bring will be key for a successful transformation of the sector.

Storage technologies can be classified in five big groups depending on the way they store energy, resulting in different energy capacity, power and time response that will define the services they can provide to the power sector. All the technologies are currently benefiting from research programs that are improving their performances and reducing costs, but it is in the group of electrochemical storage (batteries) where economies of scale are opening more opportunities.

Inside this group, pushed by the research in the electronics sector and the growth on the electric vehicle industry, Li-Ion batteries are expected to reduce their costs by 50% in the next ten years, from the current US$587/kWh in 2017 to US$270/kWh, and increase their energy densities up to 10 times from current values of 200 Wh/l. Li-Ion batteries are also promising due to their particular characteristics, since they have quite high energy density, fast response times and are subject to high modularity options. This makes them suitable to provide a wide range of services in the electric sector: balance services for the network, firm capacity and arbitrage opportunities for the integration of renewable energy, and small-size services to end consumer. Other storage technologies such as flywheels and supercapacitors are expected to provide very good performance in specific services, opening further opportunities for hybrid storage systems.

Different business models can be defined in the electricity sector using batteries. At least eight can be identified depending on who owns, who operates and who benefits from the revenues of the storage device. Special attention should be paid to those services that open the opportunity to participate in the electricity markets through arbitrage or provision of network services. Nevertheless, the cost-effectiveness of investments in storage facilities are still not clear, causing a lack of track record and experience that still influences the risk perception of investors. On the other hand, and while costs are reducing fast, regulatory challenges are considered the most important barrier to batteries development, particularly related to two aspects: the difficulty to create an asset definition that fits in the sector's operability, and the recognition of particular technical characteristics in the access and remuneration schemes of markets.

# 2 Trends in the energy sector

## 2.1 General global trends

The energy sector is currently experiencing a deep transformation led by three main processes: (i) global de-carbonization objectives, (ii) electrification of the economy and (iii) population concentrating in urban areas.

**Global de-carbonization.** On December the 12th 2015, the UNFCCC countries[i] met in Paris and reached an agreement to combat climate change and to accelerate and intensify the actions and investments needed for a sustainable low carbon future. This agreement main aim is to keep the rise of temperature well below 2 degrees Celsius during the next century compared with pre-industrial levels, which would imply seeking atmospheric concentrations of GHG in the range of 450 ppm of $CO_{2eq}$.[1] The agreement will make finance flows consistent with actions preventing climate change, promoting technology transfers and the adoption of adaptation measures. Signatory countries should deliver, and update every five years, their Intended National Determined Contribution (INDC) stablishing targets and domestic measures to reduce emissions. The European Union is expected to seek a reduction of at least 4.7 tones of CO2 per capita and the member states' common INDC stablishes a binding target of 40% reduction in GHG emissions by 2030 compared with 1990.[ii] Taking into account that the energy and heat production activities are responsible for the 25% of direct GHG emissions, this will be one of the most affected sectors.

*Figure 1: Greenhouse emissions per sector, Linares (2018)*

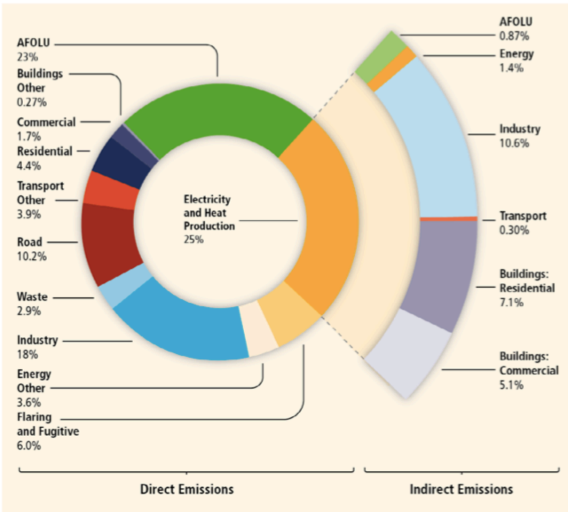
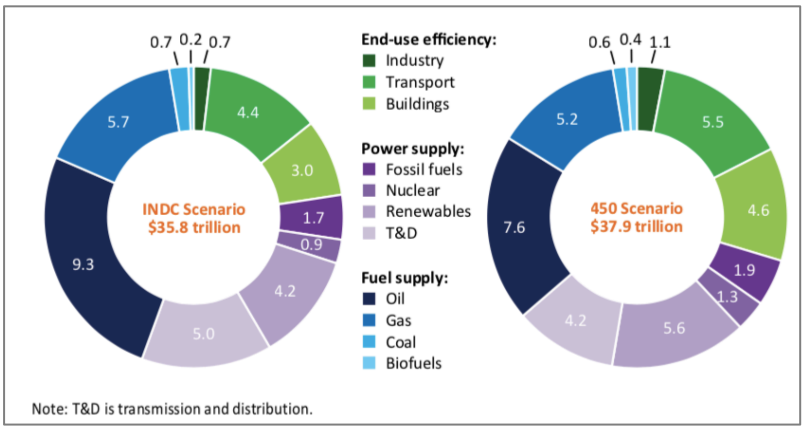
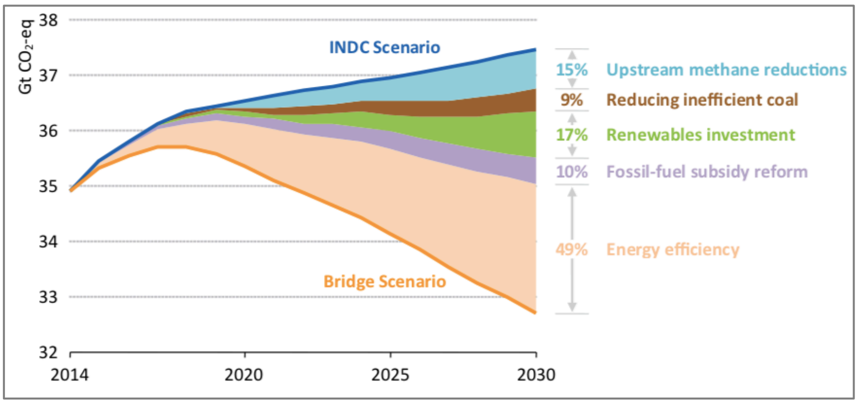



*Figure 2: Cumulative global energy sector investments by sector in 450 and INDC scenarios 2015-2030, IEA.*



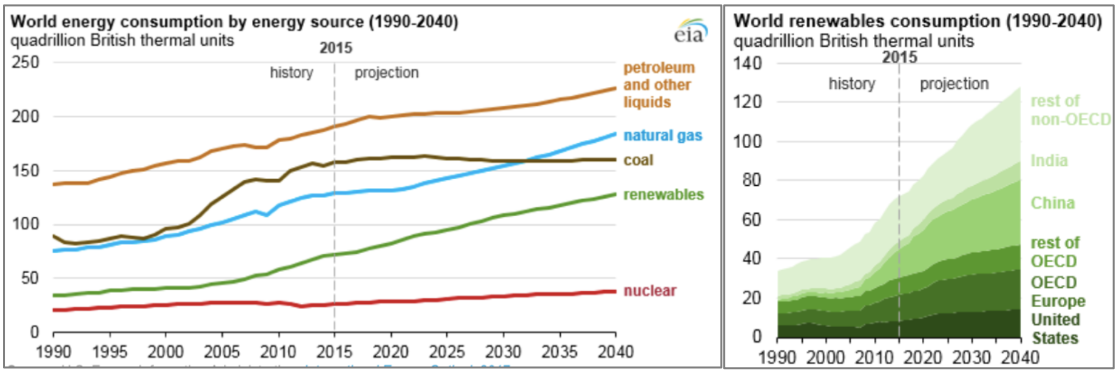

[1] *The ideal scenario proposed by the Paris Agreement is so called the "450 Scenario" which is compared with the "INDC Scenario" based on the received commitments by countries.*

*Figure 3: Global energy-related GHG emissions reduction by policy measure in the Bridge Scenario relative to the INDC Scenario, IEA.*



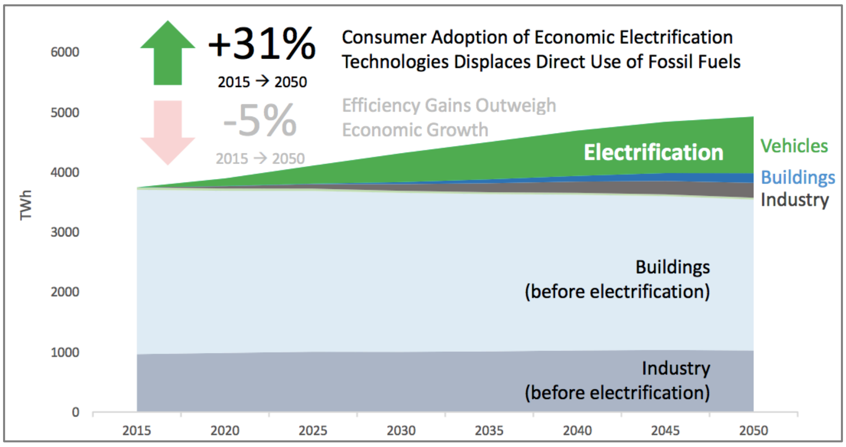

The de-carbonization trend is bringing with it the insertion of renewable generation capacity in the power sector. The IEA projections expect an expansion of 920GW in global renewable energy generation, an increase of 43% compared with current values., posing important challenges for the correct balancing of generation and demand.

*Figure 4:Projections in world energy consumption, EIA (2017)*



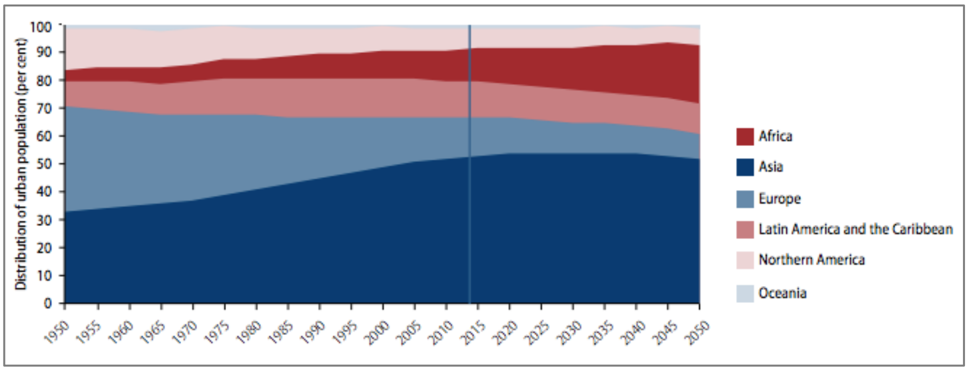

**Electrification of the economy**: in the following years it is expected an important electrification of the overall economy, and in particular, of the transportation sector that will displace direct use of fossil fuels. This trend will increase electricity demand from 18% share of current energy demand to 29% in 2040, something that will come together with the expected increase of energy demand of 60% by 2040, reaching 38,000 TWh globally.[iii]

*Figure 5: Load growth driven by electrification in the US, EPRI (2017)[iv]*



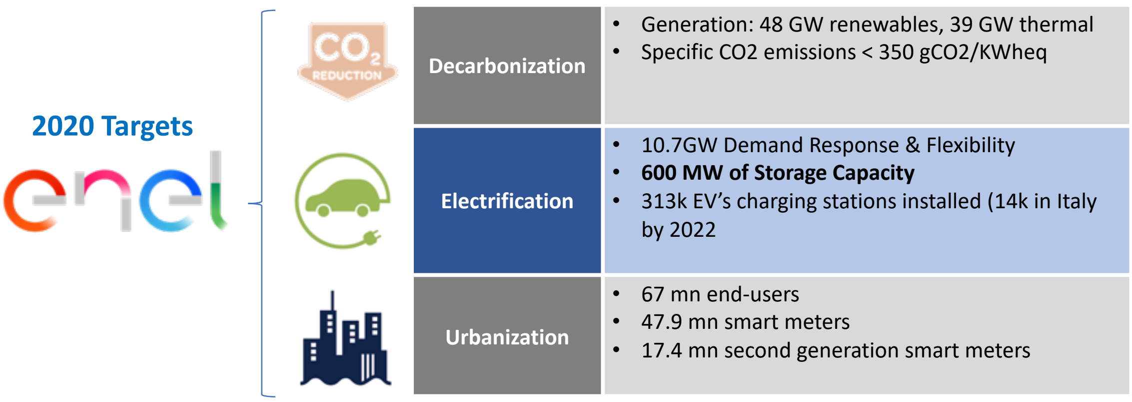
**Urbanization of the population**: It is expected that by 2050 more than 6.3 billion people will live in urban areas globally, what would mean 66% of total population, a share that could reach 85% of urbanization rate in developed countries[v]. This will influence the energy sector requiring more resilient and smart cities and a big effort from public institutions to guarantee that the urban growth implies equitable and sustainable energy access.

*Figure 6: evolution of the distribution of urban population, United Nations (2014)*




These changes are driving the global utilities business strategies towards two main key objectives: (i) digitalization and the importance of data management and (ii) increased focus on the costumer and on shared value activities.

*Figure 7: Enel, 2018-2020 Strategic Plan*

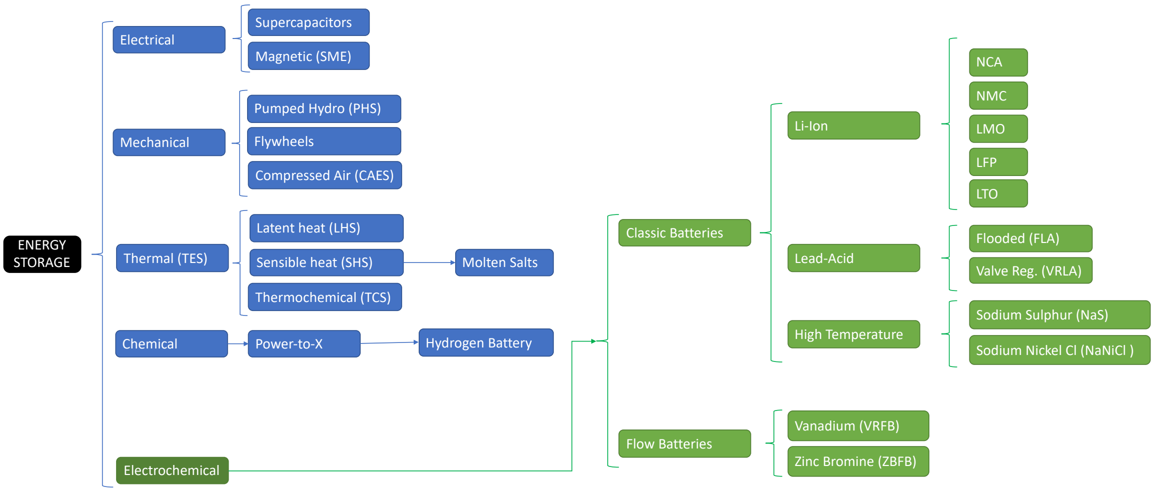



# 3 Energy Storage technologies

Energy storage technologies can be classified according to the way they store energy in five family groups[2]: (i) electrical, (ii) mechanical, (iii) thermal, (iv) chemical and (v) electrochemical, being the latter family where batteries are located.

[2] *Classification followed by the European Storage Association*

*Figure 8: Classification of Energy Storage Technologies*




## 3.1 Electrical Storage.

They store energy in electrons. There are two groups in this family: (i) Supercapacitors, which store energy in the electrostatic field between two electrodes and (ii) Superconducting magnetic Energy Storage (SMEs), which store energy in the magnetic field of a coil. They provide high power and efficiency levels, fast reaction times but low energy capacity.

Supercapacitors store electrical charge at a surface-electrolyte interface of high-surface-area carbon electrodes and they can be classified in symmetric and asymmetric, with different properties suitable for different applications. They have very high specific power rates (10-20kW/kg) but low energy density (less 8 Wh/kg). A new developing technology, the **LCAP** (lithium-ion Capacitor), is seeking to improve this drawback. Supercapacitors provide fast responses, high efficiency, high energy density and long lifetime, making them very attractive for large scale application on the grid.

SMEs also provide very good performances and extremely long lifetimes, but their construction still relies on superconductors that require low temperatures for working.

## 3.2 Mechanical Storage.

They store energy in physical principles such as the potential energy of water, the pressure of compressed air or de inertia of rotation of a wheel. Depending on this, different groups can be found in this family, particularly:

(i) pumped hydro (PHS): making use of two vertically separated water reservoirs, water is pumped from the lower to the higher one when there is a low cost of electricity and then it is run as a conventional hydro power plant during high electricity cost period.

(ii) Fly wheels: composed by mechanical devices that spin at high speeds (up to 60,000 RPM), they store electricity as rotational energy, which is then released by decelerating the flywheel's rotor and resulting in quick bursts of energy.

(iii) compressed air energy storage (CAES): this technology uses electricity to store compressed air into confined spaces, which can be then released to drive the compressor of a natural gas turbine.

Mechanical technologies have good performances to provide grid services and support RE integration, but they still have to face some challenges in the market: CAES has low energy efficiency of around 65% and flywheels have high power, but low energy compared with other storage technologies. PHS is a mature technology, widely used in Europe, that has proven to be the most efficient and flexible large-scale energy storage technology, nevertheless it still has an important geographic limitation and it is dependent on the availability of the water resource.

## 3.3 Thermal Storage (TES).

These technologies, also known as TES, store energy in the form of heat. Three main groups are in this family: (i) latent heat storage, LHS; (ii) sensible heat storage, SHS; and (iii) thermochemical, TCS. The most common TES is SHS with molten salts.

## 3.4 Chemical Storage

They store energy in the form of potential chemical reactions of particular materials, either in gas, liquid or solid form.

In this group it can be found the **Power-to-X** technologies, which transform low-carbon electricity into a gas or liquefied gas through electrolysis (hydrogen or a synthetization of it with $CO_2$ such as ammonia). Hydrogen can store energy in the long-term, and then be then burnt, producing water vapor as waste and energy that can be used in mobile or stationary applications. However, its low volumetric density requires high compression for liquefaction. In order to increase the energy density, hydrogen can be used to create synthetic fuels in the form of ammonia or methane.

Chemical storage provides high energy densities and easy transport and storage options, creating cross-sectorial convergence with other energy sectors such as gas. Due to its characteristics, it can be used for seasonal storage, indirect electrification of the transportation industry or to create "hydrogen batteries" to support RE integration, operate energy arbitrage or to provide ancillary services[3] to the grid.

Although Power-to-X are promising technologies for storage, there are still important challenges to overcome related with costs, efficiency and energy density. Some countries are making efforts to support this technology, with two development programs that can be highlighted: the German Kopernikus P2X programme and the US Energy ARPA-E Refuel Programme.

## 3.5 Electrochemical (Batteries)

They store energy in chemical reactions that create electrical currents. This family includes batteries, which are formed by a container ("the cell") having inside two electrodes (an anode and a cathode), an electrolyte material (liquid or solid), a and a separator to prevent short contact between the electrodes. By a process of oxidation-reduction of the electrolyte and the electrodes, current is created. Several cells can then be packed in series for higher voltages and in parallel for increased power outputs.

Depending on the materials used in the battery's elements and the way they interact among each other, batteries can be classified in two main groups: (i) classic batteries, mainly Lead-Acid, Li-Ion and NaS; and (ii) flow batteries, mainly Vanadium Redox.

Depending on their use, rechargeable batteries can be classified on five groups: (i) portable: size of less than 6Ah and usually Li-Ion (ii) industrial: size larger than 6Ah and usually lead-based, (iii) Starting-Lighting-Ignition: mainly for automobiles and usually lead-acid (iv) mobility: for electric vehicles and mainly Li-Ion; and (v) power grid, to provide services to the grid and integrate RE, mainly Li-Ion and flow batteries.

Batteries provide high modularity and fast reaction, which make them suitable for decentralized applications in the distribution grid. Classical batteries still have to face challenges such as high LCOE values, limited life cycles and long-term storage ability while flow batteries present better performances but lack a market to create enough economies of scale to drive prices down.

### *Lithium-ion batteries.*

Lithium based batteries can be group according to the type of anode (Li-metal or Li-ion) and the type of electrolyte (Liquid or Polymer). The most common ones in the energy industry are the ones with an Li-ion anode and a Li-ion liquid electrolyte. These batteries exchange lithium ions (Li+) between the cathode (+), usually graphite, and the anode (-), usually a lithium metal oxide ($LiMEO_2$).

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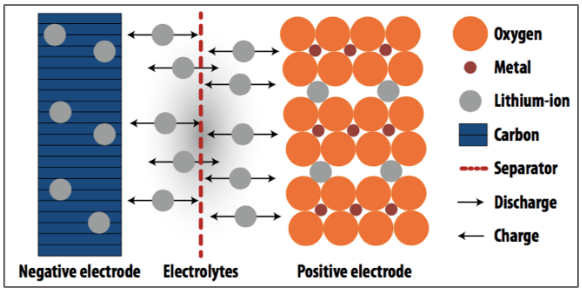
[3] *Electrolysers have the ability to react within a second or less to changes in te electricity supply/ demand (EASE, 2017)*

*Figure 9: Components and operation of a classic Li-Ion battery (ISEA, 2012)*




In general, Li-ion batteries present very high energy and power densities, fast discharge response and very good round-trip efficiency, while, on the other hand, they all need integrated thermal management to avoid reduction of lifetime[4] and eventual dangerous chemical reactions due to overheating. Nevertheless, specific characteristics can be obtained depending on the composition of the anode and the cathode, emerging this way the group of the most common Li-ion batteries in the market: NMC, LMO, NCA, FP and LTO. There different properties can be compared in the table below.

*Table 1: comparison of most common Li-Ion batteries technologies, IRENA 2017*

| Key active material | lithium nickel manganese cobalt oxide | lithium manganese oxide | lithium nickel cobalt aluminium | lithium iron phosphate | lithium titanate |
|---|---|---|---|---|---|
| Technology short name | NMC | LMO | NCA | LFP | LTO |
| Cathode | $LiNi_xMn_yCo_{1-x-y}O_2$ | $LiMn_2O_4$ (spinel) | $LiNiCoAlO_2$ | $LiFePO_4$ | variable |
| Anode | C (graphite) | C (graphite) | C (graphite) | C (graphite) | $Li_4Ti_5O_{12}$ |
| Safety | | | | | |
| Power density | | | | | |
| Energy denisty | | | | | |
| Cell costs advantage | | | | | |
| Lifetime | | | | | |
| BES system performance | | | | | |
| Advantages | -good properties combination<br>-can be tailored for high power or high energy<br>-stable thermal profile<br>-can operate at high voltages | -low cost due to manganese abundance<br>-very good thermal stability<br>-very good power capability | -very good energy and good power capability<br>-good cycle life in newer systems<br>-long storage calendar life | -very good thermal stability<br>-very good cycle life<br>-very good power capability<br>-low costs | -very good thermal stability<br>-long cycle lifetime<br>-high rate discharge capability<br>-no solid electrolyte interphase issues |
| Disadvantages | -patent issues in some countries | -moderate cycle life insufficient for some applications<br>-low energy performance | -moderate charged state thermal stability which can reduce safety<br>-capacity can fade at temperature 40-70°C | -lower energy density due to lower cell voltage | -high cost of titanium<br>-reduced cell voltage<br>-low energy density |

## *Lead-Acid batteries.*

These is the oldest and most widely deployed battery technology. They use lead-base electrodes and liquid Sulphur acid as electrolyte. They can be classified in (i) flooded or vented and (ii) valve regulated or sealed, which are more expensive but more durable. These batteries present low costs with good reliability and roundtrip efficiencies, with an already stablished market. Nevertheless, their energy density, efficiency and lifetime are low compare with other technologies such as Li-Ion.

## *NaS Batteries.*

The sodium sulphur battery presents a cathode made of molten sulfur and a beta-aluminium electrolyte. They are high-temperature batteries that require operating temperatures between 300C and 350C.

They present high energy densities and efficiencies, and they have a high recyclability rate, nevertheless, they still present important safety issues and require complex high temperature

[4] *Every temperature increase of 10C over the design operating temperature lowers the calender lifetime by 50, while below-zero temperatures may lead to severe power loss (IRENA)*

operability. Japan has lead research on this kind of battery for network applications, with a 34MW/245MWh battery already installed at Rokkasho.

*Flow Batteries.*

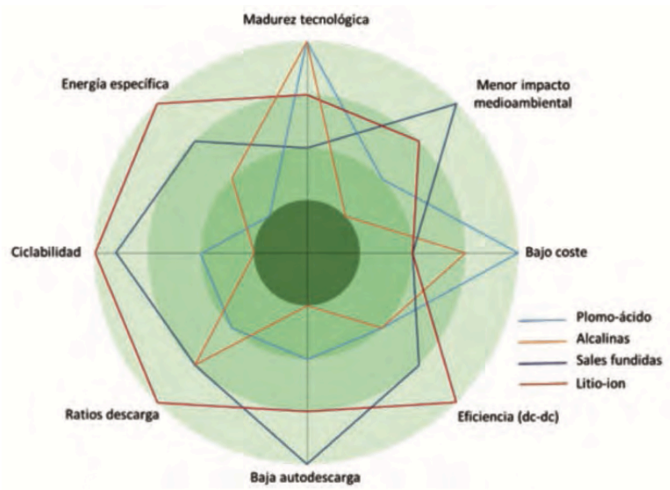
This technology differs from classic batteries in that the electroactive material is not stored within the electrode (as Li+ in the metal) but dissolved in the electrolyte solution. This way, these batteries are composed by two tanks, the anolyte and the catholyte, which pump their content into the cell stack where reaction take place. The most common one is the pure flow Vanadium redox battery.

The disposition of flow batteries, with electrolytes in separated tanks from the cell-stack, decouples the capacity (Watts measured and depending on the electrolytes volume) and the energy (Wh measured and depending on the cell stack's membrane surface), what allows convenient independent power and energy adjustment. They also present high efficiencies and long lifetimes, although their architecture is complex and requires expensive operating management. Research on flow batteries is leading to promising price reduction which some[vi] studies expecting that prices can be from 550US$/kWh to 150 US$/kWh in the next decades.

## 3.6 Comparison of the different energy storage technologies.

As it can be seen, there are a wide range of energy storage technologies with particular characteristics that will define the most suitable application they can be used to. The main characteristics defining storage technologies will be their maximum power, their energy storage capacity, their cyclability the depth of discharge and the time of answer. With these characteristics some services will only be suitable for specific storage technologies while in other situations hybrid systems of several storage technologies can be proposed for optimal operation.

*Figure 10: Qualitative comparison of main classic batteries (Real Academia de Ingenieria, 2017)*



### Table 2: Comparison of characteristics for main energy storage technologies[vii]

| CHARACTERISTICS | UNIT | CHEMICAL | ELECTROCHEMICAL (BATTERIES) | | | | ELECTRICAL | | MECHANICAL | | | THERMAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | HIDROGEN Fuel Cell | LI-ION | FLOW | LEAD-ACID | NaS | SUPERCAPACITORS | SMEs | CAES | PHS | FLYWHEELS | SHS |
| POWER RATES | *MW* | 5kW - 3MW | <100 | 1-75 | 0.01-75 | 0,5-50 | <1 | 0,1-10 | 50-300 | 300-3000 | <20 | 150 |
| ENERGY RATES | *MWh* | - | 0.25-25 | <250 | 0,25-500 | < 200 | - | - | 1000-3500 | 1700-14000 | <5 | - |
| ENERGY DENSITY | *Wh/l* | 32 kWh/kg | 200-735 | 15-70 | 50-100 | 140-300 | 6-20 Wh/kg | - | 2-6 | 0,01-2 | 10-200 | - |
| TIME TO DISCHARGE AT RATED POWER | *s* | - | 0.25-10h<br>1min-8h | 2-5h | 0.25-1h<br>min -8h | 6h | ms-min | s | 8-26h | 6-10h | s | h |
| RESPONSE TIME | *s* | s | < s | s | < s | < s | < s | < s | s-min | s-min | < s<br>10 milisec | min |
| ROUND-TRIP EFFICIENCY | *%* | 8500% | 75-95 | 60-75 | 75-90 | 85-90 | 85-98 | 70-80 | 30-60 | 75-85 | 70-85 | 80-90 |
| CYCLES LIFETIME | *#* | >100K | 1-10K<br>500-20,000 | >10K | 2.2K-4.5K<br>2500 | 1.5K-4.5K<br>5000-10000 | >100K | >100K | 5K-20K<br>50K | 20K-50K<br>20K-100K | >100K<br>>1M | - |
| Capital Cost | *USD/kWh* | 9000 USD/kW | 473-1260 | 315-1680 | 105-475 | 263-735 | 10000 | 2000 USD/kW | 50-90 | 5-100 | 1500-6000 | - |
| KEY ADVANTAGES | | > based on a very abundant material<br>> high energy contect of the H<br>> non-polluting<br>> low performance degradation | > High energy and power density compared with other batteries.<br>> High speed of discharge<br>> Very High round trip efficiency<br>> Long lifetime compared with other batteries<br>> Low self-discharge rate. | > Independent adjustment for energy and power (E/P ratio)<br>> Long lifetime (high cyclabilitilty and low morphological degradation of the electrodes)<br>> relatively good response time | > Good cost-performance ratio compared with other batteries<br>> Already existing market that offers track-record in manufacturing, operation and recycle.<br>> High round trip efficiency<br>> Good temperature performance<br>> Easy to dentify state-of-charge | > Second best battery on energy density<br>> Low discharge rates<br>> Very high recyclability and non-toxic materials<br>> Long lifetime<br>> Mature technology | > Fast Response<br>> Very long lifetime, virtually unlimited<br>> High power and energy density<br>> good efficiency<br>> good performaces at low temperatures | > Fast response<br>> high cyclability<br>> high power ramp | > Flexible scale storage, with the possibility of large scale.<br>> Long periods storage<br>> Low cost<br>> Mature technology<br>> Leverage existing infrastructure of gas turbine technologies. | > very mature technology with track record, operational experience and existing market.<br>> Low O&M cost<br>> High power<br>> Good flexibility<br>> Large scale storage<br>> Long periods storage<br>> Very low self-discharge<br>> Reasinable round-trip efficiency<br>> Long lifetime | > Fast response<br>> Very long lifetime<br>> High power density<br>> Low O&M costs<br>> Easy to identify state of charge (rotational speed)<br>> Important operational experience (motors and industrial sector)<br>> integrated A/C motor | > efficient for calorific energy storage |
| KEY DISADVANTAGES | | > very expensive due to H generation, storage and transport | > High investment costs (until now)<br>> Safety issues that require thermal management (when the cathode overheats, chemical reactions happen releasing oxigen, leading to risk in flamability) | > Low energy density<br>> Relatively low round-trip efficiency compared with other batteries<br>> Complex architecture with moving elements<br>> Safety issues: high risks of leakages<br>> High O&M costs due to complexity in management<br>> High costs of elements such as the membrane or the electrolyte storage vessels. | > environmental impact due to lead toxitcity, with limitations due to regulation in some countries.<br>> Relatively low energy density and heavy.<br>> Relatively low lifetime and risk of sulphation if stored long-term discharged<br>> Relatively low depth of discharge | > They work at high temperatures: they need thermal enclosure and electrical heater that consumes around 3% of rated power at idle<br>> Safety issues: if the ceramic seal breaks, dangerous reactions between molten Na and S can occur | > High Costs<br>> Low energy density<br>> limited energy due to associated electronics<br>> Linear discharge voltage prevents using the full energy spectrum<br>> High self-discharge | > High Cost<br>> Still in experimental phase<br>> Need to keeop coil cool and consequent energy expense<br>> High self-discharge ratio (10%) | > Geographical limitations: requires suitable geology<br>> Very low energy density<br>> Difficulties to module for small size applications<br>> Exposed to natural gas price market. | > Geographical limitations: requires large land use (large footprint), difference in hights.<br>> Resource limitation: depends on water constraints<br>> Low energy density<br>> High investment costs and long construction period | > High cost<br>> Low energy density<br>> High self-discharge (15%)<br>> Risk of failure due to unexpected dynamic loads and external shocks<br>> Security issues due to fast rotating masses and heat generation | > limited to Solar CSP applications |
| MAIN POSSIBLE APPLICATIONS IN THE ELECTRICITY NETWORK | | > Stationay Power<br>> Transportation | > Transmission system support<br>> Peaker replacement<br>> Frequency Regulation<br>> Distribution Services<br>> RE integration<br>> Residential | > Transmission system support<br>> Peaker replacement<br>> Distribution Services<br>> RE integration<br>> Residential | > Transmission system support<br>> Peaker replacement<br>> Distribution Services<br>> RE integration | > Transmission system support<br>> Peaker replacement<br>> Distribution Services<br>> RE integration<br>> Residential | > AASS<br>> RE integration<br>> Combined with Batteries, for the transport sector. | > AASS but in experimental phase | > Transmission system support | > Transmission system support | > Frequency Regulation | > RE CSP solar functioning |

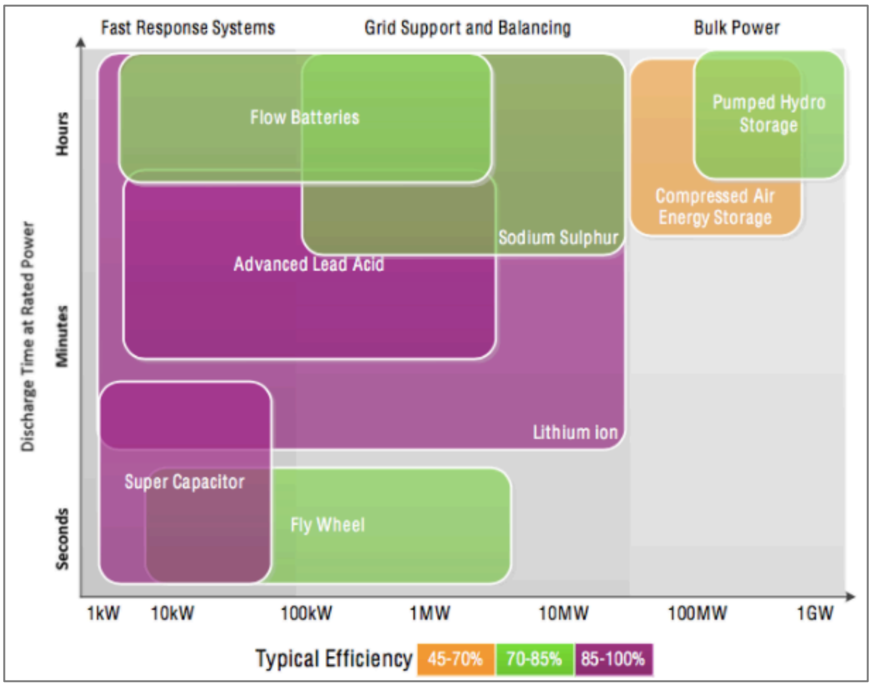
# 4 Definition of business models with storage technologies

## 4.1 Revenues streams: services provided by storage technologies.

Storage technologies can be used in a wide range of applications across the electricity networks. In general terms, most literature classifies these services depending on where the battery is located: "front the meter" (FTM), if the battery is located in the section of the grid owned by an utility or TSO, or "behind the meter" (BTM), if the battery is located on the consumer's property. Nevertheless, the classification of the services provided is far more complex. The battery's characteristics, particularly the speed of discharge time and possible rated power, will determine their possible utilization for service so different such as fast response systems, grid support, balancing, bulk power or demand side management.

The following figure, developed by ARENA, provides a fast view of the possible grid applications the different energy storage technologies can provide according to their characteristics. As it can be seen, Li-Ion battery is the most versatile one, with characteristics that are improving with time pushed by current research activity.

*Figure 11: Storage technologies and their applications to the grid (ARENA, 2017)*




Storage technologies can provide both energy and power in all sections of the power industry: production, transport, distribution, and consumption side, and either in regulated or liberalized environments. The services storage technologies can provide can be classified in five main categories[8]: (i) bulk energy, (ii) generation support, (iii) ancillary services, (iv)network services and (v) demand management:

*Bulk energy.*

The battery can be used to store energy that will be used in the future for direct consumption, a service characterized by requiring large amounts of energy storage and long duration.

- **Back-up security:** the provision of uninterruptible power supply (UPS) is one the basic applications of batteries for those costumers that require reliability of supply, particularly for industrial processes. It is estimated that electricity outages cost USD80 billion annually in the US only.[9]

- **Arbitrage:** the ability of store energy during low electricity prices (low demand, off peak) and use it in high pricing periods. It can be done at consumer level for self-consumption at high prices periods or at wholesale level, in order to be traded in the market during high period prices as a substitution of the so-called peaker generation.
- **Long term energy storage:** This service provides storage of energy for long periods, usually seasonal, such as thermal energy store in summer to be used in winter. It can be seen also as a direct substitution of fossil fuel energy storage.

*Generation support.*

The drawbacks of some generation technologies, particularly renewables, can be solved with an attached storage system that will improve their characteristics and open new opportunities in the market.

- **Variable generation firming**. Energy storage installations can help variable generation resources (such as renewable energy technologies) to be maintained at a committed level for longer periods. Also, storage helps smoothing the outputs and ramp rates of these technologies rates to avoid voltage and current alterations in the grid.
- **Management of RE curtailments**. The system operator can decide to order a reduction in electricity generation due to several reasons, usually due to an unexpected imbalance in generation-demand or to grid congestion. Renewable energies, particularly wind and solar, can be affected by grid curtailments when high production occur, leading to wasted energy that could otherwise be stored for later use if the appropriate technology is in place.
- **Ramping support.** Thermal generation technologies, although reliable, have limited reaction speed. The increase of intermittent RE in the electricity system is increasing fluctuations in the network and requiring improved flexibility services. Storage technologies can help thermal plants improving ramp response, avoid missing opportunities in the balancing market and avoid wear away traditional power plant's components.

*Ancillary services[5].*

These are the services contracted by the network operator in order to guarantee quality of supply and systems reliability. These services require relatively small energy quantities but very fast response time and many products can be found offered by TSOs.

- **Primary frequency regulation** (also known as FCR by ENTSO-e or inertial reserve by several TSOs): Momentary differences between electricity load and generation lead to fluctuation of the frequency of the electricity supply, usually stablished at a nominal value of 50Hz in Europe. Primary or inertial regulation happens with small fluctuations and is automatically done by the kinetic energy contained in rotating generation turbines, or it can be simulated by a battery (Synthetic inertia). It is detected by frequency sensors in the power plants and it requires response times of seconds. This service is not always remunerated, as it happens in Spain.
- **Secondary frequency regulation** (also known as FRR by ENTSOe or, in the US, as "spinning reserve") is the service that helps managing fluctuations of frequency larger than those than can be managed by primary regulation systems and that require the addition (upward) or reduction (downward) in generation capacity. It is automatically activated and managed by the Automatic Generation Control (AGC) and requires response times of minutes. In order to provide this service, European TSOs assign in the balancing market the upward and downward reserves band in settling times of between 15 to 30 minutes, paying both for capacity reserve and for actual energy provided when the service is called. In the US these reserves are included in the market operator's clearing algorithm.

[5] *The nomenclature of the different Ancillary Services differs depending on the market. In Europe ENTSO-e and the national TSOs use their own, which at the same time are different to the ones named by FERC in the US.*

- **Tertiary frequency regulation** (also known as RR by ENTSO-e or, in the US, as non-spinning reserve). It is manually activated when frequency deviations last longer than 15 minutes, requiring response times in the order of 10-15min and answers durations of up to 2h. In Europe, tertiary reserve is defined short in advance before the dispatch hour and the price of tertiary control price is usually defined at pay-as-bid or marginal price through ad-hoc markets.
- **Voltage control**. This service controls voltage levels in the transmission and distribution networks by the injection or absorption of reactive power.
- **Black-start.** A service that allows a power station to restart activity without taking energy from the network. This service is usually necessary in emergency situations, when a plant needs to be quickly connected.

*Network services.*

These are the services that improve the network performance, either avoiding congestions or the need to invest in new infrastructure:

- **Congestion relief:** refers to energy storage assets that temporarily address congestion in the T&D network, allowing the system operator who installs a battery at its end to avoid congestion rents to be paid to the network owner. This service is particularly attractive in the US.
- **Investment deferral**[10]: storage can help avoiding new investments in the network (mainly those necessary to avoid congestions), extending the life of the network's assets and avoiding the risk of unknown demand growth projection (mitigation of a substation overload due to growing peak demand). The storage device can provide the services by a limited time until the upgrade of the network is worth it compared with the use of the storage.

*Demand management:*

Small size storage devices can be located "behind the meter" supporting the load behavior and benefiting the end consumer and the whole network if tariffs have a well cost-reflective design[6].

- **Demand shifting:** this service consists in storing energy during low prices periods to be used by the consumer during high prices periods, what also can be seen as a load peak shaving service for the whole system. Off-grid use of batteries would be an extreme of this service in which the consumer does not use the network at all.

*Tabla 1: Services batteries can provide, technical requirements and better suitable technologies[11].*

| CATEGORY | SERVICE | POWER SIZE | TIME OF DISCHARGE | RESPONSE TIME | ANNUAL CYCLES # | APPROPIATE STORAGE TECHNOLOGIES |
|---|---|---|---|---|---|---|
| BULK ENERGY | *Back-up Security* | 1KW-10MW | 1min-10h | sec | 10-100 | 1. Electrochemical Batteries, particularly Li-Ion |
| | *Arbitrage (peaker)* | 100-2000MW | 8-24h | > 1h | 100-300 | 1. PHS, CAES<br>2. Hydrogen and Batteries with high scalability such as Flow |
| | *Long-term, seasonal storage* | 100-500MW | 2-10h (even days) | min | 5-500 | 1. PHS, CAES<br>2. Hydrogen and Batteries with high scalability such as Flow |
| GENERATION SUPPORT | *Variable generation firming* | 1-400MW | 1min-hrs | <15min | | 1. Li-Ion batteries and flow<br>2. Flywheels |
| | *Management of RE curtailements* | 10-500MW | 2-10h | min | 300-500 | 1. PHS, CAES<br>2. Hydrogen and Batteries with high scalability such as Flow |

[6] *Cost-Reflective tariff design should reflect underlying cost structure, be linked to time and location parameters and account to bidirectional power flows.*

| CATEGORY | SERVICE | | POWER SIZE | TIME OF DISCHARGE | RESPONSE TIME | ANNUAL CYCLES # | APPROPIATE STORAGE TECHNOLOGIES |
|---|---|---|---|---|---|---|---|
| | | | | | | | 3. If installed power between 10-50MW, electrochemical batteries |
| | *Ramping support* | | <1-10MW | sec-1min | ms | 1000-5000 | 1. Flywheels<br>2. Supercapacitors<br>3. Li-Ion batteries and flow |
| ANCILLIARY SERVICES | FCR | *Primary freq control* | 1-100MW | 1-30sec | ms-sec | 200-400 | 1. Li-Ion batteries and flow<br>2. Flywheels |
| | FRR | *Secondary freq control* | 1-100MW | sec - 15min | sec-min | 200-400 | 1. If >100MW: PHS, CAES<br>2. if <100MW: electrochemical batteries |
| | FRR-M | *Terciary freq control (Spinning Reserve, FRR-M)* | 1-100 | 30min - 2h | 10-15min | 200-400 | 1. If >100MW: PHS<br>2. if <100MW: electrochemical batteries |
| | RR | *Deviation management (Load following in US, RR in EU)* | 1-100 | 2-6h | sec | 200-400 | 1. If >100MW: PHS, CAES<br>2. if <100MW: electrochemical batteries |
| | | *Voltage Control* | <1-10 | sec-1min | ms | 1000-5000 | 1. Flywheels<br>2. Supercapacitors<br>3. Li-Ion batteries and flow |
| | | *Black-Start* | 5-50 | 5sec-1h | sec | 10-20 | 1. Li-Ion batteries and flow<br>2. Flywheels |
| NETWORK SERVICES | *T&D Investment diferral* | | 10-200 | 1-10h | sec | 300-500 | 1. If >100MW: PHS, CAES<br>2. if <100MW: electrochemical batteries |
| | *T&D Congestion Relief and Capacity Payment* | | 10-200 | 1-10h | sec | 300-500 | 1. If >100MW: PHS, CAES<br>2. if <100MW: electrochemical batteries |
| DEMAND MGMT | *Demand Shifting (Peak shaving by providing self-consumption and for EV)* | | 1KW-10MW | 1min-10h | sec | 300-500 | 1. Electrochemical Batteries, particularly Li-Ion |

### *Flexibility*

Most of these services are linked with the most general service of providing flexibility to the electricity system, that is, providing time sensitive response to fluctuations in the generation-load balance. This will be key as the penetration of renewable generation in the network increases. The five major types of flexibility are provided by (i) spinning reserve, (ii) tertiary reserve, (iii) ramping, (iv) daily balancing and (v) seasonal balancing. Today, most of the flexibility of the system is provided by gas turbines and CCGTs, but in the near future highly scalable technologies with low costs such as Li-Ion batteries will become the default technologies for short term reserves and daily balancing: balancing energy cost can reduce from the current US$93/MWh of a CCGT-only system to the US$72/MWH hybrid CCGT plus battery system in 2030. The main competition to flexibility provision by batteries will come from demand-management options, which still show to be the lowest price source of flexibility if price signals are properly defined.[12]

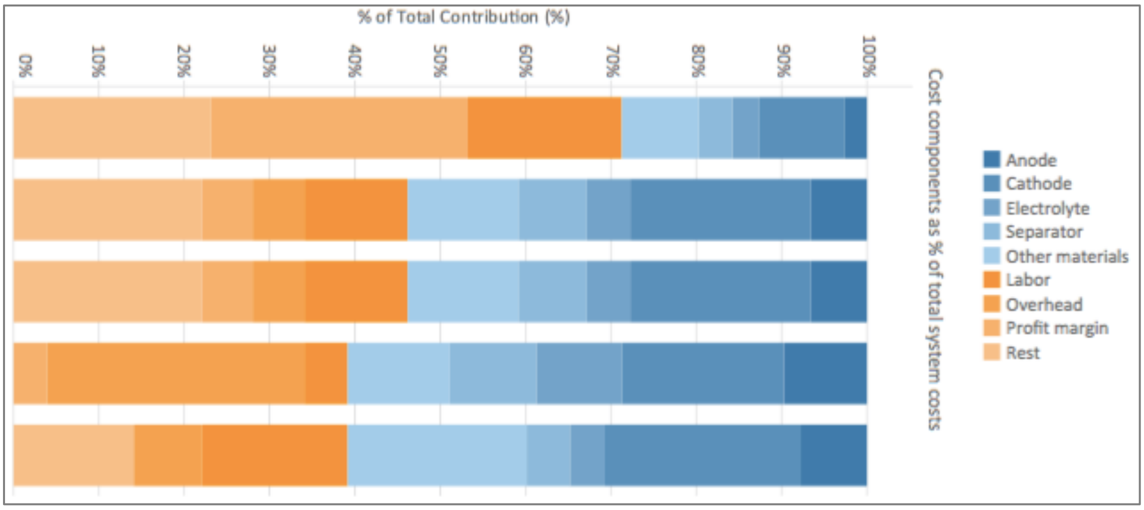
## 4.2 Costs definition: the future of Li-Ion batteries.

The advantageous characteristics of Li-ion batteries have made them the dominant technology in the markets of portable electronic and electro-mobility markets. Research and economies of scale are leading costs to decline and so making this group of batteries one of the main economic options for stationary electricity storage applications.

### *Understanding the costs.*

The cost of a Li-Ion battery pack stands at US$236/kWh by 2017. The most expensive part of a Li-Ion battery cells pack is the cathode, which can account for between 10% to 23% of the pack's price, a figure that increases in the case of expensive cobalt cathodes. In large battery installations the battery cell accounts for 35% of the pack's cost, while power electronics and periphery elements accounts respectively for 35% and 30%.[13]

Figure 12: Cost breakdown of Li-Ion battery pack costs in five different sources (IRENA, 2017)




Besides the battery pack, the installation of a utility scale battery implies costs of Balance of the System hardware (mostly climate control), EPC contract and soft costs such as overheads, taxes or costumer acquisition. In 2017, the total cost of a Battery Energy Storage System (BESS) stands at aproximately US$587/kWh. Out of this cost, 40% corresponds to the battery pack, 33% to BoS hardware, 15% are soft costs, and 12% to EPC contracts.[14]

*Increase in competitiveness and costs lowering trend.*

As explained above, the particular characteristics of Li-Ion batteries have made most electronics and EV manufactures to choose them for their product, leading to opportunities of synergies for stationary batteries. This interest showed by the market and the initiative that public institutions are showing in adapting regulatory frameworks,  is creating an attractive environment. The scale of global production capacity for Li-ion batteries is growing (from 29GWh in 2016 to 234GWh in 2020, led by CATL, Tesla and Northvolt[15]), investment in research for material is improving (LMO batteries could increase energy densities between 3 and 11 times), and more competitive supply chains and more operating experience is creating the necessary track record and performance feeding back into the industry.

All these drivers are creating impressive improved performances and declining battery costs. EVs battery pack's costs have reduced by 73% between 2010 and 2016, the costs of residential battery costs in Germany have reduced by almost 60% between 2014 and 2017[16] and utility scale BESS have decline prices by 23% in the period 2012-2017[17]

It is expected that Li-Ion BESS capital costs can reduce by more than 50% ten years, from the US$587/kWh in 2017 to US$270/kWh. Optimistic projections expect that this price decline can reach even 70% reduction in cost.

*Figure 13: cost reduction per Li-ion BESS by 2025, McKinsey 2018*

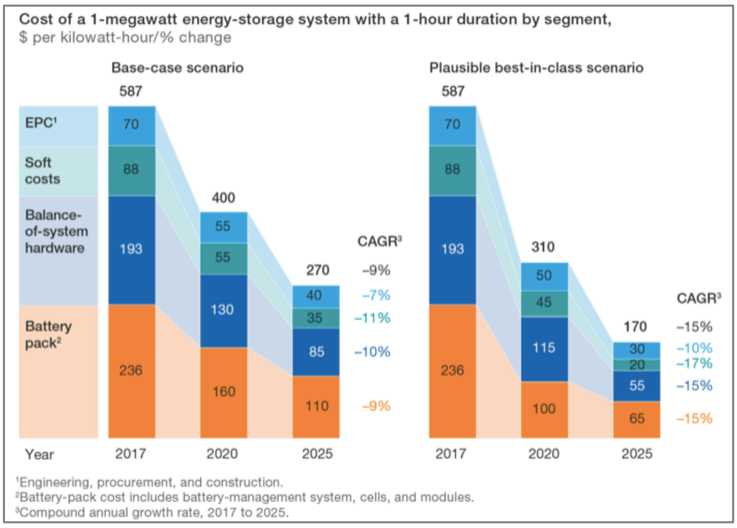
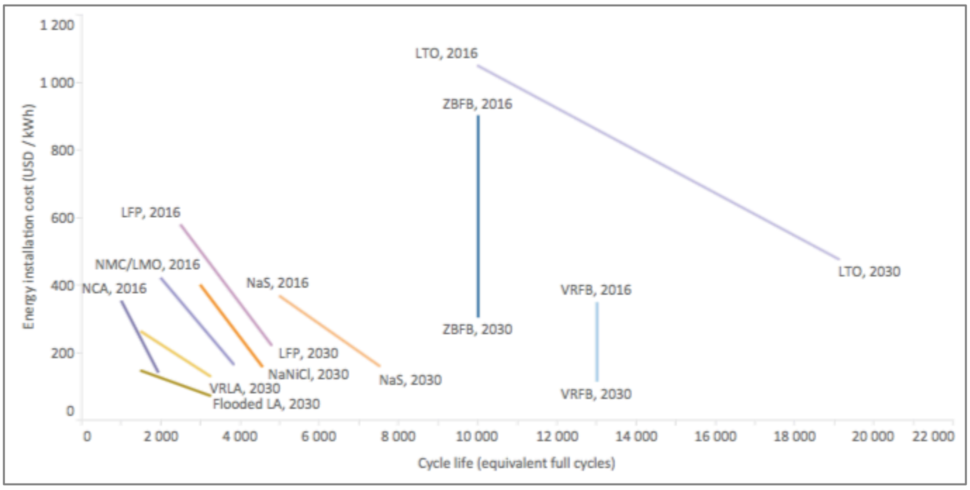



*Figure 14: Energy installation costs and cycle lifetime of battery storage technologies[7] from 2016 to 2030, IRENA, 2017*




**Levelized Cost of Storage (LCOS).** The evolution of the BESS costs can also be calaculated taking into account the lifecycle, and the operative and maintenance chacaracteristic of specific services. In 2015, Lazard Consulting published a comprehensive analysis of LCOS for the most suitable storage technologies for the most common expected energy services comparing (i) subsidized and unsubsidized scenarios, (i) typical substituting technologies options and (iii) current LCOS with those expected by 2020. This study showed that some storage technologies are already cost-competitive for some of the studied services, but still require relatively greater energy density and duration. The study also shows spectacular lowering prices in the next 5 years, particularly in lithium-based technologies which are expected to be fully competitive, in particular, for frequency regulation services.

[7] *Lead-Acid: LA = Flooded lead-acid; VRLA = valve-regulated lead-acid; High temperature: NaS = sodium sulphur; NaNiCl = sodium nickel chloride; Flow Batteries: VRFB = vanadium redox ; ZBFB = zinc bromine; Li-Ion Battery: NCA = nickel cobalt aluminium; NMC/LMO = nickel manganese cobalt oxide/lithium manganese oxide; LFP = lithium iron phosphate; LTO = lithium titanate.*

*Figure 15: Current and expected LCOE for storage technologies in front of the meter (FTM) services (Lazard, 2015)*

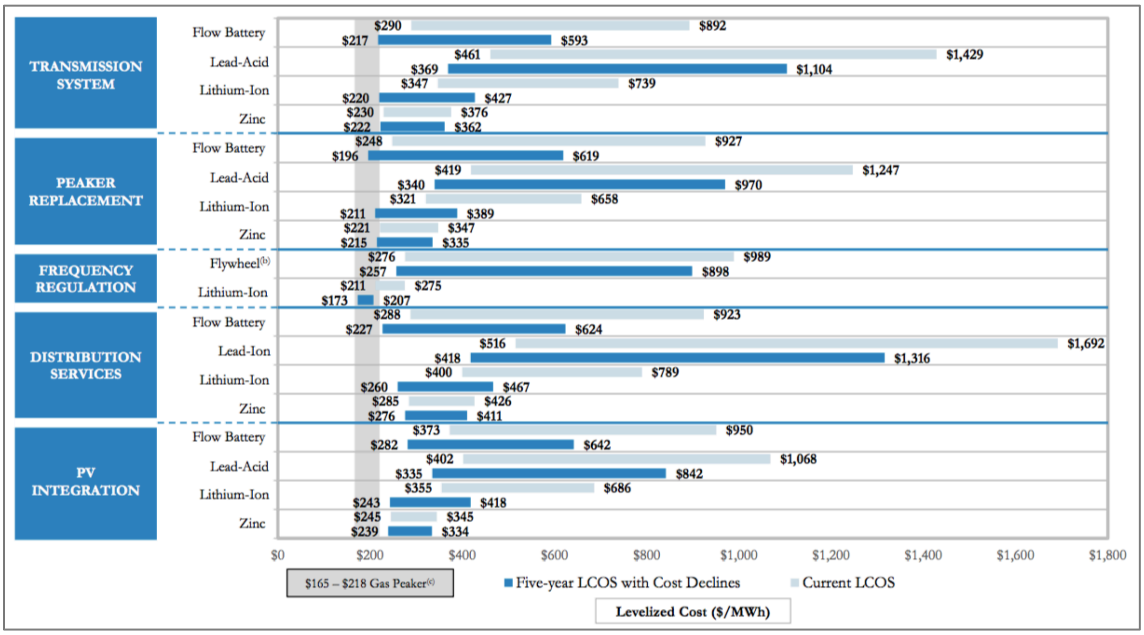
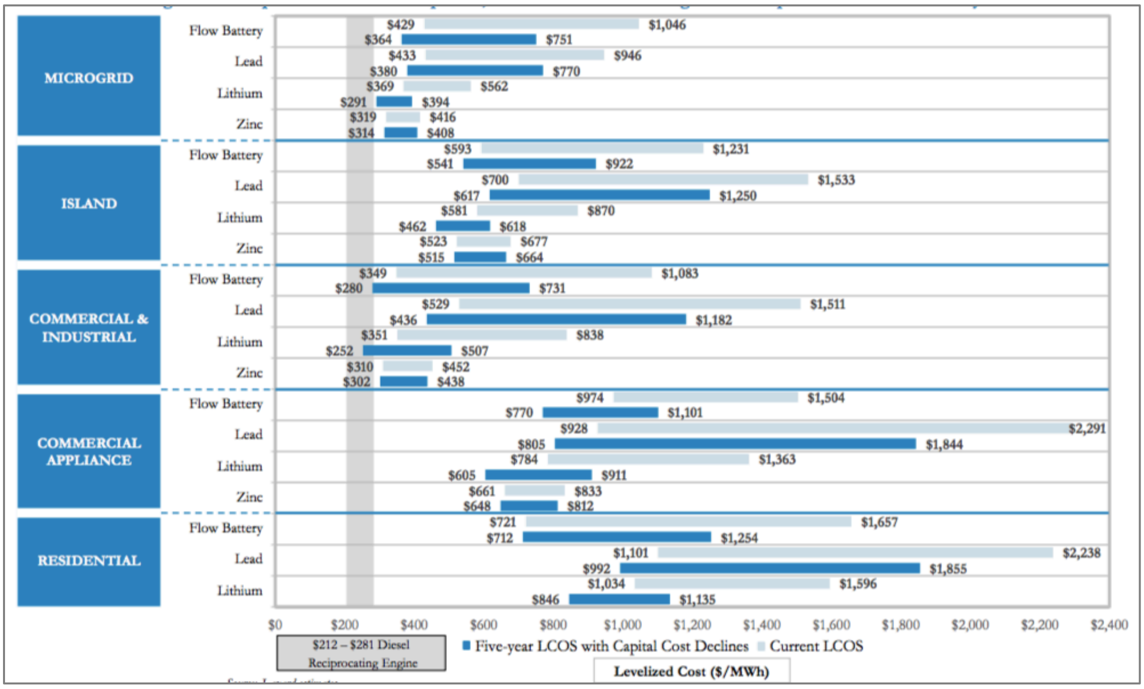



*Figure 16: Current and expected LCOE for storage technologies in behind of the meter (BTM) services (Lazard, 2015)*

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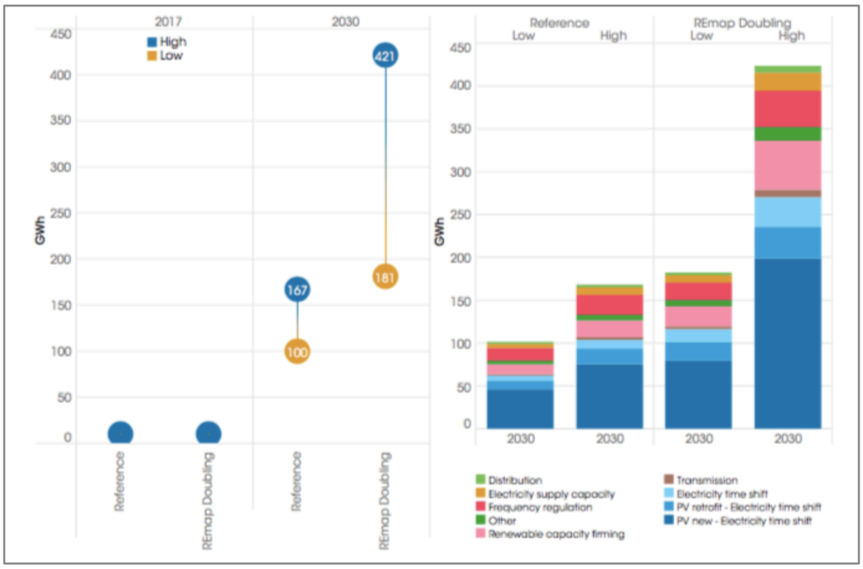
## *Growth in global installed capacity.*

The presented decrease in costs will lead to an increase in global installed capacity from the current 4.67 TWh in 2017 to the 6.62-7.82 TWh in 2030, a figure that could reach more than 15TWh installed if global renewable energy developments projections take place. The leading driver for this increase will be the ability of using batteries for energy time shifting linked to solar PV installations.

*Figure 17: Battery storage installed capacity growth and main stationary uses (IRENA, 2017)[8]*




## 4.3 Business models with batteries.

As it has been presented in the previous paragraphs, storage technologies, and Li-Ion batteries in particular, can provide a wide range of services and from which the different revenues streams can then be stacked. In order to understand the possible business models that be built with batteries, it is necessary to be make the difference between who owns, who operates and who benefits from the battery and if each of these actors belong to a regulated or to a liberalized environment (merchants). Eight major business models can be described[18]:

*Self-consumption in house/SME*

This first model represents the situation in which a small consumer owns, operates and benefits from a storage facility. In this model, the battery operates in a liberalized context, the costumer can be or not be connected to the grid and can take the energy store from a small renewable source or from the network. The service the battery will provide is mainly demand shifting, through self-deferred consumption or arbitrage in network, leading to the transformation of the consumer in an active “prosumer”. The main challenges that this model faces are: (i) difficult operation for DSO, (ii) tariff design and potential higher costs of energy for users without storage, (iii) need of new investments in distribution infrastructure, (iv) regulatory limitations for user participation in the network, such as fees. On the other hand, this increasingly popular model brings important benefits related to environmental targets and efficiency for the end-consumer and they push operators to invest in communication and information technologies (TICs). An extension of this model would be the “energy communities”, in which several battery owners aggregate their batteries in closed circuit and then contract an external entity, the “aggregator”, for the charge/discharge management.

*Active participation of prosumer with aggregation*

This model refers to the situation in which a group of small consumers, own the batteries, they are managed as a whole by an entity called “aggregator” and this entity benefits by participating in wholesale services with the aggregated energy stored. Main challenges to this model are linked to the regulatory barriers for “prosumers” and “aggregators” definition and participation in the market. At this respect it is interesting to differentiate between two figures: the “technical aggregator”, who knows the operation of the distribution network and can manage congestions, and the “Commercial aggregator” who knows the demand and state of charge of batteries,

[8] IRENA’s REmap presents two scenarios, the so-called “reference case” presenting BAU outlooks on RE development and the “doubling scenarios” presenting the optimistic roadmap designed by the Agency.

managing the flexibility capacity while communicating with the technical aggregator. DSOs are now naturally trending to becoming technical aggregators.

*Stand-alone merchant storage providing services to the network:*

This model refers to entities that own and manage stand-alone batteries, providing services to a regulated network entity, mainly ancillary services, congestion relief and investment deferral. This kind of services still require to be recognized and included in the network codes and face the challenge of network operators willing to own storage assets, facing regulatory limitations due to unbundling obligations.

*Stand-alone merchant storage supporting RE competitiveness.*

This model refers to stand alone battery owned and managed by the same entity and with services contracted by a liberalized activity, such as renewable energy generation. The services that are expected in this model are provision of firm generation, management of curtailments and an increased reliability that opens the possibility of reserve market participation. In case of thermal generation, the storage facility can also provide ramping support.

*Generation plant improving their integration in the network.*

This model is very similar to the fourth one explained above but, in this case, the generation facility owns, operates and benefits from the storage installation. The expected services are the same and has the benefit of avoiding possible regulatory limitations since it can be considered and improvement of the generation facility.

*Owned by public entity but operated by private one.*

This model is similar to the number 3 described above, but in this case the property belongs to a regulated entity (i.e. network operator). In order to avoid issues with unbundling regulation, the regulated entity will establish bilateral contracts with a third party that will be in charge of managing the storage. This way, the regulated entity can benefit from network services and the third party can participate in the wholesale market with the stored energy.

*Owned by public entity but operated by private one*

similar to the sixth one above but in this case the battery is owned and managed by the regulated entity, while the third party negotiates bilateral contracts to access the excess of energy and deal with it in the markets.

*Regulated entity owning, managing and benefiting from storage*

This model makes reference to the situation in which a regulated entity (a network operator) owns and manages a battery for its own benefit, such as investment deferral, congestion relief or ancillary services. This model faces many regulatory challenges due to the unbundling conditions for which the network operator cannot own generation assets, avoiding this way market distortions and market power situations.

Table 2: Possible business models with batteries[19]

| | | PROPERTY | | OPERATOR | BENEFICIARY OF THE SERVICE | DESCRIPTION | # |
|---|---|---|---|---|---|---|---|
| RETAIL | LIBERALIZED | Small Private Consumer | LIBERALIZED | Small Private Consumer | Small Private Consumer | *Self consumption in house/SME, connected to the grid or not* | 1 |
| RETAIL | LIBERALIZED | Small Private Consumer | LIBERALIZED | Private entity | Market | *Active participation of prosumer in the market with aggregation* | 2 |
| WHOLESALE | LIBERALIZED | Private entity | LIBERALIZED | Private entity | Regulated entity | *Private owner and operator of a stand alone storage providing services to the network operator* | 3 |
| WHOLESALE | LIBERALIZED | Private entity | LIBERALIZED | Private entity | Liberalized entity | *Private owner and operator of a stand alone storage supporting RE integration* | 4 |
| WHOLESALE | LIBERALIZED | Private entity | LIBERALIZED | Private entity | Market | *RE owner attaching a storage system to integrate the generation facility in the market* | 5 |
| WHOLESALE | REGULATED | Network Owner | LIBERALIZED | Private entity | Liberlized Market and Regulated entity for own use | *Regulated entity owner of the storage facility using it for its own network needs and contracting with third parties for management and be used in the market.* | 6 |
| WHOLESALE | REGULATED | Network Owner | REGULATED | Network Owner & Operators | Liberlized entity and Regulated entity for own use | *Regulated entity owner and manager of the storage facility using it for its own network needs and contracting with third parties to provide integration in the market* | 7 |
| WHOLESALE | REGULATED | Network Owner | REGULATED | Network Owner & Operators | Regulated entity | *Regulated entity owner and manager of the storage facility for its onw needs* | 8 |

In the case of #3 and #4, where a private entity owns a stand-alone storage facility providing services in regulated and not regulated environments the model can be extended.[20] Different contractual situations can be presented according to the level of exposure the merchant will have to face and the availability of capacity payments. Considering from low to high exposure, the possibilities can be:

- Full capacity payment in exchange for a guaranteed battery availability that can be particularly used for ancillary services (AASS).
- Full capacity payment for a limited time that allows, once the contractual term expires, the merchant to participate in the reserve and AASS market to stack additional revenues.
- Capacity payment combined with AASS market participation, considering space for arbitrage operation
- Full market participation: day ahead, intra-day and AASS. This still would require public financial support.

## 4.4 Cost-effectiveness

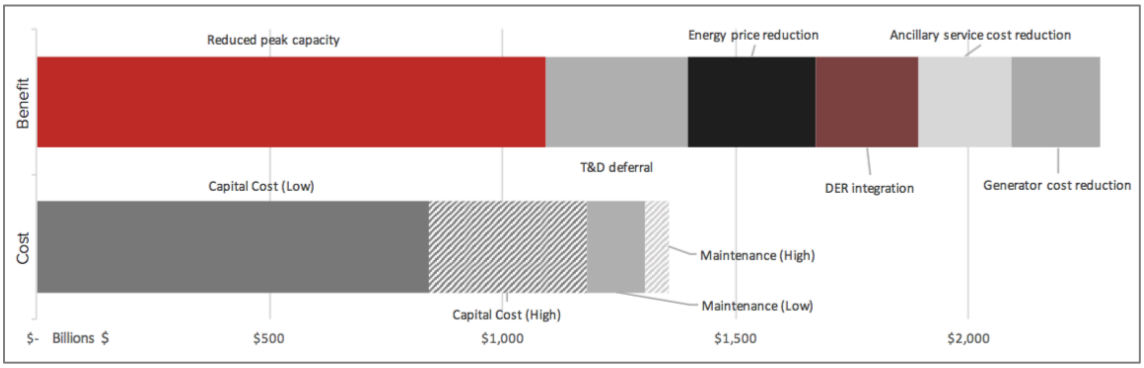
Currently, there is not a commonly accepted approach for assessing the full value of energy storage or a reference modeling tool that can be considered complete enough by the industry. The main issues that make this difficult are the wide range of services, (and so revenues sources), issues delimitating property, and the influence depending on the location in the grid.[21]

There are to approaches to evaluate cost-effectiveness of storage installations: (i) engineering studies, which consider the pure investors perspective and so they are used by utilities and industry, and (ii) system studies, which evaluate the overall system's benefit and that is more used among regulators.

Some studies[22] point out that the most immediate profitable application for the investor will be provision of AASS and supporting RE integration. Others[23] focus on the whole system's benefit, highlighting the disruption of end-user behavior that mass storage insertion will have, reducing peak demand and the need for imports. Nevertheless, they all agree that, in the short term, it will be flexibility the key service provided.

The evaluation of cost-effectiveness has been particularly studied in the United States, where several entities such as USDoE, EPRI, NERL, SANDIA laboratories, or the Massachusetts government have taken steps in defining a model that could serve as reference. All of them support the need to evaluate the different benefit streams of storage in a comprehensive way, “stacking” them to be compared with the investment and maintenance costs. Difficulties are shown and some, like the Massachusetts government, have determined that only a third of the estimated benefits of storage can be monetized and compensated under existing US regulations and market designs in their region.

*Figure 18: Analysis of storage benefits and costs, State of Charge Report (Massachussets Gov. 2016)*




Regarding modelling tools available in the American market, it can highlight the one ESCT developed by Navigant under the direction of the USDOE. In the table below, designed by IREC, a selection of storage CBA specific tools are compared according to their ability to reflect different revenues sources.

*Figure 19: Comparison of cost-effectivenes storage modelling tools in the US, IREC (2017)*

| | GRID SERVICES/BENEFITS | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TOOL | Energy Time-Shift (Arbitrage) | Resource Adequacy/Supply Capacity | Load Following | Frequency Regulation | Electric Supply Reserve Capacity | Voltage Regulation | Transmission Upgrade Deferral | Distribution Upgrade Deferral | Transmission Support | Transmission Congestion Relief | Substation On-site Power | TOU Energy Cost Management | Demand Charge Management | Reliability (Backup Power) | Power Quality | Renewable Energy Time Shift | Renewables Capacity Firming | Black Start | Wind Grid Integration | Greenhouse Gas Impacts |
| EPRI ESVT | ✓ | ✓ | | ✓ | ✓ | | | ✓ | | | | | | | | | | | | |
| ES-Select™ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | | |
| NREL REopt | ✓ | | | ✓ | | | ✓ | ✓ | | | | ✓ | ✓ | ✓ | | | | | | |
| PNNL ESS Tool | ✓ | ✓ | | | | | | ✓ | | | | | | ✓ | | | | | | |
| Navigant ESCT | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ |
| Alevo ASOT | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | | | | | | | | | | | | ✓ |

The European Union, through ENTSO-e, is developing the CBA 3.0 methodology to evaluate projects of the network, with a particular focus on storage technologies. This methodology follows the same approach as the American one, providing the vision of the regulator and stacking different revenue sources in the evaluation.

In Section C of this study, the cost-benefit analysis issue will be studied in depth, resenting a business case for a battery connected to a wind farm in Spain.

# 5 Regulatory challenges for batteries

Now that investment costs are reducing fast, regulatory frameworks can be considered as the main barrier batteries have to face for their full deployment in the market. Public administrations and main stakeholders of the energy sector are moving fast in order to satisfy the growing need of flexibility in the network.

In general, it can be said that regulation challenges concerning batteries are related with three main aspects: (i) the difficulty create an asset definition that fits in the sector operability, (ii) the recognition of particular technical characteristics batteries have in the access and remuneration schemes of markets and (iii) the lack of track record and experience that could serve as reference for investors.

The assessment of regulatory frameworks for energy storage technologies will be further developed in Section B of this report.

# V. Section B: Analysis of regulatory frameworks for energy storage technologies.

# 6 Summary of Section B.

The upcoming power sector scenario with high renewable energy generation penetration and with an increasing digitalization of the sector bringing new actors to market is putting energy storage technologies as a key option to guarantee the necessary flexibility in the system. Now that investment needs are in rapid descend, particularly for electrochemical storage, the main barriers batteries have to face for their full developments are in regulatory provisions, reason why countries are moving fast to adapt their regulatory frameworks.

The main regulatory barriers energy storage have to face can be classified in (i) the existence of a clear definition in the regulation, so it can be treated in a non-discriminatory way and subject to appropriate fees and benefits; (ii) the adaptation of wholesale, reserve and balancing markets to shorter settlement times, integrating constraints such as state of charge and rewarding fast speed response capability; and (iii) the public support of the industry by creating financing support, research, reference standards and targets.

The countries leading the development of projects of batteries are the USA, the European Union, China, and Australia, mostly directed to firm renewable energy integration and for business models based on the provision of ancillary services (almost 60% of installed capacity). It is expected that in the next fifteen years non-hydro storage technologies installed capacity will grow from 1.9GW to 125GW globally, with important players such as India, Japan and South Korea also involved.

In this report, two markets have been analyzed: the USA and the EU, both taking steps in adapting regulation to a successful deployment of energy storage technologies. Their leading regions have also been analyzed: Germany, United Kingdom, New York State and California, each of them taking particular initiatives and approaches.

The United States is leading the global movement to adapt regulation and markets to storage participation, already partially opening to them the ancillary services participation in 2007. Some characteristics of the US electricity market is facilitating the deployment of energy storage technologies: (i) the main US electricity markets function in a centralized way, integrating the management of day ahead, real-time and regulation markets under regional system operators, making it relatively easy to incorporate the constraints and rewards needed by storage technologies; (i) remuneration prices are set through locational marginal prices, increasing incentives for its efficient deployment and avoiding grid fees; and (iii) there are few market distortion, allowing scarcity prices to be reflected while the promotion of renewable energies have been made mostly through tax incentives rather than levies on tariffs. The FERC's Order 841 of 2018 already incorporates a clear definition of storage and calls to ISOs to fully integrate them in their markets, clearly defining the aspects that must be considered. The states of California and New York State, through their respective markets CAISO and NYISO, are not only adopting FERC's directions, but creating clear targets for its deployment. California has made mandatory for its four main utilities to install new 1,825MW by 2024 and NYS has stablished a general target of 1,500MW installed by 2025 that will be supported by financing programs and incentives.

The European Union is expected to approve before the end of 2018 its "Clean Energy for all Europeans" Package, directing to adapt wholesale markets requirements and remuneration to new actors such as storage, aggregators and communities, reducing bidding sizes and settlement times, as well as making these technologies participant in the regional market integration process. The EU is supporting the creation of more energy-only-like markets, taking ever more continuous designs and with more participant agents, measures that will need to be coordinated with the codes of ENTSO-e. Germany is the most advanced country of the Union in integrating storage needs in its regulation: it allows its participation in the remunerated FCR, it has clearly stated that storage will only be charged by grid fees corresponding to energy injections, and it makes it beneficiary of the EEG-surcharge feed-in scheme. Also, the EPEX market created a specific intra-day market for flexibility providers in Germany and BenetzA that can present opportunities for storage technologies participation. The UK, on the other hand, is on the process of better integrating storage in its regulation leaving the initiative to the market: FCR is also remunerated, NGET created a frequency control product specifically tailored for fast-response storage technologies (the EFR), storage is able to participate in capacity auction though subject to a de-rating factor, and EPEX is already implementing the "UK Half Hour Day-Ahead 15:30 Auction".

As it can be seen, 2018 is a key year in the adaptation of the European and US electricity markets to storage participation. Demonstrative projects and important financing programs are being developed, particularly in Europe, and clear targets have been set in the US States. Both administrations are also developing standards and effectiveness analysis methodologies that will soon help the industry and the public institutions to better assess their investments.

*Figure 20: Overview of state of measures to overcome regulatory barriers and incentives for storage in selected countries (Source: Author. Green: in place, Yellow: in progress, Red: not existing)*

| BARRIER CATEGORY | BARRIER | EU | GERMANY | UK | US | NEW YORK | CALIFORNIA |
|---|---|---|---|---|---|---|---|
| SPECIFIC REGULATION | Definition of Storage | Yellow | Yellow | Yellow | Green | Green | Green |
| | Ownership | Red | Red | Red | Green | Green | Green |
| | Grid Fees | Green | Green | Yellow | Green | Green | Green |
| PARTICIPATION IN MARKET | Wholesale Market Access and Remuneration | Yellow | Red/Yellow (striped) | Yellow/Green (striped) | Yellow/Green (striped) | Yellow | Yellow |
| | Network Services Access and Remuneration | Red/Yellow (striped) | Yellow/Green (striped) | Green | Green | Green | Green |
| | Access to Capacity Markets | Green/Red (striped) | Green/Red (striped) | Green/Red (striped) | Green | Green | Red |
| | Access to tariff Incentives for RE | Red | Green | Green | Green | Green | Green |
| | Prosumers and aggregators participation | Yellow | Yellow | Yellow/Green (striped) | Green | Yellow | Yellow |
| TRACK RECORD | Development of demonstrative and reference projects | Green | Green | Green | Green | Green | Green |
| | Existence of Targets | Red | Red | Yellow | Red | Green | Green |
| | Existence of Standards | Yellow | Yellow | Yellow | Yellow | Yellow | Red |

# 7 Assessment of Regulatory frameworks for energy storage technologies.

As it was presented in Section A of this report, regulatory barriers are considered the main challenge for the full development of energy storage technologies in the power sector, particularly batteries. Nevertheless, public administrations and main stakeholders of the energy sector are moving fast in order to satisfy the growing need of flexibility in the network and opening opportunities for new business models in the system.

Regulation challenges concerning batteries are related with three main general aspects: (i) the difficulty to create an asset definition that fits in the sector operability, (ii) the recognition of particular technical characteristics batteries have in the access and remuneration schemes of markets and (iii) the lack of track record and experience that could serve as reference for investors.

## 7.1 Methodology for regulatory assessment.

Current regulation reforms and other public initiatives adopt a wholistic approach led at opening the electricity markets to new, cleaner, technologies that could take advantage of the opportunities in new business models and new actors participation that communication technologies are offering. Storage technologies take advantage of these opportunities either in a direct or indirect way, always recognized as a key technology that can offer the necessary firm capacity and flexibility to the new framework for power sector.

In order to assess how international markets are supporting the development of storage technologies, particularly batteries, thirteen aspects have been identified. These aspects can be grouped in four categories: (i) specific regulation, (ii) access to market, (iii) market remuneration scheme and (iv) existence of track record.

*Specific regulation.*

This category makes reference to regulation, policy and strategies specifically addressing energy storage and, in particular, batteries:

- **Definition of storage**: storage technologies like batteries lack a specific definition in national regulations. Batteries can behave both as generator (injecting energy) and consumer (withdrawing energy), they can be considered an asset of the T&D network, and also, they can provide services in regulated and liberalized environment. A lack of definition makes it difficult to define aspects on market participation, ownership or fees it should be subject to. Most literature supports the need of storage to be classified as a new asset of the network by itself, together with transmission, generation, distribution and load.
- **Grid Fees**: a lack of definition of the asset creates double charging situations for batteries in many markets, which are charged by using the network twice: when charging and when discharging.
- **Ownership**: an important discussion in the energy markets is who can own batteries, in particular related with system operators facing unbundling issues if they have a generator asset such as battery. This is particularly important in the case of DSOs, which are redefining their business operations towards service provision and management of the cross-flows in smart-grids.

*Access and participation in the market.*

In most regulation frameworks, batteries do not have access to market participation and so they are not able to access important revenues streams. Besides the access to the market, an important barrier batteries face is the attractiveness of revenues streams they can obtained from it, something which is limited by the products currently offered and the possibility to stack benefits.

- **Wholesale market**: technical requirements of markets (day ahead and intraday) do not contemplate the participation of generation units with the relatively small power levels and limited energy that batteries can offer, batteries may not be recognized as renewable and therefore do not have access to priority of dispatch privileges or intra-day settlement periods may not be attractive. Also, market price clearance process will have to be analyzed: in the case of centralized day ahead and intra-day markets cleared with optimization tool, technical characteristics of batteries should be included in the algorithm. The existence of nodal and zonal pricing will also be an incentive for battery installations, which could take advantage of a location in the network with frequent high prices. Also, the recognition of energy scarcity in the price, avoiding caps, is an important market signal that batteries need. The possibility of negative prices for RE, reducing curtailments possibility's also limits the deployment of storage technologies.

- **Network Services technical requirements**: Balancing and regulation markets operated by regulators are not usually adapted to the technical characteristics batteries can offer, usually related with the reward of time of response and flexibility offered, the settlement time of the products offered in the auctions or the possibility to pool services from several sources. Main remuneration barriers are related to the kind of ancillary services (primary frequency control, for example) that are remunerated and the kind of products offered by the system operation, with too long settlement times. Also related to the penalizations participants have to face in case of not compliance, something that disincentives a technology with variable state of charge such as batteries.
- **Access to capacity markets**: the existence of capacity market and the possibility of storage participating of them, in particular in those markets with locational pricing.
- **Prosumers and aggregators participation**: In the case of behind the meter applications, an important barrier for full deployment of batteries is the lack of recognition of prosumers that through aggregators could participate in the markets. In this case further limitations exist, such as well-developed charge management and revenues sharing systems, the status of smart metering roll out or the development of vehicle-to-grid policy.
- **Access to RE incentives**: and important challenge for batteries is their ability to participate of regulation incentives traditionally designed for RE promotion: if these are rewarded on capacity or energy basis, their structure or the possibility to receive Green Certificates transfers.

*Existence of track record.*

- **Demonstrative projects and financing programs**: This a key challenge batteries development have to face for their full deployment, leading countries to promote numerous demonstrative projects, create direct financing or rebate programs for energy storage projects.
- **Existence of targets**: The same way countries around the world have designed specific targets for renewable energy installation or reduction of carbon emissions, stablishing official targets and programmes for storage is a key driver to incentivize the industry for this technology's development. Targets can be stablished by central governments, supranational organizations, by regulators or by operators, defining who is responsible for its achievement and the indicators that should be used. Official programmes help canalizing investment and research, which is key to create the necessary breakthrough of a disruptive technology such as batteries.
- **Existence of standards**: main investors and industry stakeholders have to face a lack of official standards for battery technologies that could serve as a reference to design their projects and define safety safeguards and cost-effectiveness analysis.

*Table 3: Main Regulatory challenges for battery storage*

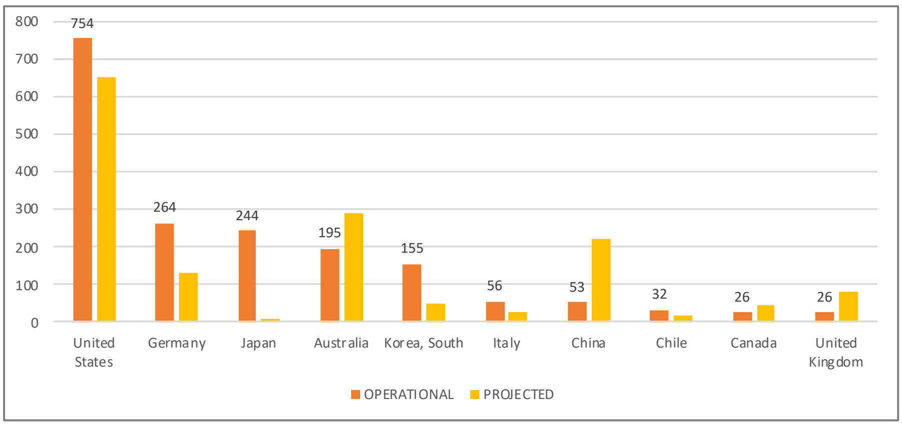
| BARRIER CATEGORY | BARRIER | DESCRIPTION of the ISSUE |
|---|---|---|
| SPECIFIC REGULATION | Definition of Storage | > Is It recognized as a network asset by it-self?<br>> Is it recognized as both network and market service provider?<br>> Is it linked with generation, consumption or neither? |
| | Ownership | > Are network operators allowed to own and manage storage assets and, if so any unbundling issue? |
| | Grid Fees | > do storage have to pay grid services as consumers and as generators? |
| MARKET PARTICIPATION | Wholesale partcipation | > Is there any technical limitation to storage participation?<br>> Is there any priority of dispatch storage can have access to?<br>> Can Storage participate in intra-day market?<br>> What are the setllement periods of the intra-day? |
| | | > Is there any method to allow scarcity to be remunerated efficiently?<br>> Are prices set on a zonal or nodal basis?<br>> Is RE curtailed at negative prices? |
| | Netwrk services participation | > What are the response times required?<br>> Is there any mechanism to reward speed of answer?<br>> Is pooling os services allowed? |
| | | > Is remuneration centralized or market based?<br>> What AASS are remunerated?<br>> Are there penalizations for not compliance? |
| | Access to Capacity Markets | > If existing, Is storage allowed to participate?<br>> Does current remuneration scheme benefit storage? |
| | Prosumers and aggregators participation | > Is Aggregation allowed to participate in the market?<br>> What is the status of smart metering roll out?<br>> Is there any advance n V2G policy?<br>> Is there any tokenization project in place? |
| | Access to tariff Incentives for RE | > is storage eligible to benefit from tariff incentives for RE?<br>> Is RE rewarded on a capacity or on an energy basis?<br>> If production based: feed-in, feed-in premium, CfD, Green Certificates? |
| TRACK RECORD | Development of demonstrative and reference projects | > Is there any direct financing program?<br>> Is there any rebate financing program?<br>> Is there any demosntrative project on track? |
| | Existance of Targets | > Is there any policy defined mandate for storage deployment?<br>> Who is appointed as responsible for its accoomplishment?<br>> What function of storage is specifically targeted? |
| | Existance of Standards | > Is there any reference standard to evaluate cost-effectiveness?<br>> Is there any safety standard in place fr storage? |

## 7.2 Leading Markets in Battery technologies

The methodology explained above will be applied in countries considered global leaders in the development of batteries and where Enel has shown particular interest for investment.

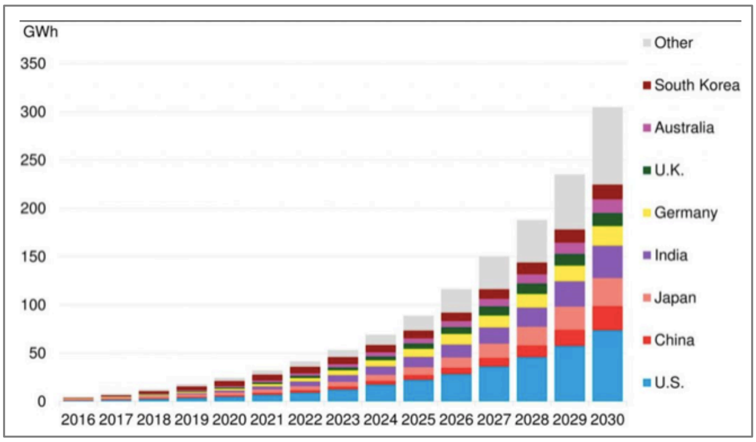
In 2016 there were 750 energy storage projects reported at global levels, accounting for a total installed capacity of 1.9GW, with more than 200 additional projects announced to be deployed in the next years accounting for new 1.3GW. These storage facilities are designed mostly for supporting renewable energy generation (32%), provide ancillary services (25%) or as bulk energy (29%). The countries leading the installation of batteries are the Unite States, which more than 750MW already installed and projection of almost doubling this figure in the next years, followed by Australia, Germany and China.[24]

*Figure 21: Global status of batteries capacity installed in MW, USDoE (2067)*



It is expected that global installed storage will reach 125GW/305GWh by 2030 with eight countries will lead this market, with 70% of capacity to be installed in the U.S., China, Japan, India, Germany, U.K., Australia and South Korea.

*Figure 22: global cumulative storage deployments, Bloomberg (2017)*




For this report, the following markets have been chosen: European Union, Germany, United Kingdom, United States, New York State and California.

# 8 European Union.

## 8.1 State of the art of battery projects

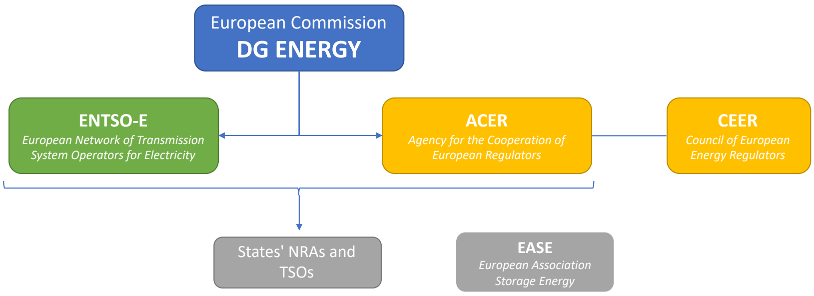
The energy storage market in Europe has been growing constantly, with annual rates of 50% growth since 2016, and it is expected that by the end of 2018 the installed base of electrical energy storage will reach 2.6GWh in Europe, compared with the 0.6GWh existing in 2015.

The segment that will present the higher rates of growth and that will largest share of the market will be at of front-of-the meter services, particularly frequency control response with Li-Ion batteries. The countries leading these developments is Germany (more than 300MWh in 63 projects of Li-Ion with 56% of them serving frequency regulation), UK (160MWh serving 92% for frequency regulation), Italy and France. Regarding behind-the-meter application at residential level, growing costumer awareness, lowering prices and new business models (aggregators, communities) is scaling up this segment, currently lead by Germany (almost 400MWh installed in more than 71,000 residential units) but with promising projection in Italy (particularly Lombardia)

## 8.2 Main stakeholders in the electricity sector for storage technologies.

The executive body of the UE is represented by the European Commission, which initiates legislation and reviews its implementation, while the legislative power is shared by the Council of the European Union and the European Parliament. The EC is divided into departments called directorates-general. European Agencies are decentralized bodies of the European Union with the mission of promoting know-how in certain areas and bring national stakeholders together. The main European institutions concerning the electricity sector and the management of regulatory issues regarding storage are the following[25]:

Figure 23: European Instituions of the Electricity Sector




- **Directorate General for Energy (DG Energy):** it is the body inside the European Commission in charge of developing the European energy policy. Its main tasks concern developing strategic analyses and policies, promote the creation of an integrated energy market in Europe, identify infrastructure needs for proper integration, monitor compliance with energy Union's targets, regulations and laws, promotes knowledge exchange among main stakeholders and leads European external energy policy.
- **Agency for Cooperation of Energy Regulators (ACER):** created in 2009 with the key role of assisting and coordinating national regulators in their EU level activities. It participates in the creation of the Network Codes, drafting the Framework Guidelines[9] they have to comply with and providing opinion and feed-back to the ENTSO-e in their development. It takes decisions on cross border issues and monitors and reports on the European energy market situation.
- **European Network of Transmission System Operators (ENTSOe):** created with the key role of developing creating the technical rules for the power network at European level in coordination with ACER and the Commission, design the network development plans, create network codes based on ACER's framework guidelines and promote regional cooperation
- **The Council of European Energy Regulators (CEER):** created in 2000 in order to coordinate national Regulatory agencies, promote coordination and exchange of best practices. It acts as the single platform from which national regulators can relate with EU.

Also, numerous lobbies exist, providing feed-back on regulation and updates on research and market status. In the case of storage technologies, **The European Storage Agency (EASE),** is the main advisor selected by the European Commission concerning policy for storage technologies.

## 8.3 European Energy Policy Overview.

The European Union uses a particular set of legal rules: Treaties, Regulations, Directives, Decisions, Recommendations and Communications, and White and Green Papers.

Regulations, directives and decisions[10] are proposed by the European Commission and presented to the member countries to obtain feed-back including, depending on the subject, opinions from the European Economic and Social Committee (EESC) and the Committee for the Regions. After this first feed-back, the European Commission starts the "first reading process": the proposal is sent to the European Parliament and then to the Council. After this first reading, the act can be approved or start a "second reading" or, if this is not successful, to a Conciliation Committee process.

*[9] So far, ACER published four FG: electricity balancing, electricity system operation, capacity allocation and capacity management for electricity, and electricity grid connection.*

*[10] Regulation (binding in its entirety and directly applicable in all member states), directive (binding, in terms of the result to be achieved, may be addressed to all or only some member states, and member states are free to choose the form and methods to implement the directive) or decision (binding in its entirety for those to whom it is addressed) of the Parliament and of the Council. Source: European Council.*

The European Energy policy has been built on three interconnected main pillars: (i) internal market (liberalization, innovation and competitiveness and low prices and efficiency), (ii) environment (nature and wildlife preservation, climate change, pollution); and Security of Supply (primary energy availability, reliability and quality and capacity). The current objectives for 2030 are: 32% penetration of RE generation, 30% of consumption reduction due to energy efficiency measures and 40% reduction in CO2 emissions.

Starting in 1996, the policy strategy in the energy sector has been developed in three main stages: A first one seeking the creation of an internal energy market, a second one seeking the definition and execution of common energy policy across the Union and a third one seeking the creation of a comprehensive EU Energy strategy. This has resulted in the issuing of directives and communications that have been building the current energy framework. The main elements of the current EU energy policy are:

- **Electricity Directives (E-Directive 96/92/EC)** establishing the rules of the common internal market of and electricity and updated with the E-Directive 2003/54/EC.
- **Third Energy Package 2009**, composed by two directives and two regulations seeking to make necessary adaptations for the Strategy of Europe 2020.
    - Directive 2009/72/EC concerning common rules for the internal market in electricity and repealing Directive 2003/54/EC. Stablishes the concept of unbundling for TSOs, proposing three schemes for its organization (OU, ISO, ITO).
    - Directive 2009/73/EC concerning common rules for the internal market in natural gas and repealing Directive 2003/55/EC
    - Regulation (EC) No 714/2009 on conditions for access to the network for cross-border exchanges in electricity and repealing Regulation (EC) No 1228/2003. It created the ENTSO-e and so stablishing the creation of network codes.
    - Regulation (EC) No 715/2009 on conditions for access to the natural gas transmission networks and repealing Regulation (EC) No 1775/2005
    - Regulation (EC) No 713/2009 of the European Parliament and of the Council of 13 July 2009 establishing an Agency for the Cooperation of Energy Regulators (ACER) and describing its main responsibilities.
- **Clean Energy for all Europeans Package 2018** ("Winter Package"). It was designed in 2016 tackling as main subjects (i) the decarbonization of the economy[11], (ii) better market adaptation to RE and distributed generation, (iii) provide uniform opportunities for all technologies, and (iv) empowerment of the consumer. The package is composed by eight legislative measures that can be grouped as follows:
    - Proposals amending existing energy market legislation: Market Design Initiative (MDI) which is expected to enter into force by 2020.
        - E-directive: amending and repealing Directive 2009/72 concerning common rules for the internal market in electricity and repealing Directive
        - E- Regulation: amending and repealing Regulation 714/2009
    - Proposals amending existing climate change legislation:
        - revised Renewables Directive 2009/28 (RED)
        - fully revised Energy Efficiency Directive 2012/27 (EED)
        - Proposal for a revised Energy Performance of Buildings Directive amending 2010/31/EU
    - Proposals for new measures on regulation and reinforcement of institutions powers.
        - Risk Regulation
        - Governance Regulation
        - ACER Regulation: regulation repealing Regulation 713/2009

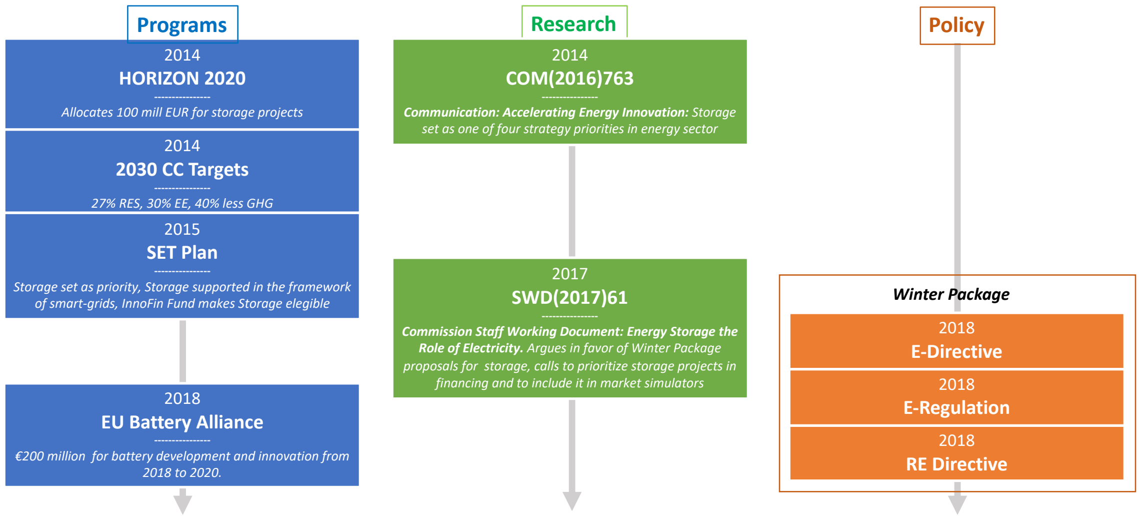
*[11] EU Targets: 27% RES generation, 30% reduction of consumption through EE by 2030*

Proposals that the Clean Energy Package will bring will be related to the shorter trading times across borders, the integration of continuous intraday trading, a revision of priorities of dispatch and other distortions in price clearance, reinforcement of an energy only market, the creation zonal prices based on structural congestions, and the empowerment of new market participants such as prosumers, aggregators and communities.

## 8.4 European Regulation for energy storage

Energy Storage has not been identified in The European Policy as a key element of the energy transition until recently. The recognition of storage and the initiatives leading for its support and promotion come hand in hand with the need to provide flexibility and firm capacity to the increased Renewable Energy coming into the grid. Since 2014 storage was included in the European Union's strategy through specific programs that finance and promote pilot projects and research and with ever more specific policy, particularly the almost implemented Clean Energy Package for all Europeans (2018).

*Figure 24: Regulatory framework for Energy Storage in Europe*




### *The Third Energy Package (2009)*

Under the Renewable Energy Directive (2009/28/EC) it is set out an EU-wide binding RES target of 20%[12] and Member States were instructed to support developments in transmission and distribution infrastructure and storage necessary to integrate a higher RES share, but no further provisions on storage were provided. Regarding energy storage: "The Member States shall take the appropriate steps to develop transmission and distribution grid infrastructure, intelligent networks, storage facilities and the electricity system, in order to allow the secure operation of the electricity system as it accommodates the further development of electricity production from renewable energy sources […]"[13]

Meanwhile, the Internal energy market directive (2009/72/EC) stablished unbundling provisions to prevent operation and ownership of generation assets by regulated entities (TSOs/DSOs). Since many Member States consider storage assets to be generation assets, this creates a framework that prohibits ownership of storage by regulated entities and therefore currently limits and complicates the value that can be realized from certain types of storage projects.

It will not be until 2011 when DG Energy publishes the Working Paper "The future role and challenges of Energy Storage**"** indicating for the first time the willingness of European Commission to address barriers to storage.

*[12] In June 2018, the target for RES penetration in the EU has been stablished at 32% by 2030. Source: The Guardian.*

*[13] Renewable Energy Directive (2009/28/EC) Article 16 par.1:*

*The program HORIZON 2020 (2014)*

As explained above, storage development by European Union has been driven by the promotion of RE, EE and reduction in carbon emissions. Horizon 2020 is the financial instrument implementing the Innovation Union, a Europe 2020 flagship initiative aimed at securing Europe's global competitiveness. It is the biggest EU Research and Innovation programme ever, with nearly €80 billions of funding available over 7 years (2014 to 2020) for more than 22 areas of economy. Under the societal challenges, secure, clean and efficient energy has 5.8 billion Euros allocated[26]. In particular, under the Research & Innovation Priorities in Horizon 2020 Work Programme 2018-2020, 389 million EUR have been allocated for storage technologies[27]. It can be highlighted projects financed by H2020 such as the STORY[28], focused on developing comprehensive cost-benefit analysis for storage technologies.

*The program Energy Technology Plan (SET-Plan, 2015)*

The SET-Plan was created to promote research and innovation efforts across Europe by supporting the most impactful technologies in the EU's transformation to a low-carbon energy system. It promotes cooperation amongst EU countries, companies, research institutions, and the EU itself, guiding works carried under the Horizon 2020 programme. The SET-Plan stablished storage as one of the priorities (number 7) in its working plan and research is currently supported under the Fuel Cells and Hydrogen Joint Undertaking within the Smart Networks for Energy Transition Platform activities.

The SET plan activities are supported by other technological platforms such as the EERA Joint Programme for Energy Storage, the EERA Joint Programme on Smart Grids and the ETIP Smart Networks for Energy Transition (SNET).

*The Communication Accelerating Energy Innovation (2016)[29]*

Published in 2016 in relation with the program Horizon 2020, the Commission seeks presenting a package of legislative measures to lay out a clear framework for action in the energy sector stablishing three overarching goals: (i) Energy efficiency first de-carbonizing the EU building stock by 2050, from nearly-zero energy buildings to energy-plus districts; (ii) Europe as the global leader in renewables and (iii) A fair deal to consumers.

Among the strategic priorities, developing affordable and integrated energy storage solutions are identified as key to facilitate and enable the transition to a low-carbon energy system (including transport) based largely on renewables, The EU recognizes the need to accelerate the full integration of storage devices (chemical, electrochemical, electrical, mechanical and thermal) into the energy system, at domestic, commercial and grid scale. This strategic priority is closely linked with electro-mobility and a more integrated urban transport system strategy.

In the framework of this communication, storage projects were included as eligible under the InnoFin fund, the strategic priorities of the Horizon 2020 program set 389 mill for energy storage and storage projects larger than 225MW were included as PCI.

*The Clean Energy for All Europeans Package (2017), The Winter Package.*

Background framework for storage in the designing of the Winter Package was published in 2017 in the European Commissions' Working Paper "Energy Storage, The role of Electricity"[30]. This communication concludes that energy storage should be allowed to fully participate in electricity markets, that it should participate and be rewarded for services provided on equal footing to providers of flexibility services, it recognizes energy storage as an enabler of higher amount of variable RESs that could contribute to energy security and de-carbonization of the electricity system or of other economic sectors and so that the cost-efficient use of decentralized storage and its integration into the system should be enabled in a non-discriminatory way by the regulatory framework. These communications set down the main guidelines on which the Winter Package would address issues related with energy storage.

**E-DIRECTIVE.** This directive amends and repeals Directive 2009/72. Due date 1 Jan 2021. The followings are the main dispositions influencing energy storage development:

- It contains definition of energy storage: "energy storage means, in the electricity system, deferring an amount of the electricity that was generated to the moment of use, either as final energy or converted into another energy carrier. This definition is based on the one given in 2016 under the Proposed Policy Principles for Energy Storage".[14]

- It contains a definition of active consumer: "a customer or a group of jointly acting customers who consume, store or sell electricity generated on their premises, including through aggregators, or participate in demand response or energy efficiency schemes provided that these activities do not constitute their primary commercial or professional activity"[15]
- It stablishes eligibility of Storage for AASS: "TSO responsibility includes contracting AASS provided also by storage. TSO shall procure these services in a transparent, nondiscriminatory and market-based procedure"[16]
- It encourages DSO use of storage technologies for network services: "Countries must enable regulatory framework for DSO to manage efficiency, including procurement of storage options services, with new network codes and market rules. DSO shall procure these services in a transparent, nondiscriminatory and market-based procedure."[17]
- It calls ENTSO-E to include in the TYDP assumptions also on the evolution of storage.[18]
- It clarifies unbundling/ownership of storage for system operators: DSOs and TSOs are not allowed to own, develop, manage or operate storage facilities. It only makes the exception if there is a proven lack of interest of other parties in tender process or they prove it is necessary for security of supply requirements, always subject to unbundling requirements and unbundle accounts. Every 5 years it should be reassessed if interest of independent agents exists via tendering processing and, if so, phase out DSO storage. For TSO this is extended to non-frequency ancillary services.[19]
- TSO must guarantee non-discriminatory connection to the network for storage facilities and the regulators must ensure so.[20]
- Countries must ensure legislation that does not hamper cross-border flows and consumer participation (opening participation to new suppliers, including through storage) and seek that electricity prices reflect actual demand and supply. [21]
- Countries must ensure legislation to organize markets in a more flexible way and integrate all players, including storage. Creation of new rules for the creation of short-term markets (intraday and balancing markets), and so specifically opening business opportunities for storage.[22]
- It includes measures that support active consumers (generation, storage, and consumption of self-produced energy, as well as participation in retail markets) and local energy communities.[23]

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[14] *Chapter I (Subject Matter and Definitions), Article 2 (Definitions), Par.47.*

[15] *Chapter I (Subject Matter and Definitions), Article 2 (Definitions), Par. 6*

[16] *Chapter V (General rules to the TSO), Article 40 (Tasks of TSOs), Par. 1.d.*

[17] *Recital 42 & Chapter IV (DSO), Article 32 (Tasks of DSO in the use of flexibility)*

[18] *Chapter VI (Operators), Section 3 (ITO), Article 51 (Network Development and Powers to make investment decisions), Par. 4.*

[19] *Chapter IV (DSO), Article 36 (Ownership of storage facilities) & Chapter VI (Unbundling of TSO), Section 4 (Designation and certification of TSO), Article 54 (Ownership of storage and provision of AASS by TSO)*

[20] *Chapter V (General rules to the TSO), Article 40 (tasks of TSO) and 42 (Decision making powers regarding connection of new power plant to the transmission system), Par.1. Chapter VII (National Reg Auth.), Article 58, Par.e.*

[21] *Recital 11 & Chapter II (General rules for the organization of the sector), Article 3 (Competitive, consumer-centered, flexible and non-discriminatory electricity market), Par. 1*

[22] *Recital 6.*

[23] *Chapter III (Consumer Empowerment and protection), Articles 15, 16*

- It entitlement for consumer to have a dynamic contract from the supplier.

**E-REGULATION.** It amends and repeals Regulation 714/2009. The followings are the main dispositions influencing energy storage development:

- It calls to create measures seeking a more liquid short-term market, so that price fluctuations can properly reflect scarcity and offer adequate incentives for a flexible grid. "When addressing resource adequacy concerns Member States shall in particular consider removing regulatory distortions, enabling scarcity pricing, developing interconnection, energy storage, demand side measures and energy efficiency"[24]
- It calls to reduce the minimum size requirements for day ahead and intraday markets, stablishing that a minimum size of 1MW or less must be available.[25]
- It opens market participation to prosumers using storage technologies: "consumers must be fully integrated in participation in the market, removing regulated prices and using available flexibility sources, such as DRM and Storage, and rules for the provision of AASS."[26]
- It calls for the development of Network Codes (via delegated acts of the CE) in new specific areas, such as (i) DR, aggregation storage and demand curtailment rules, (ii) capacity allocation, congestion management, including curtailment of generation and re-dispatching of generation and demand, (iii) connection charges and (iv) rules for non-frequency ancillary services.[27]
- It calls for network charges to take into account flexibility services. Non-discriminatory network fees must be applied between generation at transmission and distribution levels, specifically they should not discriminate storage.[28]
- It indicates that network charging guidelines should address energy storage as a class separate from producers and customers (load)[29]
- It calls for market rules to deliver appropriate investment incentives for generation, storage, energy efficiency and demand response to meet market needs and thus ensure security of supply.[30]
- The resources curtailed or re-dispatched shall be selected amongst generation or demand facilities submitting offers for curtailment or re-dispatching using market- based mechanisms and be financially compensated. This provision of market-based resources shall be open to all generation technologies, storage and demand response, including operators located in other Member States unless technically not feasible.[31]
- Access to balancing market must be granted to storage technologies[32]
- The new market design should aim at ensuring that supply prices are free of any public intervention (except duly justified exceptions) foresees scarcity pricing, reflected by

*[24] Recital 9 & Chapter IV (resource Adequacy), Article 18, Par.3.*

*[25] Chapter II (General rules for electricity market), Article 7 (Trade on DAM and Intraday markets), 3*

*Imbalance settlement at 15min by 2025*

*[26] Recital 5*

*[27] Chapter VII (Network Codes and Guidelines), Article 55 (establishment of network codes)*

*[28] Recital 22 Chapter III (Network Charges and Congestion mgmt.), Article 2 (Network Charges and Congestion income), Article 1 (Charges for access to networks), point 1*

*[29] Chapter VII (Network Codes and Guidelines), Article 57 (Guidelines), point 4*

*[30] Chapter II (General rules for electricity market), Article 3 (Principles regarding the operation of electricity markets)*

*[31] Chapter I (Subject matter, scope and definitions), Article 12 (Redispatching and curtailement)*

*[32] Chapter II (General rules for electricity market), Article 5 (Balancing Market), point 2*

removing price caps and regulated prices. Today, technical price thresholds are largely harmonized across Europe at +3000 and -500 €/MWh[33].

- It Phases out priority dispatch and balancing exemptions for RES (larger than 500KV), which could incentivize RES generators to invest in Energy Storage.[34]

**Renewable Energy Directive.** revising RED 2012/27

- It recognizes the need of using storage systems to integrate RE.[35]
- It supports renewable self-consumption and renewable energy communities (defined as SMEs and non-profit, composed by individuals, public entities & SMEs and with less than 18MW installed in the last 5 years)[36]

*Secondary Regulation and other initiatives.*

**Network Code. Commission Regulation 2017/1485**: **Guideline on Transmission System Operation.**[31] This recently approved Network Code creates uncertainty about whether minimum threshold for FCR activation can be set at 15 or 30 minutes (in CE and Nordic) by TSOs if properly justified; outcome could have significant impact on storage industry: "each FCR provider shall ensure that its FCR providing units or groups with limited energy reservoirs are able to fully activate FCR continuously for at least 15 minutes or, in case of frequency deviations that are smaller than a frequency deviation requiring full FCR activation, for an equivalent length of time, or for a period defined by each TSO, which shall not be greater than 30 or smaller than 15 minutes".[37]

Also stablishing that in case of a frequency deviation equal to or larger than 200 mHz, the activation of the full FCR capacity shall rise at least linearly from 15 to 30 second.[38]

**Synthetic Inertia Roadmap**. ENTSO-E is making efforts[32] that could lead to the definition of synthetic inertia[33] products for national grid codes, opening opportunities energy storage devices, particularly super-capacitors.

**Battery Alliance.**[34] During the Clean Energy Industrial Forum (February 2018), the EU's Vice-President for Energy Union Maroš Šefčovic presented the Battery Alliance seeking to create an action plan for the next generation of high-performance and clean batteries. This initiative is expected to bring €200 million to support European battery development and innovation from 2018 to 2020, allocate €52.6 million from the InnovFin Fund to develop a European battery gigafactory[35], and award with €10 million the development of a reliable, safe, low-cost battery for electric vehicles.

## 8.5 Electricity market overview.

European markets share a similar structure as a result of European regulation. Markets have already unbundled main activities between regulated and liberalized activities, although some of them are still doing progress on the retail level complete liberalization. The energy market is operated by the different market operators in day-ahead and intra-day markets that clear energy price through a bidding power scheme that guarantees transparency. System operators, on the other hand, are in charge of economic management of network constraints and on managing the balancing market, where they offer differently tailored products that can be accessed either by auctions or bilateral contracts.

[33] *Recital 8 & Chapter II (General rules for electricity market), Article 9 (Price Restrictions), point 1, point 4*

[34] *Chapter II (General rules for electricity market), Article 11 (Dispatching of generation and demand response), point 2.*

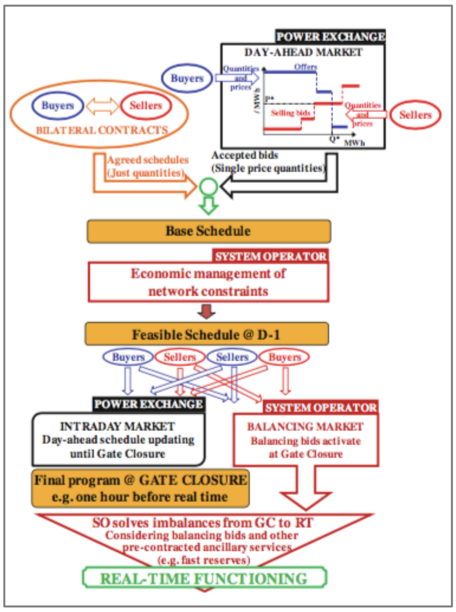
[35] *Recital 57*

[36] *Article 22 (RE Communities)*

[37] *Article 156 (FCR provision). Par.9*

[38] *Article 154 (FCR technical minimum requirements), Par. 6.d*

Figure 25: General wholesale market organization in European environments (Batlle et all, 2017)




In Europe there are six main electricity day ahead markets: (i) EPEX Spot for France, UK, Germany, Switzerland, Luxemburg and Austria;(ii) BelPex for the Nertherlands and Belgium, (iii) Omie for Spain and Portugal, (iv) NordPool, for Denmark, Scandinavia and the Baltic countries (v) OTE in Czech Republic, and (vi) GME in Italy. These markets participate in a pan-European multi-regional price coupling program, the Price Coupling of Regions (PCR), particularly aimed at short-term allocation of cross-border capacity in the markets. Particularities of the markets influencing storage development will be analyze under the Germany and UK sections of this report.

## 8.6 Assessment of regulatory barriers addressed by regulation.

### *Specific regulation*

- **Definition of storage:** The current European regulation does not contain any definition for electricity storage, nevertheless there is one definition drafted in the upcoming Electricity Directive of the Clean Energy for all Europeans: “energy storage means, in the electricity system, deferring an amount of the electricity that was generated to the moment of use, either as final energy or converted into another energy carrier”. This definition links storage technologies with generator activity, but still offers enough ambiguity to create the opportunity of stablishing a new category of asset.

- **Grid fees**: The Winter Package stablishes that non-discriminatory network fees must be applied between generation at transmission and distribution levels, specifically they should not discriminate storage.

- **Ownership:** As a general rule, the EU is clear in maintaining the unbundling requirements that imply that TSOs and DSOs are not allowed to own storage. The Winter Package makes an exception for this rule: if market doesn’t show enough interest and subject to be revised every five years. Nevertheless, both TSO and DSO are encouraged to consider energy storage possibilities for network services.

### *Participation in electricity markets*

- **Technical requirements in wholesale markets.** The new European regulation calls for opening day ahead and intra-day market to new actors, including storage assets or prosumers linked with storage, at the same time that calls for reducing participation size requirement to less than 1MW. The new regulation also makes specific declaration of allowing storage technologies to participate in cross-border activity, opening the opportunity to participate in the allocation of cross-border capacity. As it can be seen, the EU is committed with a full participation of storage technologies in the wholesale markets.

On the other hand, the EU's new regulation supports an energy-only market operation, with a direct call to avoid any price measure that could distort the market. In particular, this means that mechanisms to support RE such as capacity markets and feed-in tariffs should be avoided, removing potential direct financing opportunities for storage but allowing better market remuneration through potential scarcity prices. The Winter Package phases out Renewable energy priority of dispatch (for RE plants larger than 0.5MW) and calls to avoid any type of price cap, making it possible to the market to freely reflect scarcity situations. These measures improve storage technologies competitiveness, its attractiveness for RE plants and improves the revenues streams they can be subject to. The winter package also calls for designing continuous intraday and balancing market that, again, could benefit storage technologies fast response capabilities.

- **Technical requirements in network services.** The Winter package calls to TSOs to guarantee eligibility of storage for Ancillary Services and creation of transparent, technology non-discriminatory and market-based procedures, with a trend to create continuous markets. DSOs are encouraged to use storage technologies in their transition to offer increased network services. Nevertheless, it will be necessary to follow up on the current discussion concerning the Article 156 of the "Guideline on Transmisission System Operation", where there is uncertainty about whether minimum threshold for FCR activation can be set at 15 or 30 minutes: this would hamper the competitiveness of battery's fast response. It will also be interesting to follow up on the steps that ENTO-e may take in the inclusion of synthetic inertia for national network codes, a service that will be necessary in a RE environment.
- **Access to capacity markets:** The EU supports energy-only markets. On the other hand, the Clean Energy Package will allow storage technology to participate in cross-border capacity reserve in price coupling processes
- **Prosumers and aggregation participation:** The upcoming Clean Energy Package calls for opening the wholesale and balancing markets to new actors such as prosumers, aggregators and energy communities, which can open new opportunities for storage technologies demand and participation. AT the same time, DSOs are encouraged to take into consideration storage technologies and to increase their role in the network management by providing new services in coordination with TSOs, something that will open opportunities for aggregators businesses.
- **Access to tariff incentives for RE:** As it has been seen, the EU supports the removal of any support to RE that could distort the market price.

### *Creation of Track Record in the industry*

- **Development of demonstrative projects**: The EU is supporting the development of research and pilot projects on storage technologies with the creation of programs and with the provision of financing streams: 389 million EUR have been allocated for storage technologies under the H2020 program, the SET Plan encourages research in programs such as STORY and the Battery Alliance has just presented the allocation 200 million EUR for battery developments and the creation of a Gigafactory.
- **Existence of specific targets**: Although energy storage is widely recognized as a key technology in the achievement of the H2020 targets, the European Union has not stablished specific targets its development. Nevertheless, 225MW of storage were included project of common interest (PCI) in the context of the TEN-E infrastructure framework[39].
- **Existence of specific standards:** There are not official standards for energy storage at European level that the industry can look upon. Nevertheless, a first step will be taken when ENTSO-e includes storage in their NYDP, following the EC's directions.

*[39] In November 2017 the European Commission published its third list of PCIs, which includes 15 storage projects in electricity (11 hydro-pumped storage and 4 compressed air storage)*

# 9 United States of America (USA)

## 9.1 State of the Art

The United States (US is, by far, the leading global country in number of operational and projected energy storage projects. The has 25.2GW of energy storage installed, 94% of it on pumped hydro form. Other kind of storage technologies have been widely developed with 669MW of thermal storage, 758MW of batteries, 114MW of compressed air and 58MW of capacity in flywheels. According to the Department of Energy, more than 600MW of new batteries projects are expected to be installed in the following years.

The State that leads battery developments is California with 178MW already installed, followed by Illinois (144MW) and Texas (72MW). Out of the more than 600MW already announced, contracted or under construction, California again takes the lead with 435MW, followed by Arizona, Pennsylvania, Illinois and New York, all in the range of 200MW new storage projects.

The main uses of operational battery projects in the US are linked with frequency regulation (41%) and time shifting of energy (19%), which are the same main uses expected for new developments.[36]

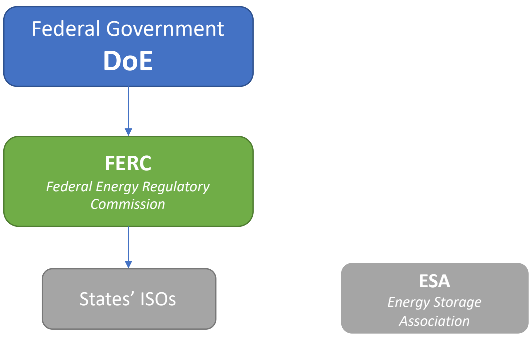
## 9.2 Main stakeholders in the electricity sector.

The executive branch of the Federal Government of the USA is organized in fifteen sectorial Executive Departments, among which energy affairs are under the rule of the United States Energy Department (USDoE)

As part of the executive branch of the government, there are also there are twenty-eight Independent Agencies, whose head's dependence from the President is limited and which creates regulations with the power of federal law. The most important agency in concerning the energy sector are the Federal Energy Regulatory Commission (FERC), the Nuclear Energy Commission (NRC) and the Environmental Protection Agency (EPA).

Each of the fifty states composing the USA will have its own executive and agency structure concerning energy sector, although taking into consideration the directions of the Federal Government.

*Figure 26: USA stakeholders on energy storage*




- **Department of Energy (USDoE)**: it is the branch of the executive power in charge of issues concerning policies regarding energy and safety in handling nuclear material. Its responsibilities include the nation's nuclear weapons program, nuclear reactor production for the United States Navy, energy conservation, energy-related research, radioactive waste disposal, and domestic energy production. It is a major physical science research financer, mainly through its network of National Laboratories (such as NREL, NETL or Sandia)
- **Federal Energy Regulatory Commission (FERC):** it is the federal agency with jurisdiction over interstate electricity sales, wholesale electric rates, hydroelectric licensing, natural gas pricing, and oil pipeline rates. FERC also reviews and authorizes liquefied natural gas (LNG) terminals, interstate natural gas pipelines, and non-federal hydropower projects.[37]

- **Energy Storage Association**: It is the main lobby association promoting the use of energy storage technologies by educating stakeholders, advocating for public policies, accelerating market growth, and delivering direct member value. It has set a goal of 35GW of new industry storage developments by 2025.

## 9.3 US Energy policy overview

The US top legislative figure is the Constitution, under which law, acts, regulations and rules follow. Once a Bill has been proposed by the Government or a member of the Parliament and passed the own Parliament and the assent of the President, it becomes a Law, either in the form of Act or Orders.

- **The Federal Power Act.** The first step in the regulation of the energy sector was taken in 1920 with the enacted Federal Power Act, which has been amended several times, the last in Energy Policy Act of 2005. This acts stablishes in its Parts II and III the legal authority of the FERC and in the last amendments it has contained main dispositions concerning liberalization of the electricity market, unbundling activities of the electricity sector, promotion of renewable energy and energy efficiency or the roll out of smart metering.
- **FERC order 888 & 889 (1996):** stablishes the rules guiding the liberalization of the electricity wholesale markets.
- **FERC order 2000 (1999):** stablishes further rules for the unbundling of the network operation and management, leading to the creation of differentiated ISOs and transmission network owners. Seven large regional transmission operators (RTO/ISO) are created: CAISO, SPP, ERCOT, MISO, PJM, NYISO, and SONE. Since this framework has been taking place, the US market has been behaviouring in quite fragmented way, with low transmission exchanges between zones and different criteria for reliability benchmarking.

## 9.4 US Regulation for energy storage

The US has been the global leader in the regulatory initiative for the development of energy storage technologies since it started in 2007.

**FERC Order 890 (2007):**[38] For the first-time storage is able to participate in the electricity market when the requirement for participation in the ancillary services includes "non-generating resources" for meeting grid reliability.

**Congress S1845, Storage Act (2011).**[39] This act amends the Internal Revenue Code (IRC) of 1986, thanks to which renewable energy investments have been benefiting from tax incentives. The Act provides an energy investment credit for energy storage properties connected to the grid making energy storage eligible for the tax incentive in section 48 of the Internal Revenue Service (IRS code), for all applications[40].[40]

**Congress S3159 Energy Storage Tax Incentive and Deployment Act (2016).** It Improves conditions estimated under S1848 (2011), expanding the 2013's Investing Tax Credit (ITC)[41] for Energy Storage. Storage technologies would only benefit from this tax credit when integrated with ITC-eligible solar resources under a narrow set of conditions and subject to recapture risks. In particular, only 30% of the energy storage expenditures can be included in the credit and only for the period 2017 to 2022, with minimum energy values of 5kWh in stand-alone storage and 3kWh for residential ones.[42]

**FERC Order 745 (2011)[43].** It addresses demand response compensation in wholesale energy markets, stablishing that demand should be compensated at the locational marginal price of the node it is connected to, always that this demand response is demonstrated cost-effective under certain rules.

**FERC Order 755 (2011)[44]**. This order mandates non-discriminatory procurement for frequency regulation, requiring ISOs to implement a performance-based payment in order to reward fast ramping services for frequency regulation. This payment should be divided in two: (i) a capacity

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*[40] S.1848 Sec2. (b): Includes "Qualified Energy Storage" in the IRC of 1986*

payment that includes the marginal unit's opportunity costs and (ii) "payment for performance"[45]through a market-based mileage payment with intervals of 4s that reflects the actual quantity of energy dispatched for frequency regulation.

**FERC order 764 (2012)**.[46] This order removes barriers for variable generation, such as renewable, in the wholesale market by introducing intra-hour 15min scheduling in wholesale pricing, and including particular constraints of these technologies, such as weather forecasts (if generators larger than 20MW).

**FERC Order 784 (2013)[47].** This order expanded the opportunities storage could obtained in the market by amending the "Avista Order" of 1999. Under the Avista Order, Transmission Dependent Utilities (TDUs)[41] were only able to procure ancillary services from the utilities (owners of transmission network) or from own resources as soon as they were deemed comparable to the ones offered by utilities. This imposed a limitation of costumers to seek faster of more efficient resources. With order 784, TDUs must take into account speed of answer for frequency control service and it opens the possibility of third party provision of AASS at market rate.[48]

**FERC Order 792 (2013).** This order opened the opportunity for small generators to be connected by utilities to the network in and just, reasonable and non-unduly discriminatory manner. These agreements and procedures are directed to generation facilities not larger than 20MW, opening the Fast Track Process for those smaller than 2MW.[49]

**FERC Docket RM16-23 (2016)[50] and FERC Order 841 (2018)[51].** The RM16-23 lead to the approval of the FERC Order 841, set at fully integrating energy storage resources into organized wholesale markets, seeking an increase in competition and lowering prices. ISO shave two years for full implementation.

First, a definition of storage is officially stablished: "Electric storage resource as used in this section means a resource capable of receiving electric energy from the grid and storing it for later injection of electricity back to the grid regardless of where the resource is located on the electrical system.". This definition clearly differentiates storage from generation or consumption activity.[42]

The, it included a Notice of Proposed Rule Making (NOPR) requiring each RTO/ISO to include in their market design the following concepts:

Accommodate the wholesale markets to recognizing the technical particularities of electric storage resources. In particular, the bidding procedures must include specific constraints for storage devices (such as state of charge), balancing market must be fully opened for storage to provide energy and capacity, the maximum capacity requirement for participation in the wholesale market must not exceed 100kW, and storage must be able to acquire electricity at nodal price (not retail tariff).[52]

Aggregators must be included as a new type of wholesale market participant and bidding parameters must be also adapted for them, allowing them to send their biddings directly in the ISOs and beneficiary of net metering programs.

**FERC Docket RM17-8 (2016).[53]** Which stablishes new and faster generator interconnection procedures. It specifically includes storage among the agents subject to these procedures and calls for ISOs to consider integrated models where storage acts both as generators and consumers.

**FERC: Policy Statement PL17-2 (2017).[54]** Through this policy statement, the FERC takes important steps in the recognition of the different revenue streams storage projects can benefit from, allowing storage technologies to capture full value acting in multiple services when receiving cost-based remuneration.

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*[41] Electrical utility that must rely upon transmission services owned or operated by another utility for the energy it needs to serve its customers, such as many municipal utilities.*

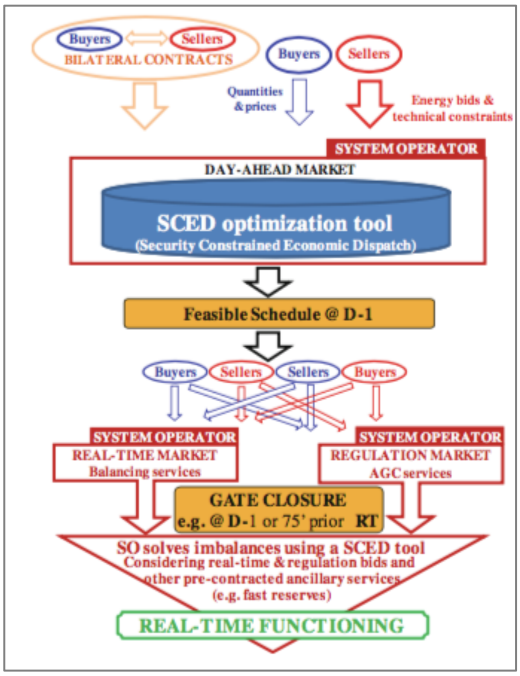
*[42] Ammendment of Part 35 Chapter 1, Title 18 of the Code of Federal Regulations. See Par. 35.28*

## 9.5 Electricity market overview

The electricity market of the USA is divided is operated by seven large regional system operators (RTO/ISO): CAISO, SPP, ERCOT, MISO, PJM, NYISO, and SONE. Since this framework has been taking place, the US market has been behaving in quite fragmented way, with low transmission exchanges between zones and different criteria for reliability benchmarking.

There are some key differences between the US and European electricity market to consider. Independent System Operators (ISOs) in the US act both as the market operator and the system operators who centralized both the day ahead and balancing markets. The market is cleared with an algorithm, so agents send their operative characteristics and costs and the ISO stablishes appropriate technical constraints, creating a more efficient but less transparent market clearance. While ISOs operate the networks, their owner is usually an utility, compared with the European environment in which the owner and operator of the networks is usually the same figure. Also, US pricing methodology for the day-ahead market is locational, creating nodal prices and allowing nodal capacity payments, while European markets tend to zonal or single pricing.

*Figure 27: general functioning of US electricity market, BAtlle et al (2017)*




Regarding the provision of Ancillary Services, the United States' ISOs use a different nomenclature and, depending on the ISO, can procure capacity and energy separately or combined. Frequency control is categorized under "Operating Reserves" which are classified as follows:

- When no event has happened yet: Regulating Reserve (automatic) and Following Reserve (manual)
- When an event happens: Contingency Reserve (instantaneous) and Ramping Reserve (non-instantaneous). These reserves are then applied for the so-called primary, secondary and tertiary frequency control, following UCTE denominations, but the NERC uses other common names to make reference to the same controls. Primary control reserve is "Frequency Responsive Response" (FRR), secondary control reserve can be either "Regulating Reserve" or "Spinning Reserve" and tertiary control is "non-spinnig reserve" or "supplemental reserve".

## 9.6 Assessment of regulatory barriers addressed by regulation

*Specific regulation*

- **Definition of storage:** The FERC provides in its Docket RM16-23 a definition for storage as clearly differentiated asset from generation or consumption: "resource capable of receiving electric energy from the grid and storing it for later injection of electricity back to the grid regardless of where the resource is located on the electrical system." This definition facilitates the integration of the storage in the grid and its participation in the market.
- **Grid fees**: storage technologies are allowed to operate their transaction at the marginal location market nodal price, as allowed by the Order 745, avoiding grid fees costs.
- **Ownership:** Since most of the networks of the US are owned by utilities, these have no limit in owning storage assets. Also, FERC Order 784 allows third party provision of ancillary services using storage technologies.

*Participation in eletricicty markets*

- **Technical requirements in wholesale markets**. Under FERC Order 841, the USA is moving forward in the full integration of storage technologies in the wholesale markets. Now ISO must adapt their wholesale markets to recognizing the technical particularities of electric storage resources. In particular, the bidding procedures must include specific constraints for storage devices (such as state of charge), balancing market must be fully opened for storage to provide energy and capacity, the maximum capacity requirement for participation in the wholesale market must not exceed 100kW, and storage must be able to acquire electricity at nodal price (not retail tariff). New market actors such as aggregators are recognized as participants to be considered, opening further opportunities to small scale storage. Also, the centralization of the wholesale markets in the US allows the FER to direct inserting constraints to better allow storage participants. Also, under PL17-2 the FERC recognizes and allows storage to benefit from different revenue sources
- **Technical requirements in network services.** ISO's wholesale market clearance includes balancing services and so FER Order 841 already considers benefits for network service participation. Also, out of the ISOs markets, the order Orders 792 allows not discrimination to small storage connection to the networks and Order 784 open opportunities for local utilities to build serve their own AASS needs with storage. Also, part of the reforms directed by the FERC for the wholesale markets includes the recognition of the speed of answer, in the form of a performance-based payment stablished under Order 755.
- **Prosumers and aggregation participation:** The US has recognized the new actors participating in the energy sector: aggregators and prosumers, opening opportunities for the deployment of small scale storage. Aggregators must be included as a new type of wholesale market participant and bidding parameters must be also adapted for them, allowing them to send their biddings directly in the ISOs and beneficiary of net metering programs
- **Access to tariff incentives for RE**: According to the S3159, up to 30% of the investments in storage can benefit from the investing tax credit (ITC) renewables investment have traditionally benefiting from.

*Creation of Track Record in the industry*

- **Development of demonstrative projects**: Intense research is promoted through the federal network of national laboratories, in particular the Sandia[55]. Nevertheless, specific programs and financing support is left at the States initiative.
- **Existence of specific targets**: The FERC has no specific targets at federal level for storage development, an initiative left at each State's side.

- **Existence of specific standards:** There are not official standards for energy storage evaluation at federal level that the industry can look upon. Nevertheless, the USDoE published the "Energy Storage System Guide for Compliance with Safety Codes and Standards" and steps are being made in developing tools for evaluation of costs and benefits from a regulator perspective, such as the Navigant tool sponsored by the USDoE.

# 10 Germany

## 10.1 State of the Art

Germany is a world-leading country in installation of battery systems for both residential and front of the meter applications. The residential (behind the meter) battery business is being driven by small solar PV installations, which between 2015 and 2017 has grown by 67%, reaching 1 million households with PV installed. Roughly 71,000 of these installations have included Li-Ion based batteries, accounting for more than 450 MWh installed, a figure that is expected to boost with the end of financing programs, descending prices of batteries and the steady high prices of electricity. The batteries installed in industrial sector are still focused for SMEs and self-consumption, with ah total market size of 25MWh, and expected to stay small in the short term.

Batteries in front of the meter services accounted for a market of 320MWh in 2017. The main services these batteries are installed for are 56% for frequency regulation (particularly for primary regulation control) and 23% for integration of renewable energies.[56]

## 10.2 Main Stakeholders in the Energy sector

*Key regulatory bodies and institutions.*

The country is part of the European Union. The government is defined as a Federal Constitutional Parliamentary Republic, organized in a bicameral parliament with a federal assembly (*Bundestag*) and federal council (*Bundesrat*). The country is subdivided in sixteen highly autonomous States (*Länder).*

In the energy sector, the Federal Government is primarily responsible for introducing legislation and the Länder are responsible for administrative implementation of national law. Energy related responsibilities are shared by several institutions, being the key ones:

- **Federal Ministry of Economics and Technology (Bundesministerium für Wirtschaft und Technologie, BMWi).** It is the main responsible for energy policy and for monitoring security of supply. It also takes care of matters of energy savings in buildings, in coordination with Federal Ministry of Transport, Building and Urban Development (Bundesministerium für Verkehr, Bau und Stadtentwicklung, BMVBS).
- **Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, BMUB).** It is the ministry in charge of overseeing the market adoption of renewable energy sources and promoting research on them. It is also in charge of all environmental regulation that affects the energy sector and, as such, supervises the Länders' responsibility of decommissioning the nuclear plants and the transportation and construction of storage for nuclear waste. The BMU, therefore, administers the Renewable Energy Sources Act (EEG).
- **Federal Network Agency for Electricity, Gas, Telecommunications, Post and Railways (Bundesnetzagentur, BNetzA).** Created in 2005, it is the federal institution in charge of ensuring compliance with the Telecommunications Act (TKG), Postal Act (PostG) and Energy Act (EnWG) and their respective ordinances. It guarantees the liberalization and deregulation of the markets for telecommunications, post and energy via non-discriminatory network access and efficient system charges. The coordination of utilities and network operators with more than 100,000 costumers connected inside a same Länder is driven from the State Regulatory bodies (Landesregulierungsbehörde), while the rest is made from the BneztA. It reports to BMWi.

- **Federal Environment Agency (Umweltbundesamt, UBA).** It is the federal insititution in charge of gathering and analyzing data related to environment issues. It is also responsible for supervising the implementation of CO2 trading regulation through the German Emissions Trading Authority (Deutsche Emissionshandelsstelle, DEHSt). It reports to the BMUB.
- **Federal Cartel Office (Bundeskartellamt, BKartA).** It is the federal competition authority in charge of market monitoring and market power control. It administers the Competition Act (Gesetz gegen Wettbewerbsbeschränkungen) and it reports to the BMWi. Other competition related authorities are the Monopolies Commission (Monopolkommission) and the Market Transparency Authority for Electricity and Gas (Markttransparenzstelle Strom und Gas), with particular focus in the application of the REMIT regulation.
- **German Energy Agency (Deutsche Energie-Agentur, DENA),** owned by the Federal Government and the public bank KfW, it is a public institution in charge of research and dissemination in subjects related with energy efficiency and energy transition adoption, as well as steering dialogue among main stakeholders of the sector.

*Key market agents.*

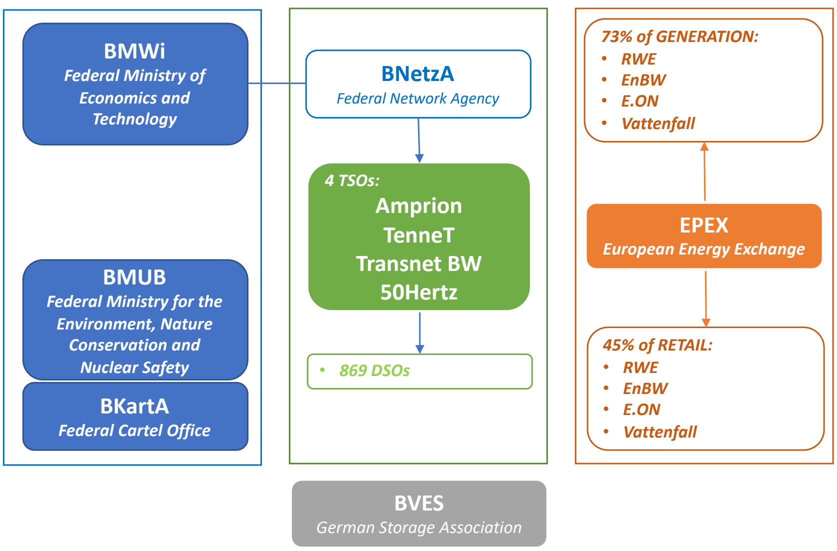
**Generation.** There are four big electricity utilities in Germany which concentrate 73% of generation production: RWE, EnBW, E.ON and Vattenfall.[57] These utilities have different participation in the current energy transition scenario, being EnBW the leader in renewable generation with 8.3TWh produced in 2016

**Market Operation.** The European Energy Exchange (EXX) was created in 2002 to operate platforms for trading electricity, Co2 allowances, coal and natural gas. The platform for trading electricity is composed by three markets: (i) The Electricity Power Exchange, or EPEX, managed jointly by France, Germany, Switzerland, Austria and UK and it includes a day-ahead and intra-day markets, (ii) Derivates market, and (iii) Over the Counter, OTC, market.

**Transmission.** There are four transmission system operators (TSOs): Mains ones are Amprion and TenneT, followed by the Transnet BW (concentrated in Baden-Wutermberg) and 50Hertz (with main activity in the former Eastern Germany). TSOs are responsible for the operation, maintenance and development of their respective sections of the German grid.[58]

**Distribution**. There are 869 DSOs in Germany, showing a highly complex and competitive market. Almost 80% of the DSOs are municipally owned (Stadtwerke), while EnBW, E.ON, RWE and Vattenfall own and operate a big portion of the market, stablishing concession contracts with municipalities. Under the Energy Industry Act, these concession agreements have to be renegotiated under non-discriminatory rules and can be cancelled.

*Figure 28: Structure of the electricity sector's main stakeholders in Germany*



## 10.3 Regulatory overview in the electricity sector

As part of the European Union, Germany is subject to the Union's initiatives, policy and regulation activity. The initiative of the German Government in the energy sector in the last years has been driven by the so-called "energiewende" (energy transition) that took legislative form through the approval of the Energy Concept 2010 and the consequent approval of the "Energy Package in 2011". In 2015 the so-called Electricity Market 2.0 project was launched by the BMWi in order to improve RES integration in the electricity market, resulting in (i) a new Electricity Market Act, (ii) the revision of the EEG, (iii) the establishment of a capacity reserve outside of the market, (iv) Act on the Digitisation of the Energy Tunraround and (v) publishment of the Interruptible Loads Ordinance (AbLaV).

**The Energy Concept 2010 ("energiewende")**:[59] This policy framework is the materialization of the "energiewende", it sets out Germany's energy policy until 2050 and specifically lays down measures for the development of renewable energy sources, power grids and energy efficiency. It marks the path for reduction of GHG emissions by 55% by 2030[43] (with the ambition of reaching more than 80% in 2050); it sets the target of load coming from renewable energy generation at 50% by 2030 and marks the need for a massive expansion of wind power installed capacity; it calls to decommissioning of the nuclear plants by 2022;it specifically supports the expansion of energy storage capacity and the participation of the electric vehicle in the grid balance. Under the "energiewende" they were also created the Energy Research Program, the Energy Efficiency Fund, the National Climate Initiative, and the National Development Plan for Electric Mobility.

**The energy package 2011**: Following the call of the Energy Concept, it concentrates on five major spheres of action: upgraded electricity grid infrastructure, a flexible electricity system, growing renewable energies, increased energy efficiency and greater investment in research and development, notably in storage technologies. It consists of seven revised acts and one ordinance: (i) Energy Industry Act (EnWG), (ii) Renewable Energies Act (EEG), (iii) Act to Accelerate the Expansion of Electricity Networks (NABEG), (iv) Nuclear Energy Act, (v) Energy and Climate Fund Act, (vi) Act to Strengthen Climate-compatible Development in Cities and Municipalities, (vii) Act on Tax Incentives for Energy-Related Modernization of Residential Buildings; and (viii) Ordinance on the Award of Public Contracts.

**The Energy Industry Act (EnWG, 2011)**: First revised in 2005 and then again in 2011, It contains the basic rules for the energy sector. This Act directs the unbundling rules of the electricity sector, establishes tasks for Lander's Network Authorities, and regulates physical connection with the transmission line in plants smaller than 100MW[44]. Under the EnWG TSOs must market power RE energy in the spot-market (EPEX).

**Renewable Energies Act (EEG, 2011)[60]**: This Act, revised in 2014 and again in 2017, seeks cost-efficient expansion of renewable energy and make most of the targets defined in the Energy Concept 2010 legally binding. The EEG stablishes a feed-in tariff system for renewable sources larger than 10MW (the "EEG Surcharge" or "EEG-Einspeisevergütung"), providing priority of connection to the grid to renewable sources and stablishing that applications providing services to the network should be selected thorough a tendering system. The revised EEG 2017, nevertheless, introduced the possibility of auctions for the installation of new RES.

**Electricity Market Act (StrommarktG, 2016)**[61]**:** It makes legally binding the provisions under the Electricity Market 2.0 project and amends various acts and ordinances, including the EnWG, the EEG and the Reserve Power Plant Ordinance. Its key dispositions are: (i) free price formation, reflecting scarcity and allowing peaks (ii) Monitoring security of supply at European level, (iii) Upholding balancing groups commitments, (iv) Prolonging the grid reserve, (v) Improving transparency with the creation of information platforms, (vi) Revising grid charges in order to avoid regional discrepancies, (vii) Introduction of a capacity reserve as detailed in the Capacity Reserve Ordinance (2GW by 2019), (viii) standing by and then decommissioning of lignite-fired plants by 2021.

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[43] *Compared with 1990 levels*

[44] *if larger, regulated by the Ordinance on the Connection of Power Plants to the Supply Grid*

## 10.4 Regulation for energy storage.

The German regulation specifically address energy storage and its promotion, focusing on promoting research and removing those issues that would hamper its competitiveness in the market.

The Energiwende in its Section D.3 It specifically calls for the removal of grid fees for new storage plants of grid access fees for longer periods than before and to approve energy storage systems for the control energy market, in its section F it recognizes that the National Development Plan for Electric Mobility will have to consider that electric vehicles will store electricity and thereby help to balance supply and demand, and its section G in stablishes that the Energy Research Programme should have as one of its main focus priorities energy storage methods and grid technology.

The EnWG envisions storage as a service to integrate RE and stablishes that new storage facilities are exempt from the usual grid charges. Under the EEG (Section 61K) this specify and stablishes that energy storage should be charge only those fees corresponding to the injection of energy in the grid while the § 19 Abs. 4 StromNEV includes that also the amount corresponding to electricity losses should be charged as grid fees. The § 19 Abs. 3 EEG also stablishes in its last revision that energy injected from storage should benefit from the feed-in tariff (EEG surcharge) designed for renewable energy generation.

## 10.5 Electricity market overview.

### *The EPEX spot market.*

Germany participates in the EPEX spot market, both for day-ahead (with France, Switzerland and Austria) and the intra-day (France). The products that can be traded on EPEX SPOT are standard contracts for the physical delivery of electricity within the respective transmission systems. The products are characterized by two different trading processes: auction and continuous trading, depending on the market.

The day-ahead market of EPEX is an auction organized market for which Germany and Austria act as the same single price zone. Block orders are allowed, included the so-called smart block orders (linked or exclusive). German TSOs have the obligation of bidding their renewable energy in the spot market. Prices are capped at €-500/MWh and the maximum €3000/MWh.

The EPEX intra-day market can be either continuous or auction based. The continuous market can be on single hours, 15min periods or block hours, accepting limit and market sweep orders as well as OTC trades. In 2011, EPEX created an auctioning approach of 15 min contracts and 0.1MW minimum bid for the German market, facilitating trading with intermittent power sources (RES) and helping dealing with intra-hour variations in production and consumption. Price limits are established at ±3,000 €/MWh.

Since 2014, the EPEX started the North-Western Europe (NWE) price coupling project, which aims at putting a price coupling in place for the day-ahead electricity wholesale for NWE region, planning and the rolling out of the Price Coupling of Regions (PCR) solution, Euphemia. The NWE includes three regions: Nordic, Great Britain and CWE (including Germany). EPEX coupling of markets is proving to be a useful tool in integrating renewable generation installed, increasing liquidity of the market and smoothing prices, and is expected to create a single price market in the zone.

### *Balancing Markets*

The ancillary services remunerated in Germany are primary (FCR) and secondary frequency (FRR) control, minute reserve, reactive power, black start capacity, re-dispatch and countertrading

Primary frequency reserve is with a weekly 6 days in advance gate closure and a minimum offer of 1MW, with a required activation time of 30s and then paid per available power. FRR Reserve (secondary frequency) are also procured auction based, with weekly 5 days in advance gate closure and a minimum offer of 5MW, with a required activation time of 15min and paid per available power and energy produced. Tertiary regulation (known as Minute Reserve Market, MCR) is paid per available power and energy produced in daily auctions, with a minimum offer of 5MWe[62]

By July 2018, new rules for the acquisition of secondary frequency reserves will be stablished by BenetzA (i) the frequency of auctions will be increased, taking place daily, (ii) two products will be available (positive and negative) with the number of slices increased and times shortened to 4h and (iii) they will be opened to offers lower than 5MW subject to bidding only to one product[63]

The German balancing market, as most Europeans, applies a dual imbalance pricing for secondary frequency control, where positive and negative imbalances are paid considering the imbalance and the deviation of the whole market. In Germany, a uniform balancing energy price (reBAP) has been in place since 2010, calculating deviations every 15 minutes[45].

The Electricity Market Act seeks larger competition in the flexibility options, opening the market to flexible power production, such as storage, and expecting to open the market soon to electric vehicle participation. The Electricity Market Act redefines the inclusion of facilities providing reserve services, opening up the definition from "generating plants" to just "plants", opening participation for the load side (and so storage), subject to comply with necessary technical requirements.[64]

The Ordinance for Interruptible Load (AblaV) has also reduced the requirements stablished in the EnGW §13.i and now all electricity customers consuming more than 10 MW (the previous limit was 50MW), that is in general medium and large companies, can offer interruptible capacity to network operators. The AblaV also ensures not discrimination for technologies in the tendering processes carried out by TSOs

*The EEG Surcharge (Feed-in Tariff)*

The promotion of new RE capacity in Germany has been mainly promoted by the establishment of two tariff scheme possibilities: a feed-in and a feed-in-premium. This tariffs are transferred to end consumer's tariff, representing in 2017 23% of final charge.

The feed-in tariff (known as EEG-Einspeisevergütung) makes the TSO acquire from DSO the energy purchased from the RES producer at a fixed price for each unit. Then, the TSO is obligated to sell this electricity in the spot market (either day ahead or intra-day). In order to cover the difference between both prices, TSO are paid the so-called EEG-levy, which is charged to end consumers in their tariff. This feed-in tariff is guaranteed for 20 years and calculated for new investments every year. In 2017 the EEG-levy was set at 6.88 EURcent/kWh and, according to Agora think-tank, this levy will peak around 2023 pushed by lowering spot market prices.

The feed-in tariff with premium scheme is based on allowing direct commercialization of RES generation in the spot market by producers. They then receive two additional premiums: one covering the difference between feed-in tariff and market price and another one to cover the management costs, also funded by the EEG-levy charged to consumers bill.[65]

*Renewable Energy Auctions*

The new EEG-2017 created a new capacity market for RES via competitive auction system,[66] seeking a reduction in costs that are now reflected in the feed-in scheme and that affects consumer's tariff. Starting in 2017, planned auctions are: 2.8GW for on-shore wind, 15GW of off-shore wind, 600 MW annually of solar PV and 150MW annually of biomass. The EEG-2017 also seeks coordination between network development and RES, section 36c, putting limits to new RES installations in areas where the network is considered weak (Netzausbaugebiet), mainly defined in the North of the country.[67]

## 10.6 Assessment of regulation and market for energy storage

*Specific regulation*

- **Definition of storage:** The energy storage in Germany is not defined as a specific asset of the network by itself and is therefore subject to provisions related to acting as electricity consumers or generators. Nevertheless, with the upcoming European "Clean Energy for all Europeans Package", Germany will incorporate the definition contented at European level.

*[45] The settlement time may increase to 30min following the last network codes published by Entso-e*

- **Ownership:** In line with the unbundling policies of the European Union, German regulated entities cannot own and operate storage facilities subject to the exceptions underlined in the upcoming e-Directive.
- **Grid fees**: The EEG-2017 section 61Kthe storage technologies connected to the grid will only pay grid fees once, related to electricity fed in to the public grid, but will not pay grid fees as consumers.

*Access to markets*

- **Technical requirements in wholesale markets**. EPEX Spot does not provide specific access to storage technologies, although its characteristics benefit storage supporting RE: priority access and short-gate closure time, with a continuous intra-day market. In 2011, EPEX created an intra-day auctioning approach of 15 min contracts and 0.1MW minimum bid for the German market, facilitating trading with intermittent power sources such as RES and opening opportunities for storage technologies to eventually participate. Also, it will be interesting to follow on the agreement between EWE AG and EPEX on launching a local market platform for flexibility sources, expected to be in demonstrative phase by 2018. This platform will stablish market-based system for flexibility agents to provide congestion management.
- **Technical requirements in network services.** It is in the provision of balancing services that German regulation has advanced the most: The StrommarktG 2016 opens participation in flexibility market to load actors, the AblaV reduces the minimum capacity requirement from 50 to 10MW and the BenetzA will make effective the new rules for frequency control market by July 2018, accepting bids to 5MW, increasing the number of products and shortening the times (4h) and promoting pooling assets.

  The fact that FCR services are remunerated has been very attractive for investors in battery storage in Germany, accounting for more than 140MW installed by mid 2017. Nevertheless, challenges may arrive due to current discussions in BneztA about aligning with the Article 156 of the European System Operator Guidelines, where the settlement time for primary frequency control (FCR) can be set at up to 30min. FRR services (Secondary Regulation), though, has been not that attractive for storage in Germany due to lowering prices and the need for a more complex bidding strategy. By July 2018, the new rules of BnetzA for Secondary control will enter into force making it possible for most battery storage technologies to participate with this minimum storage capacity of 5MW and benefitting aggregators positions. Nevertheless, if this increased competition makes prices to decrease, secondary frequency control will still not be attractive enough.
- **Access to Capacity Markets**. EEG-2017 created a new capacity market for RES via competitive auction system, nevertheless storage is no expected to allow to participate
- **Prosumers and aggregation participation:** Germany will be subject to opening the markets to new actors participation in line with the new European regulation. Germany is also developing the MieterStrom project, supported by the EU, seeking the development of a business model for aggregated solar PV generation for communities of neighbours.
- **Access to tariff incentives for RE**: The § 19 Abs. 3 EEG also stablishes in its last revision that energy injected from storage should benefit from the feed-in tariff (EEG surcharge) designed for renewable energy generation. On the other hand, old Feed in Tariffs, that were signed for 20 years, are expected to start expiring by 2020, probably boosting the front-the-meter battery market.

*Creation of Track Record in the industry*

- **Development of demonstrative projects**: The KFW has been supporting energy storage developments in the programs 203, 204, 274, 275, 291 and 230. The KfW-275, focused on peak shaving of consumers and granting up 30% of the storage-PV investment by a rebate mechanism, is considered to be one of the main drivers for behind-the-meter storage development together with private PV installations. High electricity prices and lowering feed-in tariffs, made that this program could boost residential battery storage. Rebate support has been reducing gradually and consumers will be able to benefit from it until the end of 2018 with a 10% rebate subsidy. The BMWi has also supported storage development through its Energy Storage Funding Initiative, which has been supporting since 2012 approximately 250 projects with 200 EUR million. The projects covered by the funding initiative range from batteries in households to storage systems in the megawatt range and projects for the long-term storage of renewable energy where renewable electricity is used to produce hydrogen in electrolysers. Main batteries projects in Germany have been developed to participate in primary frequency control (PCR), such as the STEAG built six new large- scale 15 MW or the 22MW is expected to install in the following year. Other innovative programs for aggregation of batteries (RegModHarz) or for the recycling of vehicle batteries are been tested (Daimler).

- **Existence of specific targets**: The German government has not specific target on storage technologies insertions, although is expected that its development be driven by the ambitious RE targets, which has been updated in 2018 to reach 65% of electricity consumption from RE sources by 2030. The country did settle a target of 1 million electric vehicles by 2020 in their National Electro-mobility Development Plan.
- **Existence of specific standards:** The country has not yet global standards for storage technologies that could serve as reference for the industry payers in assessing investments and returns. Nevertheless, the recently created BVES (German Energy Storage Association) has published safety guidelines related with behind the meter battery installations as well as guidelines on requirements for Li-Ion bulk storage systems.[68]

# 11 United Kingdom

## 11.1 State of the Art

The United Kingdom is one of the European leaders in behind-the-meter installations of batteries. There are almost 16,000 residential storage units installed, accounting for more than 35MWh. These installations are mostly linked to the PV generation on rooftops, which are increasingly demanding better batteries preparing for the end of the feed in tariffs schemes. The UK leads the European energy storage installation for commercial and industrial installations, accounting for 14MWh of Li-Ion and Flow batteries.

Regarding front-of-the meter applications, the UK has already almost 250MWh of energy storage installed, out of which 92% has as primary used the provision of frequency control services to the network.

## 11.2 Main Stakeholders in the Energy sector

*Key regulatory bodies and institutions.*

The United Kingdom is a constitutional monarchy with a parliamentary democracy. The UK is formed by four countries: England, Scotland, Wales and Northern Ireland, each with its own autonomous administrations. The Government of the UK is organized in 24 ministerial departments (headed by political ministers) non-ministerial departments (headed by civil servants to avoid political oversight) and corresponding executive agencies.

- **Department for Business, Energy and Industrial Strategy (BEIS**): it is the ministerial department that merges the departments of Energy and Climate Change (DECC) and the Department for Business, Innovation and Skills (BIS), being responsible for the UK's policy on energy, climate change and innovation, among others. Energy policy is one the matters that has not been devolved to the regions although some parliaments, such as the Scottish one, have planning capabilities to influence new generation plants developments.
- **Office of Electricity and Gas Market (OFGEM):** This non-ministerial department is the UK's government regulator for the electricity and downstream gas markets. Its main task is protecting costumers while promoting competition. The governing body of the Ofgem is the Gas and Electricity Markets Authority (GEMA).

- **Competition and Markets Authority (CMA):** This non-ministerial department is responsible for strengthening business competition and monitor and avoid market-power abuse situations.

*Key market players*

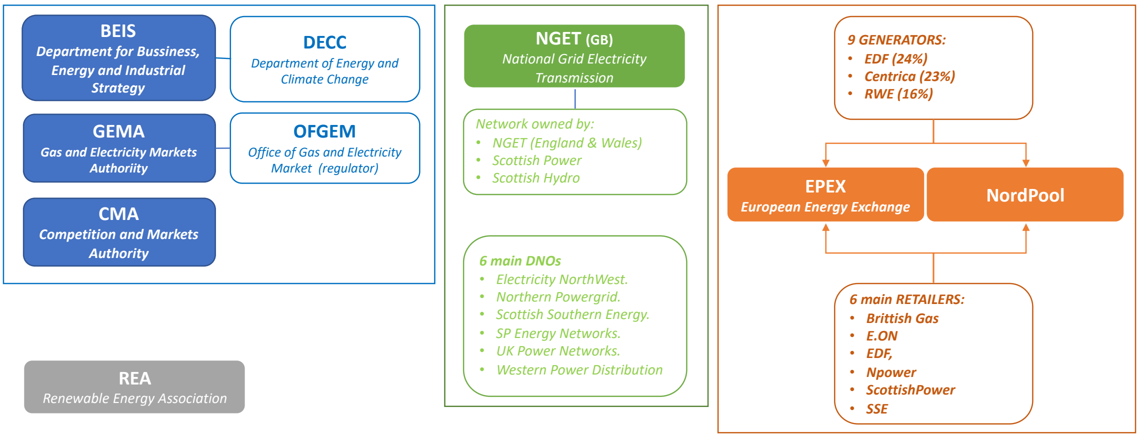
**Generation.** The UK generates annually 338 TWh of electricity and has 97.8GW GW of capacity installed, 36.5% renewable sources.[69] There are nine main generation companies, out of which EDF controls 24% of the production, Centrica 23% and RWE 16%.

**Market operation**. UK generators and load agents have access to two power markets operated by two Nominated Electricity Market Operator (NEMO): the European Energy Exchange (EPEX SPOT)[46] and the NordPool (N2EX in the UK). Both include day ahead electricity market, with EPEX including also half-hour auction day ahead market, a Spot (Intra-day) market and a prompt market.

**Transmission.** In the UK there are four TSOs owning and operating the electricity network: The System Operator Northern Ireland (SONI), Scottish Power Trans. Ltd, Scottish Hydro Transmission and the English National Grid Electricity Transmission (NGET). This study will focus on the operation and rules of the larger one, NGET.

**Distribution.** There are 14 licensed DNOs in the UK, been the main ones Electricity NorthWest, Northern Powergrid, Scottish Southern Energy, SP Energy Networks, UK Power Networks, Western Power Distribution. The UK is promoting the transition of DNOs to proper DSOs (providing services rather than only managing the networks)

*Figure 29: Main stakeholdes in the UK's electricity sector*




## 11.3 Regulatory overview in the electricity sector.

The electricity sector in the UK operates in line with specific legislation, licenses and industry codes, under the supervision of the regulator OfGem

- **Utility Act 1989**: where the license regime for generators were stablished and the duties of Ofgem defined. This act also defined the unbundling rules between regulated and liberalized activities in the electricity sector, particularly between transmission and generation activities. The amended Utility Act 2000 created GEMA as government body for Ofgem.
- **Energy Acts 2004 to 2013.** The Energy Act 2008 supported the development of renewable energy and the definition of feed-in tariff schemes for small renewable generation installations (<5MW).Subsequent Energy Acts created three approaches for the promotion of low carbon generation: (i) Contract for differences (CfD), (ii) Feed-in Tariffs (FiT) (iii) Renewable Obligations (RO). Feed-in Tariffs and RO will be phased out by CfD schemes.

*[46] The EPEX SPOT and APX Group power exchanges, including Belpex, integrated their businesses in 2015 to form a power exchange for Central Western Europe (CWE) and the UK*

The Energy Act of 2013[70] directed the Electricity Market Reform (EMR), stablishing provisions for low carbon generation and SoS. Main reforms concern the creation of The CfD framework for the promotion of low-carbon generation, the replacement of the RO schemes by the Renewable Obligations Certificates (ROCs), creation of a capacity market for new generation to provide security of supply services[47], and the approval of the Emissions performance standard (EPS) limiting the amount of emissions produced by fossil fuels generation at 450g/kWh until 2045.

- **Industry Codes**. The main industry codes influencing the functioning of the electricity sector are the Connection and Use of System Code (CUSC), the Balancing and Settlement Code (BSC), the Grid Code, The Distribution Code, the System Operator–Transmission Owner Code (STC), the Distribution Connection and Use of System Agreement (DCUSA) and the Master Registration Agreement (MRA).

## 11.4 Regulation for energy storage.

The UK's existing Acts do not directly address storage technology. The regulatory document that influences de most the development of energy storage in the UK is the Balancing and Settlement Code (BSC). The BSC contains the arrangements for the wholesale market with particular focus on electricity balancing (reserves) and settlement (actual delivery or off-take of imbalances). Under this code, the NGET organizes auctions or, if not enough demand appears, signs bilateral contracts for the provision of reserves and balance services.

*Smart Systems and Flexibility Plan (Ofgem, July 2017)*

Although storage is not specifically treated in the regulation, the Regulator of the UK 's electricity system published this plan guiding main action influencing the development of flexibility sources such as energy storage technologies. These documents include a list of the main actions Ofgem will carry out to remove regulatory barriers for storage technologies, new market design options and the creation of Government's financial plans.

The main actions that Ofgem identify to be limiting storage technologies development are the following: (i) network's residual charges[48] now collected from generators should be passed to consumers, and storage technologies should not be subject to them, (ii) a definition of energy storage should be included in the Electricity Act as a subset of generation asset, something expected to happen in July 2018, (iii) review national network planning including thresholds for storage, (iv) remove all kind of levy-charging on energy storage technologies as they should be treated as generators and make them beneficiaries of these promotion measures, including the levies for RO, CM, FITs and CFD and also Climate Change Levy, (v) develop health and safety standards for storage in collaboration with British Standards Institute, and (vi) remark the unbundling dispositions avoiding TSO to own and operate energy storage technologies.

Ofgem also calls to carry out market reforms to that will make it more attractive for flexibility providers. These reforms will be coordinated with NGET and will be directed at creating better price signals in the reserve capacity markets and they Ofgem recognizes that they should allow the participation of aggregators and allow storage technologies to stack revenues streams from capacity reserve and ancillary service provision. In particular, the BSC will be modified in its P344 to create a body in charge of allowing access of aggregators to the networks. Also, DNOs are called to be transformed in DSOs and Ofgem will consult on a new regulatory framework for the System Operator to be in place by April 2018.[71]

Ofgem's plans also related the government initiative at promoting energy storage related projects: 70m pounds for Smart Innovation (2017), 246m pounds for Industrial Challenge Fund to promote disruptive technologies, including EV batteries (2017), £9m challenge fund focused on cost reductions for storage, £20m vehicle-to-grid competition, and £7.5m competition for innovative non-domestic DSR.

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[47] *For generation not benefiting from CfD schemes. Auctions every four years, starting 2014.*

[48] *Residual charges represent around 80% of overall transmission charges, and they are top-up costs set to ensure network companies can recover their allowed revenue under Ofgem price controls. (source: utilitywise)*

## 11.5 Electricity Market Overview.

*The EPEX SPOT market for UK.*

As it was explained above, UK generators and load agents have access to two power markets operated by two Nominated Electricity Market Operator (NEMO): the European Energy Exchange (EPEX SPOT) and the NordPool (N2EX in the UK). Both include day ahead electricity market. The EPEX SPOT market is the main trading spot and is was originated when The EPEX SPOT and APX Group power exchanges, including Belpex, integrated their businesses in 2015. There are five products traded (i) hourly day-ahead auctions under the same terms described for Germany, (ii) UK Half Hour Day-Ahead 15:30 Auction, which works under the same terms as traditional day-ahead but with for 30min products and bidding lots with a minimum size of 0.1MW, (iii) the spot market, which trades physical contracts of blocks from half to four hours and starting from several days before to 30min before delivery, acting as intraday market; and (iv) the prompt market where financial and OTC contracts are traded.

*Capacity Market.*

Under the Electricity Act of 2013, the government of the UK started the creation of a capacity market for new generation. Storage technologies are allowed to participate subject to the application of a de-rating factor to their bid capacity that recognizes its limited duration. This factors to from the 21.34% for 30min duration batteries to 96.11% for those batteries with more than 4h duration (2018/19 auction).

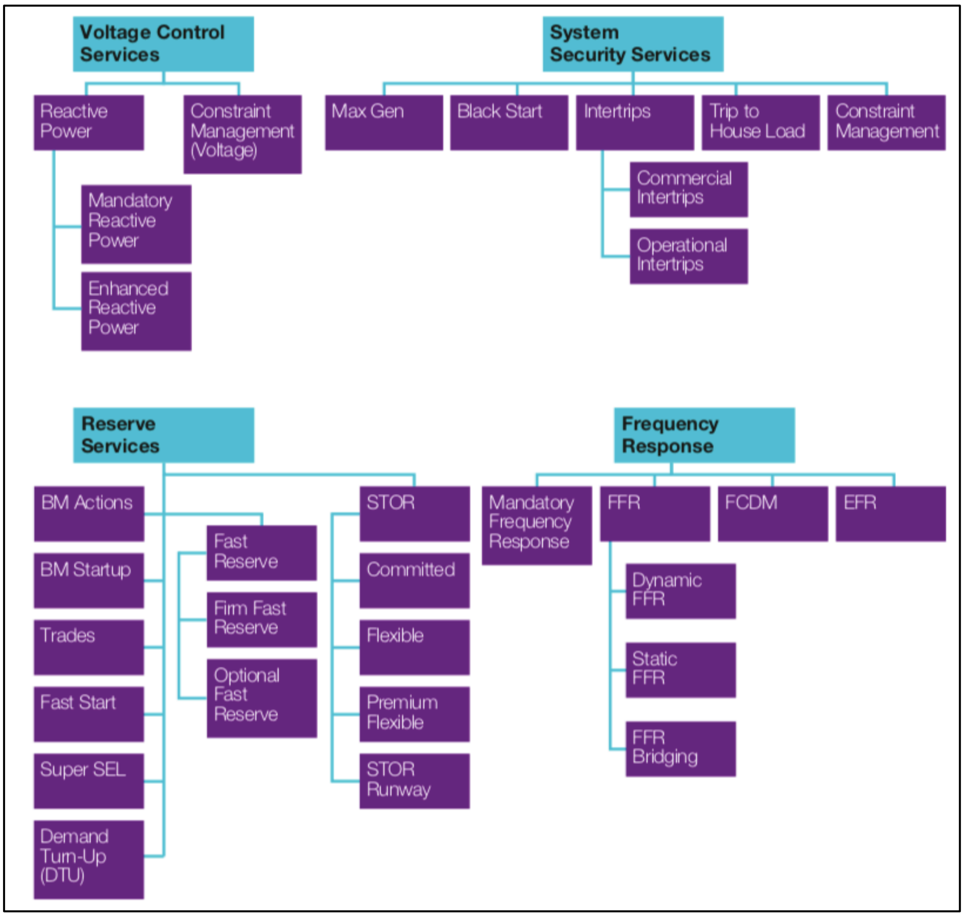
*Balancing Market.*

This market is managed NGET and the main products offered are described in the System Operability Framework 2016 (SOF 2016). The UK's balancing market is characterized by a complex suite of products developed in order to adapt to certain technical characteristics of different technologies.

The Balancing Mechanism is operated by NGET from "market gate closure", when generators have to send the Final Physical Notifications (FPNs) to the operator, through to real time. NGET procures firm volumes required for managing demand forecasting errors and large losses via regular tenders ahead of time. Closer to real time, downward and upward flexibility is managed either by balancing market or direct trading, coordinating with the intraday settlements carried out by Ofgem in the Spot Market. Portfolio participation of the generation and demand agents in the Balancing Market is recognized through the figure of Balancing Mechanism Units (BMU).

The NGET's reserve products portfolio is especially complex and suited to many needs, composed by 32 products grouped for voltage control services, system security services, reserves services and frequency response.[72]

*Figure 30:NGET's balancing market product suite, NGET (2017)*




In this suite it can be seen how Primary Frequency control (Mandatory Frequency Response, MFR) in the UK is remunerated, while NGET recognizes the participation of synthetic inertia participation. Also, how speed of answer is specifically rewarded in the "Firm Fast Reserve" (Secondary Frequency Control from units between 25 and 50MW and 2min reaction time) and how there are different products for Dynamic and Static response allowing continuous and non-continuous secondary frequency control responses. The Enhance Frequency Response (EFR), thought to properly remunerate fast response services with less than 1 second answer, is specifically tailored for storage technologies.

The current pricing method used to procure reserves is competitive and the auctions clear the price in a pay-as-bid approach and is set out in a "dual imbalance" manner. With the increasingly higher number of products and participant and the need of flexibility, a more efficient clearance with a marginal pricing approach is being studied by NGET. Also, NGET is exploring possibility of improving the aggregation of for products different from the STOR, where generation units larger than 3MW can already be aggregated.

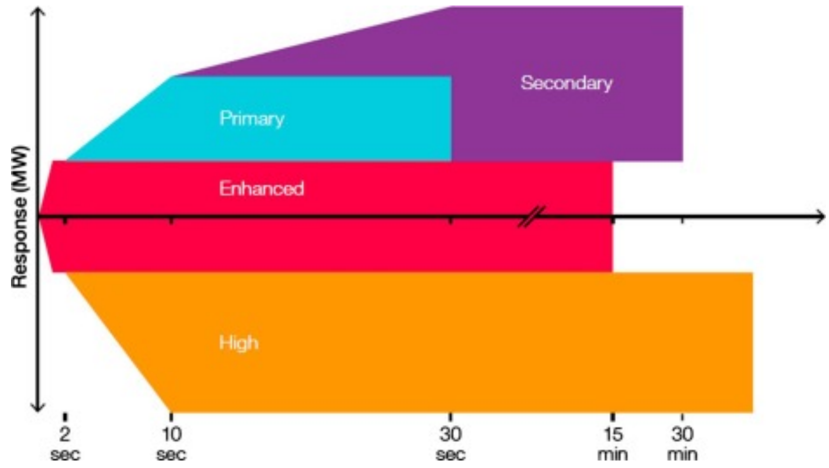
This suite is a global reference on a reserve and balancing market designed for different technologies and needs but is creating an internal debate in NGET on the excessive number of products, due to the confusion it creates in the market and the overlapping of same services under different products. This way, the NGET is currently in the process of developing a substitutive product for FFR (Secondary response) and EFR, seeking to provide flexibility closer to real time. This product will be coordinated with the expected TERRE project (UK participates), which will harmonize frequency control products in Europe starting with RR (tertiary) control by the end of 2018.[73]

### *Enhanced Frequency Response (EFR)*[74]

This product for frequency control response was introduced by NGET specifically tailored for energy storage technologies: it requires less than 1 second response answer, the provider must be able to deliver the service in either direction, it must be able to provide 100% capacity for a minimum of 15 min, must maintain an operational availability of 95% to qualify for the full payment.

Storage agents are required to response when a threshold of deviation is reached, which can be set at ±0.05 Hz or ±0.015 Hz. In NEGT's auction in 2017, it received 888MW of battery projects biddings.

*Figure 31: available frequency response services in GB, their response times, and their durations, NGET 2016*




## 11.6 Assessment of regulation and market for energy storage.

### *Specific regulation*

- **Definition of storage:** There is not a definition of energy storage in UK's regulation, nevertheless it is expected to be included in primary regulation (Electricity Act 1989) by summer 2018 as a different generation asset class.
- **Ownership:** OFGEM is positioned as TSOs not owning storage assets, guaranteeing unbundling.
- **Grid fees**: There is currently double charging for storage as consumer and generator for the grid, although Ofgem is supporting to amend Electricity Act 1984 to include storage as subset of generation technology, being subject only for fees for injecting energy and free of all levies. Also, the existing payment for "embedded generators" in distribution networks is going to be reduced by Ofgem.[75]

### *Participation in electricity markets*

- **Wholesale markets**. EPEX Spot does not provide specific access to storage technologies, although its characteristics benefit storage supporting RE: priority access and short-gate closure time, with a continuous intra-day market. In the UK there is a particular trading, the "UK Half Hour Day-Ahead 15:30 Auction", which works under the same terms as traditional day-ahead but with for 30min products and bidding lots with a minimum size of 0.1MW, what can open potential opportunities for storage to participate in the market.
- **Network services.** This EFR product for frequency control response was introduced by NGET specifically tailored for energy storage technologies: it requires less than 1 second response answer, the provider must be able to deliver the service in either direction, it must be able to provide 100% capacity for a minimum of 15 min, must maintain an operational availability of 95% to qualify for the full payment. It is allowed the stacking of revenues between the Capacity Market and ancillary services
- **Prosumers and aggregation participation:** NGET is exploring possibility of improving the participation of aggregation of for products different from the STOR, where generation units larger than 3MW can already be aggregated. Ofgem expects that 30-50% of balancing capability will be sourced from the demand side by 2020, including aggregators. Virtual Power Plants (VPP) are also being developed and expected to open new opportunities to distributed storage.

- **Access to tariff incentives for RE**: Ofgem is planning to open the available mechanisms for RE promotion (CfD, FiT and RO) for storage participation. On the other hand, storage could benefit from The Green Energy Tariff scheme that provides a feed-in tariff scheme for those consumers who also generate, as soon as double charging is avoided.
- **Capacity Markets.** The Electricity Act 2013 stablishes a capacity market for technologies not benefiting from CfD schemes and thought to provide balancing services. Capacity is assigned through auction price cap with 4 years in advance and in which the storage technologies are allowing to participate. The first auction took place in 2014. The attractiveness for participation of storage in following auctions has been limited since December 2017, when the BEIS showed intention to lower the de-rating factor in Capacity Market auctions from 96% to 17.89% in auctions for 30 minutes duration batteries.[76]

*Creation of Track Record in the industry*

- **Development of demonstrative projects**: There are two main financial initiatives by the Government: 70m pounds for Smart Innovation (2017) and 246m pounds for Industrial Challenge Fund to promote disruptive technologies, including EV batteries (2017). Also, the UK created the Battery Institute to promote research on these technologies.
- **Existence of specific targets**: There are not specific targets for storage, although it will be driven by the Electricity Act's (2013) target of 15% RE by 2020 and the Climate Change Act (2008) of 80% reduction of GHG emissions by 2050. Ofgem may create specific targets as a consequence of its “smart systems and flexibility plan” (2018).
- **Existence of specific standards:** There are not specific standards for storage facilities, although the British Standards Institute is working on a H&S framework in collaboration with Ofgem.

# 12 New York State

## 12.1 State of the Art of batteries.

The State of New York has currently 22MW of operational capacity of battery energy storage, with almost extra 20MW projects announced, contracted or under construction. Almost 70% of the current operational battery installations have as primary service providing capacity firming for renewable sources, with more than 50% of the announced projects to provide energy time shifting.[77]

## 12.2 Main Stakeholders in the Energy sector

*Key regulatory bodies and institutions.*

The government of New York State is divided in up to twenty departments, each of them grouping several sectorial offices. The state energy policy is subject to the federal direction given by FERC, as described in the US chapter.

- **Office of Air Resources, Climate Change and Energy:** This office is integrated in the Department of Environmental Conservation (DEC), is in charge of developing policies, programs and plans. They have a particular focus on guarantee sustainability of the generation system and promote reduction of GHG emissions and renewable sources.
- **New York Public Service Commission (PSC)**: it is the public utilities commission of the New York state government that regulates and oversees the electric, gas, water, and telecommunication industries in New York as part of the Department of Public Service. The PSC is also in charge of implementing the regulation regarding the electricity sector, such as the the Reforming Energy Vision (REV) or the Clean Energy Standard (CES).
- **New York State Energy Research and Development Authority (NYSERDA)**: is the public institution in charge of promoting research on the state of the electricity sector and on new technologies, canalizing financing programs at promoting energy efficiency and renewable energy development. The DEC an the PSC participate in its governance.

*Key market agents.*

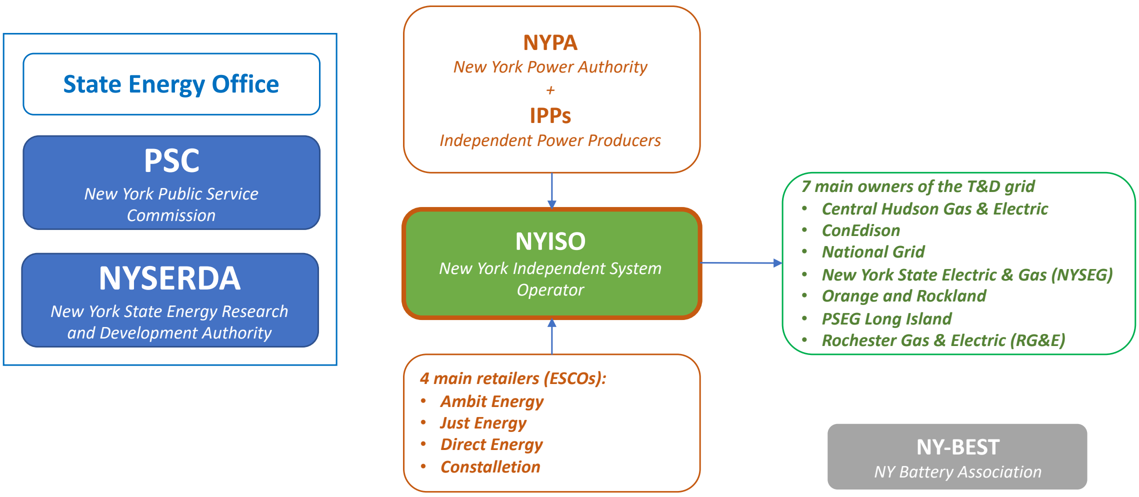
**Generation.** More than 50% of the 161TWh annually consumed by NYS are generated outside the state, while own generation is carried out by regulated public utilities and independent power producers (IPPs). IPPs generate almost 75% of the State's electricity supply[78]mostly from fossil fuel sources, being the other 25% supplied by New York Power Authority (NYPA). NYPA is the largest regulated public owned generation company, operating 16 generation power plants (with three hydro power plants providing 70% of its production).

**Market Operation**. New York Independent System Operator (NYISO) is the non-profit entity in charge of operating the State's electricity day ahead market, real-time market and the regulation market, operating the bulk energy grid and conducting long term planning of the power sector

**Transmission and Distribution**. In the NYS, as in the rest of the USA, the property and maintenance of the electricity network is on private utilities while the operation of the system is managed by the market operator. In NYS there seven main owners: Central Hudson Gas & Electric, ConEdison, National Grid, New York State Electric & Gas (NYSEG), Orange and Rockland, PSEG Long Island and Rochester Gas & Electric (RG&E).

**New York Battery Association (NY-BEST):** formed in 2010, it is the main State's lobby association promoting the development of battery installations, providing research and industry support to main stakeholder.

*Figure 32: Main stakeholders of New York State's electricity sector*




## 12.3 Regulatory overview in the electricity sector

The base for energy sector's regulation in NYS and consolidated in the "New York Consolidated Laws", inside which it is found the "Energy Law" (1976)[79]. The Energy Law contains the State's Energy Policy basic directions governing energy supply and production, energy planning, and technological standards. Particular interest for this study the section § 21-106: Co-generation, small hydro and alternate energy production facilities. Based in this law, the government then creates new regulatory proceedings, policy initiatives and plans.

- **Reforming Energy Vision (REV, 2014)**:[80] This set of regulatory proceedings and policy initiatives seeks reforming the energy market environment to facilitate investments in renewable energies and smart technologies in the sector, with a particular focus on distributed energy generation. It is divided in two tracks: (i) Track 1 (2015) focuses on shaping the new utility vision and DER ownership challenges (ii) Track 2 (2016) focuses on the necessary changes in the current regulatory, tariff, market, and incentive structures. Some of the REV initiatives lead to the creation of the Clean Energy Fund with US$5billion to support REV deployment in the period 2016-2026 and the creation of the Clean Energy Standard (CES)
- **New York Energy Plan (2015)**[81]: this plan coordinates agencies and authorities and the defines actions for energy electricity planning, stablishes regulatory reform to integrate

clean energy in the grid, redesigns programs to promote private investments, and promote innovative energy solutions. It stablishes the targets of Energy GHG emissions reduced by 40% in 1990 and by 80% in 2050, decrease buildings consumption by 23%by 2030 and 50% of energy from RE by 2030. It will be implemented through based on the REV and the CES.

- **Clean Energy Standard (CES, 2016)[82]:** It is the standard through which NYS officially sets the target of 50% of electricity consumption from renewable resources by 2030. It creates energy credits mechanisms directed at suppliers (known as Load Serving Entities, retailers) to achieve this target, with two components: (i) the Zero Emissions Credit Program (ZEC)[49], and (ii) the renewable energy standard credits (RECs) for new renewable energy. The CES stablishing that a certain percentage of the energy supplied must be purchased with these credits, increasing annually and reaching 4.8% by 2021 and considering that one REC is equivalent to one MWh. In order to guarantee new renewable supply, NYSERDA will be in charge of entering in long term contracts with new generators for 20 years[83]. RECs started in 2016 and are managed by NYSERDA.

## 12.4 Regulation for energy storage.

The regulation influencing energy storage development is mostly in line with the dispositions mandated by the FERC, particularly in the Order 841 (2018) calling at full integration of storage technologies in the electricity market.

The REV in its Track 2 (2016) presents necessary changes in the current regulatory, tariff, market, and incentive structures of the electricity sector towards a 50% renewable generation structure, something that will drive most of the storage developments. Since 2018, PCS has included energy storage as potential beneficiary of the clean credit program of the CES and increased the maximum rated capacity for projects from 2MW to 5MW.

*Energy Storage Roadmap (2018).*

This is the main initiative driving energy storage developments, particularly batteries in the following years. It started with the approval of the Storage Mandate (S.5190/A6571)[84] through which the government committed to have 1,500 MW of energy storage installed by 2025. In 2018, the roadmap for a new market participation model was published[85] settling for regulatory reforms allowing storage to participate in wholesale markets and grid service, opening regulatory reforms and settling financing programs.

Most of the objectives of the roadmap will be achieved through NYISO integration of storage technologies in the wholesale markets, with a expected new Market Design by the end of 2018. The roadmap will follow FERC Order 841 directions and will be divided in three phases: (i) Energy Storage Integration phase (2017-2020), (ii) Energy Storage Optimization (2019-2022), (iii) Renewable and storage aggregation (2020-2023).

During Phase 1 a new model category for market participation[50] will be defined for energy storage technologies, identifying the necessary new bidding parameters. The proposal is NYISO to create a single offer model that would allow storage agents to change between generator and consumer within 1 hour period, remove ELR (Energy Limited Resource) limits that require 4h guaranteed supply, open the possibility of storage settling price at nodal price, and reducing the limit for market participation from 1MW to 0.1MW. During phase 2 NYISO would proposed the owners of the storage technologies to become the manager of the state of charge of the devices, so this constraint can be included in the market clearance system of the ISO. In Phase 3, NYISO would start pairing storage a renewable energy sources, adapting the market clearing software to consider energy firming.

NYISO would also recognized the need of stacking revenues from different sources for energy storage, and so it is also studying dual participation (in wholesale and retail markets), the integration of storage technologies in the provision of ancillary services. NYISO is considering stablishing a system with response time at 6 seconds, allowing storage technologies to participate

[49] *For electricity from nuclear generation: it does not count in the target of 50% renewable generation for 2030.*

[50] *In 2009 NYISO was the first ISO in the US to allow storage participation in the regulation market although defined only as producer, following FERC's Order 890*

in regulation capacity and movement, awarding the ability to transition between upward (injection) and downward (withdrawing). For frequency control, settling times will be stabilised at 15min (RTC) and 5min (RTD) periods, rewarding the storage technology in relation with the nodal price it is connected to.

The Energy Storage Roadmap will also unleash financing resources for storage technologies: US$ 350 in market acceleration incentives and US$200 million from the NY Green Bank.

## 12.5 Electricity Market Overview.

Th electricity sector in NYS started to be liberalized at the end of the 90's, being fully deployed by 2002. As part of the USA market system, the operation of the wholesale markets and regulation markets are centralized under NYISO management.

The wholesale market is designed in a two-settlement auction process: the first settlement for day ahead bids (resulting in scheduling dispatch) and the second on real time bids (Real time Commitment, RTC, and Real time Dispatch, RTD). 40% of the energy necessary is arranged through bilateral contracts, and out of left 60%, 94% of the energy in settled in the day ahead market.

Clearance of prices reflect geographic conditions dor supply and demand and other constraints resulting in nodal prices called "Locational Based Marginal Prices". NYISO also avoids inserting price caps by its Scarcity Pricing System, stablishing a clear and transparent price for reserves.

## 12.6 Assessment of regulation and market for energy storage.

### *Specific regulation*

- **Definition of storage:** The State of New York uses the definition set at federal level included in the RM16-23 and the FERC Order 841.
- **Grid fees**: storage technologies are allowed to operate their transaction at the marginal location market nodal price, as allowed by the Order 745, avoiding grid fees costs.
- **Ownership:** Since most of the networks of the US are owned by utilities, these have no limit in owning storage assets. Also, FERC Order 784 allows third party provision of ancillary services using storage technologies.

### *Participation in electricity markets*

- **Wholesale markets**: Following FERC order 841, The NYISO Market Participation Model (2018) is integrating the bidding parameters tailored for storage. The proposal of NYISO is to create a new bidding product category in form of single offer model that would allow storage agents to change between generator and consumer within 1 hour period, remove ELR (Energy Limited Resource) limits that require 4h guaranteed supply, open the possibility of storage settling price at nodal price, and reducing the limit for market participation from 1MW to 0.1MW. Aggregation of Storage and RE participation will be considered in the period 2020-2023.
- **Network services:** Following FERCs order 841, a performance-based remuneration scheme will be stablished for storage to provide reserve services. Storage will be allowed to participate in reserve market, as well as VSS and Black start. NYISO would also recognized the need of stacking revenues from different sources for energy storage, and so it is also studying allowing dual participation (in wholesale and retail markets) and the integration of storage technologies in the provision of ancillary services. NYISO is considering stablishing a system with response time at 6 seconds, allowing storage technologies to participate in regulation capacity and movement, awarding the ability to transition between upward (injection) and downward (withdrawing). For frequency control, settling times will be stabilised at 15min (RTC) and 5min (RTD) periods, rewarding the storage technology in relation with the nodal price it is connected to.
- **Prosumers and aggregation participation:** Aggregation of Storage and RE participation will be considered in the period 2020-2023
- **Access to tariff incentives for RE**: Following FERCs: Storage can benefit from the tax incentive under the ITC. Storage is allowed to stack multiple services

- **Capacity Markets.** The NYISO MPM follows FERCS Order 841, storage is allowed to participate in the regional capacity markets managed by the ISOs.

*Creation of Track Record in the industry*

- **Development of demonstrative projects**: Energy Storage Roadmap will unleash financing resources for storage technologies: US$ 350 in market acceleration incentives and US$200 million from the NY Green Bank.
- **Existence of specific targets**: Yes, with the approval of the Storage Mandate (S.5190/A6571) which the government committed to have 1,500 MW of energy storage installed by 2025. In 2018, the roadmap for a new market participation model was published
- **Existence of specific standards:** NYSERDA is creating standards for the safe installation of battery storage projects[86]

# 13 California

## 13.1 State of the Art

The State of New York has currently 178MW of operational capacity of battery energy storage, with almost extra 435MW projects announced, contracted or under construction. Almost 25% of the current operational battery installations have as primary service providing capacity firming for renewable sources,18.5% electric supply capacity, 17% services on back start and 12% capacity reserve for secondary frequency control.[87]

## 13.2 Main Stakeholders in the Energy sector

*Key regulatory bodies and institutions.*

- **California Natural Resources Agency (CNRA):** cabinet level agency in charge of responsible for protecting historical, natural and cultural sites, monitoring and controlling state lands and waterways, and regulating fish and game use
- **California Energy Commission (CEC):** it is the main public agency in charge of energy policy and planning, being under the jurisdiction of the CNRA. Among its duties, it carries out forecasting for energy demand, it promotes renewable energy and energy efficiency programs, directs financing plans, promotes research and innovation.
- **California Public Utilities Commission (CEPUC):** it is the agency in charge of regulating privately-owned utilities ("Investor Owned Utilities", IOU) in the sectors of electric power, telecommunications, natural gas and water. Among its duties are establish standards and safety rules, authorize utility rate changes, inhibit market power abuse, implement energy efficiency and conservation programs, oversee the merger and restructure of utility corporations, and enforce the California Environmental Quality Act for utility construction, among others.

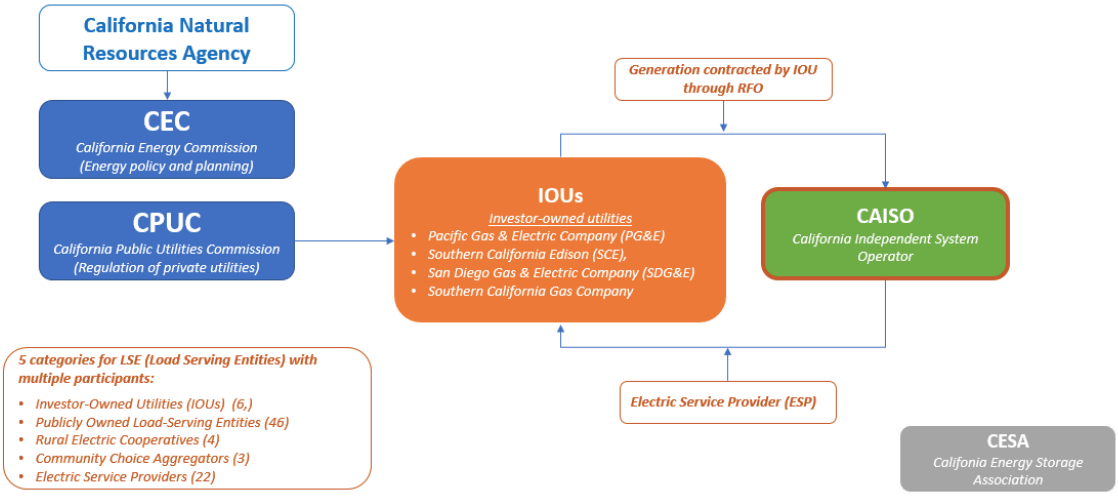
*Key market agents.*

**Generation.** Approximately, 70% of electricity demand is generated inside the State, with more than 1,000 generating units over 1MW.

**Market Operation**. The California Independent System Operator (CAISO) is non-profit entity in charge of most of the wholesale market operation and the provision of balancing services (actually is many times referred as the Balancing Authority).

**Utilities.** Utilities are referred as Load Service Entities (LSE) and they are grouped in five categories: Investor-Owned Utilities (4 IOUs), Publicly Owned Load-Serving Entities (46), Rural Electric Cooperatives (4), Community Choice Aggregators (3) and Electric Service Providers (22). In California there are four "IOUs": Pacific Gas & Electric Company (PG&E), Southern California Edison (SCE), San Diego Gas & Electric Company (SDG&E) and Southern California Gas Company

*Figure 33: California's main electricity sector stakeholders*




## 13.3 Regulatory overview in the electricity sector

The State of California has not defined energy law, regulating the functioning of the system through different Senate Bills, Assembly Bills and the initiative of the CEC and the CPUC.

## 13.4 Regulation for energy storage.

- **Senate Bill 1068 "Renewable Portfolio Standard" (RPS, 2002)[88]** was the first attempt to promote renewable energy technologies, requiring utilities to purchase or generate an increasing percentage of electricity from "green" resources like wind and solar and indirectly promoting the development of the energy storage market.
- **Assembly Bill (AB) 2514 (2013)[89],** continued by AB 2868 (2016): approved a mandate to IOUs to procure and install over 1325MW (increased in 500MW in 2016) of energy storage resources by 2024. The procurement must be done via competitive solicitations and subject to the approval of the CPUC, and take place every two years at least. Hydro-pumped projects are outside of this mandate's target and 25% of the extra 500MW approved in 2018 must be in behind the meter applications. According to the Rule #6 the storage technologies will not be able to stack revenues from different reliability sources.[51]
- **AB 1637 (2016)[90]** "California's Self Generation Incentive Program (SGIP)": this program offers energy consumers (mainly industrial level) financial incentives to install renewable and efficiency new technologies. Available funds have reached $166 million with 85% of those funds must be allocated for energy storage projects, particularly large scale.
- **AB 546 (Sept.2017)[91]:** this bill administrative procedures for customers to install behind-the-meter energy storage systems.[52]

### *CPUC initiative*

**Market Rules For Storage participation (CPUC, 2018)**[92]: The CPUC, following FERC initiative, adopted 11 rules outlining how multiple-use energy storage applications should be evaluated, along with definitions of service domains, reliability services and non-reliability service. It includes stacking services, allows aggregation and multiple service provision.

**The CPUC's Decision (D.17-04-039)** approved new station power rules and permitted netting rules for in-front-of-the-meter energy storage.  It stablishes the principles to link nodal prices to

[51] *See Cal. Pub. Util. Code §§ 2835-2839, 9620*

[52] *e Cal. Gov't Code § 65950.8.*

flexibility providers and includes storage as part of the California's IRP. The IRP 2018-2030 recommends +2000 MW of storage to support RE in the state.

*CAISO initiative*

**Energy Storage and Distributed Energy Storage (ESDER)**:[93] this is a workgroup tasked to follow FERC's initiative in the integration of storage technologies in the electricity markets. The ESDER defined a work line of three phases around identifying the constraints related with storage technologies and the inclusion of the state of charge in the bidding process. This has led to the revision of the "Flexible resource adequacy criteria and must offer obligations (FRAC-MOO 2) - 2017"[94]of CAISO, which may open opportunities to storage technologies by increasing requirements of ramp rate response.

**Models for storage participation in AASS market**[95]: it creates two new bidding figures: (i) Non Generator Resource (NGR), able to act as generator or as consumer with a limit imposed by its capacity level, designed for smaller, energy-constrained resources that are able to provide energy, regulation, and operating reserves; and (ii) The Proxy Demand Resource (PDR) model, a bidirectional product that would allow storage resources to consume excess load on direction from an ISO dispatch, so it would bb designed for BTM storage resources to provide load curtailment but not inject power onto the grid.

## 13.5 Electricity Market Overview.

The Californian electricity market is characterized, as the part of the USA system by a system operator (CAISO)[96] operating day ahead, real time and regulation markets. Also, prices are cleared at locational marginal price.

## 13.6 Assessment of regulation and market for energy storage.

*Specific regulation*

- **Definition of storage:** From Federal regulation, definition of electricity storage is included in the RM16-23 and the FERC Order 841.
- **Grid fees**: storage technologies are allowed to operate their transaction at the marginal location market nodal price, as allowed by the Order 745, avoiding grid fees costs.
- **Ownership:** Since most of the networks of the US are owned by utilities, these have no limit in owning storage assets. Also, FERC Order 784 allows third party provision of ancillary services using storage technologies.

*Participation in Electricity Markets*

- **Wholesale markets**: The CAISO's ESDER defined a work line of three phases around identifying the constraints related with storage technologies and the inclusion of the state of charge in the bidding process. This has led to the revision of the "Flexible resource adequacy criteria and must offer obligations (FRAC-MOO 2) -2017" of CAISO, which may open opportunities to storage technologies by increasing requirements of ramp rate response.
- **Network services:** Following FERCs directions, a performance based remuneration scheme will be stablished. CAISO's ESDER creates two new bidding figures: (i) Non Generator Resource (NGR), able to act as generator or as consumer with a limit imposed by its capacity level, designed for smaller, energy-constrained resources that are able to provide energy, regulation, and operating reserves; and (ii) The Proxy Demand Resource (PDR) model, a bidirectional product that would allow storage resources to consume excess load on direction from an ISO dispatch, so it would be designed for BTM storage resources to provide load curtailment but not inject power onto the grid.
- **Prosumers and aggregation participation:** according to the CPUC's Market Rules For Storage participation, they adopted 11 rules outlining how multiple-use energy storage applications should be evaluated, along with definitions of service domains, reliability services and non-reliability service. It includes stacking services, allows aggregation and multiple service provision
- **Access to tariff incentives for RE**: Following FERCs directives, Storage can benefit from the tax incentive under the ITC. Storage is also allowed to stack multiple services

- **Capacity Markets.** There is not centralized capacity market in California.

*Creation of Track Record in the industry*

- **Development of demonstrative projects**: There are several financing programs promoting storage projects, like the California's Self Generation Incentive Program (SGIP, US$141M)for large storage finance
- **Existence of specific targets**: according to the Assembly Bill (AB) 2514 (2013) and continued by AB 2868 (2016), there is an approved a mandate to IOUs to procure and install over 1325MW (increased in 500MW in 2016) of energy storage resources by 2024. The procurement must be done via competitive solicitations and subject to the approval of the CPUC, and take place every two years at least. Hydro-pumped projects are outside of this mandate's target and 25% of the extra 500MW approved in 2018 must be in behind the meter applications. According to the Rule #6 the storage technologies will not be able to stack revenues from different reliability sources
- **Existence of specific standards:** No standards have been developed at State level, although some safety guidelines for residential batteries are being taken at county level.[97]

## 13.7 Summary table of countries measures

*Source: Author. Colour Code: (Red: not existing), (yellow: about to be approved), (green: functioning)*

| BARRIER CATEGORY | BARRIER | EU | GERMANY | UK | US | NEW YORK | CALIFORNIA |
|---|---|---|---|---|---|---|---|
| SPECIFIC REGULATION | Definition of Storage | > Pending: a definition for storage technologies will be included in the e-Directive by 3Q2018<br><br>> ambiguous definition biased towards generation | > Pending: a definition for storage technologies will be approved by 3Q2018 through EU Regulation<br><br>> ambiguous definition biased towards generation | > Pending: a definition for storage technologies will be included in the Electricity Act by 1984<br><br>> Subset of generation asset | > Existing definition in FERC Docket RM16-23<br><br>> Totally differentiated asset in the power market participation | > Incorporates existing federal definition in FERC Docket RM16-23<br><br>> Totally differentiated asset in the power market participation | > Incorporates existing federal definition in FERC Docket RM16-23<br><br>> Totally differentiated asset in the power market participation |
| | Ownership | > Pending: TSOs not allowed with exceptions | > Pending: TSOs not allowed | > Pending: TSOs not allowed | > Yes: owners of networks are utilities, not ISOs, so they can provide these services. | > Yes: owners of networks are utilities, not ISOs, so they can provide these services. | > Yes: owners of networks are utilities, not ISOs, so they can provide these services. |
| | Grid Fees | > Winter Package specific call to avoid discrimination or double charging | > Yes: EEG-2017 storage only to pay fees as generator | > Electricity Act 1984 to be amended storage as subset of generation technology and free of levies.<br>> The classification of Embeded Generation to reduce charges | > Yes: Order 745 establishes to let storage technologies to operate at nodal price | > Yes: Order 745 establishes to let storage technologies to operate at nodal price | > Yes: Order 745 establishes to let storage technologies to operate at nodal price |
| PARTICIPATION IN MARKET | Wholesale Market Access and Remuneration | > Pending: Specific provisions for electricity storage participation to be approved by 4Q2018.<br><br>> Call to participate in Day ahead, intra-day and reserves and balancing markets.<br>> Call to Reduce size of DA bid to 1MW<br>> Call to open participation in cross border capacity allocation | > Pending: EPEX is adapting to new technologies and still EU directives.<br><br>> It has continuous intra-day market<br>> Germany has a specific intra-day auction market for flexibility providers with 15min settlement time and 0.1MW minimum bid<br>> EWE AG and EPEX will launch a market | > Pending: EPEX is adapting to new technologies and still EU directives.<br><br>> It has continuous intra-day market<br>> Uk has a particular Day-Ahead market: "UK Half Hour Day-Ahead 15:30 Auction" - 30min products and bidding lots with a minimum size of 0.1MW,<br>> EWE AG and EPEX will launch a market platform for flexibility sources | > Yes: Under FERC 841 (2018) regional ISO are called to complete integrate storage technologies in their markets.<br><br>> Include constraints such as state of charge<br>> Include minimum bidding size at 0.1MW<br>> Operation at nodal price<br>> Aggregators allowed<br>> FERC PL17-2 to allow | > Pending: The NYISO Market Participation Model (2018) will incorporate main considerations of FERC call.<br><br>> single offer model to change between generator and consumer within 1 hour period.<br>> remove ELR (Energy Limited Resource) limits that require 4h guaranteed supply<br>> By 2023, RE will be | > Pending: CAISO's ESDER is identifying constraints to be included, in line with FERC's call and CAISO ys revising the "Flexible resource adequacy criteria and must offer obligations (FRAC-MOO 2) - 2017" to reward speed. |

| BARRIER CATEGORY | BARRIER | EU | GERMANY | UK | US | NEW YORK | CALIFORNIA |
|---|---|---|---|---|---|---|---|
| | | > Call to create energy only market and reflect scarcity: no prices caps, no dispatch priority to RE and removal of feed-in tariffs.<br>> Call for continuous intra-day and balancing markets. | platform for flexibility sources (phase I by 2018)<br>> Prices are still capped at plus minus 3,000EUR | (phase I by 2018)<br>> Prices are still capped at plus minus 3,000EUR | storage to stack different revenues streams | allowed to bid firmed by storage. | |
| | Network Services Access and Remuneration | > Pending: Cclean Energy Package calls TSO to incorporate energy storage in their reserve and balancing auctions.<br><br>> Challenge: ENTSOe still debating on the Article 156 of the "Guideline on Transmsission System Operation" where settling time for FCR (primary) is set at 15-30min<br><br>> Opportunity: ENTSOe may include sythetic inertia in network codes. | > Yes: The StrommarktG 2016 opens participation in flexibility market to load actors<br>> the AblaV reduces the minimum capacity requirement from 50 to 10MW<br>> BenetzA new rules for frequency control market by July 2018, accepting bids to 5MW, increasing the number of products and shortening the times (4h) and promoting pooling assets<br><br>> FCR is remunarated | > Yes: NGET's EFR product for frequency control response tailored for BESS:<1s response, service in either direction, 100% capacity for a minimum of 15 min, must maintain an operational availability of 95% to qualify for the full payment<br><br>> stacking of revenues between the Capacity Market and ancillary services | > Yes: FERC 841, call to complete integration n markets<br>> FERC 755: performance-based payment<br>> FERC Order 792: not discrimination to network connection<br>> Order 784 open opportunities for local utilities to build serve their own AASS needs with storage | > Yes: The NYISO MPM (2018) Single offer model to change between generator and consumer with settling times at 15min (RTC) and 5min (RTD) periods, use nodal prices (LBMP), and require 6s time response<br>> stacking revenues from different sources<br><br>> NYISO also avoids inserting price caps by its Scarcity Pricing System, stablishing a clear and transparent rice for reserves. | > Yes: CAISO's ESDER creates two new bidding figures:<br>(i) Non-Generator Resource (NGR), able to act as generator or as consumer with a constraint imposed by its capacity level<br>(ii) The Proxy Demand Resource (PDR) model, a bidirectional product allowing to consume excess load on direction from an ISO dispatch, designed for BTM to provide load curtailment but not inject power onto the grid. |
| | Access to Capacity Markets | > EU supports energy-only markets<br>> EU will allow participation in cross border capacity market coupling. | > No: storage not allowed to participate in capacity auctions<br>> Access to EU cross border coupling | > Yes: Storage actively participation in capacity auctions developed under Electricity Act 2013<br>> De-rating factor applied to batteries has been increased. To almost 18% (<30min) | > Yes: FERC Order 841 allows storage technology to participate in capacity markets | > Yes: NYISO MPM (2018) allows storage participation in capacity market | > No: California has not stablished capacity markets. |
| | Access to tariff Incentives for RE | > EU supports energy-only markets. | > Yes: § 19 Abs. 3 EEG: storage to benefit from | > Pending: Ofgem may ope CfD, FiT and RO for | > Yes: S3159, up to 30% of the investments in | > Yes: following federal S3159, up to 30% of the | > Yes: following federal S3159, up to 30% of the |

| BARRIER CATEGORY | BARRIER | EU | GERMANY | UK | US | NEW YORK | CALIFORNIA |
|---|---|---|---|---|---|---|---|
| | | | EEG surcharge (feed-in)<br>> Old PV's EEG-surcharges to expire by 2020, opportunities for storage | storage. Also opening the Green Energy Tariff for prosumers. | storage can benefit from the investing tax credit (ITC) | investments in storage can benefit from the investing tax credit (ITC) | investments in storage can benefit from the investing tax credit (ITC) |
| | Prosumers and aggregators participation | > Pending: Clean Energy Package calling to include aggregators and communities in the markets. Also, increased collabortion between DSO and TSO | > Pending: subject to EU regulation. Germany developing the MieterStrom project for PV communities | > Yes: STOR reserve product for aggregating 3MW units<br>> Pending: Ofgem expects that 30-50% of balancing capability will be sourced from the demand side by 2020, including aggregators. | > Yes: FERC 841 calls to include aggregators a new actor in the market | > In NY MPM, Aggregation of Storage and RE participation will be considered in the period 2020-2023 | > Pending: CPUC's Market Rules For Storage participation include aggregated storage participation. |
| TRACK RECORD | Development of demonstrative and reference projects | > Yes: several ongoing programs for financing research and projects | > Yes: several ongoing programs for financing research and projects | > Yes: several ongoing programs for financing research and projects | > Yes: several ongoing programs for financing research and projects | > Yes: several ongoing programs for financing research and projects | > Yes: several ongoing programs for financing research and projects |
| | Existence of Targets | > No specific targets.<br><br>> Driven by existing targets for RE, EE and GHG. | > No specific targets.<br><br>> Driven by existing targets for RE, EE and GHG and the target of 1M Evs by 2020. | > Pending: No specific targets but they will be set as part of the "Smart Systems and Flexibility Plan" (Ofgem)<br><br>> Driven by existing targets for RE, EE and GHG. | > No specific targets.<br><br>> Driven by each State's initiative | > Yes: 1,500 MW installed by 2025according to the "Storage Mandate" (S.5190/A6571) | > Yes: 1,825MW by 2024 according to AB2514&AB2868. |
| | Existence of Standards | > Pending: ENTSO-e will include Storage Technologies in the next TYDP and is also designing the CBA 3.0 for effectiveness assessment of storage projects. | > Pending: BVES (German Energy Storage Association) has published H&S guidelines for BTM batteries and technical requirement guidelines for bulk energy batteries. | > Pending: British Standards Institute is working on a H&S framework in collaboration with Ofgem. | > Pending, USDoE published the "Energy Storage System Guide for Compliance with Safety Codes and Standards" and It is also developing a general CBA assessment tool in collaboration with Navigant | > Pending: NYSERDA is creating H&S standards for residential batteries. | > Not existing. Initiative at county level. |

# VI. SECTION C: A business case for a battery connected to "Sierra Moncayo" wind power plant.

# 14 Summary of Section C.

Endesa's wind Power Plant at Sierra Moncayo (Soria, Spain) is composed by five windfarms adding a total installed capacity of 78.71MW. During 2017 the plant produced 144.6GWh of energy, while a potential additional 17% of energy was lost due to curtailments of the grid. These curtailments happen mostly due the congestion of the node to which the windfarms are connected, which capacity limitation is set at 45MW.

The proposed analysis seeks to evaluate the economic viability of a battery charged with the now lost curtailments and able to use them when the node is uncongested, increasing the revenues of the renewable generation facility.  After considering different options of physical location and revenue streams, the most profitable structure of the installation results on a Li-Ion battery system operating in the sport market and connected to the node corresponding to the windfarms of Cortado1&2 with capacity limit of 16.29MW.

Assessing the cost-effectiveness of the installation, it results that neither at current or near future prices of batteries this installation will be profitable, being necessary to revise the administration of the curtailment orders to assess new business scenarios. Nevertheless, some conclusions are extracted from this exercise: the need of stacking revenues from different sources is necessary to justify large storage investments, the secondary frequency control revenues are less attractive that the spot market participation, the battery has important operative constraints related with the state of charge or the inability to inject and withdraw at the same time and in the next years the support of financing programs will still be necessary if there are not new revenue streams available.

Also, the methodology of the CBA 3.0 has been followed and other economic benefits of the installation of the battery system will be tested resulting in, for example, the avoidance of 151tCO2 a year by a 500kW/250kWh due to an increase of clean energy participation in the market.

# 15 Background

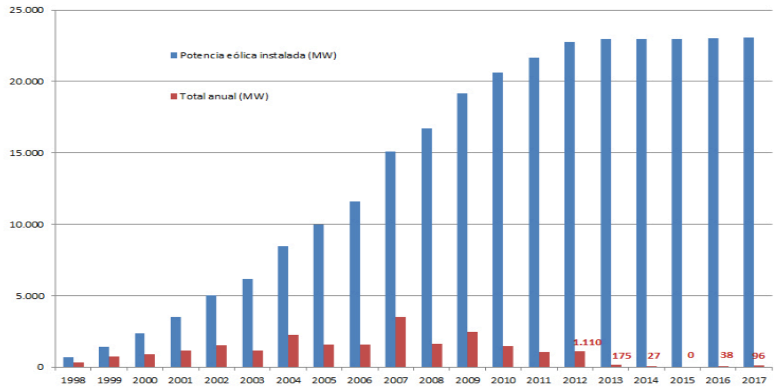
## 15.1 Wind generation curtailments in Spain.

The curtailment of generation in Spain is regulated through the Real Decreto 661/2007 and through REE's Operation Procedures (PO). According to the PO 3.7[98], there are five reasons why a REE can order to reduce production to generators: (i) risk of generation losses due transitory instability; (ii) limited short-circuit power that could put into risk surrounding substations protections; (iii) viability of the balance of the electric power; (iv) congestion at the generation's connection; and (v) excess of generation due to inaccurate load/demand forecasting. On the other hand, the PO 3.2[53] establishes a priority order for additional technical restrictions curtailments depending on type of technology and on the ability for its management, being the wind generation among the last ones to be curtailed.

During the last years, REE has been reporting an increase in wind generation curtailments orders. These have been taking place almost at a daily basis since March 2013, a year when curtailments in wind generation accounted for more than 138 GWh, causing important economic losses to utilities. Approximately 95% of this energy curtailed was due to an excess in generation in the system, being wind generation was the most affected renewable technology[99].

[53] *Paragraph 3.8.1.1.5.2. Wind power generation can be classified as "unidades de generacion renovable no gestionable" (non-manageable renewable energy generation)*

*Figure 34: Wind Power Capacity Installed in Spain (source: AEE)*




There are 23GW of wind generation capacity installed in Spain, standing as the third source of generation (22.4% of total installed capacity) and almost half of all renewable energy installed (44%).

## 15.2 Sierra Moncayo Power Plant.

The "Sierra del Moncayo" wind power plant is composed by five windfarms accounting for a total installed capacity of 78,71MW[54]. It was put into service by Endesa S.A. in 2013. It is located in the province of Soria, Spain, on the South border of the Ebro river's valley, an area well known for being one of the main wind energy corridors in Spain.

*Picture 1: Location of Sierra Moncayo Power Station*

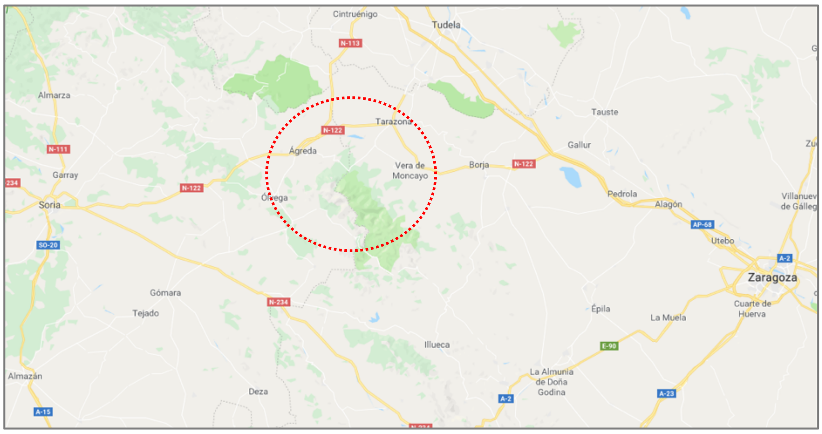


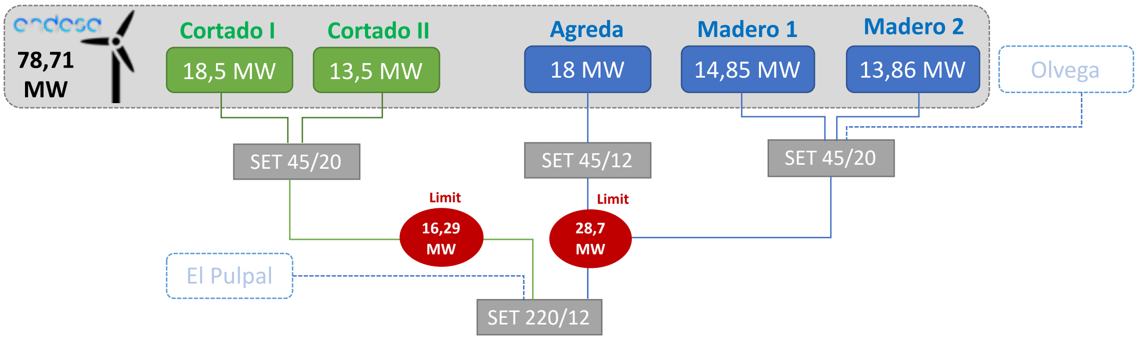

*Table 4: Sierra Moncayo wind farms installed capacity*

| Wind Farm | Installed Capacity (MW) |
|---|---|
| Cortado 1 | 18.5 |
| Cortado 2 | 13.5 |
| Agreda | 18 |
| Sierra Madero 1 | 14.85 |
| Sierra Madero 2 | 13.86 |
| TOTAL | 78.71 |

Sierra Moncayo's windfarms are connected to a node with a maximum contracted capacity of 50MW. This figure is constantly overtaken by the production of the windfarms and causes steady curtailments on production. As it can be seen in the figure below, the capacity limit imposed by the node is divided among the windfarms in two groups: a limit of 16,29MW for Cortado 1 and 2, and another of 28,7MW for Agreda and Madero 1 and 2.

[54] *There are two other windfarms connected to the same node but not owned by Endesa: El Pulpal and Olvega*

*Figure 35: Sierra Moncayo Power Plant node connection scheme*

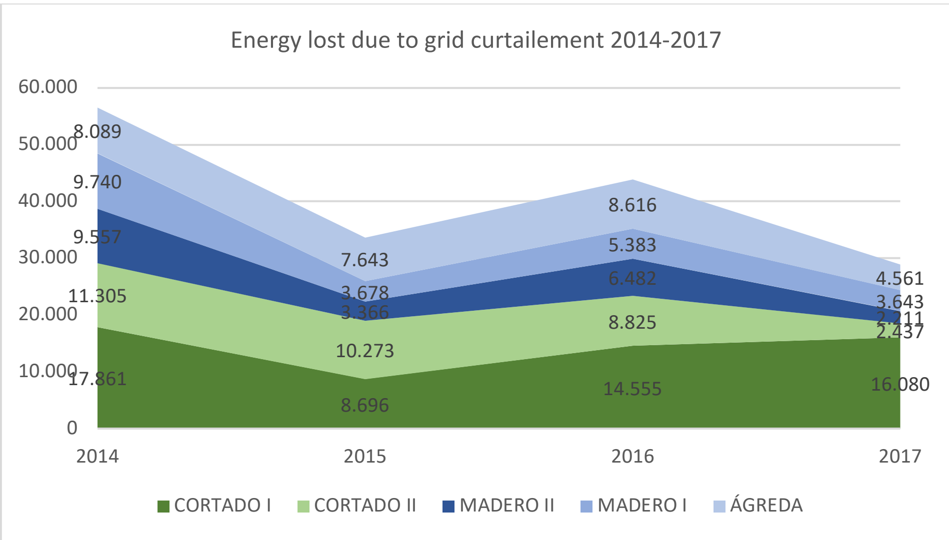



# 16 Analysis of the Information

## 16.1 Justification and objective of the analysis.

Grid curtailments in Sierra Moncayo during the last four years have accounted for a total 163 GWh lost, causing consequent economic impact for Endesa. In 2017 the plant produced 144.6GWh of energy, while 28,9232 MWh was lost mostly due to curtailments ordered by REE, a figure that represents 17% of total annual production.

*Figure 36: Curtailments in Sierra Moncayo windfarms 2014-2017*




The objective of this analysis will be to determine the profitability of connecting a battery system to the windfarms complex in order to absorb the now lost curtailed energy and use it in the market.

This Section C is envisioned as a practical application of the issues researched under Sections A and B, facing costs reported by the industry and real operative challenges.

## 16.2 Methodology and cost-benefit analysis with storage technologies.

*Discussion on existing CBA methodologies.*

As it was briefly presented in Section A, there is not currently a commonly accepted approach for assessing the full value of energy storage or a reference modeling tool that can be considered complete enough by the industry. The main issues that make this modeling difficult are the wide range of services batteries can be used for, their possibility to participate either in regulated or liberalized power business segments, and the various issues concerning delimitation of property, ownership and benefit allocation.

As a general view, it can be two approaches to evaluate cost-effectiveness of storage installations: (i) engineering studies, which consider the pure investors perspective and so it's used by utilities and industry, and (ii) system studies, which evaluate the overall system's benefit and that is more used among regulators.

Current research is discussing on which storage service will be the one providing higher benefits. Some[100] point out that the most immediate profitable application from the investor's perspective will be provision of AASS and supporting RE integration. Meanwhile, other studies[101] focused on the whole system's benefit, highlight the disruption of end-user behavior that mass storage insertion will have, reducing peak demand and the need for imports. Nevertheless, they all agree that in the short term it will be all services linked with flexibility of the system the ones that should be seek by both private investors and public entities.

The evaluation of cost-effectiveness of storage systems has been particularly studied in the United States, where several entities such as USDoE, EPRI, NERL, SANDIA laboratories, or the Massachusetts Government have taken steps in defining a model that could serve as model for the reference for the industry and the public regulators. All of them coincide in the fact that storage CBA cannot be limited to the traditional analysis and they support the need to evaluate the different benefit streams of storage in a more comprehensive way that allows "stacking" different revenue streams. Nevertheless, difficulties are shown when trying to define and monetize this benefit streams and some, like the Massachusetts Government, have determined that only a third of the estimated benefits of storage can be monetized and compensated under existing US regulations and market designs in their region.[102]

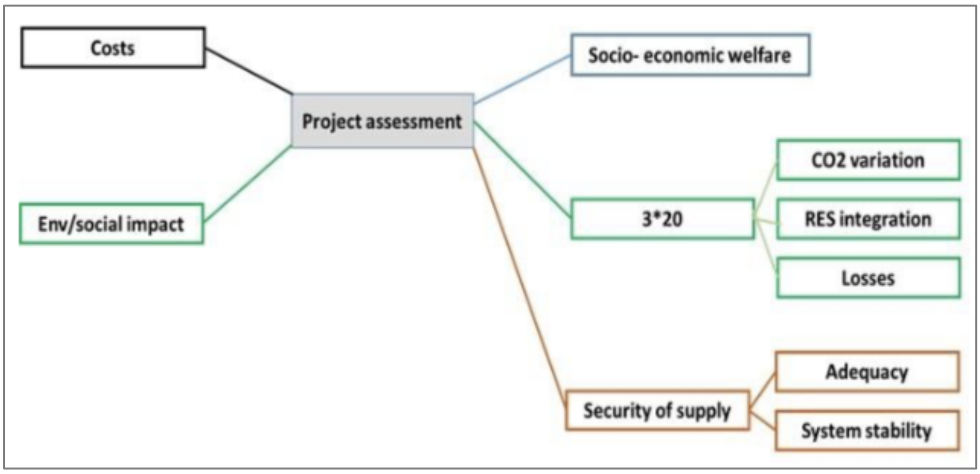
#### *European Cost-Benefit Analysis Methodology 3.0*

The ENTSO-e will publish during 2018 the third version of its "Guideline for Cost-Benefit Analysis of Grid Development Projects"[55]. This CBA methodology is meant to support the development of the Ten Years Network Development Plans (TYNDP), including in this third version an specific section for storage technologies that will provide European public entities with a reference tool to properly assess storage projects in a common and uniform manner.

ENTSO-e's methodology is designed for public organizations, providing a comprehensive view of the benefits storage can provide to society and supporting the need to identify, monetize and stack all these different benefit streams. The methodology identifies the main costs to be considered when analyzing a storage projects making a difference between (i) total project expenditure and (ii) environmental impact. On the other hand, the benefits the project are calculated on a with-or-without approach and are divided in three categories: (i) socio-economic welfare, (ii) generation avoided costs including reduction in carbon emissions, contribution to renewable energy integration and reduction on system losses, and (iii) contribution on security of supply providing adequacy and stability.

*[55] As mandated by Regulation (EU) No. 347/2013*

*Figure 37: CBA 3.0 Impact Indicators methodology diagram, ENTSO-e, 2018*




Regarding this storage projects, the European CBA methodology does not distinguish between regulated activities or liberalized activities of the services provided. Some comments regarding that indicators and the proposed Sierra Moncayo project:

- Costs: all costs for the project would be possible to be identified in coordination with the Business Development teams in Enel.
- Environmental and social impact cost: The environmental and social impact of a storage project is different from transmission, and highly dependent on technology. No costs associated with environment or society will be inserted since they are considered minimum.
- Socio-economic welfare: the benefit of connecting a battery system to a windfarm can be measure analyzing the total surplus approach in the market, considering that it will provide higher participation of the wind farm in the spot market causing a reduction in wholesale prices. Also, it can be interpreted from the generators point of view with the arbitrage opportunities provided.
- Security of supply: adequacy can be calculated at the price of Expected Energy Non-served when the battery participated in an event and from the avoided extra capacity investment in new generation of other technologies to cover this service. The CBA 3.0 does not propose a methodology for monetizing the contribution to system stability, but it proposes a ranking methodology to identify the ability of a storage system to provide frequency regulation services.
- Carbon emissions reduction: this indicator will measure the avoided conventional generation avoided thanks to the implementation of the new project, monetizing the emissions at CO2 market prices[56]. The battery installation under study contributes to a higher share of clean energy in the market and thus reducing potential CO2 emissions from other sources. The CBA 3.0 internalizes this benefit as part of generation avoided costs.
- Losses reduction: the battery we are considering would not avoid technical losses from the network but curtailments due to congestions in a node. These reduction in curtailments are interpreted in the CBA 3.0 as part of the RES integration indicator.
- RES integration: this indicator is measured as (i) new MW of renewable energy connected to the network thanks to the new project and (ii) avoided MWh curtailed due to congestion in the network. This last indicator, the most representative one for the

[56] *The European CO2 emission allowance is set at approximately 15 eur/tCO2 by May 2018.*

project that is going to be analyzed here, is included as part of the indicator B4 "reduction in generation costs" of the European CBA 3.0.

This methodology presented by ENTSO-e will still have to solve the lack of instruments for monetization and weighting of some of its indicators, particularly on environmental and social impact, making it difficult to compare and stablish rankings of priorities. The methodology proposes a star-diagram analysis which can actually lead to inconsistent results.

*Methodology followed for Sierra Moncayo proposal analysis.*

This TFM analysis will focus on analyzing the cost-effectiveness of the battery installation from a pure investor's point of view, making a quick assessment of other economic impacts at the end of the section. The study will seek to determine the net present value (NPV) of cashflows and the investment rate of return (IRR) under the base-case scenario, determining the most profitable scenario.

In order to simplify the model and avoiding regulatory limitations, it will be assumed that the battery installation will be integrated with the existing windfarm participating in the market as a whole. T

These will be the steps that will be followed in the analysis:

1. Analysis of the data provided.
2. Simulation of the battery functioning under certain scenarios determining most profitable revenue stream services.
3. Determination of investment needs
4. Analysis of NPV and IRR under base case scenario and determining the most efficient size of the battery.
5. Analysis of the sensitivity of the NPV and the IRR to the evolution on battery prize, average wholesale market price and variation in curtailment inputs.
6. Simple assessment of other economic benefit indicators.

## 16.3 Analysis of initial data.

Endesa provided the information of the operation of all Sierra Moncayo windfarms with a settlement period of 10 minutes for the 2017. This large amount of information was consolidated on an hourly basis in order to reduce its size and make it possible to analyzed on the Microsoft Excel tool. It will be, therefore, assumed that the energy production and curtailments are uniform during each hour of the year.

**Operative States.** First, it was necessary to understand the different operative states under which a windfarm can be set and identify those that can provide energy inflows to the proposed battery installation.

*Table 5: Operative possible Status of Sierra Moncayo Windfarm*

| CATEGORY | POSSIBLE STATUS OF MONCAYO WIND FARMS |
|---|---|
| OPERATION | **TURBINE IN OPERATION** |
| | **INEFFICIENCY** |
| MAINTENANCE | **INTERNAL (FORCED) MAINTENANCE** |
| | **INTERNAL (PLANNED) MAINTENANCE** |
| TURBINE NOT PRODUCING | **GRID CURTAILMENT** |
| | **HIGH WIND SPEED** |
| | **SELF DIAGNOSIS** |
| | **VIBRATIONS** |
| | **GRID UNAVAILABILITY** |
| | **LOW ENERGY PRICE** |
| | **ENVIRONMENTAL PARAMETERS** |
| | **AUTOMATIC ACTION** |
| | **ANCILLIARY SERVICES** |

Out of these states, the following ones are identified as a potential source of energy streams for the proposed battery:

- **Operation under inefficient conditions**: the turbine is connected and producing but small amounts of energy are curtailed and lost.
- **Turbine not producing due to grid curtailment**: under this state the wind farm is disconnected from the grid due to REE orders stablished on its PO 3.7.
- **Turbine not producing due to low energy prices**: the company voluntarily decides not to participate in the market due to excessively low energy prices that would not justify operative expenses.
- **Turbine not producing due to ancillary services**: which reflects the disconnection the plant experiences due to downwards reserve orders from REE.

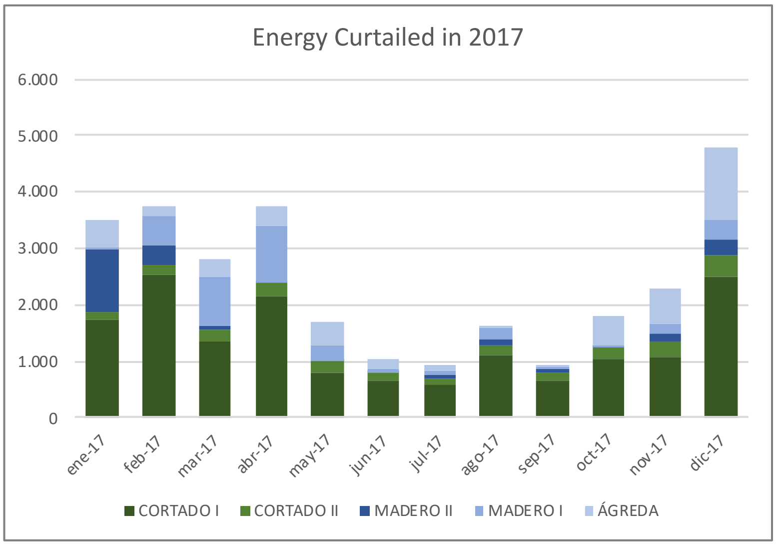
During 2017, 85% of potential energy to be used by the battery (24GWh) was due to **grid curtailment** orders from REE. For the purpose of this study and in order to simplify the amount of sourced data, it will be assumed that this is the only source of energy for the battery.

*Characteristics of the curtailed energy.*

Some facts about Sierra Moncayo operative characteristics and curtailments can be deduced from the provided information:

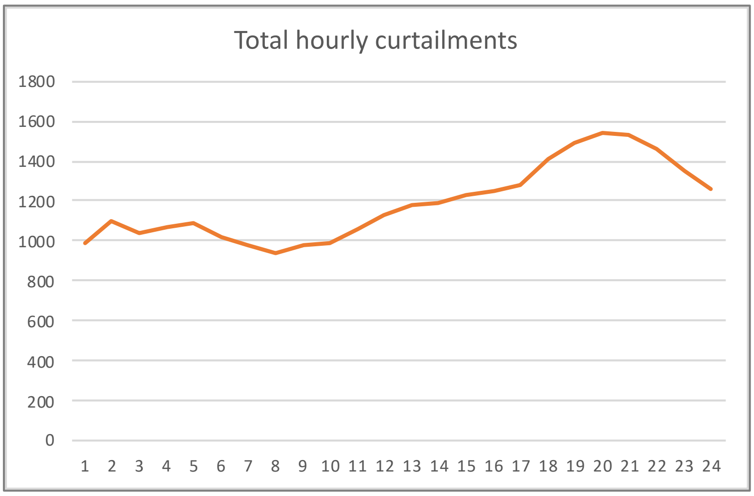
- Total energy produced by Sierra Moncayo Power Plant during 2017 was **144,595 MWh.**
- Total energy curtailed due to orders from REE in Sierra Moncayo accounted for **28,932 MWh**, what means that more than **17%** annual production was lost.
- More that 55% of the energy curtailed happened in **Cortado 1** windfarm what, according to the field's team is due to the particular technical characteristics of this farm that makes it easier to disconnect.

*Figure 38: Monthly curtailed energy in Moncayo windfarms during 2017*



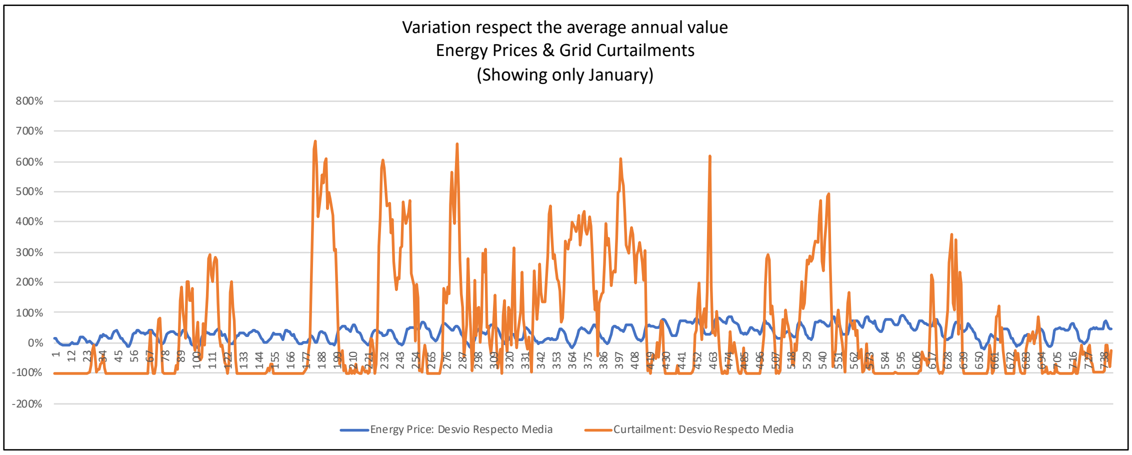

- The average hourly energy curtailed stands at 4,73 MWh, with a maximum of 17,84 MWh taking place in Cortado 1 windfarm during December.
- Most of the energy curtailed in 2017 took place during the end of each day and concentrated in the months of the beginning and end of the year. This links them directly to wind speed and, therefore, with energy production and the consequent congestion of the node.

*Figure 39: Hourly concentration of curtailed energy during 2017 in Moncayo windfarms*




- Curtailments happen with very high frequency at any of the wind mills of the park, basically on a daily basis, and they can last for **more than 24h continuous**.
- An additional analysis was made to ensure this grid curtailments are **not directly linked to spot market energy prices,** this way it can be proved the curtailment orders from REE are due to specific congestion of the node Moncayo Windfarms are connected to and not to an excess of renewable energy in the system.[57] Applying the Pearson's correlation, the information on both figures results in an index very close to 0 (P=-0.09) what shows that these values are not correlated, as expected.

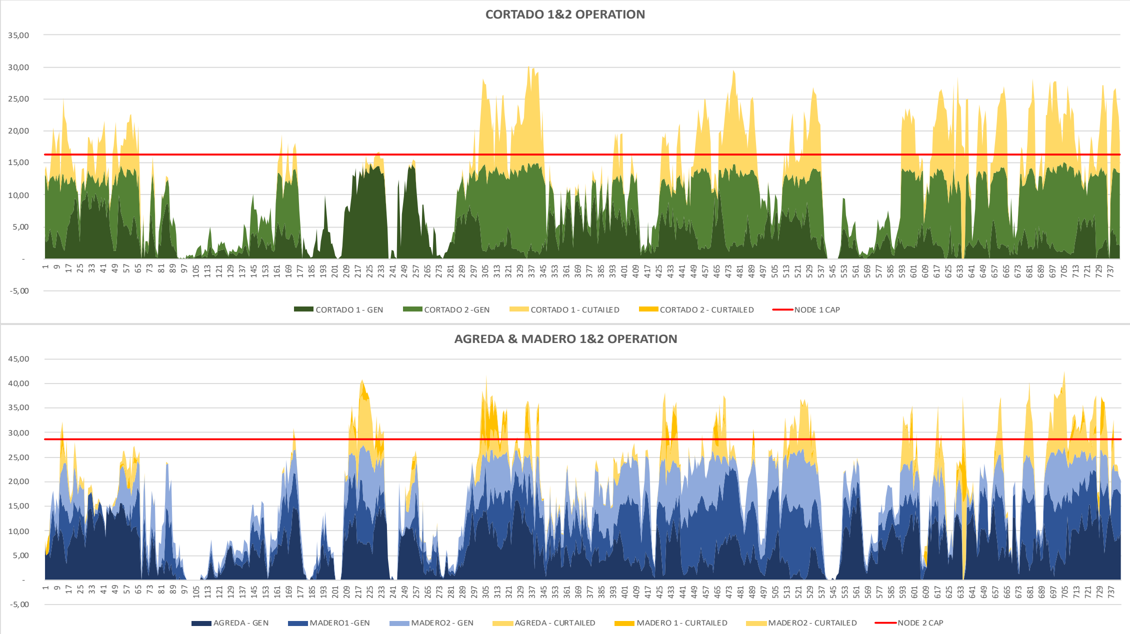
*Figure 40: Relation of energy spot prices and Moncayo curtailed energy in January 2017*




The following graph represents the energy produced and the curtailed energy in Moncayo Windfarm, representing also the node cap they are subject to (data for December 2017, the month with higher levels of curtailed energy). From it, it can be visually seen how the majority of the orders of REE to curtail production are due to the capacity limit of the node.

*[57] In Spain, spot market is cleared at marginal price. Since RE have very low operational costs compared with thermal generation, an excess of it will make prices drop and, if not expected or for longer periods, pose some operational risks for thermal units.*

*Figure 41: Energy production diagram in Sierra Moncayo , December 2017*




# 17 Operative scenarios and revenue sources.

Once the energy inflows are understood and identified, the next step is to define what for and under which constraints this energy will be used. As explained at the beginning of this section, it will be assumed that the battery system will be integrated as part of the wind power plant and so avoiding considerations on connection limitations due to regulatory restrictions for storage.

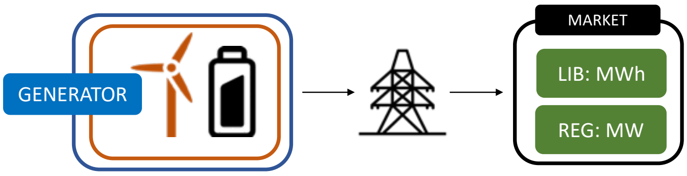
## 17.1 Criteria for the business scenario.

In the proposed project scenario, the battery will support the RE power plant's participation in the energy market with the energy absorbed from curtailment orders. This enhanced participation could be either in the competitive environment of the wholesale markets, where the windfarms could offer higher energy outputs for each hour or in the regulated environment of reserve and balancing market, where the battery could offer firm capacity and energy for ancillary services. As seen in Section A, the current regulatory environment in Spain does not facilitate the participation of the batteries in the energy markets, and so in order to carry out this study some hypothetical assumptions will be taken:

- The participation in the energy markets is subject to specific technical limitations, as presented in Section A, so the analysis will be made assuming an ideal scenario in which the battery has full access to the market with no regards to the required minimum size capacity bid or required time of response.
- Renewable energy generation cannot participate in the reserve and balancing markets due to their lack of firm capacity, nevertheless, it will be assumed that the proposed batter would have access to them regardless of its size or available time of response.
- The battery will be attached to the windfarm generation and so no subject to extra grid capacity fees. Nevertheless, the extra produced energy will still be subject to existing volumetric network fees for generators.
- The battery will be charged exclusively with energy curtailed from the windfarm, obtaining it at no cost.

Out of the presented business cases presented in Section A, this disposition would be the fifth business model presented: a private entity (utility) owns and operates a battery installation linked to a generation facility that can potentially be used to participate in regulated or not regulated markets.

Figure 42: Proposed business model scheme




## 17.2 Definition of the scenarios.

### *Revenue Scenarios*

The energy the battery would absorb can be used to obtain revenues from different services, either from a liberalized environment or from a regulated one. Out of the possible services a battery can provide (presented in section A), the following options will be disregarded: (i) bulk energy service will not be considered since the assumption is that this battery will be fed and attached to a wind farm and will provide energy as part of it and not by itself, with the regulatory and fees implications this has; (ii) network services such as infrastructure investment deferral and congestions management will not be considered since the assumption is that this battery will be owned and operated by a generator; and (iii) demand management services since this battery is located in front of the meter activity. Therefore, in this business model two categories of possible revenues streams will be considered: (i) generation support, and (ii) ancillary services.

- **Sc. A1) Generation Support:** in this case the battery will be supporting RE integration providing certain firm capacity and flexibility. This would mean participation of the battery's energy in a liberalized environment obtaining revenues from the spot market, increasing the actual wind farm's energy output when low wind occurs and space constraints in the node allows it.
- **Sc. A2) Ancillary Services (AASS):** Regardless existing technical limitations for storage technologies, in this scenario the battery would be participating in a regulated environment. Out of possible AASS to be provided, only upwards secondary regulation will be considered: on one hand primary regulation is not remunerated in Spain and tertiary requires duration times still challenging for batteries; on the other hand, downwards reserve is easily satisfied by the windfarm itself while upwards can only be provided by a technology able to inject additional energy at will. This case would create two revenues streams that will be stacked: (i) reserve secondary band payments based on provided capacity, and (ii) payments for energy used for upwards secondary control upon call of the operator.

### *Operative Scenarios.*

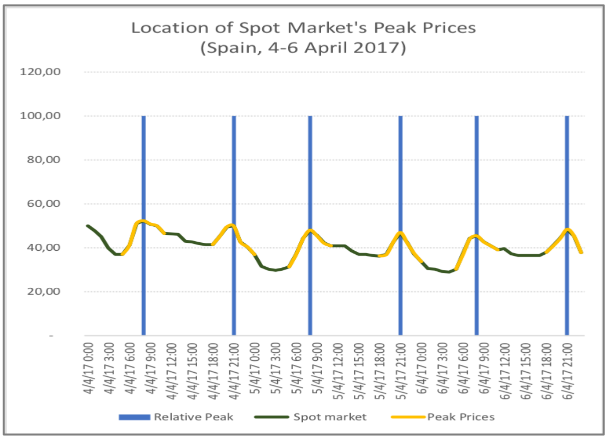
It will be assumed that the battery can operate discharging in partial cycles: no need to reach zero charge in each energy injection, since this provides not benefit at operational level. This means that the battery will take any chance to fulfill any capacity space available in the connection node. Nevertheless, additional possible scenarios will be taken regarding the reaction of the battery to the market[58] when providing those services:

- **Sc. B1) Discharging at any market price:** the battery will discharge only depending on the state of charge and the availability of space in the node, regardless of the relative price of the market and so taking the first available volumetric opportunity to discharge.
- **Sc. B2) Discharging only when peak prices:** the battery will discharge not only when its charged and there is space available on the node, but also taking into consideration the existence in that moment of market peak prices. Since not seasonal storage is assumed in this proposal, peak prices will be define at a daily basis in order to perform

[58] *Spot market prices are obtained at an hourly basis from REE Esios database for Spain for 2017.*

arbitrage service. Peak price will be assigned to those hours with higher values in 12h periods.

*Figure 43: Location of Spot Market peak prices in Spain, 4-6 April 2017*

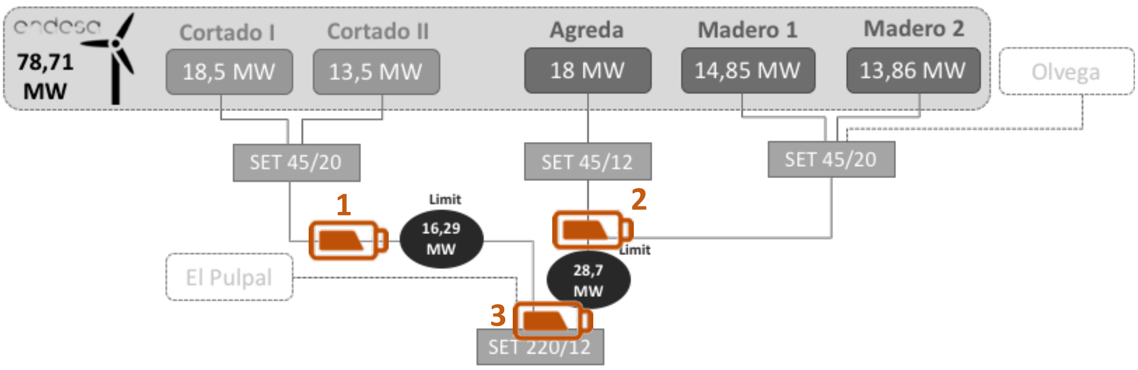



### *Battery Localization Scenarios.*

As it was described at the beginning of this section, the node to which the Sierra Moncayo is connected has a contracted capacity limit at 45MW, nevertheless this capacity is internally shared by to different groups of windfarms. The particularities of the node arrangement will make it necessary to consider three possibilities for the location of the battery system:

- **Sc. C1)** Located in front of **Node 1** (Cortado 1&2) and subject to a limitation of 16,29MW
- **Sc. C2)** Located in front of **Node 2** (Agreda and Madero 1&2) and subject to a limitation of 28,7MW
- **Sc. C3)** Located in front of the **shared node** of the whole wind power plant, taking the hypothesis of null production in third parties' power plants connected to the same power station, and subject to a total limitation of 45MW. This hypothesis will be subject to real physical dispositions.

*Figure 44: Possible locations to consider for the proposed BESS*




## 17.3 Potential revenues of the operative Scenarios

### *Scenarios*

The above presented scenario options result in the definition of nine possible scenarios.

Table 6: Possible Operative Scenarios to analyze for Sierra Moncayo Windfarm

| Location | Revenue | Price criteria | Scenario |
|---|---|---|---|
| **Node 1** | Spot Market | Any price | **Sc 1** |
| | | Peak price | **Sc 2** |
| | AASS | Any price | **Sc 3** |
| **Node 2** | Spot Market | Any price | **Sc 4** |
| | | Peak price | **Sc 5** |
| | AASS | Any price | **Sc 6** |
| **Node1&2** | Spot Market | Any price | **Sc 7** |
| | | Peak price | **Sc 8** |
| | AASS | Any price | **Sc 9** |

### Comparison of scenarios

The next step is to evaluate the potential most profitable scenario. In order to do so, the total annual revenues of a standard size battery will be tested and compared among scenarios. The chosen testing storage device will be a Li-Ion battery with a size of **2MW/4MWh**[59]. Based on the research made on Section A, the general characteristics of the Li-Ion battery tested will be as follows in the teable below:

Table 7: Technical characteristic of the testing battery

| Battery Characteristics | | *Unit* |
|---|---|---|
| **Type of battery** | Li-Ion | |
| **Battery Power Rating** | 2000 | *kW* |
| **Battery Duration** | 2 | *h* |
| **Battery available Energy** | 4000 | *kWh* |
| **Battery Round-trip efficiency** | 90% | *%* |
| **Usable energy from battery** | 3600 | *kWh* |
| **Max life full cycles** | 10.000,00 | *#* |
| **Depth of discharge** | 100% | *%* |
| **Time of response** | 1,00 | *seg* |

This same characteristic will be used in the following calculations made under this analysis.

### Revenues test of scenarios

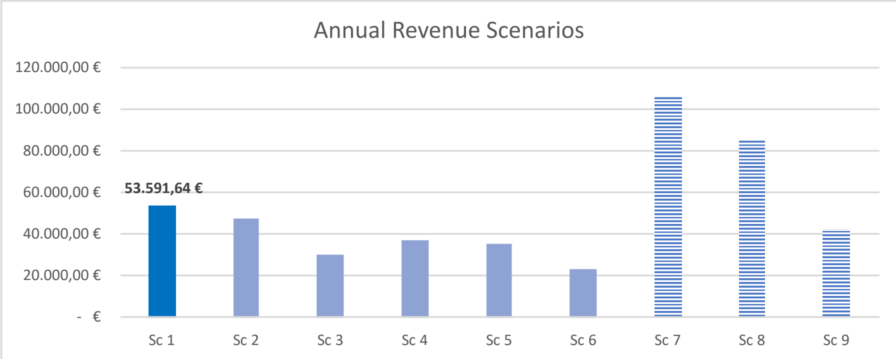
In order to test the scenarios, a simulation of the operative BESS was carried out on Excel software tool. The results of this first test of annual revenues in the different proposed scenarios are showed in the table and graph below:

Table 8:Comparison of annual revenues of proposed scenarios for a standard BESS in Sierra Moncayo windfarms

| Location | Revenue | Price criteria | Scenario | Energy injected | Annual Revenue |
|---|---|---|---|---|---|
| Node 1 | Spot Market | Any price | Sc 1 | 1.031,95 | € 53.591,64 |
| | | Peak price | Sc 2 | 864,86 | € 47.497,64 |
| | AASS | Any price | Sc 3 | 758,04 | € 30.528,59 |
| Node 2 | Spot Market | Any price | Sc 4 | 695,38 | € 37.067,30 |
| | | Peak price | Sc 5 | 624,47 | € 34.930,96 |
| | AASS | Any price | Sc 6 | 523,57 | € 23.522,55 |
| Node1&2 | Spot Market | Any price | Sc 7 | 2.010,91 | € 105.602,59 |
| | | Peak price | Sc 8 | 1.519,38 | € 84.870,86 |

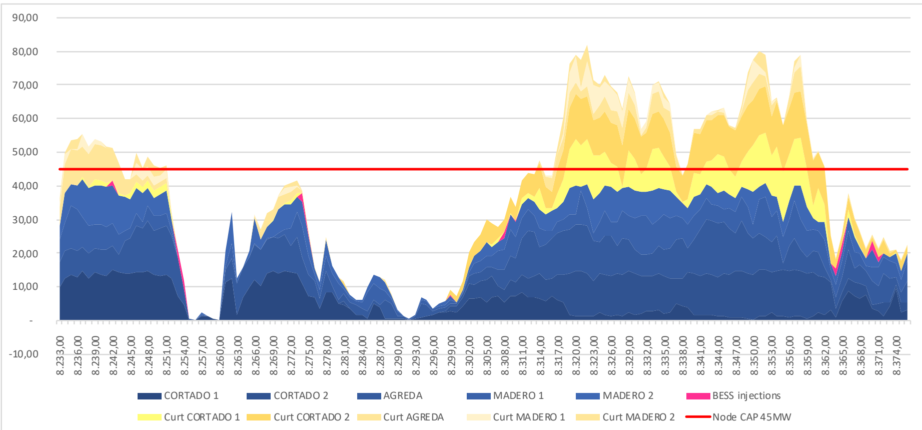
[59] *The average hourly curtailment of Moncayo windfarm stands at 4MWh, so this size of battery is considered a good benchmark for a first test of annual revenues.*

| Location | Revenue | Price criteria | Scenario | Energy injected | Annual Revenue |
|---|---|---|---|---|---|
| | AASS | Any price | Sc 9 | 972,29 | € 42.283,49 |




Although the scenarios in which revenues are higher are seven to nine, these are considered not technically viable due to the real disposition of the substation buses and the internal limitations scheduled. Therefore, the possible scenario providing the higher amounts of revenues is scenario 1: the battery connected to Cortado 1&2 node and operating in the Daily Spot Market.

*Figure 45: Production and curtailed energy with a BESS installed under Scenario 1 (graph detail for days 10-15$^{th}$ December 2017)*




## 17.4 Definition of the expenditure.

The identification of the project's expenditure will consider (i) material costs, (ii) administrative costs, (iii) design and construction costs, (iii) operative and maintenance costs, and (iv) life cycle costs including replacements and decommissioning. No specific environmental costs will be analyzed[60].

### *Investment general conditions.*

- **Project's lifetime:** it will be set at **20 years**, a standard value for a battery project and close to ENTSO-e's CBA 3.0 methodology, which proposes 25 years periods for network investments, including storage.
- **Project's discount rate:** it will be set at **3%.** The ENTSO-e recommends in its CBA 3.0 methodology for network and storage projects to use a 4% discount rate for projects with a 25 years lifetime and in a uniform way across Europe. Another reference to consider would be the approximate 2% value of annual inflation, which is used in much of the CBA analysis when the discount rate is not well defined. Considering the lifetime of this project at 15 years, 3% can be considered a valid figure.
- **Taxes:** the amount of taxes the project will have to face will be set at **5%** of investment. These taxes include the Spanish ICIO (tax on constructions, installations and works) plus

*[60] costs avoided, mitigated or compensated under existing legal provisions and specific environmental costs for maintenance or dismantling.*

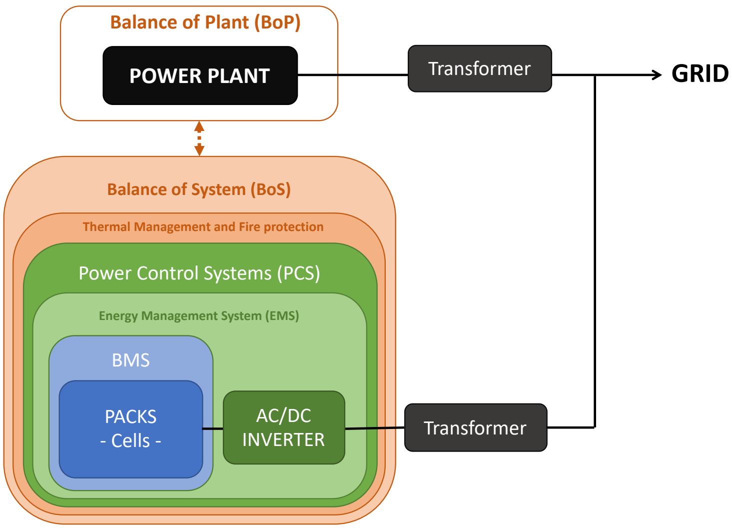
other smaller taxes, taking as reference the standard values taken in Enel's projects in Spain.

- **Contingencies:** all projects need to consider a small amount of the project investment to absorb eventual contingencies. Enel reference value for storage projects set it at **5%** on investment, which is the value that will be consider in this study.

*Investment costs.*

In order to define the investment needs, first it will be necessary to understand the necessary elements that compose a battery energy storage system (BESS) that will be connected to a power plant. A general scheme can be seen in the figure below.

*Table 9: general scheme of elements for a BESS connected to a Power Plant*




- **Storage module**, composed mainly by
  - *Pack of batteries*: batteries cells are mounted on racks that are packed on packs.
  - *Battery Management System (BMS):* it is any electronic system that manages a rechargeable battery such as by protecting the battery from operating outside its Safe Operating Area, monitoring its state, calculating secondary data, reporting that data, controlling its environment, authenticating it and balancing it
- **Power Control System**, composed by:
  - *AC/DC inverter*: an element that will be necessary to connect the DC flow with the AC grid.
  - *Energy Management System (EMS*): the electronics, switchers and breakers used for managing remaining battery voltage and control the battery charging.
- **Balance of** System (BoS), composed the container, the monitors and, the very important for Li-Ion batteries: the thermal management and fire protection systems.
- **Transformers**: necessary for the connection to the grid and usually at 10/0.4kV, considering that batteries cells work at levels of around 50V.
- **EPC Contract**: Which involves the engineering, procurement and construction of the project. These contracts, also called turn-key, are signed by third parties so that the promotor of the project receives it ready to operate. Taking as reference McKinsey's 70 EUR/kWh.

Taking these elements, reference costs considered by Enel's specialists will be applied to the project, as it can be seen in the table below:

*Table 10: Investment expenditure considered for Sierra Moncayo BESS*

| INVESTMENT NEEDS | | Unit |
|---|---|---|
| **Project design, constructiona and commissioning** | | |
| ○ *EPC - contract for the engineering, procurement, construction and commissioning* | 70 | *EUR/kWh* |
| ○ *Owner services* | 33,00 | *EUR/kW* |
| **Physical Elements** | | |
| ○ *Battery Li-Ion + AC-DC Converter + Transformer + Auxiliary devices and thermal management* | 230,00 | *EUR/KWh* |
| **Software and wiring elements** | | |
| ○ *Energy Management System (EMS)* | 34,50 | *EUR/kWh* |
| ○ *Plant Control Systems (PCS)* | 63,00 | *EUR/kW* |
| ○ *Balance of Plant (BoP)* | 84,00 | *EUR/kW* |
| ○ *Integration and others* | 62,00 | *EUR/kW* |
| **Others** | | |
| ○ *Spare Parts* | 4,3% | % |
| ○ *Automatic Generation Control (AGC)* | 200.000,00 | *EUR/project* |

*Operation and Maintenance Costs.*

- **General O&M:** A general value of **3% on investment** will be used to consider O&M cost. A battery system requires not fuel supply and, in this case, energy is received directly from a power plant on which the battery is integrated, so energy is obtained at no cost.
- **Network charges:** Grid fees for connection will not include payments for capacity, as the battery is inserted in the wind power plant and this is considered to be already contracted through the nodes. The energy injected will be subject to a network fee of **0,5 EUR/MWh**, according to the Spanish "Real Decreto 1544/2011" where charges for connections to generation facilities are defined.
- **Replacement and decommissioning.** It will also be necessary to consider replacement costs of the battery packs, which depends on the cyclability and use of these. The battery that will be simulated is set at a maximum **10,000 cycles** after which it will be replaced. Decommissioning costs will be set at **3%** of investment, as usually considered in these projects by Enel.

# 18 Results of the analysis

## 18.1 Objective of the NPV and IRR analysis

Once revenue streams and necessary expenditure is defined, it will be possible to determine annual cashflows under different hypothesis and make the next step analysis:

- **Define the optimal size of the battery**: the analysis of the revenues was carried out using a standard battery that would allow comparing the different revenues streams, now it will be necessary to define the optimal size of the battery considering the costs implications this decision has.
- **Profitability of the optimal hypothesis**: the definition of revenues and costs will allow to determine the proposed project's cashflow and analyze its Net Present Value (NPV) and Internal Rate of Return (IRR). The Project will seek positive values of the NPV and IRR larger than 5%, which will ensure enough profitability.
- **Evolution in price markets that will enhance profitability**. The Project will be tested with the current cost and revenue streams provided by the industry, nevertheless it will

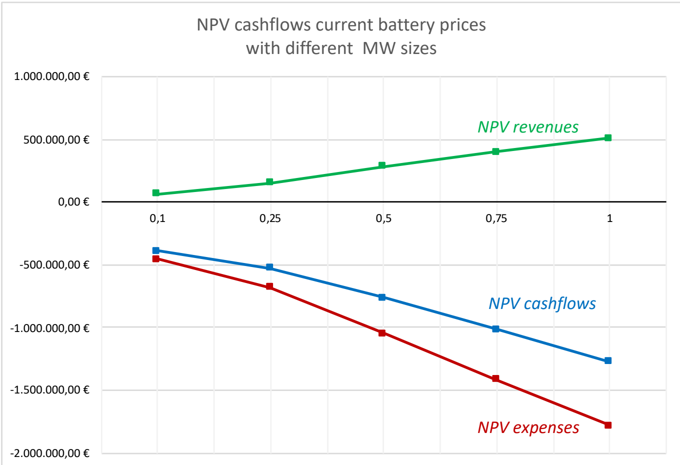
be important to analyze the possibilities that lower prices will have on the viability of the Project and how this may allow larger battery sizes to be proposed.

## 18.2 Size of the Battery

Once the costs and revenues streams for the presented project have been identified, it will be tested the changes in NPV results (20 years project) compared with an input of an increasing size of the battery system installed.

The results be seen in the figure below. As it can be seen, the project shows how under the proposed hypothesis the project results not profitable even for small sizes of the batteries. This is mainly due to the fact that the continuous curtailed orders in the nodes of Sierra Cortado do not allow the battery system to take enough revenue streams from the collected energy: it would be necessary to consider different curtailment administration. This result is in line with the industry analysis, which considers that large battery installations still need to lower investment prices or being subject to public grants in order to show attractive profitability.

*Figure 46: Net Present Value of the proposed project with different battery sizes installed*




Supposing that a battery the size of 250kW/125kWh is installed to Cortado 1&2 nodes, the total investment necessary will stand at 192,000 EUR, or 1,750EUR/kW, and a LCOE= 78 EUR/MWh. The NPV of cashflows for a project of 20 years will be negative at -117,350EUR and IRR=-5%, what shows that financing grant programs are necessary for the full development of batteries. Lazard's studies show capital costs at 2,172 US$/kW and LCOE at 494 US$/MWh for Li-Ion batteries used for microgrid applications, a scenario for which they consider operative conditions similar to the ones that are presented in this analysis. The smaller value of the LCOE in this study can be explained due to the much higher operational costs assume by studies like the one carried out by Lazard, which takes into consideration charging costs that would not apply in our project, higher replacement costs than the ones reported by Enel and battery sizes larger for the compared applications.[61]

With this exercise it is possible to put a critical view on the wide range of battery prices that publications and industry currently show. First, it is shown how critical the use the battery is for defining a proper LCOE, which in existing literature can range from values around 200 eur/kWh in front the meter applications to more than 1,200 eur/kWh in behind the meter applications, as it was seen in Section A. Regarding the capital investment necessary, this study reflects how values of around 2,000 eur/kW make reference to the whole battery system investment needs, not only the battery pack. Also, the study shows the limitations that the state of charge and discharge poses for higher revenues streams.

### Sensibility analysis.

[61] *According to Lazard 3.0, for batteries in microgrid, the capital costs of the AC-DC system stands at 517 US$/MWh, with a small EPC cost. Nevertheless, replacement costs are set at 32% of the cost of the BESS and annual O&M are more than 50% of the capital investment, compared with the 3% considered in the case of this report.*

As it has been seen, under the proposed scenario, there are not profitable options for batteries. Nevertheless, three aspects should be measured as sensible for the project: (i) the presented decline in battery price, (ii) variations in curtailment inflows, and (iii) the variations in energy prices.

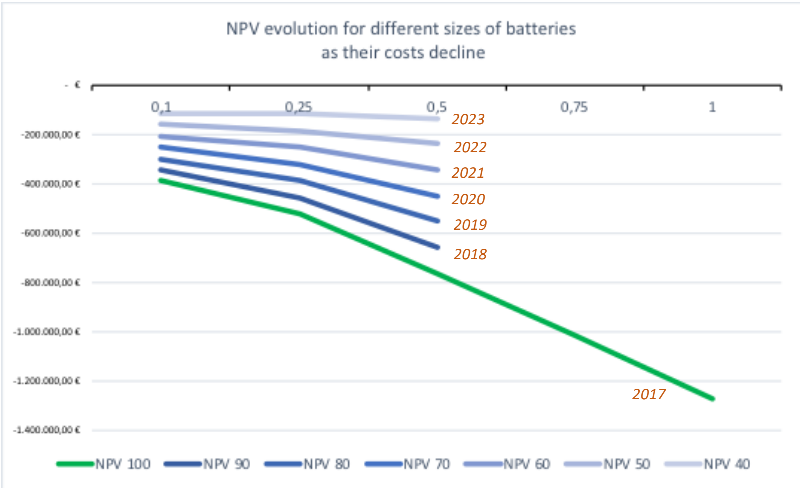
### *Effect of descending battery prices.*

The benchmark price considered for the BESS capex has been 1,750 EUR/kW. As it was seen in Section A, current literature presents different expected values for the evolution of battery prices in the following years, with values that expect a reduction of 60% by 2025 compared with 2017.

The figure below shows, assuming that this reduction is concentrated in the BESS CAPEX, how as BESS costs reduce, the profitability of larger sizes of batteries grow fast. This can interpret also as the need of an initial grant that a profitable battery should obtain today.

As it can be seen in the figure below, the operative hypothesis will not be profitable even at expected price reduction during next years. With this operative conditions, a battery with a size of 0.5MW/1MWh would need a reduction of prices as much as 80% in order to show a positive NPV of 74,500EUR and IRR=8%.

*Figure 47: NPV evolution as BESS market price declines*

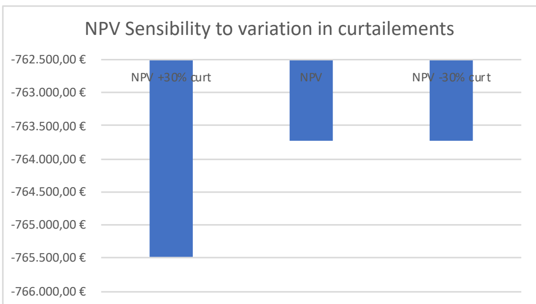



It can be concluded that the proposed project of a battery feeding from the energy curtailed in Sierra Moncayo windfarm provides not enough economic incentives.

### *Effect of the variation in curtailments inflows.*

The curtailments taking place in Sierra de Moncayo in 2017 are 30% lower than the average curtailments taking place in last four years, so a variation of ± 30% in curtailments inflows will be tested on the NPV and IRR, considering that the 30% will be a more likely scenario as higher penetration in renewable generation will increase the frequency of the power plants curtailments.

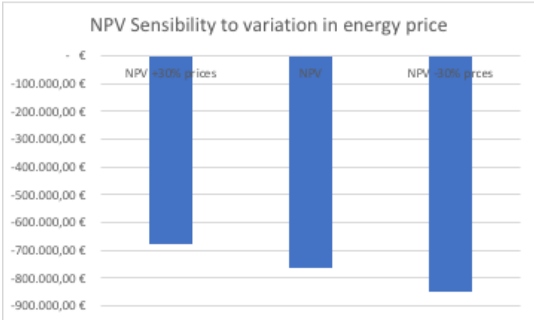
*Figure 48: Sensibility analysis to variations in available curtailments*




As it can be observed, a reduction in available curtailments will not affect much the resulting profitability, since even with base-case value most of the curtailments are wasted due to the limited size of the battery and the node cap. Nevertheless, an increase in curtailments will have an important effect since the battery will be able to operate with higher injections when operating under the cap.

### *Effect of variation of market prices.*

Prices in the sport market in Spain have been increasing in average in the last years, this trend is not expected to change in next five years. Nevertheless, sensibility at $\pm$30% variation in market prices will be tested.




### *Additional economic benefits*

The analysis carried out on this section follows the investment agent approach and taking as main indicators of the profitability of the project the return on investment from a financial perspective. Nevertheless, other benefit streams should be considered and stacked together when analyzing storage investment, particularly if the CBA is conducted by public bodies. We will address the different indicators proposed by the ENTSO-e CBA 3.0 methodology for the proposed BESS system in Sierra Moncayo supposing capacity installed of 500kW/250kWh.

- **Project Costs**: for a BESS of the selected characteristics, the required initial expenditure will be approximately **742,600 EUR**, plus the annual operational expense of almost **21,800 EUR**. It is important to remember that the proposed BESS operates under very advantageous conditions since it charges with energy at no cost and it is not subject to greed fees related with connected capacity.
- **Environmental and social impact costs**: these costs may be related with (i) environmental cost of manufacturing, installation and decommissioning and (ii) social impact of space occupied. Given the small size of the battery and its integration in an already existing infrastructure, both impacts will be considered neglectable except for the decommissioning cost standing 3% of the required investment, which is approximately **22,280EUR**.
- **Socio-economic welfare**: a higher participation of the windfarm in the market will increase the renewable participation in the market and a slight reduction in prices, benefiting the demand, at the same time that the arbitrage activity benefits the generator. The reduction in spot market price can be considered neglectable given the small size of the battery and the benefit the generator obtains can be set at approximately **110,000 EUR/year**.
- **Security of Supply**: in the proposed project and as result of the selected Scenario 1, it will be considered that Sierra Moncayo battery does not directly contribute to security of supply since it will not participate neither in reserve or balancing market.
- **Reduced carbon emissions**: As presented, the BESS will inject to the network 320MWh annually. This energy provides from clean wind generation and will increase the share of renewable energy in the market, displacing more pollutant generation. Assuming this displaced generation will be the marginal one, usually Coal generation, and considering

the conversion factors for final coal energy consumed at 0,472 kgCO2/kWh[62], the emissions the battery would avoid **151 tCO2 a year**. Taking as reference the European CO2 allowances for May 2018, 15 eur/tCO2, the battery will provide annual benefits at **2,265 EUR** from avoided carbon emissions.

- **Losses Reduction**: the proposed battery is not providing network services and therefore it will be considered that it not contributes to reduce losses in the network.

**RE integration**: The BESS would contribute with its own capacity (500kW) total and injected energy (320MWh/year) to a higher integration of the renewable generation from the wind farm. The monetization of this will be integrated in the socio-economic welfare indicator with the extra revenues the generator obtains and the reduction in prices it would cause.

[62] *Factores de emisión de CO2 y coeficientes de paso a energía primaria de diferentes fuentes de energía final consumidas en el sector edificios en España, Ministerio de Industria y Energia, 2014*

# VII. Conclusions

In the near future scenario of decarbonization, electrification of the economy and increase in urban population, the provision of flexibility will be key for the evolution of the power sector functioning. Lowering prices in energy storage solutions and the evolution of communication technologies are opening new business opportunities for the power sector industry. There is a need for both private and public stakeholders to understand the energy storage options, the possible opportunities they can offer and the main challenges they have to face.

The results present how energy storage performance in the electricity sector can be analyzed in based on three key aspects: (i) speed of discharge, (ii) energy capacity and (iii) round-trip efficiency. From a technical point of view, Li-Ion batteries, show very good performance thanks to their modularity, high energy density (~200Wh/l), fast response (<1sec) and efficiencies of 95%, being able to provide balance services for the network, firm capacity and arbitrage opportunities for the integration of renewable energy, and small-size services to end consumer. Pushed by the research in the electronics sector and the growth on the electric vehicle industry, Li-Ion batteries are expected to reduce their costs by 50% in the next ten years and increase their energy densities up to 10 times from current values.

Main regulatory barriers for energy storage can be classified in three groups: (i) the existence of a clear definition in the regulation, so it can be treated in a non-discriminatory way and subject to appropriate fees and benefits, (ii) the adaptation of wholesale, reserve and balancing markets to shorter settlement periods, integrating the constraints such as state of charge and rewarding its fast speed response capability, and (iii) the public support of the industry by creating financing programs, research, reference standards and targets.

The **USA is leading** the regulatory initiative for integration of batteries: the FERC has called to insert particular constraints and technical characteristics in the **centralized markets. California** has defined mandatory targets for utilities while **New York State** defining targets to be achieved through financing and incentive programs.

**The EU will approve in 2018** the Clean Energy for All Europeans Package calling for adapting wholesale and balancing markets, seeking energy only prices, reducing bid sizes as much as possible and calling to reward speed of answer. **Germany** is inserting storage in the regulation to define the asset, make it beneficiary of RE incentives and promoting adapted wholesale markets. **UK** is already experimenting with specifically tailored balancing products and capacity market auctioning. The key service provided so far has been FCR balancing, which will face challenges due to upcoming ENTSOe networks codes.

Meanwhile, both the US and EU are deploying important financing programs for demonstrative storage projects and research, while they work in the definition of standards and cot-effectiveness analysis.

In general, it can be said that the key characteristics of the markets where battery developments are being success fur are related to the remuneration of primary frequency control (synthetic inertia), to the access of storage technologies to incentives similar to those used with RES and to the existence of mechanisms rewarding speed of response.

**Sierra Moncayo** business case ends up not being profitable under the taken hypothesis: a battery absorbing the curtailed energy from the Cortado 1&2 windfarm park and operating in the sport market. The lack of profitability of this option, even when it is the one providing higher revenue streams, responds to the particular administration of curtailments and the constraints related to it not allowing to create positive NPV cashflows. Nevertheless, this case demonstrates how main revenue source for storage in Spain will be participating in the spot market rather than secondary frequency control, the need of stacking revenues from different sources is necessary to justify large storage investments, and the necessary financing support. In this particular case, how important the constraint of “state of charge” is, and how still financing support is necessary. Also, the exercise has been useful to understand the costs related with battery projects and to apply the methodologies under development for CBA at European level.

## 18.3 Next Steps

The complexity of the energy storage industry and the relatively recent development of profitable business models, open a wide range of investigation possibilities, for example:

- The power industry and mainstream literature are focused on the development of electrochemical Li-Ion based technologies. Nevertheless, it is important to understand the good performance of other technologies and the possibilities of hybrid systems, particularly those of electrochemical storage with either flywheels or supercapacitors.
- The United States and the European Union are leading the regulation initiative to integrate storage in the Western World, nevertheless China, South Korea and Australia will lead also new developments and present interesting and innovative approaches for the integration of these technologies.
- 2018 has been the year that US and EU started deploying key regulation for the integration of storage technologies in power markets, it will be interesting to follow up on the adoption the States take ad the new challenges that appear.
- Sierra Moncayo business case represents a very particular situation where a windfarm is constantly curtailed, making the battery also subject to the curtailment orders. Also, the energy the energy the energy the battery withdraws from the system is free. It will be interesting to study business models based arbitrage and firming of common RES power plants and for stand-alone batteries connected to the network, as well as analyzing the stacking of several revenue sources.

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