Public Policy Frameworks of Li-Ion Battery Energy Storage Systems Applications

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Abstract

In the two decades from 2020 to 2040, battery energy storage systems installations are expected to grow more than 50-folds. Among these technologies, Lithium-Ion batteries are forecasted to follow a 50% price reduction in 10 years.

The Master's Thesis presents the available technologies of Li-Ion BESS, highlighting strengths and weaknesses of its alternative compositions. BESS applications are then analysed, for both Behind of the Meter operations, Microgrids and Front of the Meter operation. BESS are then compared to other Energy Storage solutions. Following this section, the Master's Thesis restricts its focus on the first renewable energy tender in continental Europe with a PV + Storage option: The 2020 Portugal Solar Auction.

The study of BESS technologies, applications and public policy frameworks is used to support the hypothesis that *a short duration LFP BESS is the favourite choice for the 2020 Portugal Solar Auction, although long duration LFP and NMC BESS will become the technologies to yield the most value in the future decades*. Moreover, it is attempted to estimate the required volume of Back-Up systems and BESS to meet the targets of the PNEC 2030. It is forecasted that *by 2030 a volume range between 5-10 GW of additional Back-Up power will have to be provided. The share of BESS will depend on public policy frameworks and it can be estimated not to surpass 1 GW*.

As the future share of BESS will be greatly impacted by public policy frameworks, a final list of public policy actions is presented.

Keywords: Battery Energy Storage Systems; Li-Ion BESS; Front-of-the-Meter; Behind-of-the-Meter; 2020 Portugal Solar Auction, PNEC 2030

1: Introduction

As battery energy storage systems installations are expected to follow a 50-folds increase in the next two decades, this sustained growth will be at the centre of a profound restructuring of the energy market. If renewables integration of wind and solar continues rising its share in the world electricity mix, new issues of electricity supply, frequency balance and price stability will become critical. When solar and wind reach the main share of a nation's electricity generation assets, it will not remain feasible to operate the grid without storage. From 20 GW circa of currently operative battery storage installations in the world, BloombergNEF predicts volumes around 1,095 GW by 2040, as shown in figure 1.

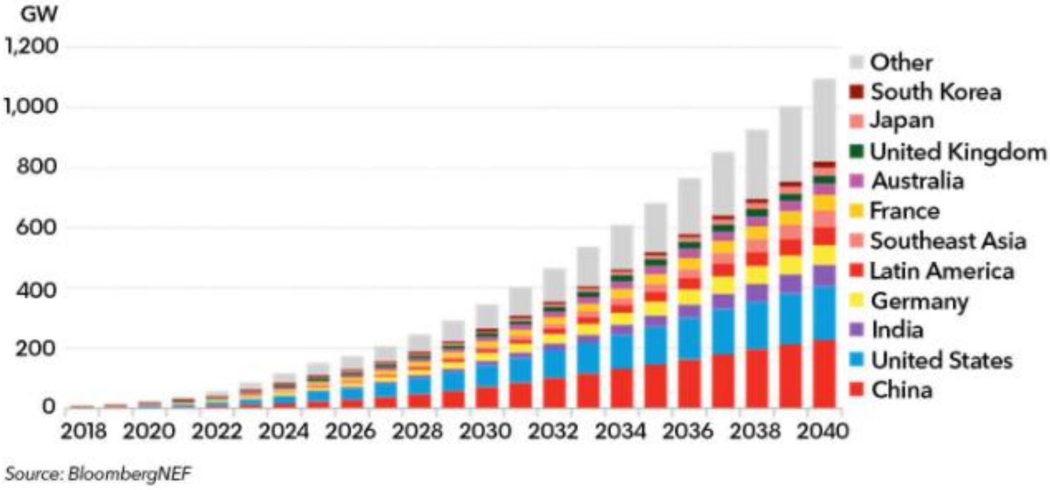

Figure 1: Global cumulative battery energy storage installations [2]

This worldwide market expansion will require investments in the order of over $600 billion [2], redefining the way that renewable projects are financed and the degree of understanding that the world will need to gain on this technology.

In this regard, it is pivotal that a series of stakeholders involved in this market restructuring phase can understand the potential of energy storage and will be able to take advantage of it. Regulating authorities will need to design public policies that are able to favour a thriving market. In this way, TSOs and DSOs will be able to use battery systems to enhance their grid resilience and flexibility. At the same time, power utilities will manage to deploy electricity with better power purchase agreements and by capturing new opportunities in the electricity trading markets.

Among all the energy storage technologies, the one that has been deployed the most in recent years, showing exponential growth, is that of Lithium-Ion battery systems [3,4]. Being the technology of choice for electric vehicles, Li-Ion represents a core solution for both the motor and the energy sector. This resulted is a particular effort in its Research and Development, which is expected to bring a 50% price reduction within the next 10 years [5]. Given these reasons, a focus on Li-Ion battery is due.

Being Li-ion battery energy storage a relatively new field with very limited track of records on all of its potential applications, it is fundamental in this moment in time to bring more clarity on the issue, so that all the stakeholders can appreciate the opportunities hidden underneath the complexity of such technology.

The purpose of this work is to present in a structured way the current state of development of Li-ion batteries, explain the multitude of its potential applications, compare it with the currently available alternatives, understand how it is currently being deployed and favoured with new tailor-made policy frameworks, estimate and analyse its future deployment considering the current targets of decarbonization and provide recommendations for the future on how this technology should be enhanced with proper policy frameworks.

In order to focus on the public policies that are being designed at this moment in time and on the efforts that will need to be taken for future decarbonization national plans, it was decided to use Portugal's electricity market as case study. It is for these reasons that Chapter 4 focuses on the 2020 Portugal Solar Auction with Storage, while Chapter 5 analyses the targets of the 2030 National Energy and Climate Plan (PNEC 2030)

and attempts to define an Energy Storage roadmap.
The hypothesis brought forward in this Master's Thesis is that, given the various considerations of technical and economic nature made across all chapters, a short duration LFP Li-Ion technology is the favourite choice for the 2020 Portugal Solar Auction, but that both LFP and NMC Li-Ion batteries with long duration discharge time are the solutions that will yield the most value with future applications. This hypothesis is proved with an analysis of the public policy frameworks of the 2020 Portugal Solar Auction. In addition to it, the Master's Thesis work attempts to define a volume range of back-up systems and BESS needed to accomplish the targets of the PNEC 2030 and tries to formulate specific public policy frameworks to adopt in order to facilitate the roadmap to achieve these targets.

Having sustained which technology of Li-Ion is the most suited one for both the immediate future and the long-time approach,and having presented which policy actions should be taken in order to favour the adoption of BESS to successfully achieve the targets of the PNEC 2030, it is believed that this work can have the value of contributing to the efforts for clarity in the field of battery energy storage systems.

2: Methods

The three research problems investigated were to identify which Li-Ion technology is the most suited for the 2020 Portugal Solar Auction, which Li-Ion technology is the most suited for the electricity market in the next decade and what volume range of battery energy storage should be deployed to meet the PNEC 2030's decarbonization target.
In order to answer the first question, it was first attempted to systematically describe the characteristics of the different Li-Ion technologies, comparing them one another and with other energy storage technologies. For this purpose, it has been necessary to perform a recollection of both quantitative and qualitative data. All information reported was secondary data that can be retrieved in the bibliography, as no primary data recollection was performed for this study. Quantitative data was recollected for indicating the gravimetric and volumetric energy density of different battery technologies [4] and the price curves of different energy storage technologies [5], Qualitative data was instead collected to rank different Li-Ion technologies in terms of safety, performance, life span, cost, capacity and specific power [6,7]. In order to understand which of these aspects are the most relevant for the electricity market, it was necessary to explore the different applications for which energy storage systems are employed. The information collected was sourced from scientific papers and internationally accredited organizations such as IEA, IRENA and ESA. Some examples of battery storage installations were also cited from News outlets, with the attention of selecting internationally acclaimed sources such as Bloomberg NEF.
In order to understand which of these applications could be employed to participate in the 2020 Portugal Solar Auction, the rules and remuneration schemes of the auction were analysed and reported. This information was gathered attending the online seminar of the Portugal Directorate General for Energy and Geology [8] and from the literature presented in the seminar [9,10]. Through the analysis on the requirements and remuneration schemes of the 2020 Portugal Solar Auction, with the support of the information gathered in the previous sections on the State-of-the-Art of Li-Ion BESS technology and BESS applications, it was possible to assert which BESS technology constitutes the most suited solution for the 2020 Portugal Solar Auction and which

technologies are likely to remain suited to the electricity market in the next decade.
In order to quantify a volume range of battery energy storage needed for the PNEC 2030, it was necessary to first gather from the PNEC 2030 the exact values of its decarbonization target and its forecasted values of total installed renewable energy capacity in 2020, 2025 and 2030. After gathering this data, in order to estimate the back-up needs it was necessary to make the assumption that for countries in which Variable Renewable Energy (VRE) penetration surpasses 40-50% it is advisable that every GW of VRE installed is balanced by 0.8 GW of back-up asset to maintain security and reliability of the grid [11]. Having obtained the value of back-up asset required for the total VRE capacity installed, it was then possible to reduce the value of the necessary back-up power by considering the improvements of the Spain-Portugal interconnection defined the PNEC 2030 [12]. Hence, it was possible to provide a range of power to be covered by a combination of Hourly Ramping of non-dismissed fossil-fuel peak plants, Demand Response programs and Energy Storage technologies. The real value of BESS installed by 2030 can be finally determined by the economic competitiveness of VRE+Storage options in the coming national public tenders. Finally, following the trends outlined by BloombergNEF [13], an optimistic scenario of covering of back-up power with BESS was indicated.

3: Results and Discussion

In order to present which Li-Ion BESS technology is the most suited for the 2020 Portugal Solar Auction, it is necessary to make a distinction between different Li-Ion technologies, in order to select the most suited one to operate as stationary storage systems. A graphic summary comparison of the Li-Ion technologies presented is shown in Figure 2.

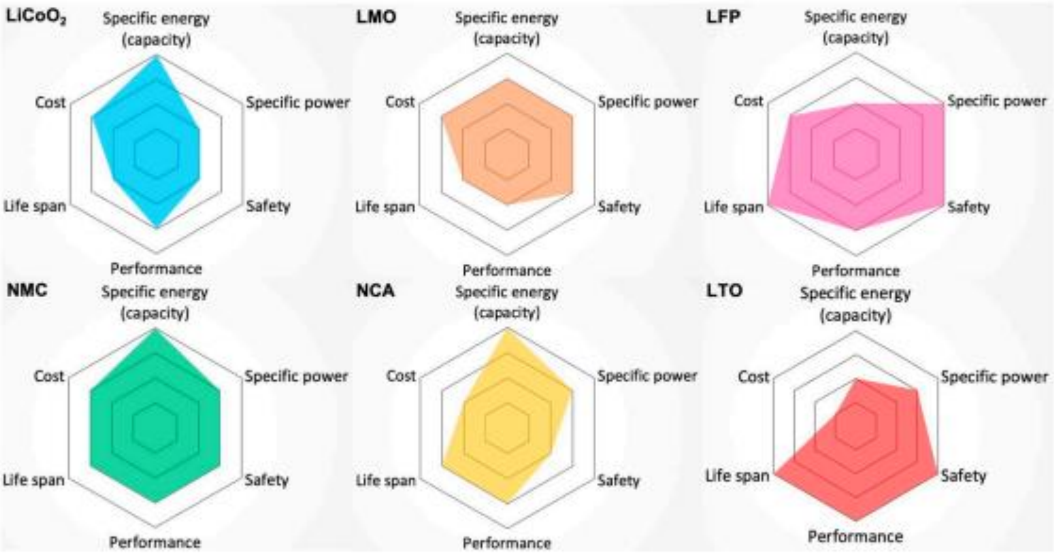

Figure 2: Graphic comparison of the most employed Li-Ion technologies. Every characteristic is rated on a scale from 1 to 4 in relation to the other competing technologies [6, 7].

Following the assessment of strengths and weaknesses of compositions such as $LiCoO_2$, LMO, LFP, NMC, NCA and LTO, and the analysis of BESS applications both for Behind of the Meter operation (Renewable Self-Consumption, Tariffs Optimization, Peak Shaving, Load Shifting and Back-Up) and for Front of the Meter operation (Wholesale Market participation, Frequency Control, Ancillary Services, Capacity Market, Time

Arbitrage, Ramp Control, Transmission Congestion Avoidance and Grid Investment Deferral), it appears that the most suited technology solution for stationary storage systems is obtained by a trade-off between maximizing lifespan, minimizing cost and allowing for high levels of both specific energy and specific power. According to which BESS application the system is required to perform, specific energy can be prioritized over specific power or vice versa. If short duration and high power rating are required, LFP is likely to figure as the best suited solution, while in case of long duration and high energy capacity the best option appears to be NMC.

Given the analysis of the 2020 Portugal Solar Auction presented in the elaborate, it appears that the only reason that would justify the installation of long energy duration batteries is the existence of a business case for energy arbitrage, in which consistent revenues can be made through peak shaving and load shifting. To validate such business case, one must look at the daily price spread of electricity tariffs during on-peak and off-peak times. If this time spread is higher than 30 €/MWh, the installation of BESS can be motivated. In case that this time spread is maintained daily over long periods of time (tariff peaks of several hours), then the battery storage system should be ideally sized with as much capacity needed to shave the entirety of the peak. However, the Portuguese wholesale electricity market does not experience price spreads higher than the indicative value of 30 €/MWh and therefore energy arbitrage alone is not a sufficient application to motivate the investment. For this reason, bidders do not wish to rise their development costs in order to increase capacity, therefore they align on offering batteries of 1 hour discharge EoL, the lowest accepted by the auction. For 1 hour systems, technologies with high specific power result more technically interesting than technologies with high specific energy. In this case, LFP li-ion solutions are considered to perform best than NMC li-ion, which would have instead been the favourite choice in the event of long durations required for an energy arbitrage business case. Another major point to consider is that of the battery life span. Due to high cycling, degradation of the BESS can cause a considerable loss of energy capacity over the 15 years of operation required by the tender. The way to prevent the battery to reach a capacity below 1 hour discharge before the End of Life (set at 15 years) is either oversizing the system, adding a capacity Beginning of Life superior than 1 hour, or substituting on a yearly basis some modules of the battery which are not functioning at 100% of their rated capacity. In both cases, it is desirable to opt for a technology that maximises the battery lifetime. In this case as well, LFP seems to have reached better performances than NMC [6,7]. Finally, being Cobalt an element that particularly increases the cost of batteries, NMC li-ion systems are usually more expensive and can hardly compete with LFP batteries when specifications are for a C-rate equal to 1. For the reasons presented, it is believed that LFP li-ion battery storage solutions are able to provide the best NPV to the 2020 Portugal Solar Auction.

With the current market remunerations for wholesale electricity and frequency regulation, the business case that motivates the installation of BESS is mainly constituted by the revenue streams coming from secondary and tertiary frequency regulation. This situation is however expected to vary in the future. As it happened in the past years with a more mature and structured market for frequency regulation such as the United Kingdom, the progressive installation of more BESS from different competitors brought the market to a fast saturation and saw remunerations to drop drastically. Developers that decide to install extremely high specific power batteries (with duration between 15 minutes to 1 hour of discharge), usable only for frequency control and other ancillary services, can face unexpected profit reductions and in some cases be forced to file for bankruptcy [14]. On the other hand, those developers that install systems with more energy capacity can prove to be more resilient and are able to draw revenues by stacking different applications. Another expected trend, with the scheduled future increase of solar energy share in the electricity mix, is the increase of the daily price spread [15]. The increase in the daily price spread will unlock the business case of energy arbitrage, making it profitable to add energy capacity able to provide power for the entirety of the peak. Considering these two trends, long duration batteries (discharge time over 2 hours), both of LFP and NMC composition, will become a more interesting option than short duration batteries (discharge time below 1 hour) over the next decade.

The third and last question that the research attempted to address was to quantify a volume range of battery energy storage needed for the PNEC 2030. In order to provide an answer, it was necessary to gather from the PNEC 2030 the exact values of its decarbonization target and its forecasted values of total installed renewable energy capacity in 2020, 2025 and 2030, which are shown on Table 1.

Table 1: Total installed capacity (GW) of each renewable source in Portugal for the PNEC 2030. Other Renewables accounts for Biomass, Biogas, Waste, Geothermal and Wave [12].

	2020	2025	2030	2020-2030 difference
Hydro	7.0	8.2	9.0	2.0
Wind	5.4	6.6	8.8	3.4
Solar	1.9	5.5	8.1	6.2
Other RES	0.5	0.5	0.7	0.2
TOTAL	14.7	20.8	26.6	11.9

After gathering this data, it was assumed that for countries in which Variable Renewable Energy (VRE) penetration surpasses 40-50% it is advisable that every GW of VRE installed is balanced by 0.8 GW of back-up asset to maintain security and reliability of the grid [11]. Having obtained the initial value of back-up asset of 13.52 GW for a total VRE capacity installed of 16.9 GW [12], it was possible to reduce the value of the necessary back-up power by considering the improvements of the Spain-Portugal interconnection to 4.2 GW by 2030, according to the PNEC 2030's targets [12]. Hence, it was possible to provide a range of power to be covered by a combination of Hourly Ramping of non-dismissed fossil-fuel peak plants, Demand Response programs and Energy Storage technologies of 5-10 GW. Of the back-up power needed, it is likely that the majority of it will be constituted by hourly ramping of fossil-fuel peak power plants in decommissioning phase, which will still constitute 20% of the electricity mix by 2030. However, in the event of rising tariffs on carbon footprint and incentives for Energy Storage, BESS would be considered as a valid alternative and some cases as a more economically viable one. The real value of GW of BESS installed by 2030 will indeed be finally determined by the economic competitiveness of VRE+Storage options in the coming national public tenders. Following the trends outlined by BloombergNEF [13], an optimistic scenario would be that of covering 1 GW of back-up power with Battery Energy Storage Systems. As previously mentioned in Chapter 4, the ideal duration for BESS in order to cost effectively balance the grid and carry out load shifting, peak shaving, frequency control and ancillary services is around 4 hours with 100% Depth of Discharge. Therefore, the capacity suggested for a 1 GW BESS is 4 GWh. According to this scenario, the ideal BESS volume to be deployed in order to meet the PNEC 2030's decarbonization target is 1 GW of specific power and 4 GWh of installed energy capacity.

The cost of deploying such an amount over the course of the next decade is estimated to be in the range between 0.55 and 1.025 billion EUR [16].

Conclusion

As the market of Battery Energy Storage Systems is expected to grow exponentially in the next decades, as such, public policy frameworks will need to be accurately tailored in order to better address the many issues related to the incorporation of such a disruptive technology in the status quo of the electricity sector.

The study of BESS technologies, applications and public policy frameworks was used to support the hypothesis that a short duration LFP BESS is the favourite choice for the 2020 Portugal Solar Auction, although long duration LFP and NMC BESS will become the technologies to yield the most value in the future decades. In order to define the needs of BESS in the next decades, it was attempted to estimate the required volume of Back-Up systems and BESS to meet the targets of the PNEC 2030, the Portugal National Energy and Climate Plan for 2030. It was estimated that by 2030 a volume range between 5-10 GW of national Back-Up power will have to be provided by Hourly Ramping fossil-fuel peak plants, Demand Response programs and Energy Storage technologies excluding PHS. The share of BESS will highly depend on future public policy frameworks and it can be estimated not to surpass 1 GW of installed power.

As a follow-up to this work one should analyse the operation, revenue schemes and degradation over the lifetime of a short duration LFP BESS so as to to quantitatively compare it with long duration LFP and NMC. Another suggested research topic would be to evaluate the competitivity of BESS over Hourly Ramping fossil-fuel peak plants in order to establish which price point can increase the share of BESS and help define with more granularity the the volume of BESS needed to be deployed for the PNEC 2030 to be achieved. Finally, it would be interesting to analyse and quantify the effects of each proposed public policy in order to compare each one and suggest an order of priority specific to the Portugal electricity market. With this thesis and the suggested future studies, it is envisaged that a relevant contribution to understanding the use of BESS can be achieved. The hope is to see the implementation of public policies that not only focus on incentivizing new energy production, but also strive to store energy efficiently, championing the use of flexible low-impact technologies that will contribute to a rapid transition to carbon neutrality.

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