Energy Storage in Ireland: Barriers and Policy Interventions

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# Executive Summary

In this report, first, we have reviewed the energy policy of Ireland in the electricity sector that is going to move from a gas-fired dominated generation system toward an 80% renewable penetrated system. Based on the climate action plan 2021, by 2030, Ireland will achieve at least 5 GW of offshore wind farms installed capacity, up to 8 GW of onshore, and between 1.5 to 2.5 GW of solar PVs. In addition, micro and small generation will lead to 760 MW of renewable energy capacity that may be accompanied by behind-the-meter Battery Energy Storage Systems (BESSs). These renewable energy targets make Ireland the world leader in renewable energy utilization and simultaneously increase our reliance on the power system flexibility (see section ‎4).

Reviewing the European projects of common interest in the transmission sector, we find that most of the planned interconnections (except the Celtic project) will link Ireland’s power system to Great Britain which has similar renewable ambitions and a highly correlated wind regime with the whole Island. Due in no small part to the geographical characteristics of our country, namely the limited potential of interconnections to the European member states, and a very limited potential to deploy pumped Storage Hydroelectric power plants (PSHs) as a promising flexibility resource, our flexibility requirements should be met by alternative domestic flexible resources such as green fueled gas power plants or energy storage technologies. Unless the operational problems, such as dispatch down of the renewables will prohibit our electricity end-user to capture the whole economic benefits of a high renewable penetrated electricity system (see section ‎4).

Flexible resources such as BESSs require promising revenue streams to be developed in the electricity sector, especially in the technology transition phase. We have reviewed the DS3 program that provides a growing bed for the BESSs as one of their main revenue stream, namely provision of the ancillary services. We find that the annual expenditure limitations determined by the regulatory authorities, and the approach, which is adopted by the Transmission System Operators (TSOs) to deal with this budget limitation can generate the wrong economic signals for the BESSs investors. We have argued that neither the BESSs nor other service providers have not been contracted for the provision of the fast post fault active power response, and the dynamic reactive power response while these services are designed to increase the power system flexibility. Although the academic literature believes that BESSs have a significant potential to provide the system inertial response, provided to the presence of proper control systems and fault detection equipment, they have not been qualified for providing these services through the DS3 program (see sections ‎4 and ‎9).

Subjected to the result of the qualification process, BESSs are allowed to participate in the capacity markets. We find that the existing BESSs are not eager to participate in the capacity markets and the new BESSs manifest a limited willingness to do so. This indicates that the technical/operational limitation of the BESSs, the de-rating factors, and the obligations associated with the capacity markets leads to a very limited revenue stream for the BESSs in the capacity markets (see sections ‎4 and ‎9).

We have reviewed the BESSs relevant high-level legislation and plans, electricity market regulation, and the TSOs and distribution system operators' (DSOs) instruction, in our country and reflected the potential BESS deployment barriers that may cause by them. We find that by high-level national development plans, the BESSs are recognized as a complementary approach to the transmission and distribution system reinforcement but there is not any regulation/program to deploy this important potential of the BESSs in Ireland. We find that in spite of the proven ability of the BESS to provide the system restoration services, not only they have not currently been contracted, but also there is not any clue indicating that they will be deployed for the provision of such services in the future (see sections ‎4 and ‎9).

Reviewing the trading and settlement code of Single Electricity Market (SEM), we find that the BESSs must have obligatory zero bidding behavior in the ex-ante electricity markets. The consequences of this instruction are the inefficient dispatch of the BESSs especially for the charging mode, and prevention of arbitrage as an important revenue stream for the BESSs. It also indicates a discriminatory treatment in comparison to other technologies participating in the ex-ante electricity markets. We have argued that there is a global discriminatory approach in dealing with the side payments to the different technologies when it comes to negotiating with their operational/technical characteristics in the electricity markets. For instance, the market must guarantee the recovery of the start-up cost for the conventional generation fleet, however, there is no room for the BESSs to discuss the procedures addressing their cycling issues and the associated costs (see sections ‎4 and ‎9).

We have notified the definition of the energy storage system in Ireland. Although in some cases, they are recognized as a generation asset, they will be treated as demand for the payment of network charges. We have also addressed the Enduring Connection Policy (CEP) proposed by the Commission for Regulation of Utilities (CRU) that puts a limit on the number of primarily storage projects, not considering the power and energy capacity of the BESSs. We have reviewed the regulations instructing the aggregation of the BESSs. While the Single Electricity Market Committee (SEMC) believes that there is no need to introduce a specific definition for the aggregators and the Demand Side and Aggregated Generating Units (DSUs, and AGUs) will cover the aggregation requirements, we find that the current regulation will not allow capturing the full potential of the BESSs. The time aggregation of the utility-scale BESSs could be a promising solution to the energy capacity limitations of the BESSs and enables them to provide the services that require longer discharging capabilities such as ramping margins and replacement reserves (see sections ‎4 and ‎9).

Then we have summarized the benefits of the BESSs in the generation, transmission, distribution, and regulatory sectors. The potential ability of the data centres as a significant portion of the demand in Ireland by 2030, in accompanying with the BESSs has been notified in the distribution sector to resolve the System Non-Synchronous Penetration (SNSP) Issues and results in a market uptake for the BESSs in the demand sector as well. Considering the future of the power system and the presence of the prosumers having high levels of self-sufficiency, we have proposed a new look into the electricity market design, the definition of the level playing field for different sectors and, the role of BESSs in that era to implement the new design. The presence of micro and small generators underpinned by the supporting schemes will accelerate the movements toward emerging the prosumers in our electricity sector. These projects are accompanied by BESSs and are encouraged to self-consumption up to 70% of their total generation. In the transition phase, it is a good opportunity for the policy makers to stimulate the design of peer-to-peer markets activating an efficient tool for managing the excess power of the prosumers while reducing the clean export tariffs (see sections ‎5, ‎and ‎9).

The high-level policies adopted by the leading countries in the deployment of the BESSs, namely China, USA, South Korea, Japan, Germany, and Australia are reviewed in this report. We have focused on the generation mix, the renewable energy policies, and the overview of storage mix in these countries. Conducting a comparative analysis with Ireland, we find that the storage mix in our country differs significantly from the mentioned leaders in terms of the deployment of seasonal and long-duration energy storage technologies. This happens due in no small part to the limited potential of the whole Island in the deployments of PSHs. A solution to these problems would be the development of technologies that are capable to replace the PSHs such as power to gas options (green hydrogen) or utilizing the time aggregation of utility-scale BESSs (see section ‎6).

We have done a detailed review of the European level directives and legislation targeting the BESS, renewable energies, and their electricity market integration. We find that there are some inconsistencies with the existing regulation and instructions at the national level in our country with the European ones that may prohibit us from capturing the full potentials of BESSs for the benefits of the electricity end-users (see section ‎7).

We have reviewed different technologies of energy storage from a high-level point of view. We find that the global trend is to deploy the Li-ion batteries for power system applications while they have high Levelized Cost of Energy (LCOE) and Life Cycle Cost of Storage (LCCOS). We argue that although the Li-ion market uptake may result in multisector benefits (for the automotive and electricity sector as well as emission reduction in the transportation sector), from the technology point of view, other kinds of electrochemical energy storage, such as NaS and flow batteries, may suit for power system applications since they have much lower LCOE & LCCOS in comparison to the Li-ion batteries and attractive technical characteristics (see section ‎‎8).

We have proposed high-level policy solutions to alleviate the concerns regarding the comprehensive development of BESSs in Ireland. The recommendations are classified into short-term (for the next three years), medium-term (until 2030), and long-term (until 2050) and tackle the existing concerns that should be mitigated by these millstones in the electricity sector of our country (see section ‎10).Following this executive summary, we have organized the structure of the report as follows:

Section 2: Introduction

Section 3: Background

Section 4: Ireland Current Electrical System, Market Status, and Future Potential

Section 5: Energy Storage Value Streams/Benefits and Key Actors

Section 6: Policy International Initiatives and Strategies

Section 7: EU Policy Initiatives on Storage Technologies

Section 8: Storage technologies

Section 9: Barriers to storage Deployment

Section 10: Policy Recommendations to enable the Development of the Irish Energy Storage Market

# Introduction

The goal of this introduction section is to provide a general overview of Energy Storage Systems and their emerging applications in the fields of energy generation, transmission, distribution, and consumption.

In energy generation, three types of ancillary services that require generators to be able to rapidly increase output, can be distinguished: contingency, regulation, and flexibility reserves [1]. After describing these services briefly, information about the potential applicability of Energy Storage Systems (ESS) and the current state of the art in relation to these services will be provided.

Contingency reserves are sources of electric power that can be ramped up very quickly to improve the reliability of the grid in emergency operating conditions and to deal with sudden variations of loads. [Transmission operators](https://www.storage.school/content/transmission-operators) usually, operate [generators](https://www.storage.school/content/generator) reserving a percentage of their capacity such that in case of loss of the largest [generator](https://www.storage.school/content/generator), the complete system can be maintained in operation with the remaining generators supplying the load. Moreover, when additional reliability is desired even larger power reserves are required. A common distinction between power reserves is between spinning and non-spinning ones. Spinning reserves comprise generation capacity which is on-line and synchronised with the grid and that can be used to supply grid demand within ten minutes. Supplemental non-spinning reserves are off-line but can be brought into operation within ten minutes when needed. Maintaining such spinning and non-spinning reserves results in an inefficient operation of generators; the usage of energy storage to implement contingency reserves is a promising approach to improve generation efficiency because they can detect immediately frequency deviations responding to them very quickly thanks to their control system and can deliver the full output power desired within ten minutes [2].

The *regulation reserve* is also known as frequency-response reserve and is determined by the automatic reaction of generators to a loss in supply. The generators initially slow down when a loss in supply occurs, because of their load increases. Their governors can provide a slight increase to their output power and that supports the system output frequency. The regulation reserve is usually limited and not controllable from the system operator, therefore not considered part of the operating reserve. The provision of reserves for frequency control is considered among the applications that has highest value for a battery storage system [3]. Frequency regulation using storage was proposed in early 2000’s at the U.S. Department of Energy (DOE) national laboratories and Oak Ridge National Laboratory (ORNL). Other investigations on the subject were conducted at PNNL, Sandia National Laboratories (SNL), Idaho National Laboratory (INL) and Lawrence Berkeley National Laboratory (LBL). Some transmission system operators such as EirGrid in Ireland and ENTSO-E and AEMO, are introducing new services such as the FFR (fast frequency response) using non-synchronous devices (and therefore possibly storage) [4].

The *flexibility reserves* are the sources of electric power that can be effectively modulated to compensate the output of the intermittent renewable energy sources (RES), such that a reliable power system operation can be guaranteed even under uncertainty and variability of the operating conditions (intermittent RES balancing). Availability of such reserves may also facilitate the integration of new RES. More in general, flexibility can be defined as the ability of a power system to cope with the variability of the residual load curve at all time. The residual load can be calculated by subtracting variable RES generation and the dispatchable generation from the demand, over the entire year. The flexibility need can be defined for a day, a week, or a season and it is the deviation of the residual load from its average (in case of daily flexibility, it is defined as the deviation between the hourly residual load and its average for the considered day). The result of flexibility analysis can be expressed as a volume of energy per day (TWh per day) or volume of energy per year (TWh per year) [5]. The traditional technologies to fulfil flexibility needs associated with seasonal variations of the residual load are the flexible generators, grid interconnections and the Pumped Storage Hydropower Plants (PSHs). Novel approaches are based on the system integration of battery energy storage systems (BESS), electrolysers, Gravity Energy Storage (GES), Liquid Air Energy Storage (LAES) and Compressed Air Energy Storage (CAES). Other storage technologies such as flywheels, supercapacitors, and Superconducting Energy Storage (SMES) are better suited to provide the flexibility required by rapid residual load variations.

Other services related to energy generation provided by the ESS are the *energy arbitrage* and the *system black-start.* The energy arbitrage service uses ESS to store the electricity produced during the periods of low demand and sells it during high demand periods, when electricity price is higher. This service requires ESS that offer a long storage duration (from hours to days) and a high round trip efficiency, such as BESS, CAES, LAES, GES, and PHS. Black-start is the power generation restart after a power system collapse; ESS that have a fast response time, such as BESS and supercapacitors, are used to supply the required power without drawing it from the grid.

Energy storage systems are also being increasingly integrated into transmission and distribution networks, offering technical, economic, and environmental advantages such as: demand shifting, load levelling and peak shaving, network expansion and overall cost reduction, reduction of PV fluctuations, reduction of energy losses in the network, GHG reduction. Other advantages they can provide when applied in distribution networks, are the power quality improvement and more precise voltage regulation and improved voltage stability [6, 7]. Barriers for storage implementation are the high initial investment required and the utility regulations which are not favourable. Furthermore, there is insufficient stakeholders’ awareness of ESS benefits [8].

Demand shifting involves modifying the energy demand pattern seen from the grid side by charging and/or discharging the storage. A demand shift can also be achieved by changing the scheduling of some loads, such as the space heating. Demand shifting may allow to reduce large fluctuations in customer demand (load levelling) or to reduce the maximum peak load (peak shaving) or to reduce energy costs.

In low-voltage distribution networks the charging strategy may be related to line congestion, such that charging occurs when there is congestion whereas discharging occurs otherwise [6]. Another possibility is to control the storage such that abrupt fluctuations in PV outputs are mitigated and evening peak loads are reduced [9]. Smoothing of PV outputs can also be coupled with energy losses minimization [10]. An aggregator may implement a power balancing service using a real-time control algorithm to coordinate a set of distributed ESS. The benefits of including ESS in a distribution network are maximised when ESS locations are chosen properly (ideally, they are optimized).

Energy retailers may use optimally placed ESS to better manage variable loads and improve network security while increasing their profits and satisfying consumers’ expectations. Presence of ESS will favour decisions of operators to add more solar and wind generation to the grid supply mix.

Energy storage technologies are characterized by features that determine whether they are suitable for a certain application. Most important storage features are: energy and power densities, lifetime, capital and operating costs, storage capacity and duration, round trip efficiency, response time, maturity of technology [7].

The *energy and power densities* are respectively defined as the rated power output divided by the volume of the device (unit is W/kg or W/l) and the actual energy stored divided by the volume of the storage device (Wh/kg or Wh/l). ESS with highest energy storage densities are Hydrogen Energy Storage (HES) systems, namely the gas engine (33,300 Wh/kg) and the fuel cells (800–10,000 Wh/kg) followed by Zn-Air BESS (150–3000 Wh/kg). Other batteries with quite high energy storage densities are the NaS (150–240 Wh/kg) and the Li-ion (75–200 Wh/kg). ESS with the highest power densities are the supercapacitors (500–5000 W/kg), the Li-ion BESS (500–2000 W/kg), the SMES (500–2000 W/kg), the flywheel (400–1500 W/kg) and the fuel cells (>500 W/kg).

The *lifetime* of an ESS is its expected service duration in years. The ESS which have the longest life are those based on mechanical technologies such as PHES (40-60 years), CAES (20-60 years), GES (30-40 years), SMES and LAES (20 years). Other ESS have usually a life between 5 – 15 years. Among the BESS, those which have the best lifetime are NaS and NaNiCl with a minimum expected duration of 10 years.

The *cost* of an energy storage technology includes both the *capital* and *operating* costs. The operating cost comprises all the costs associate with operation, maintenance, disposal, and replacement. The capital cost also includes the cost of auxiliary components required to the ESS to operate. The utilisation of ESS may be economically convenient only above a minimum energy content and power output. ESS cost can be given as cost per kWh, cost per kW and per kWh per cycle. The capital cost per kWh of PHES (0.1 – 1.4 $/kWh-per-cycle), CAES (2 – 4 $/kWh-per-cycle), Zn-Air is low compared with other technologies. Novel technologies such as GES are expected to have costs in the same range of PHES. LAES is another emerging technology that is expected to have a low capital cost. When considering the cost per kWh (instead of the cost per kWh-per-cycle) CAES has an even lower capital cost than the PHES (in the range of 2 – 50 $/kWh and 5 – 100 $/kWh respectively), but it has a minimum round-trip efficiency of only 50%, whereas lowest PHES efficiency is about 65%. Other technologies such as flywheel, SMES, supercapacitors have high capital cost per kWh (1000–5000 $/kWh, 1000–10,000 $/kWh and 300-2000 $/kWh, respectively), but low cost per kWh-per-cycle (e.g., flywheel: 3–25 $/kWh-per-cycle, supercapacitor: 2–20 $/kWh-per-cycle) with respect to other technologies, such as some BESS technologies like VRB, ZnBr or Li-Ion (5–80 $/kWh-per-cycle, 5–80 $/kWh-per-cycle and 15–100 $/kWh-per-cycle, respectively). For this reason, these technologies are used for applications that require a high output power for a short time interval.

The quantity of energy that can be stored in the storage system is the *storage capacity* measured in Wh. PHES and CAES are two mature technologies with large storage capacity suitable for grid scale energy storage. Other technologies under development such as LAES and GES are scalable and might also be suitable for grid scale applications if they are based on reliable and proven mechanical components.

The most important grid services using energy storage were reviewed in [11]. These services require a variable storage duration and have been associated to the different storage types in [7] in Table 1. The goal of this preliminary analysis is to determine the storage technologies which can be used to implement the grid services related to the sectors of energy consumption, generation, transmission and distribution. The suitable energy storage types must have a storage duration which matches with the duration of the grid service to be implemented. Most of these technologies have a size variable within quite a large interval, therefore there are multiple choices which can be used to implement each of the energy services.

Typical market values for the considered energy services are shown in Figure 1 (based on US data) [12]. The energy service which has the highest market value is the Time of use energy cost management (*demand shifting).* This service applies to energy end users and involves the storage’s charging during off-peak time periods when the electricity price is low, and the storage’s discharging the energy during times when peak energy tariff is applied. Other services that have a high market value are the *renewable capacity firming*, the *renewable energy time-shift*, the *transmission congestion relief* and the *load following*. The services which have the lowest market value are the *substation on-site power reserve*, the *area regulation,* and the *T&D Upgrade Deferral 90th percentile*, followed by the *wind generation grid integration (short duration)*. This service applies to energy end users and involves the storage’s charge during off-peak time periods when the electricity price is low, and the storage’s discharge the energy during times when peak energy tariff is applied. The *renewable capacity firming* refers to adding a small storage capacity to on-site PV. Even though PV production occurs mostly during times when energy demand is high, the PV alone does not provide emergency or backup power in absence of sufficient solar irradiation, therefore the effective deployment of PV power plants requires the installation of storage to firm its capacity. Capacity firming also applies to wind generation when considering grid integration issues; storage may add capacity value when the utility needs the firm capacity or when the end user uses the storage along with the wind power supply to reduce demand charges. The short-term firming service for wind energy is providing less value to the market than the long-term service. The *renewable energy time-shift* can be used to decouple in part the energy production using renewable sources from the actual energy consumption, thereby increasing the capacity value which can connected to the grid and operated with a sufficiently high utilization factor, given the fact that renewable sources are not controllable. Distributed storage can be charged when load is minimum or whenever available supply exceeds the load. The high value of *transmission congestion relief* service depends on the fact that many transmission lines may be operating close to their thermal limits, therefore storage can be used to supply part of the downstream electricity demand, to relieve overload conditions, to reduce the occurrence of outages and to operate the transmission system safely. Storage can be charged when the load is low. A service that is associated to transmission line congestion is the upgrade deferral. Here the idea is to provide incremental supply capacity to defer an investment in new T&D capacity. This service is advantageous to be implemented especially in those cases where the critical loads occur just for a few days in a year and for just a few hours per year. Usually storage support for T&D deferral is applied only to a fraction of the qualifying peak load (e.g., the 50%) whereas too high peak supply would not be cost-effective. Load following based on storage is another high valued service because storage can perform it better than conventional load following based on power generation. Many storage technologies have quicker response time than conventional generation enabling to follow faster load variations. Moreover, storage efficiencies are less dependent on the energy stored and the charging/discharging rates. Storage utilization for load following will enable to operate more generators at constant output power, reducing fuel consumption and air pollutions, as well as interventions of variable maintenance. The area regulation based on storage is an emerging service that uses storage to balance supply and demand within certain geographical areas managed by a power system operator. The storage is an additional resource which can be used to smooth the intermittent power production and to address the balancing issue, thereby contributing to grid stability and grid frequency regulation.

Table Grid energy services using storage and storage technologies associated with them

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Grid services** | **Duration** | **Description** | **Sector** | **Category** | **Storage Types** |
| Electric Energy Time-shift [Demand shifting, Energy Generation Arbitrage] | 2-8 h | Storage is used to shift the time of energy consumption by charging and discharging it | Consumption | Electric Supply | PHES, CAES, LAES, GES, HES, BESS (VRB, ZnBR, ZnAir, Li-Ion) |
| Electric Supply Capacity  [Peak Demand Management, Peak Shaving] | 4-6 h | Storage is used to increase the supply capacity in the peak demand hours | Generation | Electric Supply | PHES, CAES, LAES, GES, HES, BESS (VRB, ZnBR, ZnAir, Li-Ion) |
| Load Following | 2-4 h | Storage changes power output in response to changes in load, to balance variations in supply and demand. Load following’s timeframe is longer than grid frequency regulation | Generation & Consumption | Ancillary Services | PHES, CAES, LAES, GES, HES, BESS (VRB, ZnBR, ZnAir, Li-Ion) |
| Area Regulation [Provision of regulation reserve] | 15 – 30 min | Storage is used to balance electricity supply and demand within geographic balancing areas | Generation & Consumption | Ancillary Services | Super-capacitor, SMES, Li-Ion, Flywheel |
| Electric Supply Reserve Capacity [Provision of operating reserve] | 1-2 h | Storage output power is used to compensate a rapid variation in the load which may be caused by the loss of a power generation unit | Generation | Ancillary Services | PHES, CAES, LAES, GES, HES, BESS (NaS, NaNiCl, VRB, ZnBR, ZnAir, Li-Ion), SMES |
| Voltage Support | 15 min – 1 h | Storage can be controlled to supply or consume reactive power such that a specific voltage level is maintained on the grid. | Transmission & Distribution | Ancillary Services | PHES, CAES, LAES, GES, HES, BESS (NaS, NaNiCl, VRB, ZnBR, ZnAir, Li-Ion), SMES, Flywheel |
| Transmission Congestion Relief | 3-6 h | Storage can be used to supply power downstream from a congested transmission line which is operating close to its thermal limits, minimizing transmission capacity requirements and potential congestion charges | Transmission | Grid operations | PHES, CAES, LAES, GES, HES, BESS (VRB, ZnBR, ZnAir, Li-Ion) |
| Transmission Support | 2 – 5 sec | Fast support-service to transmission network | Transmission | Grid operations | Flywheel, supercapacitor, SMES, BESS (NaS, NaNiCl, Li-Ion) |
| T&D Upgrade Deferral | 3-6 h | Transmission capacity upgrade is deferred using storage support | Transmission & Distribution | Grid operations | PHES, CAES, LAES, GES, HES, BESS (VRB, ZnBR, ZnAir, Li-Ion) |
| T&D Life Extension | 3-6 h | Storage is used to reduce the load on existing equipment that is reaching its expected life, possibly extending its life | Transmission & Distribution | Grid operations | PHES, CAES, LAES, GES, HES, BESS (VRB, ZnBR, ZnAir, Li-Ion) |
| Substation on-site power | 8-16 h | Storage provides a power reserve installed in a substation | Transmission & Distribution | Grid operations | PHES, CAES, LAES, GES, HES, BESS (VRB, ZnBR, ZnAir, Li-Ion) |
| Time-of-use Energy Cost Management | 4-6 h | Storage is used to reduce electricity- cost by means of retail energy time-shift when end-users adopt time-of-use (TOU) electric energy pricing | Consumption | Electric Supply | PHES, CAES, LAES, GES, HES, BESS (VRB, ZnBR, ZnAir, Li-Ion) |
| Demand Charge Management | 5-11 h | Storage is used by utility customers to reduce their demand during peak periods specified by the utility, thereby reducing their electricity costs | Consumption | Electric Supply | PHES, CAES, LAES, GES, HES, BESS (VRB, ZnBR, ZnAir, Li-Ion) |
| Electric Service Reliability [Energy Resilience] | 5 min – 1 h | Storage is used to ensure electricity supply without interruption. It needs to provide power and energy required to ride through outages | Generation | Grid operations | PHES, CAES, LAES, GES, HES, BESS (NaS, NaNiCl, VRB, ZnBR, ZnAir, Li-Ion), SMES, Flywheel, supercapacitor |
| Electric Service Power Quality | 10 sec – 1 min | Storage is used to protect on-site loads from poor power quality supply from the grid such as voltage short-term spikes or dips, longer term surges or sags and high frequency transients or oscillations | Distribution | Grid operations | Flywheel, supercapacitor, BESS (NaS, NaNiCl, etc) |
| Renewables Energy Time-shift | 3-5 h | Storage is used to shift the time of renewable energy generation power availability, to better supply electricity demand | Generation | Grid operations | CAES, LAES, GES, HES, BESS (VRB, ZnBR, ZnAir, Li-Ion) |
| Renewables Capacity Firming [Provision of flexibility reserve] | 2-4 h | Storage is used to balance the power fluctuations of intermittent renewables such as wind and PV or to provide backup and emergency services | Generation, Transmission & Distribution | Grid operations | CAES, LAES, GES, HES, BESS (VRB, ZnBR, ZnAir, Li-Ion) |
| Wind Generation Grid Integration, Short Duration | 10 sec – 15 min | Storage is coordinated with wind turbine to improve prediction, scheduling, managing and control of wind power in the short term. | Generation | Grid operations | Flywheel, supercapacitor, BESS (NaS, NaNiCl, VRB, ZnBR, ZnAir, Li-Ion) |
| Wind Generation Grid Integration, Long Duration | 1-6 h | Storage is coordinated with wind turbine to improve prediction, scheduling, managing and control of wind power in the long term. | Generation | Grid operations | PHES, CAES, LAES, GES, HES, BESS (NaS, NaNiCl, VRB, ZnBR, ZnAir, Li-Ion) |

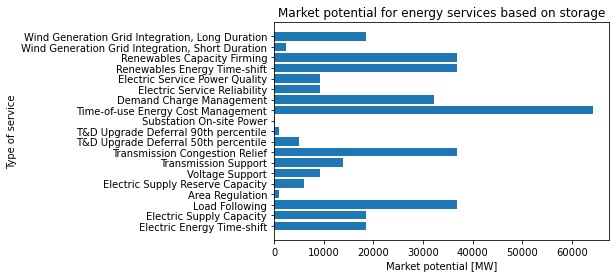


Figure Market potential for energy services based on storage (US data)

Table Energy storage applications in EU in transmission, distribution and end user areas.

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Application context of energy storage** | | |
| **Storage Application Areas** | **Transmission Network** | **Distribution Network** | **End User** |
| Balancing demand and supply | Seasonal / weekly fluctuations  Large geographical unbalances.  Strong variability of wind and solar. Renewable capacity firming.  Wind generation grid integration. Integration of electricity and gas storage.  Load following. | Daily / hourly variations. Peak shaving. Integration of electricity and heat/cold storage.  Renewable capacity firming.  Wind generation grid integration. Integration of electricity and gas storage.  Load following. | Daily variations. Integration of electricity and heat/cold storage. Load following. Demand charge management. Time of use energy cost management. |
| Grid management | Voltage and frequency regulation. Voltage Support. Provision of primary and secondary reserves (electric supply reserve capacity)  Complement to classic power plants for peak generation. Electric supply capacity. Participation in balancing markets.  Area regulation. Cross-border trading. | Voltage and frequency regulation. Novel ancillary services with lower CO2. Voltage support. Electric service power quality. Participate in balancing markets | Aggregation of small storage systems providing grid services. Prosumers. |
| Energy Efficiency | Improved efficiency of the global energy mix, with time-shift of off-peak power generation into peak energy (Renewable Energy Time Shifting). | Demand side management. Interactions between grid and end user. | Local production and consumption. User behavior change. Electric energy time shift. Increased utilization of PV and wind. Energy efficient buildings. Integration of local energy supply with district heating /cooling and CHP. |

The storage deployment in US has followed the evolution processes of the stationary energy storage industry and of the entire power system. The deployment process can be exemplified distinguishing four phases. The first phase is about deployment for the services of peaking capacity, energy time shifting and operating reserves. In the second phase, the deployment of further storage capacity for the operating reserves continued. In the third phase more storage for peaking capacity services was deployed. In the third and fourth phases more storage is deployed for the energy time-shifting service, and respectively for diurnal capacity and multiday to seasonal capacity.

In Europe the storage deployment in the transmission, distribution and user areas is following the application areas shown in Table 2 [13] which can be associated with the relevant services previously defined in Table 1. The most attractive category of ESS has been for quite some time the PHES, especially when the European network included many weakly connected regional grids. Nowadays, the storage is becoming an increasingly attractive solution for delivering temporary power supply to fill-in the gaps due to limitation in the ramping-up time of conventional power generation, when a fast increment of energy demand and/or drop in renewable generation occurs. These services are also known as ramping margin services.

Table 2 shows that most of the applications of ESS are similar at the distribution and transmission levels; power fluctuations that need to be compensated by ESS have diverse time scales in the two types of electricity networks: they are seasonal or weekly in the case of transmission network, whereas they are daily of hourly in the case of the distribution network. Renewable capacity firming and wind integration are energy services that apply to both networks. Energy efficiency aspects concern the mix of the global energy sources and the possibility to shift in time the renewable production, whereas at the distribution network level the opportunities are related the demand side management and the interaction with the end users. Furthermore, power quality problems in distribution networks may be more numerous and include voltage dips, voltage swells, flicker, spikes or surges in voltage, over-voltages, under-voltages, short and long interruption, oscillatory transients, harmonic distortion, and frequency deviations. ESS may provide power quality support through converters which can exchange active and reactive power at the point of common coupling [6].

More than 2.5GW of grid-scale battery storage is currently in development stages in Ireland with many projects that will be deployed in 2021 and beyond. The first two utility-scale battery storage projects are operational since 2020: they are the 11MW Kilathmoy project by Statkraft on the border between Limerick and Kerry counties and the 100MW Lumcloon project from Hanwha Energy and Lumcloon Energy [14]. The first project by Statkraft is a hybrid battery-and-wind project which combines battery storage with 23 MW of onshore wind, which is operative since early 2020. The storage plant will be used to offer service reserves to the national grid in the case of abrupt power supply shortages. The second project is a battery storage facility in Co. Offaly in Ireland, which will provide fast response system services to the national power system, especially storage services supporting wind and solar capacity deployment, having secured a contract with the transmission operator EirGrid through its flexibility market [15]. In addition to electric energy supply services such as the electric energy time shifting (Table 1), the transmission operator EirGrid has defined a list of ancillary services as part of the program “Delivering a Secure, Sustainable Electricity System” (DS3) [16]. The relevant services are summarized in Table 2. Most important services are the following.

Primary reserve is the power reserve that works in the timescales of a few seconds to counteract the frequency drop that is following an incident.

Secondary reserve is the power reserve that operates from the 15 seconds to 90 seconds following an incident with the goal of restoring the system frequency of 50 Hz.

The tertiary reserve is the reserve replacing the lost generation when a plant outage occurs or used to supply unexpected variations in demand from 90 seconds after the initial incident until when the plant can be restored, or the demand returns to the levels before the incident, or a replacement power plant begins to operate. Two bands were defined for the tertiary operating reserve: Band 1 with a required duration between 90 sec to 5 min, and Band 2 with a required duration between 5 minutes to 20 minutes replacement reserve acts over periods of time from 20 minutes to four hours following an initial incident.

The ramping margin is the increased unit output in MW that can be provided at a point in time for a specific duration and with a required ramp-up time

A BESS will be controlled such that it can deliver any output power in the MW range requested by the TSO via SCADA (or a similar system) within its operating range (i.e., the interval between its maximum active power import rate and maximum active power export rate), if it has sufficient capacity and stored energy to fulfil the request. For this reason, storage systems can in principle deliver the services that require the provision of active power to the main network for a limited time period (which depend on the service). Moreover, each BESS is characterized by the rate of change of active power which the BESS can deliver when a set point for active power is applied by the TSO [16], which is a parameter that can be used to select the services that the BESS could provide. For example, the Ramping Margin services defined in DS3 (Table 2) have variable ramp-up requirements from 5 min to 3 h.

Table 3 Electric supply and ancillary services in the Irish market

|  |  |
| --- | --- |
| **Service** | **Description** |
| Electric Energy Time Shifting | Storage is used to shift the time of energy consumption by charging it during low demand periods and discharging it during peak demand periods |
| Fast Frequency Response | Rapid delivery of active power increase or decrease using either generation or load within 2 seconds or less, to balance supply and demand and regulate managing power system frequency |
| Primary reserve | Spinning reserve from 5 to 15 sec |
| Secondary reserve | Spinning reserve from 15 to 90 sec |
| Tertiary reserve | Spinning/non-spinning reserve from 90 sec to 30 min |
| Replacement reserve | Non-spinning reserve from 20 min to 4 hours |
| Ramping Margin | increased unit output in MW with a specific duration and with a required ramp-up time |
| Black start | It is the restoration process of an electric power station without relying on the external electric power transmission network |
| Synchronous Inertial Response | It is the response of large rotating masses that contrasts the immediate imbalance between power supply and demand in the electric power systems. Normally it is provided by synchronous generators, synchronous condensers, and some synchronous demand loads, it can be emulated by inverters (virtual inertia) |
| Dynamic Reactive Response | It is the ability of a unit to deliver a reactive current response for voltage dips exceeding the 30% which would result in a reactive power in Mvar of at least 31% of the registered capacity at nominal voltage |

Other ancillary services that are not related to supply of active power are the synchronous inertial response and the dynamic reactive response.

The synchronous inertial response (see Table 3) is obtained by multiplying the kinetic energy of a dispatchable synchronous generator, dispatchable synchronous condenser or dispatchable synchronous demand load operating at nominal frequency by the SIR Factor (SIRF). The SIRF represents the ratio of the kinetic energy at nominal frequency to the minimum MW output at which the unit can operate and provide reactive power control. Although some synchronous generators can operate as synchronous condensers providing reactive power at zero load, they cannot operate below their minimum load [17]. BESS are considered a viable solution to provide inertial response and primary frequency regulation and may behave similarly to conventional synchronous generators. The BESS is sized for a target power imbalance and/or for the rate of change of frequency [18].

The literature has presented control strategies for grid-connected BESS to mitigate the effects of voltage dips and to provide low-voltage ride-through capabilities. In [19] it is shown that the BESS can inject into the three-phase grid a capacitive reactive current using the grid-side inverter, which has the effect of increasing the voltage at the point of common coupling, regardless of the operation condition of the BESS. The magnitude of the current injected is determined by the control strategy and depends on the grid-code regulations. The Dynamic Reactive Response service defined in the DS3 programme in Ireland has specific requirements in terms of magnitude of the reactive current injected and in addition it requires that the current must be supplied with a rise time less or equal than 40 ms and a settling time less or equal than 300 ms. Therefore, the BESS technology has a good potential to be used for the provision of the dynamic reactive response service or any other similar services that will be defined by the TSO.

General overview of storage in the context of energy generation, transmission, distribution and consumption. Key developments in the deployment of energy storage. Overview of document.

# Background

The BESS global market is expected to grow at a rate of 23% by 2030 driven by the national energy and de-carbonization plans according to Frost & Sullivan, reaching more than 437 GWh of cumulated capacity and $16 billion market by 2030 (from $2 billion in 2020) [20]. The IEA forecast of installed capacity in 2030 is 585 GWh, with an average annual growth rate of 38% and over 120 GWh of battery storage capacity added in 2030, starting from only 5 GWh in 2020 [21].

Renewable integration and grid modernization are two of the main drivers for the adoption of ESS, especially BESS will be integrated with solar PV, with the US expected to be a leader in this market segment thanks to a steadily declining cost of solar PV and batteries and favourable regulations for hybrid plants on wholesale electricity markets. The deployment of energy storage assets at renewable energy generation plants allows to stabilize renewable production and to ensure a firm capacity throughout peak demand periods. The synergy between solar PV plants and batteries enables to provide dispatchable energy while supporting grid stability. In India, the first large-scale auction of PV-plus-storage was held in 2019 and concerned 1.2 GW generation capacity with mandatory storage capacity of 50% of the generation installed. Other similar initiatives will be happening in Asia and US. In Singapore 200 MW of PV with storage will be installed after 2025. In US the utilities promote the development of the combined system, and it is foreseen that a capacity of about 15 GW will be shortly available [22].

Recent research has highlighted that dynamic pricing needs to be considered to deliver more cost-effective hybrid PV-BESS solutions to the customers. The traditional power-driven (PoD) control algorithm determines the control actions for the BES system to maximize the storage of produced PV-power which is not used to supply the current load, such that it can be used at a later time. On the other hand, novel price-driven (PrD) control algorithms have been recently introduced to take into account dynamic pricing. The price-driven (PrD) control algorithms compare the electricity prices with the levelized cost of energy storage and take a decision about charging/discharging the storage or selling/buying electricity from the grid. When the produced PV power is greater than the load the surplus of power can either be sold to the grid or used to charge the battery. If the selling price to the grid is higher than the levelized cost of energy storage then the power is sold to the grid, otherwise it is used to charge the BESS. If the produced PV power is lower than the load then the shortage of power can be either purchased from the grid or taken from the BESS discharge. The power is purchased from the grid when the levelized cost of storage is greater than the current Time-of-Use electricity price, and it is taken from the battery otherwise [23].

Hybridization opportunities will also apply to conventional power plants and hydropower plants. The technical solutions that will be developed must be scalable and suitable for aggregation, such that they can be operated by centralized control systems, to offer the flexibility required by the future applications in the electric grid. The market of BESS solutions will also be characterized by powerful software based on artificial intelligence algorithms, machine learning, forecasting algorithms for energy price to the benefit of grid operators and strategists.

However, the de-carbonization of all the economy’s sectors will require multiple green energy technologies including batteries and electrolysers for hydrogen production as remarked but the IEA analysis. Nowadays, batteries and hydrogen-technologies should be surely part of any package of economic measures that a government would deliver to stimulate economy.

Some of the BESS technologies which will have a prominent role in the market in the forthcoming years are the Lead-Acid, the Li-Ion, the NaS, and the Flow Battery (VFB). The Lead-Acid technology is the oldest technology but still in use because of the valuable properties of electricity conduction of the Lead (Pb) electrodes immersed in an electrolyte consisting of diluted sulphuric acid that enables the charging and discharging chemical reactions. Lead-Acid BESS are available in large quantities and in various sizes. There are no concerns related to the security of supply with this type of BESS. The market of Lead-Acid batteries is significantly growing and its estimated valued is €82,6 billion by 2026. The Li-Ion technology works with the exchange of Lithium ions between the anode and the cathode for the battery charging/discharging, which derive from the electrodes made of lithium compounds. This technology has low requirements for maintenance and does not require periodic discharge, while offering high output currents and high-power densities. The volume of a Li-Ion BESS can be even a tenth of that of a Lead-Acid of the same capacity and the battery is also lighter. The market of Li-Ion batteries is growing even faster than Lead-Acid and will have a value of €95,6 billion by 2026 [24]. The NaS BESS use electrodes made of molten sulphur and molten sodium, which need to be kept at a temperature above 300 °C, with a solid ceramic electrolyte separating them (the sodium beat aluminium). These batteries are considered a cost-effective solution for storing substantial amounts of electricity with a storage duration of hours and are finding many applications for firming wind and solar generation as well as in industry for grid stabilization and power supply in emergency conditions [25]. The NaS BESS are not sensitive to air pressure and temperature and have very high efficiency, high power density and life cycle. The NaS BESS global market size is growing at a rate of 9.6% since 2020 and the predicted value by 2027 is $480.4 million [26]. The Flow BESS use [electrochemical cell](https://en.wikipedia.org/wiki/Electrochemical_cell)s energy is stored by means of two chemicals [dissolved](https://en.wikipedia.org/wiki/Solution_(chemistry)) in liquid carriers which are pumped through the separate sides of a membrane. This type of batteries has several advantages over the conventional technologies and only few disadvantages. They are robust, safe and reliable means to store energy; they can stay in the discharged state indefinitely with no risk of damage and the mixing of the electrolytes produces no damage as well. The electrolytes are aqueous and inflammable. Among the disadvantages, a rather low energy density, high weight and quite low efficiency if compared to other battery technologies. For this type of BESS there is no limitation on the energy capacity. The market of Vanadium Flow BESS is growing at a rate of 18.4% from 2021 through 2028 and will have a value of $698 million by 2028 [27].

The market drivers for the grid connected energy storage is largely determined by the value of the services which have been introduced in the previous section, along with future electricity prices and storage technology costs. The drivers for ESS deployment can also be associated to the services described in section 1 (introduction) in the tables I, II and III.

The most important drivers are:

* Increasing amount of renewable production
* Reduction of carbon emissions
* Operational cost savings or increased profits
* Capital costs of storage
* Power system modernization and expansion
* Improving grid resilience

The increasing penetration of renewables in the power system is the main driver for the implementation of utility-scale ESS. The need to use ESS for aligning supply and demand as much as possible to reduce energy curtailment will be a driver for the development of renewable energy time shifting services based on energy storage. In addition, ESS will be used to implement other services like the renewables capacity firming and wind generation grid integration to reduce renewables fluctuations and to make their output more predictable.

The IEA has estimated that additional investments of $13.5 trillion will be required to achieve the goal of reducing harmful emissions such that global warming can be limited to less than 2°C with respect to pre-industrial levels, as prescribed by the Paris Agreement in 2015. The progressive cost reduction of renewable generation along with the national commitments in reducing the emissions is leading to the decommissioning of several coal-fired power plants. The replacement of conventional generation with renewables determines the need of including new sources of inertia in the power system to maintain stability. In fact, the inertia provided by the rotating mass of the conventional power generators helps to maintain system stability and to perform frequency regulation when a portion of generation or transmission assets go temporarily offline because of a fault. Driven by the replacement of fossil-fuelled power plants, more ESS will be deployed to implement services like the synchronous inertial response.

Economic drivers such as cost savings or increased profits, increased competitiveness may determine higher investments in innovative products, services and production processes. The electricity and natural gas price variation is one of the main market drivers for energy storage deployment. These variations determine the volatility of prices and drive the adoption of pure or hybrid ESS for the energy arbitrage service. Pure energy storage converts electricity to another form of energy while charging the ESS, like potential energy for the PHS and electrochemical energy for BESS, and converts it back to electricity when discharging. Hybrid energy storage requires both electricity and natural gas to operate, an example is the CAES which requires natural gas to burn air which has been previously expanded from the reservoir in the storage discharge phase. The energy arbitrage service involves the load shifting through the storage charging when prices are low and storage discharging when prices are high. A common assumption is that the ESS is a price taker, which means that the charging and discharging power exchanged with the grid are so low which do not determine energy price variations. A large penetration of ESS in the grid will determine lower prices when the storage is discharging and higher prices when the storage is charging as a secondary effect and therefore will also contribute to the reduction of the need for arbitrage. The drivers for technology selection are both the net revenue generated and the capital cost of storage. In [28] it was found that PHS can generate a higher net revenue than CAES, but CAES has lower capital costs. Moreover, CAES has a limited ability to arbitrage low off-peak prices because of its need to use natural gas for dispatching stored energy. When comparing costs of PHS and CAES to those of BESS, it is worth noticing that the manufacturing of BESS requires 3 to 7 times more energy than PHS or CAES. However, in order to maximize the value of electricity storage the ESS should provide both reserve service and arbitrage. In UK BESS could triple their profits when combining participation in the reserve market with the arbitrage service [29]. Therefore, the availability of control algorithms that can control the storage to provide arbitrage with reserve may become a market driver for the development of energy services based on storage and for ESS deployment.

Capital costs associated with storage deployment have an influence on the decision-making process of installing ESS in the grid therefore reuse/recycling of BESS may determine higher level of storage adoption and better environmental impact. The reuse of decommissioned EV Li-Ion BESS may create new and expanded market opportunities and job creation. These batteries often keep ~80% of their original capacity and their use in stationary BES applications (or even in secondary mobile applications) requiring less-frequent battery cycling may be viable and economically convenient alternative to brand new BESS. Moreover, the recycling of Li-Ion BESS parts enables to recover valuable materials, such as cobalt, nickel, iron, graphite, lithium, and manganese (from the cathode) and electrolyte, black mass, and anode portions of the battery. Recycling may allow to further reduce the costs of brand-new BESS [30]. There will be an increasing availability of decommissioned BESS, since plug-in car sales have increased worldwide from the 60,000 units in 2011 to 0.77 million in 2016 and 1.2 million in 2017 [31]. Furthermore, materials demand for ESS production is imposing significant limits on Li-ion, VRB and PHS development and more relaxed limits on NaS and CAES technologies, which confirms the importance of materials recycling [32]. Circular economy principles may help to achieve further ESS cost reductions, which are required for their successful deployment at scale, since the current revenue streams are not sufficient to justify the high BESS investment costs [29].

Grid modernization and expansion is another driver for ESS deployment. In fact, many of the existing grid infrastructures are aging or need to be updated to supply power to the growing populations and also to the 30 percent of the global population who still does not have access to electricity. The ESS deployment can support grid modernization through multiple services that can defer transmission capacity expansion (such as T&D upgrade deferral, T&D life extension, transmission congestion relief and other similar) or improve the power quality (electric service power quality, voltage support). Moreover, an increased market participation of the consumers, who were previously mainly passive and now are becoming prosumers by installing local generation such as photovoltaic (PV) systems and possibly BESS for the management of their self-consumption will also be part of the grid modernization process. The utilisation of BESS in conjunction with PVs is particularly profitable in markets where the grid electricity cost is high compared to the electricity cost generated with PVs and feed-in remuneration is low or absent. BESS deployment in decentralized residential installations can contribute to better integration of distributed PVs in the power system lowering the PV production during midday hours and reducing the net demand during evening hours, which in a future scenario will be significantly affected by the peak demand due to the simultaneous EV charging [33].

In addition to infrastructure modernization, another driver for the ESS deployment is the need of improving grid resilience. The metrics usually used to quantify grid resilience are the customer outage time, the fraction of load not supplied, the time to recover from an outage [34]. Moreover, the costs associated to an outage such as the loss of revenue, cost of damage, and the cost to recover can be also used to quantify the level of resilience achieved when the ESS presence can avoid such an outage. The ESS may be a more resilient solution than the traditional backup power generators (like diesel generators). Diesel generators are dependent on fuel supply chains which may be damaged in natural disasters or fuel may be eventually used for other needs which are considered higher priorities. Furthermore, their maintenance in order to provide the required storage duration is more critical than in BESS. The BESS can be used not only to provide the backup service, but also high value services while grid-connected (like capacity services and voltage support), making it a more flexible and profitable solution than Diesel generators. Energy services relevant with grid resilience are: electric service reliability, substation on-site power, black-start and other similar.

Other drivers for the energy storage market are determined by EU-wide or national policies. In Europe several key actions which may influence the development of energy storage technologies, and particularly batteries have been defined in the Integrated Strategic Energy Technology Plan (SET Plan).

A tool for the coordination of EU and national efforts towards an increased reliance and security of the energy system was established in action 4 of the SET Plan. The needs for research and innovation in relation to energy storage in the future energy system were determined in the 2018. Implementation Plan, which has a particular focus on system integration issues, and highlights the importance of pursuing R&I work, which could potentially enable tangible cost reductions [35].

The SET Plan sets the objective for Europe to enhance competitiveness in the global battery sector with the aim of promoting applications related to e-mobility and energy storage, in the key action 7. This tool also enables the coordination of EU and national efforts. The Implementation Plan [TWG7-IP] analyses the existing technical and non-technical barriers hindering the competitiveness and puts forward proposals for specific R&I activities which might allow Member States and private stakeholders to improve competitiveness by achieving the desired targets in relation to performances and costs of the EU battery technologies. The R&I activities defined by the SET Plan are within the three focus areas: 1) Material/Chemistry/Design/ Recycling; 2) Manufacturing; and 3) Application and Integration.

In October 2017, the EC launched the European Battery Alliance (EBA) targeting the creation of a competitive European manufacturing value chain for sustainable battery cells and other related technologies, which requires a cross-border cooperation between EU Member States. The EBA will establish a Technology and Innovation Platform on Batteries getting inputs from the Implementation Plan for Batteries of the SET-Plan-Action 7, for all the aspects related to R&I.

The EBA provided recommendations to the European Commission for the 2018 Strategic Action Plan on Batteries, which determines actions related to: access to raw materials; recycling; manufacturing of cells; support to research and innovation capabilities; sustainability issues; establishing a regulatory framework.

Furthermore, a 10-year Roadmap for stationary battery storage was developed in the Batstorm project [36]. The roadmap gives particular attention to Li-Ion batteries. In fact, the diffusions of the Li-Ion batteries also in the stationary sector is favoured by the economies of scale determined by the e-mobility sector which is expanding rapidly. In addition, it is hoped that Li-Ion successor technologies such as solid-state lithium batteries and metal-air batteries will enable further cost reductions to the benefit of both e-mobility and stationary energy storage.

In Ireland the policy expects that all the grid services will be provided by zero-carbon assets such as battery storage by 2030. The Irish grid will be expanded with the Celtic Interconnector, which will require the provision of at least 700 MW of fast frequency response and operating reserve from zero-carbon sources. Furthermore, it has been envisaged that 1200MW of 2-hour battery storage will be required by 2030. This battery storage will be used to provide longer-duration grid services such as the replacement reserve [37].

The policy recommendation is to incentivize the connection to the grid of new units which can provide grid support services with zero-carbon emissions and that can be possibly cheaper for the consumer; the goal is to minimize the dispatch or the positioning of conventional units by the TSOs for the grid services provision. The policy will implement mechanisms for the prioritisation of the procurement and dispatch of low or zero carbon sources for the provision of the various grid services and the fulfilment of all system operational constraints by means of zero-carbon sources.

The policy driving the market design and the long-term investment should balance the risk between system operators and storage service providers. Ideally, the system operators should decide in advance the type of services they require out of a list of available services. When no services are required, the storage unit can be used for price arbitrage functions thereby contributing to lower the wholesale electricity prices.

The TSO policy aims at establishing a phased approach in the introduction of the new storage technologies imposing a limit on the volume of high availability storage technologies that can be qualified for the provision of services. This is the so-called “Volume-Capped” competitive procurement [38]. Industry has observed that the expected lifetime of BESS may be diminished by the frequent cycling with a possible impact on the resulting cost for the services provision. It was advised to limit the dispatches at 10 per year, not considering the frequency events. Within this regulatory framework, the constraint on the number of cycles should be properly balanced with the possible obligations of a BESS on the Capacity Market, since capacity provision might be limited by the cycling constraint for the volume-capped services. In addition, the TSO policy should carefully evaluate a model where a BESS would provide services solely in frequency response mode, without requiring that the BESS to work as a controllable device. Since there is interest in industry for this option, the TSO should evaluate it in the light of a means to foster the development of more cost-effective services.

Another issue with the current policy is related to the network charges applicable to the storage. In fact, the TSO normally applies Transmission Use of System (TUoS) charges to generation and demand customers, which depend on the Maximum Export Capacity (MEC) and Maximum Import Capacity (MIC). The Irish Trading and Settlement Code includes a ‘Battery Storage Unit’ classification; under this classification BESS are currently subjected to both the charges applied to generation and demand.

Moreover, the BESS connected to the distribution networks are also liable to pay Distribution Use of System (DUoS) charges. The application of the double charges to the BESS is considered unjustified; Ireland will be likely following the GB example, where several consultations were initiated to get rid of the double charging, among the other regulatory objectives. The policymaker should recognize that BESS should not be classified as the final demand customer because the stored electricity is reinjected into the grid at a later stage. The revision of the policy disclosed in the Trading and Settlement Code with respect to battery storage is encouraged by the EU’s Clean Energy Package under Regulation (EU) 2019.943 on the internal market for electricity. According to this EU package, the network tariffs should not introduce discrimination of energy storage, disincentivize their participation in demand response or hinder energy efficiency improvements.

The market of medium-term storage products, congestion management products and other products like reactive power support should be consolidated to allow the policymaker to establish an effective policy for congestion management and network expansion deferral. Currently the business cases for developers determining investment decision in BESS are weak. Both technology availability and policy should promote the development of long-term network support contracts by TSOs and DSOs. There is some potential for these services to be available in Ireland by 2030.

To summarize the above considerations about the current regulatory framework, it is noticed that current policy about storage is affected by technology availability, technology-related constraints, and market conditions. The challenge for the policymaker is to recognize technology maturity and the potential for novel application of BESS to support the grid, incentivise the development of innovative grid energy services to foster the related market's growth. High level overview of energy storage technology for electrical systems and energy storage market. What are the key market drivers: movement towards renewables, grid modernization, desire for self-sufficiency, financial incentives and other national policies etc.

# Ireland Current Electrical System, Market Status, and Future Potential

## Ireland Energy Policy

Until 2020, the most important legislation [39] that drives the renewable energy expansion in Ireland and also the European Union is the Renewable Energy Directive [40]. Based on this directive, the overall renewable energy share and the renewable energy deployment in the transportation sector are two important targets the must be met by Ireland at the end of 2020.

The overall renewable energy share target sets out that renewable energies must account for at least 16% of the gross total energy consumption in Ireland by 2020 [40]. Renewable energies used in the transportation sector must contribute at least 10% of the total energy used in the transportation sector (rail and road). To be able to meet these targets, Ireland defined two national targets regarding the deployment of renewable energies in the heat and electricity sector. The national renewable electricity target sets out that renewable energies must account for 40% of total gross electricity consumption by the end of 2020. The national renewable energy heat target mandates that renewable energy resources must supply 12% of the total energy used in the heating and cooling sectors in 2020.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Target** | **Progress %** | | | **Target**  **2020** |
| **2010** | **2015** | **2019** |
| **Overall Renewable Energy Share** | 5.7 | 9.0 | 12.0 | 16 |
| **Renewable Energy Share in Electricity** | 15.6 | 25.5 | 36.5 | 40 |
| **Renewable Energy Share in Heat** | 4.3 | 6.2 | 6.3 | 12 |
| **Renewable Energy Share in Transportation** | 2.5 | 5.9 | 8.9 | 10 |

Table . Ireland progress toward a renewable dominated energy system [39]

Table 4 summarize the 10 years progress of Ireland toward a renewable dominated energy system. Renewable energy based electricity generation experienced a six-fold increase in 2019 (11780 GWh) in comparing g to 2005 (1873 GWh). The climate action plan 2021 sets out a new target for the contribution of renewable energies in electricity generation [41]. Renewable energies will account for up to 80% of the electricity generation by 2030 in Ireland. The offshore wind energy has also been assigned to expand to at least 5 GW. These new targets enable Ireland to electrify other sectors such as heat and transportation using renewable energy resources. According to the climate action plan, greenhouse gas emissions in Ireland must be 51% reduced by 2030. EirGrid and SONI assume a renewable generation mix in their studies [42] in which offshore wind farms’ contribution is assumed to be 5100 MW, onshore windfarms account for 8150 MW, solar achieves to 2100 MW by 2030.

European clean energy package mandates the member states to support the deployment of less than 50 kW renewable generation by households; in addition a microgeneration support scheme will be introduced. It is expected that this scheme will cover 260 MW of new renewable microgeneration by 2030 in Ireland [41].

To enhance the viability of the small energy communities, a small-scale generator support scheme will also be introduced for the farmers, and commercial consumers, enabling them to generate their own electricity and feed the extra energy to the grid. Community-based renewables account for at least 500 MW of supply.

Last January, the power system experienced its all-time peak demand equal to 6.78 GW. It is reported by EirGrid & SONI that considering the high demand scenarios, the total energy requirement peak could achieve 8.87 GW by 2030. The total power loss in distribution and transmission level has been estimated to be 7-8% based on the historical 10 years data in the whole island. Power system adequacy needs to be ensured to preserve the continuity of the supply. Ireland’s future power system deploys conventional generation capacity, demand-side management, battery storage units, and renewable energies. Climate action plan 2021 envisages around 2 GW new flexible gas-turbine power plant to accommodate a high penetrated renewable power system. Since the lifetime of a gas turbine generator is 25 years, any new investment in this generation asset will remain in operation until 2030. Respecting the zero or negative emission policies that may be taken in the future, new gas turbine-generators should use renewable gases as fuel such as syngas, hydrogen, or biomethane. In addition, decommissioning the peat and coal combusting power plants will be completed.

Due to the increase in carbon price and the European legislation to reduce the emissions, coal and peat generation should be decommissioned in near future, the conventional generation fleet will be dominantly gas-fired power plants (by 2025 in the published studies [43]). Based on the climate action plan 2019, the coal power plant will be completely phased out by 2025 and the peat-fired plants in Midlands will also be decommissioned by 2028 [44].

## Ireland Generation Mix

Based on the data provided in [45] the Ireland’s generation mix is illustrated in Figure 2. Two points are noticeable. The first one is the share of wind power, which significantly dominates the other renewable resources especially the solar power. The latter is the small amount of electricity power export, which implies the level that we could rely on export (net import is -1.5%) option in case of excess power in our network. It is reported that the total electricity consumption in the whole Island was around 36 TWh by 2019 [39].

Figure . Generation mix in the whole Island, source [45]

A total share of 42.5% of the total electricity demand is supplied by renewable energies in the whole Island in 2020. As is shown in Figure 3, wind power has the greatest share (85.8% of total renewables), other renewables account for 7.3%, hydropower achieves to 5.7%, and finally solar power contributes to 1.2% of the total load supplied by renewable energy resources.

Figure . The share of renewable energy resources in Ireland’s renewable target

Currently 9.7 GW of dispatchable generation units has been installed [46]. More than 4300 MW wind and 706 MW of solar is also operating in the whole Island [47].

## Energy Storages Mix & Overview in Ireland

Climate action plan 2021 sets out a 20-30% contribution for flexible demand by 2030 that could be interpreted as the expansion of demand-side storage facilities. It also acknowledges that the emission reduction plan beyond 2-4 Mt will necessitate the expansion of long-duration & seasonal storage for renewable energies. In addition to the stationary storages planning, Ireland must achieve the one million electric vehicles target by the end of 2030. Figure 4 depicts the six targets determined by Ireland’s climate action plan 2021 that drive the deployment of battery storage.

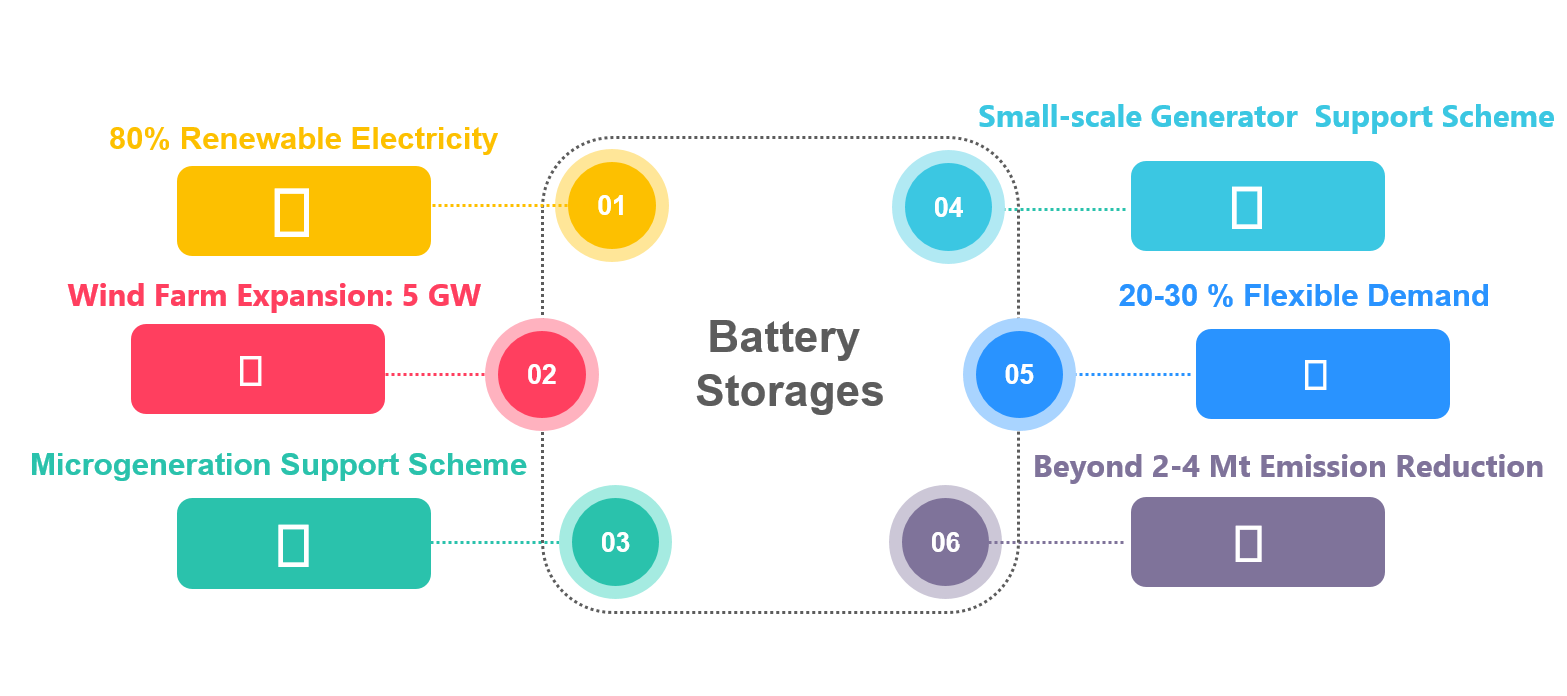


Figure . Ireland’s Climate action plan 2021, implies a significant expansion in deployment of battery energy storages

Ireland has installed only one pumped storage hydro power plant with the capacity of 292 MW at Turlough Hill, Co. Wicklow [39]. Silvermines Pumped Storage in north Tipperary, with the budget of €650 Million, will be commissioned until 2023 that add 360 MW of pumped storage hydro power capacity [48]. There is also another[[1]](#footnote-2) 750 MW pumped storage hydro power plant in the construction pipe lines [49].

A 300 kW ultra-capacitor unit with the capacity of 150 kWh, located in Tallaght [50], is operating and active in frequency response services. A 4.6 MW thermal energy storage is also operating in coupled mode with an on-campus wind turbine in Dundalk University of Technology [51]. Four 150 kW flywheel energy storage units are operating and it is planned to couple them with the BESS in near future [52]. Based on the information provided by [53], 1.547 MW capacity of battery storage are currently operating in Ireland. This information does not include behind the meter storages in the whole Island. The Kilroot Battery which is a 10 MW unit is also operating and mainly used for system service procurement. It was in 2021 that, the first two utility-scale battery storages were energized, namely 11 MW Kilathmoy project by Statkraft, and 100 MW Lumcloon project from Hanwha Energy [54]. It was planned to energize about 250 MW of the battery storage projects at the end of 2021, which were in construction phase during the year [14]. Excluding 250 MW units that should be installed at the end of 2021, Figure 5 illustrates the current storage fleet in the whole Island.

Figure . Ireland Energy Storage mix 2020

In Ireland, six different phases exist for battery storage project evolution, namely pre-application, application submission, planning agreement, planning and grid connection approval, construction, and operation. In 2021, more than 1400 MW of battery storage were in the planning permission phase, around 150 MW, in the pre-application phase, more than 300 MW submitted their application, more than 200 MW have also received their grid connection approval [54]. Based on this statistics, around 2.5 GW of battery storage fleet are in the pipelines to emerge in near future.

Figure . Ireland Energy Storage statistics

Figure 6 illustrates some informative indices on the status and overview of the energy storage units in the whole island with respect to the renewable energy and conventional generation fleet. As is seen, the ratio of battery storage[[2]](#footnote-3) volume to the total installed capacity of renewables is currently around 2.5%. This ratio will achieve 12.5% in the target year (2030). It represents 10% growth with respect to the current situation. It is remarkable that the battery storage growth will be around 2000% at the target year. Inclusion of the pumped storage hydro capacity gives us 8.3% for the status and will achieve more than 19% in the target year. It is remarkable that the ratio of energy storage to the total generation unit installed capacity is currently around 2.8 % and will achieve more than 3% in the target year. Currently, renewables contributed to 34% of the total installed generation capacity. At the target year, the renewable installed capacity will be more than four times that of the today capacity.

## Ireland Transmission System

### Tie-Lines to other European Countries & System Operation Policies

#### European Policies on the Expansion of the Interconnections

European Union supports the Projects of Common Interest (PCI). The EU Regulation number 347/2013 on Guidelines for Trans-European energy infrastructure [55] determines the designation criteria for PCI interconnections through Europe. European Energy Security [56] set a target for all member states to achieve an interconnection level at least equal to 10% of the installed electricity generation capacity by 2020 and 15% by 2030. It was in 2017 that the European Commission set out a target for the interconnection capacity to be at least 30% of the renewable generation capacity for the member states [57]. It is reported by the European Commission that the interconnection level for Ireland is equal to 7.4% [58, 59].

#### Ireland’s Policies on the Expansion of the Interconnections

In the light of the European and Ireland interconnection policies, sections ‎1.3.2.3, ‎1.3.2.4, and ‎1.3.2.5 present an overview of the existing interconnections and the plans in Ireland’s electricity system. The important point is that since the European renewable energy targets and the interconnection levels are linked together, expansion of the existing interconnections is a key point to enable Ireland to achieve the targets. The interconnection level has also a profound effect on the economic justification of the energy storage projects since interconnections not only can provide energy export opportunities but also can redeem the transmission bottlenecks and reduce the price difference between regions that may limit the arbitrage opportunities for the storage devices.

### Current Cross-border Interconnections

Currently, two HVDC transmission systems connect Ireland's power system to Great Britain [60]. East-West Interconnector (EWIC) is a submarine and subsoil HVDC connection providing 500 MW transmission capacity in both directions. The length of this 200 kV transmission system is 261 km and connects the converter stations located in Portan, Ireland to Shotton in Wales, GB.

Another transmission system connects Northern Ireland to Great Britain. Moyle provides 500 MW of transmission capacity with 63.5 km 250 kV HVDC transmission line and connects  Ballycronan More, County Antrim in Northern Ireland to Auchencrosh, South Ayrshire in Scotland which is in turn connected to the GB via a 275 kV AC transmission line.

In addition to the cross border connections between Ireland and GB, there are three high voltage AC transmission connections between the Republic of Ireland and Northern Ireland [61].

* Corraclassy to Enniskillen 110 kV transmission line
* Letterkenny to Strabane 110 kV Transmission line
* Louth to Tandragee 275 kV transmission line

Only Louth to Tandragee 275 kV provides a liable transmission capacity and this requires great attention since this connection could be lost due to a single event.

### Cross-border Interconnections that will be Surely Energized by 2030

Greenlink project (ENTSO-E TYNDP project 286) will provide the third connection to GB [62].  Linking the Great Island substation in Wexford and Pembroke substation in South Wales by a 320 kV HVDC submarine transmission line, 500 MW could be bidirectionally transported between Ireland and GB within a length of 195 km. It is remarkable that the commissioning date will be 2023.

The Celtic interconnector is also another transmission project (ENTSO-E TYNDP project 107), a 700 MW 320/500 kV HVDC transmission system that will link Knockraha substation in [Cork](https://en.wikipedia.org/wiki/County_Cork) to the La Martyre substation in [Finistère](https://en.wikipedia.org/wiki/Finist%C3%A8re), France. The submarine cable will be 500 km in length that passes through the waters of Ireland, GB, and France.  The Celtic interconnector will be commissioned in 2026.

A 400 kV AC overhead transmission line with a length of 138 km, from Woodland, Ireland to Turleenan Northern Ireland is approved by ENTSOE as Project 81 to be constructed. The aim of the project is to facilitate the integration of renewable energy resources, improve the North-South interconnection, and increase the security of supply [63]. The commissioning date of this interconnector will be in 2021.

### Cross-border Interconnections That Will be Hopefully Energized By 2030

RIDP I, an Extra high voltage 83 km transmission line that links Srananagh in Co. Sligo to a new substation in south Co. Donegal. Then, a 58 km cross border 275 kV transmission line connects Donegal to Omagh in Northern Ireland. Subsequently, the project links Omagh to Turleenan with a 61 km 275 kV transmission line. The whole project is called ENTSOE TYNDP project 82 [64]. All three aforementioned transmission lines are scheduled to be commissioned by 2029.

The MAREX Organic Power Interconnector (ENTSO-E TYNDP project 349) is an HVDC transmission line that links Connah's Quay (or CION alternative) and Mayo [65]. It also includes the installation of various transmission equipment in three different voltage levels namely 400 kV, 320 kV, and 245 kV. The project reinforced the republic of Ireland transmission system and finally links Ireland to GB. The commissioning is scheduled to be in 2025.

ENTSO-E TYNDP project 1040 which is also called LirIC [66] aims to increase the liability of interconnections between North Ireland and Scotland by an HVDC 320 kV transmission line that will be commissioned by 2028. The length of the transmission project is 133 km that links Kilroot in Northern Ireland to Kilmarnock in GB. This project has also great implications on alleviating the [system’s non-Synchronous penetration constraint that put limits on the wind power generation in Ireland and avoid wind curtailment.](https://www.eirgridgroup.com/site-files/library/EirGrid/SNSP-Formula-External-Publication.pdf)

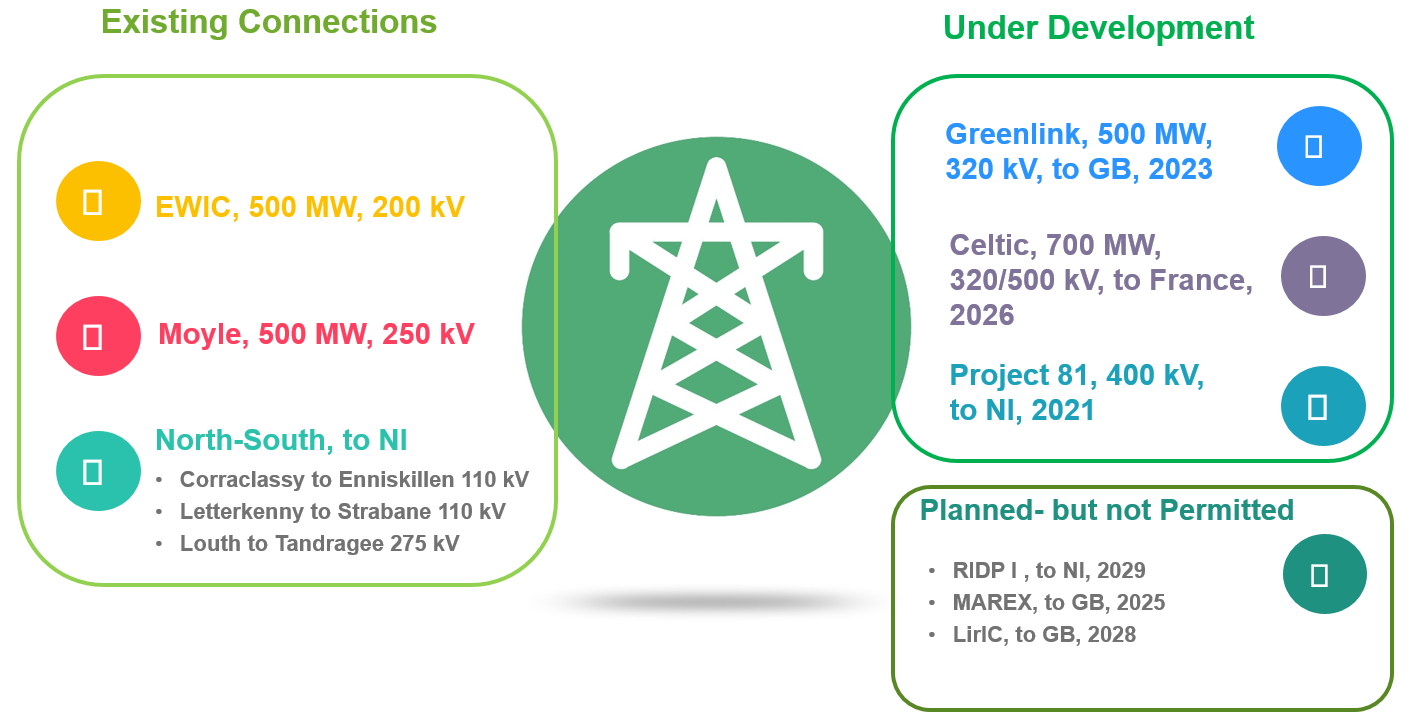


Figure . Ireland’s cross border interconnections

Figure 7 illustrates the North-South transmission systems and cross border interconnections between Ireland, GB, and France.

The climate action plan 2021 emphasizes the energizing of the transmission projects to GB, France, and Northern Ireland. It also plans to update the national policy statement [67] on electricity interconnection to cope with the amendment of guidelines for trans-European energy infrastructure [68] and manage the Brexit challenges.

### National Transmission System Development

In addition to the expansion of cross-border interconnections described in ‎4.4.2, ‎4.4.3, and ‎4.4.4, a number of national-wide transmission expansion projects in both jurisdiction areas (Republic of Ireland and Northern Ireland) are capitally approved and planned to be delivered before 2030. New overhead lines, cables, new air-insulated or gas-insulated substations, series capacitors and reactors, and installation of transforms, busbars, and STATCOMs are included in this plan. The complete list of these projects could be found on the EirGrid and SONI joint report [42] titled “Shaping our electricity future, a roadmap to achieve our renewable ambition”.

## *Ireland Power System* Operational Policies

### Non Synchronous Penetration Level

To maintain the stability of the power system, an operation policy is to put limits on the level of non-synchronous generation operating within the power system. The System Non-Synchronous Penetration (SNSP) level is defined to monitor this limit. It refers to the ratio of non-synchronous generation on the system at a given time, which includes the non-synchronous generation and net interconnector imports, and the summation of the net interconnector exports and system demand. It is currently set out to be less than 70% and includes wind power generation, PV production, and the net import from Moyle and EWIC interconnectors. Real operation data shows that during 2020, SNSP lies between 25% and 50% for 39% of the times, and is preserved more than 50% for 32% of the times. Monitoring the system between 15 January 2021 to 30 March 2021 showed that SNSP for 312 hours, remained above 65% that facilitates to achieve the wind power generation all times record of 4489 MW at 12 February.

### Rate of Change of Frequency and Inertia Limits

Power system usually manifests frequency change after a large event. The Rate of Change of Frequency (RoCof) depends on the system inertia response. The higher inertia is available on the system, the lower post event RoCoF will be manifested by the power system. Too high or too low frequency may cause costly damages to some of the power system elements such as generators. To protect them against this damage, RoCoF relays sense the rate of change and disconnect the intended element from the power system before the frequency achieves to forbidden operating point for that element. In the whole island, RoCof should be less than 0.5 Hz per second. Since 17 June 2020 SONI and EirGrid commenced a 1 Hz per second RoCof trial. The inertia limit currently ensures that the existing inertia in the whole island does not fall below the 23000 MWs.

### Tie-line Constraints

The scheduled flows between both jurisdiction areas are constrained to maintain the operating condition of the tie lines and entire power system within the safe bounds. A 20 MW safety margin is also included to the constraint. The following inequalities explain the constraint on the tie line connecting Republic of Ireland to Northern Ireland.

() refer to the positive scheduled flow from (to) the Republic of Ireland to (from) Northern Ireland. The second term in the left hand side of the inequalities define the reserve capacity requirement on the tie line that should be available in the event of the loss of the largest single in-feed in the jurisdiction area of the destination. For the Republic of Ireland and Northern Ireland it is referred by and respectively. and are representing the scheduled primary operating reserve in the Republic of Ireland and Northern Ireland respectively. represents the maximum allowed flow from the Republic of Ireland to the Northern Ireland and is currently determined to be 400 MW. Correspondingly, is the maximum allowed flow from Nothern Ireland to the Republic of Ireland and it equals to 500 MW.

### Dispatch-down of Renewable Energies

Dispatch-down of the renewables reflects the amount of renewable energy that cannot be accommodated by the power system although it is available to be absorbed. If the power system limitations cause to dispatch down, it will be referred by curtailment. Whenever the local network limitations cause to dispatch down, it will be known as constraints.

In 2020, more than 13700 GWh of wind energy was generated in the whole island, while 1909 GWh was subjected to the dispatch-down. Based on these statistics, 12.1% of the total available wind energy resources could not be absorbed by the power system. A breakdown of the statistics shows that 1448 GWh of wind resources were subjected to dispatch down in Ireland (11.4% of the total available wind energy), while 461 GWh dispatch-down was reported for Northern Ireland (14.8% of the total available wind energy) [45].

Table . Annual trend of renewables dispatch-down in the whole island

|  |  |  |  |
| --- | --- | --- | --- |
| **Dispatch-down of Renewables** | **2018** | **2019** | **2020** |
| **Wind** | 6.0% | 7.7% | 12.1% |
| **solar** | NA | 4.2% | 8.7% |

Table 5 contains the annual trend of dispatch-down for wind and solar energy between 2018 and 2020. It is addressed that wind curtailment is mainly an overnight problem but considering the 70% renewable penetration, the curtailment can happen all day long [45]. The new target determined by climate action plan 2021 to achieve 80% penetration of renewables will exacerbate the curtailment problem. Based on the reported studies, achieving to the previous 70% renewable penetration is theoretically possible but due to the curtailment problem, it requires to huge amount of investment to meet the target since without taking mitigating measures, the curtailment level will achieve to 45% [43].

Several types of system security limits may cause curtailment. As is reported by EirGrid, Stability problems, reserve requirements, reactive power issues, and System Non-Synchronous Penetration (SNSP) limit are the most pertinent factors. High-frequency problems and minimum level of conventional power plant fleet on the system have also great contributions to the roots of the curtailment problem. High-frequency limits and minimum required conventional generation constraint are mainly touched during the night. Constraints are the main reason for the dispatch-down between 9:00 and 22:00. SNSP takes the third rank and it mainly touched during the night hours.

The capacity factor of the wind farm and total installed wind capacity is reported by EirGrid to be the most pertinent factors that affect the threshold on the maximum amount of wind power generation. In 2019, a meaningful correlation is observed between the times of higher wind farm’s capacity factor and higher amount of dispatch-down based on the data provided in the EirGrid “Annual Renewable Energy Constraint and Curtailment Report 2019”.  Generation unit outages have also affected the dispatch-down. Demand level can obviously be an important factor since higher demand levels enable the power system to absorb higher levels of wind and solar generation. Modification of system operation policies such as dispatch/dispatch down priorities has also a profound effect on the amount of dispatch down in the whole Island. Figure 8 summarizes the root cause of the dispatch-down of renewables in the whole Island.

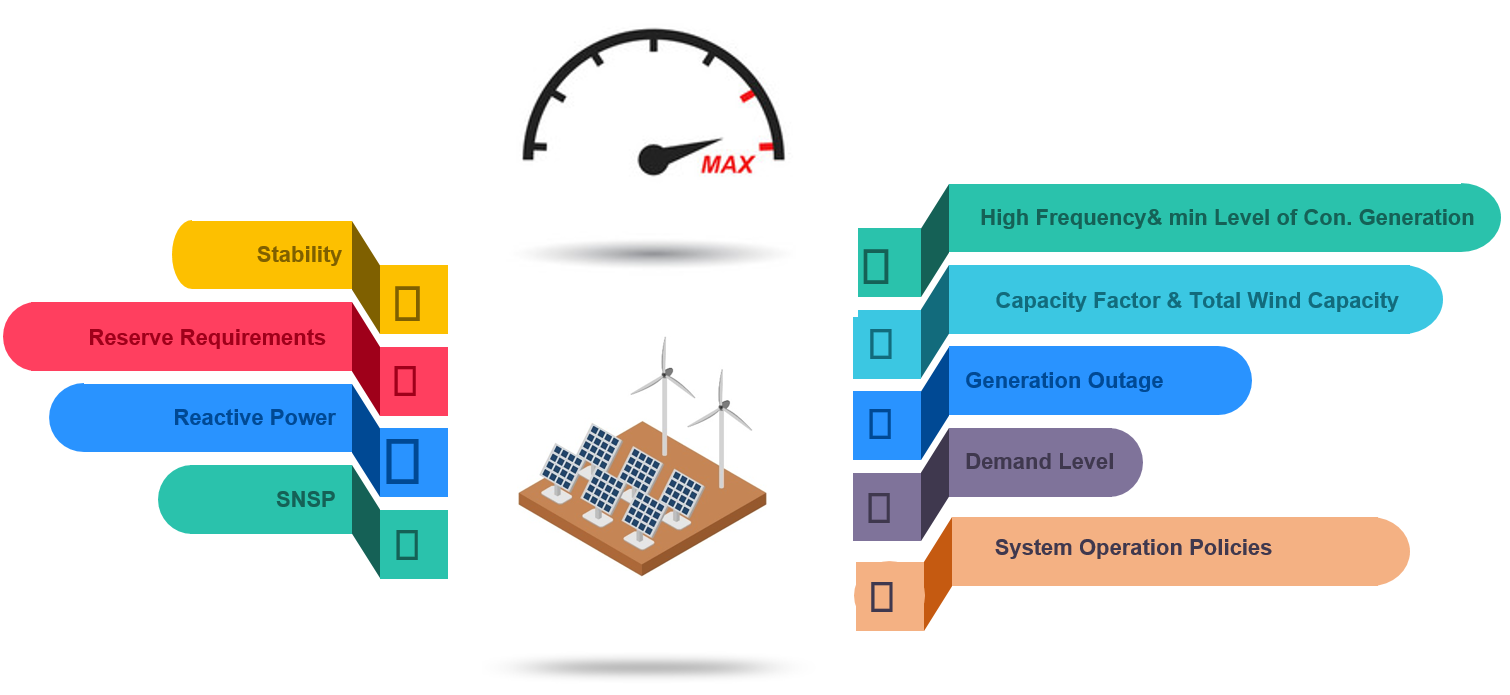


Figure . The most pertinent factors affecting dispatch-down in the whole Island

As is seen in Figure 8, many of the pertinent factors could be partly or entirely resolved by the energy storage facilities. Reactive power problems, some kind of reserve requirements, stability issues, SNSP, and demand level are within the grasp of BESS solution.

### The whole Island Power System Reserve Requirements

The recent rapid growth of renewable energy integration, while provides sufficient resistance to the climate change, exacerbates the importance of post event power system frequency response. Increasing the penetration level of the renewable energy resources, along with the intermittent behavior of wind and solar power, challenges the ability of power system to preserve the frequency within the satisfactory bounds. Ireland’s power system like any other electricity interconnected system needs operating reserve for frequency control.

#### Primary Operating Reserve (POR)

POR is to supply additional MWs or reduce the demand, in comparison to the pre-event operating point, at the point in which the frequency nadir occur from 5 to 15 seconds following an event. If the frequency nadir do not occurs in the mentioned timeframe, the minimum post event frequency observed in this period is taken for POR monitoring purposes.

#### Secondary Operating Reserve

Secondary Operating Reserve is to supply additional MW or reduce the demand in comparison to the pre-event operating point. The service must be procured from 15 seconds following an event and maintain until 90 seconds after the event.

#### Tertiary Operating Reserve 1

Tertiary Operating Reserve 1 is to supply additional MW or reduce the demand in comparison to the pre-event operating point. The service must be procured from 90 seconds following an event and maintain to 5 minutes after the event.

#### Tertiary Operating Reserve 2

Tertiary Operating Reserve 2 is to supply additional MW or reduce the demand in comparison to the pre-event operating point. The service must be procured from 5 minutes following an event and maintain to 20 minutes after the event.

#### Ramping

##### Replacement Reserve (De-Synchronised)

Replacement Reserve (De-Synchronized) (RRD) is to supply additional MW or reduce the demand in comparison to the pre-event operating point. The service must be procured from 20 minutes following an event and maintain to 1 hour after the event.

##### Replacement Reserve (Synchronised)

Replacement Reserve (Synchronized) (RRS) is to supply additional MW or reduce the demand in comparison to the pre-event operating point. The service must be procured from 20 minutes following an event and maintain to 1 hour after the event.

Figure . Operation Reserve Requirements in Ireland’s Power System

Figure 9 illustrates the categorized reserve requirements enabling the power system to satisfy the desirable frequency bounds based on the definitions provided in EirGrid & SONI codes [69].

Figure 10 depicts the amount of reserve requirement in the whole Island based on the percentage of the largest generation unit in-feed. It is remarkable that based on the power system status, sometimes the POR and SOR percentage increased up to 80% to maintain the transient security of the system. When at least one unit is in pumping mode in the pumped-storage plants in Ireland, lower bounds are defined for POR, SOR, TOR1, and TOR2, which should be procured by the regulating resources. In Northern Ireland, lower bounds are defined without any obligation for the procurement by certain generation units.

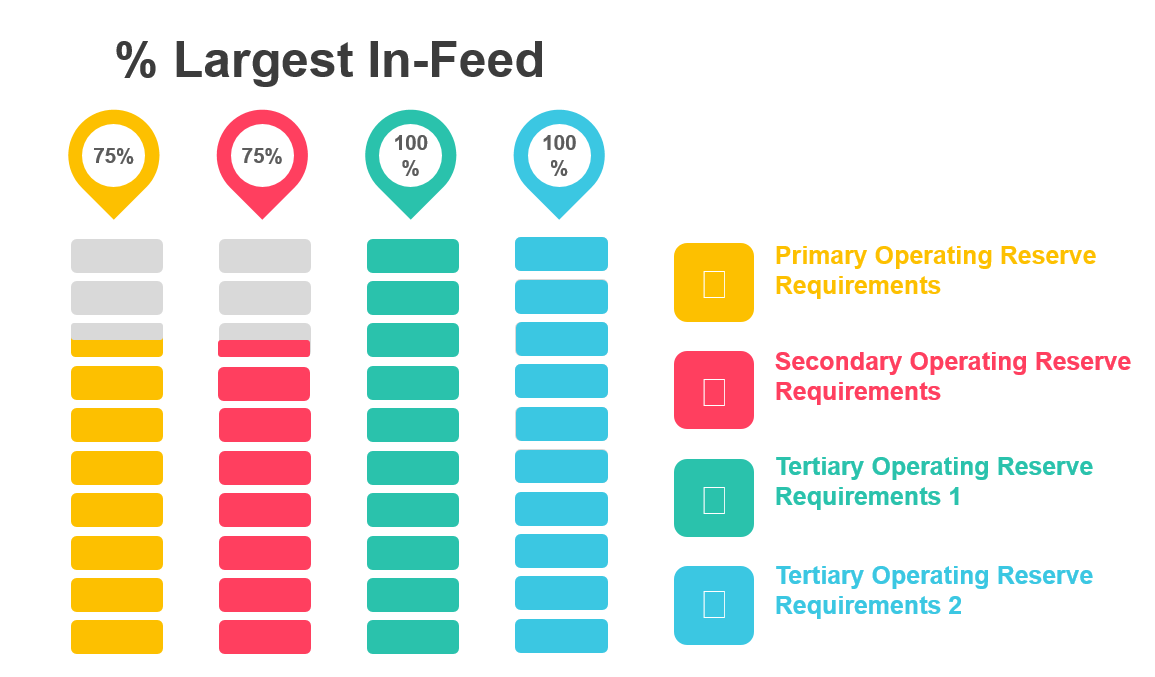


Figure . The amount of Reserve Requirement in the whole Island

Based on the last version of the “operational constraints update” report published by EirGrid & SONI [69], non-event reserve requirements are mainly procured by synchronous generation units in the whole Island. In Ireland, the following resources supply non- or partially regulating reserve:

        23 MW from Battery Storages

        Up to 75 MW from EWIC Interconnector

        45 MW from the Responses of Demand Side Units

        Turlough Hill Units Operating in Pumping Mode

 However, in Northern Ireland, non- or partially regulating reserve is supplied by the deployment of the following resources:

        60 MW from Battery Storages

        5 MW from Demand Side Units

        75 MW form Moyle Interconnector

 The negative ramping reserve requirement in Ireland was 100 MW, which has been permanently reduced to zero since 14 January 2021. In Northern Ireland, the negative ramping reserve is equal to 50 MW, is defined as MW output power of a conventional generation unit operating above its minimum power capability, and should be delivered at or above five MWs per minute. It is remarkable that since 1 April 2021, both of the transmission operators have employed their battery storage fleet to procure non- or partially regulating reserve on a trial basis to enhance the operational experiences, coordinate the IT infrastructures, and evolve the business process.

Dynamic stability requires that at least five machine to be on-line and loaded at all times in the Republic of Ireland. For the Northern Ireland, it is set out to be three machines. Replacement reserve requirements put limits on the combined output power of the open cycle gas turbine generators to be less than 698 MW in Ireland. In addition, 325 MW is also required to act as replacement reserve. Correspondingly, the upper limit of the open cycle gas turbine generators is determined to be 272 MW, and 125 MW capacity should be available as the replacement reserve. Black start is also a service that could be provided by the power plants having the capability to start at least one of the generation units from shutdown without any requirement to external power supply.

## Delivering a Secure, Sustainable Electricity System (DS3)

Delivering a Secure, Sustainable Electricity System (DS3) is a program introduced by EirGrid and SONI to accommodate a high penetration of renewable energies in the Island’s power system. In this program, some new services were defined to increase the capability of the power system to absorb the renewable energy resources more than before. The following subsections define the required new services and their specifications.

### Ramping Services

In order to mitigate the forecast error subjected to the renewable energy resources, three different ramping margin constraints are defined in the whole Island as the ability to increase the output power or reduce the demand within a specified time after receiving the dispatch instruction and the capability to maintaining that MW output for a specified time duration. The mentioned ramping margin constraints are namely Ramping Margin 1 (RM1), Ramping Margin 3 (RM3), and Ramping Margin 8 (RM8). The time specifications of RM1 to RM8 are illustrated in Figure 11.

Figure . The time specifications of the ramping margins

As is documented by the TSO’s in both jurisdictions [70], the aim of the DS3 program was to increase the SNSP up to 75% by 2020, while the renewable electricity target sets out a 40% contribution for renewable energy resources. In addition, the curtailment of the wind should be reduced to approximately 5% per annum. Based on the last updates of the system operation constraint report [69], the SNSP is currently up to 70% and on 22 April 2021, the TSOs commenced a trial for 75% SNSP. It is remarkable that the renewable electricity target for 2020 is completely met and 2.5% additional renewable electricity was procured in comparison to the predetermined target.  Although the pandemic causes delays to meet the 75% SNSP, it is remarkable that 75% of SNSP is set in the situation of achieving to 40% of renewable electricity while it was 42.5% by 2020.

### Synchronous Inertial Response (SIR)

The ability of a unit to provide active power and synchronizing torque following an event is called the inertial response. Synchronous generators and synchronous condensers are the most common units that can provide post-event inertial service for the power system. Recent researches showed that by the deployment of new control approaches, the kinetic energy in the wind turbine blades could also provide such a response. Flywheels are also have similar capabilities. These kinds of responses are distinct from SIR since the providers are non-synchronous but the potential of the synthetic inertia providers could not be neglected. Single electricity market committee acknowledge that some non-synchronized technologies may provide sufficient fast inertial response and the potential of these technologies should be analyzed by the TSOs in both jurisdiction areas [71]. The power system inertial response has a profound effect on the RoCoF following a large event. Providing the inertial response at low output power operating points supports the power system to accommodate higher levels of penetration for non-synchronous generation units.

As a classic definition, the kinetic energy of a synchronous unit (generator or motor) multiplied by a factor, which is called the SIR factor, and defined as the ratio of that kinetic energy to the lowest deliverable output power in MW while the unit is in reactive power control operating mode, is known as SIR service. Based on the definition, the dimension of the SIR factor is second and the upper bound and lower bound of the desired service should be 45 and 15 seconds respectively [71]. Figure 12 depicts the SIR factor bound designated by the SEM decision paper. The lower bound necessitates that the provider unit should be able to serve in low MW output power. The lower bound necessitates that the provider unit should be able to serve in low levels of output power and excludes the units that have not this capability. The upper bound gives space to other providers since there is no additional value of the service by the deployment of a single unit beyond a specified operating point.

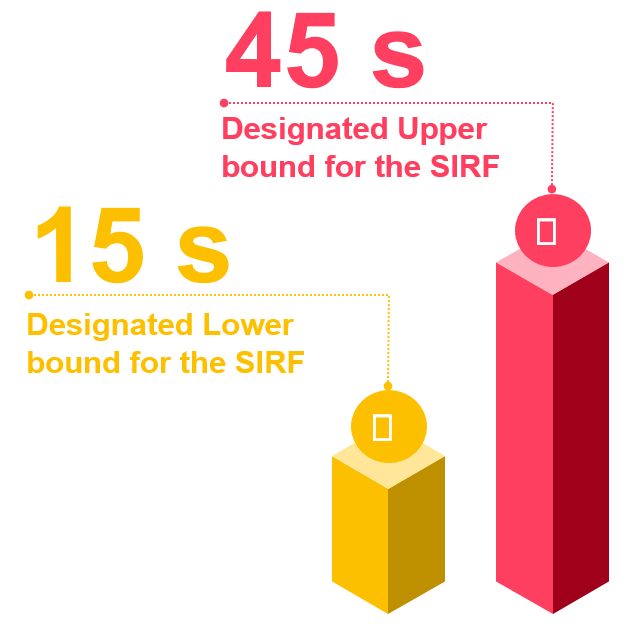


Figure . SIRF upper and lower bound designated by decision paper of SEM (SEM-13-098)

### Fast Frequency Response (FFR)

Fast frequency response acts as a complementary service to the inertial response of the power system. If a unit can maintain or increase its output power after the SIR procurement, it could also serve as a fast frequency response provider. In comparison to the primary operating reserve service, FFR provides faster MW support for the power system, decreases the post-event RoCof, and so extends the time to achieve the frequency nadir. Actually, FFR covers the timeframe within 2 seconds after the beginning of the event and must maintain at least eight seconds. Generation units supplying additional MWs or the demand side reducing their consumption conforming the aforementioned timeframe could either provide this service. The amount of energy provided by the intended unit in that eight seconds timeframe should not be less than any energy absorption within 10 seconds after the provision of the service. Some concerns exist for the service provider that states the TSOs should put a value on the faster response technologies that act before two seconds but they are not immediate. The SEM argued that the main goal is not to enhance the power system frequency response capability as much as possible.  Instead, the procured services should bring value for the end-user customers. While the analysis of the TSOs in both jurisdiction areas shows that the FFR is required only within two seconds after the fault, any faster technology will not add any value to the end-user customers and will be categorized as an overqualified technology to serve in the context of FFR service.

### Fast Post‐Fault Active Power Recovery (FPFAPR)

Following a voltage disturbance (for instance a short circuit occurrence on the transmission lines), the power system requires some units that are capable to recover their output power very quickly in order to avoid severe frequency transient and preserve the security of the system. Fast post fault active power recovery (FPFAPR) is defined to mitigate this problem. The unit providing FPFAPR must be capable to recover its post fault output power within 250 ms after the instant of voltage recovery (achieving 90% of the pre-fault voltage level), to at least 90% of its pre-fault output power, for any fault that will be cleared within 900 ms. The provider unit must remain connected at least 15 minutes after the fault occurrence. Although the trigger point of this service is voltage dependent, it is inherently a frequency control service and enable the power system operator to take preventive frequency actions.

### Dynamic Reactive Response (DDR):

By occurrence of any voltage dip in excess of 30%, if a unit is capable to inject reactive current to provide Mvar and achieve at least to 31% of its registered capacity at the nominal voltage, within up to 40 ms rise-time and manifest up to 300 ms settling-time, the mentioned unit is providing the dynamic reactive power response. This service is required in the high penetration levels of renewable energy resources that are inherently non-synchronous. In this situation, the electrical distance between few conventional generation units, existing in the power system, increases. This necessitates compensating the weakened synchronizing torque that put the power system together as a whole. DDR could be provided by the windfarm during the voltage events.

### *Steady*‐state Reactive Power (SSRP)

Reactive power support is not inherently a new service and from the conventional power system era, the reactive power requirement of the power system should be supplied by the conventional generation units. However, in the high renewable penetrated power systems, this is not only the conventional generation units that are able to procure reactive power service. Steady –state reactive power (SSRP) for a conventional generator is defined as the despicable reactive power that could be provided by that unit within the whole range of its active power operating points, which is normally from minimum to maximum capable output power. For the wind power generators, the range of reactive power capability is defined across the corresponding active power range (from 12% of the registered capacity or a minimum operating point based on the design or grid codes to the registered maximum output power capacity).

### Procurement of the DS3 Services & the Associated Payments

Figure 13 illustrates the services required by the power system to be able to host a high penetration level of the renewable energy resources based on the DS3 program. As is seen, replacement reserve has been categorized to synchronous (RRS) and de-synchronous (RRD) pillars. RRS addresses the providers that are synchronized to the Power System (applicable for synchronous generators). In case of energy storage units, or power park modules, the unit should provide more than 0 MW before receiving the RRS dispatch instruction. RRD addresses three types of providing units: 1) In case of synchronous generators when they are not synchronized by the power system 2) In case of storage units when they are taking the role of demand and operate below the 0 MW level 3) demand side units. Therefore by definition, BESS are able to provide RRS and RRD services as well.

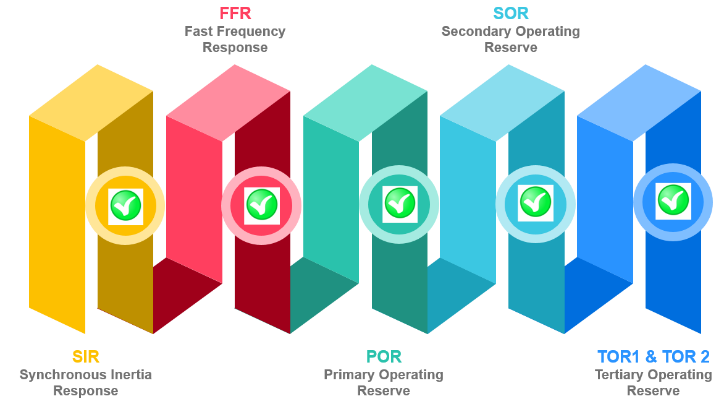
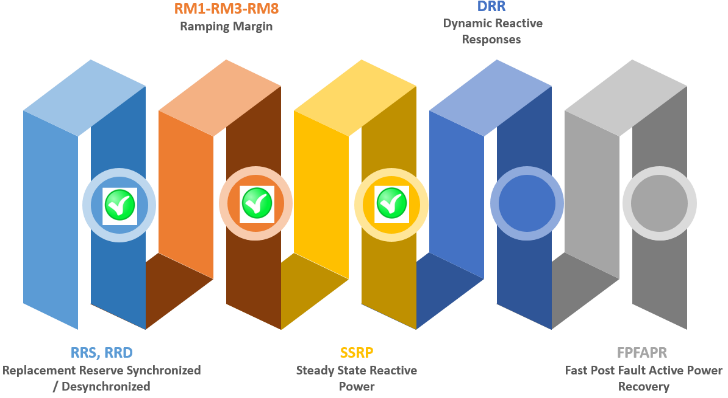


Figure . System Required Services to Accommodate High Penetration of Renewable Energy Resources

In DS3 program two mechanisms have been designed for the service providers in order to access to the revenue stream.

* Volume-capped arrangement
* Volume-uncapped arrangement

The volume-uncapped arrangement is a regulated framework in which the service providers sign an agreement with the transmission system operator. The agreement will continue until 30 April 2023 [72]. The payment in this arrangement is regulated and subjected to the tariffs determined by regulatory authority (SEM)[73]. In this arrangement, only the approved technologies via qualification trial process could be known as the service providers. The volume uncapped arrangement has been in place since 1 May 2018 and four gates has been opened the procurement results have also been published.

The volume-capped arrangement is another regulated framework and is only applied to a subset of the intended DS3 program services, namely FFR, POR, SOR, TOR1 and TOR2. This arrangement is regulated since a volume cap is determined by the regulatory authority to be procured via this framework. The providers submit competitive prices to participate in this arrangement. The terms and conditions of the volume-capped arrangement differs from the volume-uncapped arrangement. To incentivize the new entries, before commencing the provision of the intended services, the volume-capped arrangement is going to allow a time span for build phase [74]. It is remarkable that a service provider could not be contracted in both armaments for the same DS3 service. In addition TSOs require that the providing unit contracted via volume-capped arrangement must simultaneously provide FFR, POR, SOR, TOR1 and TOR2 with a similar amount in order to ensure the security of the power system.

### Associated Payments of the Volume-uncapped Arrangement:

#### POR, SOR, TOR1, and TOR2

For the POR, SOR, TOR1, and TOR2 the payments are calculated based on the available volumes within a specified trading period multiplied by the POR, SOR, TOR1, or TOR2 payment rate, and the total payment will be adjusted by the corresponding scalars (scaling factors). The POR, SOR, TOR1, or TOR2 available volume are the minimum of the following values:

* Time-weighted averaged MW volume of the obtained reserve (output MW or reduction) based on the definition of the intended service
* The declared value for the intended service by the providing unit

Each MW of provided services will be subjected to the corresponding payments in each trading period. The payment is equal to the multiplication of the intended service available volume, the corresponding payment rate, duration of the trading period, and the associated scaling factor. The scaling factor consists of the multiplication of the following scalars:

* The performance scalar: It depends to the result of performance assessment carried out by the TSOs.
* The product scalar: It depends on the reserve trigger type and reserve trigger scalar compared by 49.3 Hz.
* The locational scalar: The minimum value equals 1 and reflects the geographical location of the providing unit.
* The temporal scarcity scalar: It reflects the situation of the system in terms of SNSP level and clusters it to below 60%, between 60% and 70%, and more than 70%.

It is remarkable that all of the aforementioned services fall in the category of static responses in which a discrete step increases in MW Output or discrete steps in MW Reduction will be supplied to the power system by the providing units.

#### RRS and RRD

For the RRS and RRD services the payment details are similar to the POR, SOR, TOR1, and TOR2 except that for the replacement reserve services the product scalars are not defined and the scaling factors consists of three embedded scalars instead of four.

#### SSRP

For the SSRP the payments are calculated based on the SSR available volume within a specified trading period. The available volume of SSR is equal to the multiplication of steady-state reactive power range, reactive power factor, the portion of the trading period in which the providing unit is Synchronized or connected to the power system and have the capability to provide the intended service. The steady-state reactive power range equals to the sum of the declared reactive power in either leading or lagging mode within the trading period. The reactive power factor is defined to be equal to 1 when the providing unit is nor operating as a generation unit. In case of being in a generation mode, the reactive power factor is defined as the ratio of the whole active power range (the difference of registered capacity and the minimum power in which the unit is capable to control the reactive power) and the registered capacity of that unit. Each Mvar of the provided SSRP will be subjected to the payment in each trading period. The payment is equal to the multiplication of the SSRP available volume, the SSRP payment rate, duration of the trading period, and the SSRP scaling factor. The scaling factor consists of the multiplication of the following scalars:

* The performance scalar: It depends on the result of performance assessment carried out by the TSOs.
* The product scalar: If the unit is in the automatic voltage control mode while it is providing the SSRP service, this scalar will be 2, otherwise it will be 1.
* The SSRP Wattless Scalar: If the unit provides SSRP while the injected active power equals 0, this scalar will be 2 and otherwise it will be zero.
* The locational scalar: The minimum value equals 1 and reflects the geographical location of the providing unit.
* The temporal scarcity scalar: It reflects the situation of the system in terms of SNSP level and clusters it to below 60%, between 60% and 70%, and more than 70%.

#### SIR

For SIR service, the corresponding available volume within a trading period is equal to the multiplication of the providing unit kinetic energy, the difference of SIRF with 15, and the portion of the trading period in which the unit is synchronized with the power system. The kinetic energy itself is defined as the contracted kinetic energy of the intended unit for that specified trading period. The SIRF is considered to be 45 seconds for the synchronous compensators/motors. For synchronous generators it is defined as the ratio of that kinetic energy to the lowest deliverable output power in MW while the unit is in reactive power control operating mode. The payment is equal to the multiplication of the SIR available volume, the SIR payment rate, duration of the trading period, and the SIR scaling factor. The scaling factor consists of the multiplication of the following scalars:

* The locational scalar: The minimum value equals 1 and reflects the geographical location of the providing unit.
* The temporal scarcity scalar: It reflects the situation of the system in terms of SNSP level and clusters it to below 60%, between 60% and 70%, and more than 70%.

#### FFR

For the FFR, the payments are calculated based on the FFR available volume within a specified trading period multiplied by the FFR payment rate, and the total payment will be adjusted by the corresponding scalars (scaling factors). The FFR volume is defined to be the minimum of the following values:

* Time-weighted averaged MW volume of the obtained reserve (output MW or reduction) based on the definition of the intended service
* The declared value for the intended service by the providing unit

Each MW of provided FFR service will be subjected to the corresponding payments in each trading period. The payment is equal to the multiplication of the FFR available volume, the corresponding payment rate, duration of the trading period, and the associated scaling factor. The scaling factor consists of the multiplication of the following scalars:

* The performance scalar: It depends to the result of performance assessment carried out by the TSOs.
* The product scalar: It depends on the dynamic trigger and dynamic trajectory scalars compared by 49.8 Hz while the FFR fall in the category of dynamic responses by which the MW output or MW reduction of the providing unit is controlled in a continuous framework and react proportionally to the power system frequency. For static responses, static trigger scalar, static hysteresis scalar, and static step scalar are used to compare the response to 49.3 Hz.
* The FFR continuous scalar: It will be set to 1.5 if the unit is available to support the system for POR, SOR, TOR1, and FFR during the trading period, otherwise it will be set to 1.
* The FFR fast response scalar: It scales how fast the provided response is. It divided the response into three time spans, namely less than 0.15 second, between 0.15 and 0.5, and between 0.5 and 2 seconds, and rewards the faster responses.
* The locational scalar: The minimum value equals 1 and reflects the geographical location of the providing unit.
* The temporal scarcity scalar: It reflects the situation of the system in terms of SNSP level and clusters it to below 60%, between 60% and 70%, and more than 70%.

A generic reserve characteristic curve has been defined in the agreement for the providing units that procure POR, SOR, TOR1, TOR2, RR, and FFR by the deployment of some parameters. The units should determine the intended parameters enabling the TSOs to drive the characteristic curve. In the agreement, it is addressed that if a wind farm power station is curtailed to the operating point less than its minimum active power level and it still is able to provide FFR or other reserve services, it should have two sets of reserve characteristic parameters.

#### FPFAPR

For the FPFAPR, the payments are calculated based on the FPFAPR available volume within a specified trading period multiplied by the FPFAPR payment rate, and the total payment will be adjusted by the corresponding scalars (scaling factors). The FPFAPR Available Volume is defined as the average of Output MWs injected to the power system by the provider that is synchronized or connected to the Power System and have the capability to support the power system by providing the intended service. Based on this definition it is not limited only to the synchronous generators.

Each MW of provided FPFAPR will be subjected to the corresponding payments in each trading period. The payment is equal to the multiplication of the FPFAPR available volume, the corresponding payment rate, duration of the trading period, and the associated scaling factor. The scaling factor consists of the multiplication of the following scalars:

* The performance scalar: It depends to the result of performance assessment carried out by the TSOs.
* The locational scalar: The minimum value equals 1 and reflects the geographical location of the providing unit.
* The temporal scarcity scalar: It reflects the situation of the system in terms of SNSP level and clusters it to below 70% and more than 70%.

#### RM1, RM3, and RM8

For the RM1, RM3, and RM8 the payments are calculated based on the corresponding available volume within a specified trading period multiplied by the intended payment rate, and the total payment will be adjusted by the corresponding scalars (scaling factors). The available volume for each services is defined to be the minimum of the following values:

* The possible ramping margin capability of the unit in one hour, three hours, or eight hours for the RM1, RM3, and RM8 respectively.
* The lowest declared RM1, RM3, or RM8 by the unit for the intended trading period
* The MW difference between the average additional output power/ power reduction and the minimum of the availability within the timeframe starting from the beginning of the intended trading period and the following three hours, eight hours, or sixteen hours for the RM1, RM3, or RM8 respectively.

The technical offer data, namely the cold/warm/hot start-up time and the ramping limitation are the most pertinent factors determining the so-called possible ramping margin. Each MW of provided RM1 will be subjected to the corresponding payments in each trading period. The payment is equal to the multiplication of the intended service available volume, the corresponding payment rate, duration of the trading period, and the associated scaling factor. The scaling factor consists of the multiplication of the following scalars:

* The performance scalar: It depends to the result of performance assessment carried out by the TSOs.
* The locational scalar: The minimum value equals 1 and reflects the geographical location of the providing unit.
* The temporal scarcity scalar: It reflects the situation of the system in terms of SNSP level and clusters it to below 60%, between 60% and 70%, and more than 70%.

#### DRR

For DRR the payments are calculated based on the DRR available volume within a specified trading period multiplied by the DRR payment rate, and the total payment will be adjusted by the corresponding scalars (scaling factors). In the last version of volume uncapped arrangement, the available volume for DRR is defined on a MW basis which seems not to be correct [72].

The payment is equal to the multiplication of the intended service available volume, the corresponding payment rate, duration of the trading period, and the associated scaling factor. The scaling factor consists of the multiplication of the following scalars:

* The performance scalar: It depends to the result of performance assessment carried out by the TSOs.
* The locational scalar: The minimum value equals 1 and reflects the geographical location of the providing unit.
* The temporal scarcity scalar: It reflects the situation of the system in terms of SNSP level and clusters it to below 70% and more than 70%.

### Summary of the Performance of the DS3 Program

#### All Technologies:

Sine 1 May 2018, the volume-uncapped arrangement has awarded contracts to the service providers. Procurement has been made through phase 1, phase 2, and gate 1 to gate 4b openings. The service providers have the right to amend the previous contracted volume by the new openings. Due to the pandemic effects on the service providers, gate 4b gives the opportunity to the service providers to adjust their contracted volume conforming to the imposed situation. Figure 10 and Figure 11 illustrate the total contracted volumes awarded to the service providers for DS3 program required services in the Republic of Ireland and Northern Ireland respectively. All of the amendments result in a decline/incline of the contracted volumes have not been doubly accounted for in the total contracted volumes, so the reported values show the resulting volume after excessing all of the amendments. As is seen from these figures, no contract has been awarded to the service providers for the procurement of DRR and FPFAPR since May 2018. In both jurisdiction areas, in terms of the total contracted volume, all of the services have an overall increasing trend from phase 1 to Gate 4 except RRS, RM3, and RM8.

Figure . Total Contracted Volume; Volume Uncapped DS3 System Services Regulated Arrangements, Republic of Ireland, from 2018

Figure . Total Contracted Volume; Uncapped DS3 System Services Regulated Arrangements, Northern Ireland, from 2018

#### Battery Storages and DS3 Contracts:

In addition to the conventional generation units, renewable energy-based power plants and energy storage units could also provide the intended services in the DS3 program. Table 3 contains the list of service providers that use only battery storage technology to provide the intended services. As is seen from Table 3, among all of the services defined in DS3 program, FFR, POR, SOR, TOR1, TOR2, and SSRP have been contracted to be procured by the BESSs [75-88].

Table . The volume-uncapped successful battery storage service providers since 2018

|  |  |  |
| --- | --- | --- |
| **Opening** | **Battery Storage Service Providers** | **Contracted Services** |
| **Phase 1** | --- | --- |
| **Phase 2** | --- | --- |
| **Gate 1** | Kilroot Battery | FFR |
| **Gate 2** | B&T-2 ESPS (Winter Winds Limited) | POR, SOR, TOR1, TOR2, FFR, SSRP |
| **Gate 3** | --- | --- |
| **Gate 4** | Kelwin 2 ESPS, Mullavilly Storage | POR, SOR, TOR1, TOR2, FFR |
| **Gate 4B** | Lumcloon ESS-1 and Lumcloon ESS-2, B&T-2 ESPS | POR, SOR, TOR1, TOR2, FFR, SSRP |

It was on 1th October 2019 that the results of DS3 service procurement has been announced for volume-capped arrangement. Eighteen service providers submitted their bids via the competitive framework of volume-capped arrangement and among these, three service providers were successful. The auction resulted in awarding the contract to totally 110 MW service providers that were all solid-state BESSs located in Ireland. It is estimated that the total cost of these contracts achieves €6 million annually. Table 7 contains the battery storage service providers and their corresponding volume of contract. [89].

Table . The volume-capped successful battery storage service providers in 2019

|  |  |
| --- | --- |
| **Providing Unit** | **Contract Size** |
| **Gorman Energy Storage Station** | 50 MW |
| **Porterstown Battery Storage Facility** | 30 MW |
| **Kilmannock Battery Storage Facility** | 30 MW |

Based on the terms and conditions of the DS3 volume-capped arrangement contracts, it is expected that the contracted service providers commence to procure the intended services from October 2021 since there is a two years given time to the contract holders for the build phase.

## FlexTech program

FlexTech program brings all relevant parties in the whole Island to facilitate the deployment of new technologies in order to breach the barriers associated with the effective usage of renewable energy resources more than before. Regulators, transmission system operators (SONI & EirGrid), distribution system operators (ESB and NIE Networks), industry, and many other stakeholders are working together to make this achievement possible.

Expansion of the non-synchronous renewable generators through the system, the low inertia future power system, and exacerbated congestion problems, and the alteration of the consumption profile due to the deployment of smart devices necessitate the utilization of storage systems, stronger interconnections, development of sophisticated demand-side integration, and the alteration of the operation polices.

FlexTech has the following structure:

* Industry Forum
* System Operator Task Force
* TSO working groups

The industry forum acts as a consulting unit to address the potential remedies associated with key existing challenges of high renewable penetrated future power systems and discover the opportunities from the new technologies. As an opening view, the industry forum will tackle the topics including deployment of hybrid technologies (PV, Wind, EVs), small-scale generation and renewables, demand-side management, energy storage technologies, and large-scale energy consumers such as data centers.

The system operator task force is a joint commission consisting of transmission system operators (SONI &  EirGrid) and the distribution system operators (DSOs) in both jurisdiction areas. This could alleviate the future power system challenges since the challenges will be associated with both levels of transmission and distribution and require a unique and coordinated solution approach.

The connection application of energy storage units are fast-growing in both jurisdiction areas. SONI, EirGrid, ESB, and NIE Networks are currently processing some of these applications resulting from ECP-1 2018 and T-4 capacity market auction. In addition, the possibility of awarding a contract to the storage units via DS3 program volume capped arrangement is also a great incentive for the energy storage units to attract the attention of the investors. It is remarkable that the number of connection applications is a way far from the successful projects awarded a contract in the volume-capped arrangement and as a result, these projects are actively seeking opportunities to access a revenue stream. The displaceability of the storage units and having a justified estimate for the dispatching procedure have great importance for realistic measuring the effect of these technologies on the future grid. It is well-known that the frequent cycling of the battery storage has a profound negative effect on their expected lifetime.  Accordingly, the cost associated with the services that could be procured by the battery storage is directly affected by the operation regime. Capacity market obligations impose challenges for battery storage units concerning the impact of frequent cycling on their expected lifetime. Based on the SEM instructions, all units above 10 MW must be recharged via a dispatch instruction. The controllability of the units below 10 MW of capacity should also be considered. FlexTech introduces the following issues associated with the deployment of the energy storage and the corresponding priority areas:

* Operating mode for the energy storage units
* Grid access issues and the competition between storages and renewables
* Fast response capabilities of the battery storage units
* Modification of the Grid/distribution Codes

FlexTech acknowledges that in the storage technology the focus is on Battery Energy Storages because this is a rapidly expanding sector and the innovations result in lower costs associated with the manufacture and operation of the battery storage units. It is required to identify the best deployment procedures for battery storages to be able to design the supporting schemes for attracting a sufficient amount of investment. Based on the Industry Forum remarks in June 2019, Ireland has the experience of operating Kilroot Battery which is a 10 MW unit mainly used for system service procurement. At that time, 179 MW of new battery storage units that are mostly located in the Dublin area, were contracted via Capacity Market T-4. The battery storages mainly provided the services ranged from FFR to TOR2 including the flat provision of energy. Taking the role of fast-acting demand, batteries served as a solution to the over-frequency problems. The batteries were dispatched up to ten 10 times in addition to the frequency service provision and In case of unavailability, they were penalized.

The challenges associated to battery storage units (as is currently addressed by FlexTech) were mainly categorized as follows:

**Revenue Stream:** The battery storage owners should know the revenue opportunities in advance to b be able to come into decision from and economic liability point of view.

**Investment Signal:** DS3 Volume capped arrangement and T-4 capacity market provided long-term investment signal while might impose some availability obligation, which affect the lifetime of the battery storages. However, based on the design of the volume-uncapped arrangement, before testing the units, it was not permitted to sign the contract with a provider unit.

**Technical Requirements:** The battery storage developers should know about the signaling requirements, Grid Codes, testing procedures, etc. At that time, because of the limited experience with the battery storages, these issues were hard to define. Due to the fast response time of the battery storages, the TSOs and DSOs should analysis what level of fast acting service could be handled in the system.

## Capacity Market

Capacity Market enables the responsible parties to ensure that the continuity of supply is guaranteed through a market based and competitive mechanism. The mechanism provides incentives for the capacity auction winners to supply the required capacity when the system is under stress. The stressed times are clearly defined based on the reference prices and the strike price [90]. When energy prices exceed the strike price, the suppliers (market players who purchased the electricity on behalf of the consumers) will be paid by the difference of the energy price and the strike price. The financial resource for these payments is procured by the capacity auction winners who received the regular capacity payments and will be charged if the imbalance settlement price exceeds the strike price in a trading period.

If a capacity provider fails to be available during the stressed condition, it will be exposed to the strike price. This provide strong incentive for the auction winners to be on at times that the reference price exceeds the strike price because they must pay capacity difference charges regardless of being scheduled on or not [90].

The auction participants could be aggregators (demand side units, and aggregated generating units), different technologies of generators, the interconnectors, and different technology of storage units provided to be qualified. Demand-side units are able to pool consumer loads to participate in the capacity auctions [91].

Capacity providers could participate in the capacity markets for the provision of new or existing capacity. Long-term capacity auctions are held four years before the time of delivery and are called the T-4 capacity market. Additional auctions will be held allowing the participant to adjust their position closer to the capacity year and are called T-1 capacity markets. BESSs can participate in the capacity markets individually (the generators definition includes the energy storage units [90]) or via aggregators. It should be noted that participation in the balancing market is mandatory for all dispatchable generators having a maximum export capacity above the de minimis threshold (10 MW). For dispatchable generators below this threshold the participation in balancing market is voluntary. Balancing market is important since the generators that wish to qualify for the capacity market must be registered in the balancing market as well.

The transmission system operators and single electricity market operator shared the responsibilities of the capacity market operation. Qualification of the capacity market participants, determining the amount of required capacity, designating the local constraints, scheduling and running the capacity auctions, and some other responsibilities are on the shoulders of the transmission system operators. The single electricity market operator manages the credit risks and do the settlement relevant tasks [90]. After qualification process, the participants can offer their capacity in the auction.

Based on the document published by SONI and EirGrid reporting the results of T-4 capacity auction for 2024/2025, demand-side units by 265 MW and battery storages by 77 MW of net derated new capacity were qualified to participate in the auction. Pumped storage hydro power plants have no new capacity and were qualified to participate in the auction by 203 MW of existing derated capacity. In total, close to 452 MW of derated new capacity wins the auction that includes gas turbines, demand-side units, wind power plants, and battery storage [92]. The auction results for T-2 2021/2022 indicates that demand-side units by 636 MW (303 MW existing and 333 MW new capacity) and battery storages by 54 MW of net derated new capacity were qualified to participate in the auction. In total, close to 183 MW of derated new capacity wins the auction that includes gas turbines, demand-side units, wind power plants, and battery storage [93].

## Neglected Potentials of the BESSs in DS3 Program

As is reflected in section ‎4.6.9.2, the BESSs contributed to the following services in the DS3 program: FFR, POR, SOR, TOR1, TOR2, and SSRP. Based on the list, the potential of the BESS has not fully been deployed.

SIR is a service that supports the power system in the early instances after event occurrence. Rotary speed reduction causes the kinetic energy, which is stored in the rotor mass of the synchronous generators to release, and within 0.05 seconds, the output power increases between 7% to 14% of the total capacity for a typical synchronous generator [94]. This inertial response is limited in terms of the amount of power increase for each unit of the synchronous generator so a number of units are needed to be simultaneously in operation in order to preserve the frequency in the satisfactory bounds. Synchronous generators are constrained by their minimum output power and keeping a number of synchronous generators in operating mode displaces the corresponding amount of renewable-based generation. As is stated before, dynamic stability requires that at least five machines be online and loaded at all times in the Republic of Ireland (three machines in Northern Ireland). Finding a solution for the provision of inertial response could affect the minimum required number of synchronous generation fleet and open the space for renewable-based electricity generation.

Battery storage has no moving part but it could provide a synthetic inertial response for the power system. As quickly as the fault could be detected, the battery storage can respond to. Due to the limitations associated with fault detection, the battery storage provide a slower synthetic inertial response but their response is not limited in terms of the amount of output power, since they could achieve the full output operating point in less than 0.2 second. This ability could be improved by more sophisticated control systems. A study showed that Kilroot battery storage responds to the system event (July 2017) within 0.04 to 0.06 second. Control systems could enable the battery storage to achieve the maximum output power in 0.05 second [94].

FFR and SIR act as complementary services. As is reflected in ‎4.6.8.5, the fast response scalar of the FFR service divides the response time into three-time spans, namely less than 0.15 second, between 0.15 and 0.5, and between 0.5 and 2 seconds, and rewards the faster responses. For less than 0.15 second responses, the scalar takes the value of 3 that puts more value on faster responses. Figure 16 and Figure 17 illustrate the trend of FFR and SIR in the openings of DS3 program since 2018. Although the information of FFR is not available to reflect the procured amount based on the response time, faster FFR is able to replace the classic inertial response of synchronous generation in the future power system.

The statistics published by SONI and EirGrid showed that it is forecasted to spend €16.1 million and £3 million for SIR in the Republic of Ireland and Northern Ireland respectively. Considering the emission that could be avoided by modifying the required minimum number of conventional plants for preserving the dynamic stability (1.4 Mt additional emission [94]), and technical advantages such as reduced post fault clearance oscillations by the provision of SIR using battery storages, it could be a valid suggestion to analysis the economic viability of the battery storage for the provision of SIR or putting more values on the faster responses in FFR.

It is acknowledged that the amount of faster FFR or synthetic inertial response that could be provided by battery storage is currently far away from the power system requirements, but the study showed that 360 MW battery storage is able to provide the same amount of power after 0.1 second as 3000 MW of synchronous generators [94].

Figure . Comparison of SIR and FFR Trend, Republic of Ireland,

Figure . Comparison of SIR and FFR Trend, Northern Ireland,

FPFAPR is a service defined to prevent severe frequency transient resulting from a voltage event. One of the liable technologies that can provide this service is battery storages. As is stated before, this service require active power recovery to 90% of the pre-fault operating point within 250 ms after event occurrence which is fully within the grasp of battery storage technology capabilities. This service has not been procured via the DS3 program since 2018 not only by battery storage, but also by the other technologies whereas, it is acknowledged that FPFAPR is vital for the power system in the whole Island [95].

Although there are some technical challenges to the deployment of the BESSs for both active and reactive power services, studies showed that the provision of reactive power services by battery storage is a liable solution [96]. As is stated Table 6, BESSs contributed to the SSRP. Whereas, the liability of the battery energy storages are well-known for their fast response provision they have no contribution on the provision of the DRR in DS3 program. It should be noted that for this service, no contract has been awarded to any other technology as well. The current version of the technical definition for DRR has significant shortcomings since the available volume of the DRR is defined based on the MW output of the providing units [71].

BESSs have not been contracted for RR, RM1, Rm3, RM8 as well. Looking into the time specifications of these services reflects that RR service requires the providing unit to deliver RR within 20 minutes and sustain at least for one hour. These time requirements are even longer for RM1 (commence within 1 hour and sustain for 2 hours), RM3 and RM8. This may happen because it is not technically possible for a single BESS or even by aggregated action of current battery storages to procure such long-duration services.

It remains an open question whether the energy storage requires supporting policies to achieve to the point that enables them to procure long-duration services or the market forces drive the technology to find its way correctly. However, we should keep in mind that, if these long-duration services are to be procured by conventional power plants as more economic prefereable choices for the current situation (considering the carbon price, capital price, etc.), it may have negative effects on the emission-free plans and renewable dominated electricity system for the future. Seeking an answer to this question, one should review the supporting policies, such as feed-in tariffs, that enables renewable resources to sustain in the competition with the conventional generation units.

Table . The rate that the services were purchased from the providing units

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Rate 1000 Euro/ Unit of Service** | | | | | | | | | | | | |
| **Period** | POR | SOR | TOR1 | TOR2 | RRD | RRS | RM1 | RM3 | RM8 | FFR | SSRP | SIR\* |  |
| Oct 2018- Sep 2019 | 13.93 | 8.96 | 6.93 | 5.48 | 3.32 | 0.63 | 0.47 | 0.50 | 0.48 | 4.90 | 4.72 | 0.55 |  |
| Oct 2019- Sep 2020 | 16.19 | 10.33 | 7.77 | 6.81 | 4.07 | 0.89 | 0.64 | 0.82 | 0.79 | 8.01 | 3.43 | 0.37 |  |
| Oct 2020- Sep 2021 | 19.22 | 10.17 | 7.82 | 5.98 | 6.84 | 0.68 | 0.98 | 1.13 | 1.07 | 32.51 | 3.22 | 0.46 |  |

\* SIR factor is considered to be 15 s, SIR rate dimension is 1000 Euro per MWs

Based on the data provided by SONI and EirGrid in the procurement summary documents [97-103], the forecasted rate of payment for the services are derived and presented in Table 8. As is seen, the maximum rates are allocated to the POR, SOR, TOR1, TOR2 (except for Oct 2020 – Sep 2021) as the classic reserve requirements of the power system. For the period of Oct 2020 to Sep 2021, the purchase rate for FFR has been significantly increased. It is due in no small part to the achievement of Ireland to the renewable energies target and the exacerbated power system requirements to the FFR to host high penetration levels of the renewable energies[[3]](#footnote-4). In the active power-relevant services, the aforementioned services are interested in battery storage since they are able to access the higher revenue stream. RM1, RM3, and RM8 are purchased at low rates, and this fact along with the inability of the battery storages to procure long-duration services cause that no contract has been awarded to the BESSs for procuring such services. The strategy in the Irish power system is to enhance the provision of the system services by low carbon technologies. To this end, one of the options is to adjust the purchase rate for the RM services but, in the meantime, it will increase the revenue stream for the technologies that are currently procuring such services. A wiser option is to indirectly subsidize the long-duration battery storage projects that are able to provide such services for the future Irish power system.

## Regulations and Policies

### The National Development Plan

Based on the national development plan, the reliability of the electricity supply will be enhanced by investing in the transmission and distribution grid, further interconnections with neighboring power systems such as Celtic and UK connectors. As a complementary approach, the government of Ireland mentioned the investments in the energy storage units and utilization of the smart meters [104]. Management and moderation of energy usage are also attributed to the energy storage facilities.

Investment in the grid-scale energy storage facilities is addressed in the plan along with the expansion of the conventional generation fleet to preserve the adequacy of supply in case of the lower supply from the renewable energy resource. Especially to ensure the security of supply, investment on the grid infrastructures, interconnectors, and energy storage facilities such as batteries are addressed [104]. To develop the battery technology, private investment is mentioned as a crucial factor for the sustainability of the required mineral supply.

### Assignment to the Regulatory Bodies and Policy Makers

Policy statement on mineral exploration is also addressed in 2021 climate action plan [41] to ensure the sustainability of battery manufacturing. In addition to meeting the 2030 targets, the electricity sector needs to increase the energy storage capacity to support the rapid build-out of renewable energies. Hydrogen is recognized as seasonal storage for renewable energies. Based on the 2021 climate action plan of Ireland, the commission for regulation of utilities is assigned to review the regulatory treatment of the energy storage addressing the licensing, charging, and market incentives for the energy storage facilities. In addition, the Department of Environment, climate, and communication must develop a policy for the storage facility to ensure the achievement of the 2030 targets. Long duration and seasonal storage for renewable energies are addressed as a key measure enabling Ireland to meet the 2030 sustainable energy system.

In the program for the government document published by the department of Taioseach (October 2020) [105], the green hydrogen is notified as a multipurpose fuel, applicable in electricity generation, energy storage, and transportation. Investment in research and development in green hydrogen is also emphasized. It is addressed that the greening of the taxi fleet will be supported by the government to deploy battery-electric and plug-in hybrid vehicles [105].

### Capacity Mechanism

It is explained in section ‎4.8 that a capacity market scheme procures the required capacity for each capacity year in Ireland. Prior to the capacity auction, an information pack is published by SONI and EirGrid that contains the required information for the auction participants [106]. It contains derating curves, final capacity requirements, indicative load curves, auction price cap, and etc. Based on the unit size and the technology, different derating factors are defined to adjust the nominal capacity of the qualified capacity providers for participating in the capacity auction. From the derating factors point of view, the energy storage technologies are classified into two different categories, namely the pumped storage plants and other storage technologies. In addition to the unit size that affects the attributed derating factors, the hour of storage also affects the derating factors for all storage technologies. For a DSU that has more than 6 hours demand reduction capability, the hours of demand reduction capability will not affect the derating factor but for the demand side units that their demand reduction capability is less than 6 hours, different derating factors have been attributed to different demand reduction hours (similar to the storage technology).

Out of 77 MW qualified battery storage units for T-4 capacity auction 2024/2025, only 22 MW (28%) have offered their capacity and the final results showed that all of the offered capacities were successful. For all of the other technologies, 100% of the qualified capacity has been offered and won the auction except the demand site units by 79% and gas turbines by 81% [107]. As is addressed in section ‎4.8, the whole 77 MW qualified battery storage capacity was new and no existing battery storage capacity has participated in the mentioned auction. As another example, out of 54 MW new qualified capacity of the BESSs in T-2 2021/2022 auction, only 6 MW was offered and successful (almost 11%) [108]. These numbers shows that:

* The existing BESS (if any) do not offer their capacity in the capacity auctions
* Either the capacity remuneration mechanism cannot attract the battery storage units or the interaction of obligations in the DS3 program prevent BESSs to participate in the capacity auctions.

### Black Start

Pumped storage hydroelectric power plants act as black start units in the Ireland based on the existing contracts [109]. The BESSs capabilities to procure system restoration services will be addressed in section ‎5.1.2. Currently, no BESS contribute to the system restoration services in Ireland.

### Technical Requirements

Energy storage that provides DS3 services must provide a real-time signal indicating the remaining available energy. In addition, for the provision of DS3 services (except for the frequency services), the storage units must limit their ramp rates complying with the grid code requirements [110].

Other technical requirement details such as active power control (charging of the battery storage unit), ramping requirements (active power control set-point ramp rate, frequency response ramp rate, and capacity limited ramp rate), and the frequency response technical details are addressed by [111].

### High Availability Units and the Volume Capped Arrangement

In order to manage the risk of over expenditure, a category of service providers had been defined in Ireland, which was called high availability units. This category addressed the units whose availability is not linked to the energy dispatch. These technologies are able to provide high levels of availability for a subset of reserve services, namely, FFR, POR, SOR, TOR1, and TOR2. To avoid breaching the expenditure cap, TSOs proposed a separate procurement process [112] to limit the volume of such high availability technologies contracted and the regulatory body approved the proposal [73]. The separate procurement process was called ‘Volume Capped’ for which the eligible service providers should offer a competitive price as part of their tender. Batteries and demand-side units were categorized as high availability technologies. One auction has been held for this specific category, but currently these kinds of units are allowed to participate in the volume-uncapped arrangement as well.

### Budget Limitations and the DS3 Program Payment Rates

Based on the budget determined by the SEM, SONI, and EirGrid published a sensitivity analysis on the required payment rate reduction for the DS3 service payments associated with FFR, POR, SOR, TOR1, and TOR2 services per additional capacity of the fast-acting technologies (such as storage). The mentioned analysis estimates a 30% required rate reduction for all technologies to stay within the budget limits for 2022. Further reduction may also be required (up to 45%) if the high wind scenario will be realized for 2022 [113].

Although the TSOs proposition is reasonable from the budgetary point of view, it addresses a problem in the DS3 arrangement design. High wind scenarios mean higher demand for the services procured by the providing units through the DS3 program. Suppressing the price of the required services by the reduction in the payment rates means weakening the signals for the investors to provide the capacities required for the service provision.

### Renewable Energies Curtailment Treatment in Ireland

One of the important pieces of legislation that is noticed by the TSOs in the whole island is the European commission regulation for the curtailment. As is addressed in [114], member states must ensure that the required measures are taken for the minimization of the renewable energy resources curtailment. Based on this regulation the regulatory bodies should receive the reports from the responsible transmission system operators if the renewable energy resources are curtailed due to the security of supply. Conforming to this regulation, SONI and EirGrid publish comprehensive annual curtailment reports [45] and make outstanding progress to remove the barriers in order to achieve lower level of curtailment.

### Payment of the DS3 System Services

One of the discriminatory treatments that were criticized by the stakeholders and were modified by the regulatory bodies In Ireland was the payment of the system services based on the volume of the service that has been acutely provided [115]. In the mentioned arrangement, I-SEM registered synchronous generators that provide FFR, POR, SOR, TOR1, TOR2, RRS, and RRD were subjected to higher payments compared to the market or physical dispatch position. Where other technologies such as demand-side units, wind resources, and battery storage were paid based on the physical dispatch position. This treatment arises criticisms from the stakeholders because of the discriminatory preference for the synchronous generators and finally the issue has been resolved.

### Obligatory Zero Bidding in ex-ante Markets

Based on the trading and settlement code scheduling essentials attributed to the pumped and battery storage in [116], these families of storage units are classified as predictable price maker generation units in the market process that are allocated to have positive value for the market schedule while discharging and negative value for charging mode. However, it is clearly stated that for these technologies, price-quantity pairs in all cases must equal zero. In addition to the price-quantity pairs, BESSs should record some other information in the commercial offer data such as target charge level at the end of the trading day [116]. Market scheduling software takes this as a minimum constraint for the charging level that should be satisfied at the end of the trading day. These statements show that BESSs will be scheduled by the electricity market software.

Looking at this issue more deeply, we encounter a family of market players who will be scheduled (negative for charging or positive for discharging), but they are not able to submit non-zero price-quantity pairs. It means that the scheduling of these families has no direct cost impact on the objective function of the market scheduling optimization problem. The indirect effects on the objective function total cost come from the power balance constraint which necessitates that the exported power by these families should be generated by a counterpart that submitted non-zero price quantity pairs for its generation and this affects the objective function total costs. A similar explanation is applicable for the discharging mode since the imported power should be consumed by a supplier and the suppliers’ offer will affect the objective function costs. Based on this manner, the energy storage units are treated as cost-neutral dispatchable units (since their price-quantities are zero) and their generation/consumption capacity will be deployed only for managing the power mismatches caused by the interactions of the constraints and biding strategies of the other market players. This is obvious that this manner prevents the energy storages from gaining the maximum arbitrage profits in the ex-ante markets and in contrast to the classification, they are treated completely as price takers, because to function as a price maker, a participant should be able to submit non-zero bidding prices.

This treatment is not non-discriminatory as is required by the European-level legislation since all of the participants should have access to a level playing field in the electricity markets [117]. Obligatory zero bidding in the day-ahead market is not acceptable from the regulatory point of view since it may cause serious problems in the merit order of the participants and may increase the possibility of exercising market power for the competitors.

Obligatory zero bidding raises some conflicts with the current instructions published by SONI and EirGrid. For instance in a document [118] titled “Volume Capped: I-SEM Interactions for Battery Energy Storage Systems” it is stated that “In order to recharge, we would expect Providing Units to purchase energy through the normal market mechanisms, i.e. by bidding to purchase power in the ex-ante energy markets”. Although the submission of the target charge level at the end of the trading day (as obliged in the trading and settlement code [116]) may enable BESSs to be dispatched and achieve the desirable state of the charge, it will not be based on the bidding strategy of the BESS since they should have zero bids in the ex-ante markets. This is discriminatory since the battery storage may have some preferences regarding the time of charging based on the obligation that they confront. For instance, in the same document [118] it is stated that “If a Providing Unit recharges by completion of the first trading period ending 8 hours after a frequency event, it will not see a reduction in its Availability Performance Scalar for its unavailability during that 8- hour period.” Conforming to the expectations of the TSOs regarding the charging during the first trading period, the BESS should be able to submit non-zero bids in the ex-ante markets.

### Balancing Market and The Energy Storage Units In Ireland

Physical notification reflects the expected output of a participant in the balancing market that should be technically feasible as well. The physical notification conveys a power profile extended over a time period from the participant side to the TSOs. For instance, it consists of 1-minute intervals (or greater) time series with the corresponding power levels within an imbalance settlement period (30 minutes) in the balancing market. It should be based on the ex-ante market position of the intended generation unit [90]. In the Day-ahead market, the physical notification should be announced to the TSOs, 30 minutes after receiving the market outcomes and it consists of power profiles for each hour of the trading day. Balancing market participants are able to modify their physical notifications up until 1 hour before the start of each 30-minute imbalance settlement period in the balancing market.

Dispatchable generators must submit physical notifications, Technical Offer Data (TOD), and Commercial Offer Data (COD), as required by the balancing market [90]. TOD describes the physical characteristics of the generation units including information on the capacity, minimum power constraint, start-up, and shut-down relevant information, ramp up/down limits, and any energy limitation. The provided information is used by TSOs to decide on the dispatch instructions. Generators are able to update TODs for each imbalance settlement period but if no new submission has been made, the TSO uses the available standing data. The participants should submit their COD that reflects the costs at which the generators are prepared to increase or decrease their output. If the physical notification of a certain generator is required to deviate in the balancing actions of the TSOs, the TSO dispatches the corresponding bids/offers to increase/decrease generation/demand to preserve the power system balance and the security margins.

Although the battery storage units with more than 1 MW/5 MW in EirGrid/SONI jurisdiction areas are recognized as dispatchable units [111], it is admitted by TSOs that the physical notification position of the battery storage should be zero prior to entering the balancing market [[4]](#footnote-5) [118]. Whereas, as a providing unit, the energy storage units are expected to bid into the balancing market to meet the trading and settlement code obligations, in the scheduling software they will be treated in a manner that guarantees no different consumption/ generation schedule in comparison to the submitted physical notification irrespective to their bids (it is called Follow PN rule). Considering the follow PN rule, the allocated power for generation/consumption will be zero for the BESS in the balancing market similar to the day-ahead market outputs if they submitted a zero physical notification. This treatment may affect the efficiency of the schedule given to the BESS in the balancing market.

To make the whole contracted services capacity available, the dispatch of the energy storage units would not be based on an economical ground and it will be triggered manually by the system controllers [118]. Although at the national level, this treatment sounds reasonable since battery storage that has been contracted for all of its available capacity for procuring the reserve requirement of the power system through the DS3 program, it will cease the utilization of the BESSs to actively participate in the electricity market and earn benefit from the arbitrage. To conform with the European level legislation, that addresses the efficient dispatch and re-dispatch of the energy storage unit should only be subjected to the technical feasibility [117], the energy storage units should have the capability to actively participate in the electricity markets.

Obligatory zero bidding applied to the energy storage technology is not only a discriminatory treatment but also could cause serious market distortion considering that the energy storage capacity is expanding.

### Following the Discharging Dispatch Orders by the Battery Storage and the Charging Mechanism

Based on the Battery ESPS Grid Code Implementation Note published by TSOs [111], the BESSs having a registered capacity greater than 1 MW/ 5 MW must be controllable and dispatchable in the EirGrid/SONI jurisdiction area respectively. The charge controller of the battery storage unit should be capable of adjusting the MW import/export of the unit based on two inputs:

* A MW set point dictated by TSOs via SCADA.
* A set point determined by the unit operator, following receipt of a dispatch instruction via electronic dispatch instruction logger

Respecting to this instruction, the aggregative operation of the battery storage units necessitates that the aggregator have access to the electronic dispatch instruction logger to be able to manage the BESSs under its supervision.

There is currently a MW level of pre-agreed charging that is acceptable as instructed by the TSOs via electronic dispatch instruction logger. The battery unit can charge from zero MW to a maximum range as defined by the following instruction: *The minimum of the following values 1) 5MW, 20% of maximum export capacity 3) the maximum import capacity.* The charging level outside this range should be explicitly instructed by the TSOs.

As is addressed by [118] a battery storage unit should be recharged within the trading period starting after the frequency event and lasting until 8 hours. In this case, the battery storage unit will not be subjected to the availability performance scalar reduction that reduces the payments to the intended unit in the 8- hour trading period. To be able to recharge, the battery storage unit must purchase the energy by bidding in the ex-ante energy markets. The negative schedule should be announced to the TSOs by submitting a negative physical notification. If the TSO has not encountered security issues in the effective period of the negative physical notification for that unit, there will be no reduction on the performance availability scalar for the intended storage unit. This is a regulatory conflict that has been mentioned in section ‎4.10.10 since a BESS should submit zero price-quantity pairs as is required by the trading and settlement code [116]. The BESSs are obliged to be recharged within 8 hours (the ending time of the trading period that contains the frequency event) while they are not able to affect their charging duration by adopting a proper bidding strategy in the ex-ante markets.

It is remarkable that based on the pre-agreed charging instruction, a BESS is able to import at most 5 MW of energy without being instructed. Considering the limited available capacity of the BESS (for instance the Kilroot BESS with 5 MWh energy capacity), this instruction may be reasonable but considering the new capacities that have been energized during 2021 (for instance, Lumcloon units with 100 MW power capacity), these instructions should be reviewed. This report is not taking a position to recommend enabling the BESS to draw hundreds of MWs from the network without being instructed but the instructions should be cleared and applicable for all the existing BESSs and those that will be energized in near future.

Because of the aging and cycling issues associated with battery storage units, it is accepted by the TSOs that battery storage must not be dispatched more than 10 times per year excluding the dispatches that occurred in response to the frequency events and the discharging period length will not be longer that 20 minutes after the event. When a battery storage unit conforms to the expectations of the TSO and because of that request, the realized output power diverges from its physical notification, the providing unit will be paid based on its biding prices at the balancing market [118]. This mechanism works only for dispatches resulting in longer than 20 minutes of discharging. It is stated in [118] that if the energy storage unit removes the 10 times dispatch limit from their contract they will be treated like any other service providers in the market and the follow PN rule will not be implemented anymore.

### Constraint Payment

In case of a difference between the dispatching orders and the electricity market schedule, compensative payments will be made to the affected units. These payments are made regardless of the causes of difference and are called constraint payments [116]. The first problem that arises here is that since the storage units (pumped storage or batteries) offering prices is equal to zero, there is no reference price to calculate the required difference for the constraint payment to these technologies. This issue is addressed in [98] and the system marginal price in the intended trading period will be considered as the dispatch offered price of these technologies. Regardless of this statement in the day-ahead market regulation, it is clearly stated that: “There shall be no Constraint Payments in respect of Pumped Storage Units or Battery Storage Units” which reflect an unfairly discriminatory manner dealing with different technologies in the electricity market. A simple example could shed a light on this issue. This is due in no small part because of the zero physical notification and the follow PN rule resulted from 10 times dispatch limitation per year.

Based on the experiences that a conventional generator has in hand for participating in the electricity market, it may recognize the tight situation in the power system and could offer very high prices in the day-ahead market. As a result, it will not be scheduled in the day-ahead market (in extreme conditions). But because of the power system requirements, it could be dispatched and receive the constraint payment with its own offered price which could be very higher than the system marginal cost [116].

A question arises here about the treatment with recharging energy storage having a negative physical notification while a frequency deviation occurs and the storage unit should respond automatically to the frequency deviation based on its defined response characteristic determined in Schedule 9 of its contract.

### Side Payments to the Conventional Generation Plants

“The Market Operator shall procure that, the System Marginal Price shall allow the recovery of the Start-Up Costs and No-Load Costs of Price Maker Generator Units. Each Price Maker Generator Unit shall recover the Start-Up Costs and No-Load Costs that it incurred in each Contiguous Operation Period. However, System Marginal Price will not necessarily allow for the recovery of all of the running costs incurred by scheduled Generator Units in all circumstances”. This statement picked from the trading and settlement code of the SEM [116], is addressing a very important market design issue in the electricity markets adopting a uniform price clearing mechanism. Make a whole payment, uplift payment, and start-up/shutdown cost recovery payments are different terminologies that address the same problem in the electricity markets [119]. The minimum power constraint of the conventional generation units along with the associated start-up costs imposes the presence of the integer variables in the electricity market scheduling optimization problem. As a result, the nodal-pricing mechanism (locational marginal price) which is also adopted in the Pan-European electricity market suffers from cost recovery issues. In other words, based on the adopted pricing mechanism, the cost of the producers may not be recovered and side payments are required as a compensatory measure. Therefore, an inherent specification of a certain technology, along with the market design issues, cause to adopt side payments in favor of a certain technology in the electricity markets. Energy storage units have no start-up shutdown cost but the deep charge and discharge cause serious aging problems. Keeping the side payments that are already existing in the electricity markets for the conventional generation fleet, it will not be a mind-breaking theoretical market design failure to treat the energy storage in a manner that could survive in their transition phase from developing technology to a mature tool in power system operation.

### Energy Storage Definition

Energy storage units are defined in the DS3 System Services Protocol as a function that captures energy for the purposes of consumption at a later time [110].

### DS3 Program

As is comprehensively explained in section ‎4.6, the DS3 program was designed to enable the Ireland power system to accommodate the high renewable penetration levels until 2020 with two possible 18-month extensions. Sine 1 May 2018, the volume-uncapped arrangement has awarded contracts to the service providers. Procurement has been made through phase 1, phase 2, and gate 1 to gate 4b openings. Based on the term and conditions of the DS3 contracts for the volume uncapped arrangement [112], the awarded contracts continue to be effective until 30 April 2023. In the new openings (every six months), the new entries are allowed while the previously contracted service providers have the right to amend the contracted volume.

The volume capped arrangement underpinning the high availability technologies such as battery storage units leads to an auction on 1th October 2019. Among eighteen potential service providers that participated in the auction, three service providers were contracted (110 MW of battery storage units in total [89]). The volume-capped arrangement was a fixed price long-term contract securing certainty of revenue stream for the service providers.

The investors and the supporting stakeholders such as banks require certain revenue streams to evaluate the financial profitability of the project. The budget cap determined by the regulatory bodies imposes uncertainty on the regulated tariffs of the volume-uncapped arrangement [113]. Therefore, the volume uncapped arrangement cannot provide sufficient certainty for the investors. The volume-capped auction has also been held just for one time. The capacity market is not attractive for the BESSs as is explained in section ‎4.10.3. The lack of revenue stream certainty may affect the long-term required incentives for the investors to support the battery storage expansion in Ireland. By deploying the most competitive and efficient market design schemes, the ancillary services markets will be a single buyer market and have to be regulated. In this condition, underpinning energy storage projects solely through the ancillary service market may not be able to provide the required incentives for the investors. Multiple revenue streams are required to provide sufficient economic signals for the investors.

### Transmission Network Charges

Transmission revenue requirements are determined annually by CRU based on a tariff scheme. The allowed revenue requirements fall into two main categories, namely, System Services” costs and “Network Costs” that contributed to 40% and 60% of the collectable revenues in 2020/21 tariff year [120]. 100% of the system service cost is charged to the demand side based on their energy usage. The network cost, itself is divided into two different categories, namely, Demand Transmission Use of the System (DTUoS) and Generation Transmission Use of the System (GTUoS) contributing to 75% and 25% of the total collectable revenues from the network costs in 2020/21 tariff year. Before October 2020, the energy storage units were subjected to pay the transmission network charges as a demand and as a generator. This treatment was on the ground that the storage units in the charging mode were classified as demand and should pay the DTUoS charges proportional to their maximum import capacity and while discharging they were treated as generator and should pay the GTUoS charges proportional to their maximum export capacity [37]. It was on 29th September 2020 that the commission for regulation of utilities published its interim decision on the regulation of transmission charges that should be paid by the energy storage units [121]. Initially, three options were proposed and assessed by the commission to deal with the network charging issues of the energy storage units.

* Charging only DTUoS to the storage units
* Charging only GTUoS to the storage unit
* Treating with the storage units similar to the auto producers that pay one of either GTUoS/DTUoS charges based on which is the larger of their Maximum Import Capacity (MIC) or Maximum Export Capacity (MEC).

Based on the assessment, consulting with the TSOs, and considering the comments of the stakeholders, the CRU ceased the doubly charged regime of the storage units and decide to apply the DTUoS charges to the energy storage unit as an interim solution. It is remarkable that the structure of the GTUoS tariff, and the balance between GTUoS and DTUoS, are determined by the SEM [120]. The proposed interim solution commenced being effective from 1th October 2020 until a tariff review will be taken place in 2021 and adjust the charging mechanism that reflects the transmission system costs and the technical specifications. In October 2021, CRU published a report addressing that in spite of the game-changing modifications that have been occurring in the electricity system, the network tariff in Ireland has remained unchanged (no major change) since 2000 [120]. Publishing this report could be taken as a program led by CRU to adopt the necessary changes in the network tariffs conforming with the new challenges the current power system faces with.  The game-changing modifications addressed by the CRU are as follows [120]:

* A generation system is emerging at the distribution level (household and communities micro-generation)
* Smart metering the dynamic prices and tariffs
* Demand response
* Increasing penetration of the electric vehicles, energy storage and heat pumps.

Although the energy storage facility has only been mentioned directly in one of the intended changes, the role of energy storage is fully addressed in all other changes noticed by CRU. The mentioned report aimed to focus on the reviewing of the structure of the tariffs intended to recover the network cost associated with the development, operation, and maintenance of network infrastructure in Ireland. Other collectable revenues covering the losses, connection costs, and non-network costs (for instance interconnector services and I-SEM project associated costs) were outside the scope of the review [120]. On the ground of this statement, CRU aimed to review the tariff structure only for the DTUoS at the transmission level. As is addressed in Table 1, transmission system upgrade deferral and transmission congestion relief are the services that could be delivered by the energy storage. This may affect the costs attributed to the transmission system operation and maintenance. In addition to the operation and maintenance cost of the transmission system, it is recommended that the costs associated with the losses should also be reviewed and the value of energy storage on the transmission/distribution loss reduction should be recognized by the regulatory bodies.

### Distribution Network Charges

Allowed revenue requirements associated with the distribution use of the system (DUoS) are determined by the CRU [122] and include a day/night rate[[5]](#footnote-6) [122]. 67% of the collectable revenues come from the consumption charges (€/kWh), while 23% will be covered by the standing charges (collectable €/customer) and the remaining 9% are obtainable from the capacity charges (€/ kVA of maximum import Capacity/year). It is remarkable that DUoS contributes to 25% of the customer’s bill [122].

At the first glance, the biggest part of the cost associated with the distribution companies is recovered by the consumption charge. Based on the global trend, emerging the prosumers [123], the philosophy of the active distribution networks, the future of peer to peer trading environment [124], and the concept of blockchain in the energy network [125], in which the energy storage units are the cornerstone of all of this revolution, the distribution companies will not be the main electricity supplier at the distribution level. In the implied era, the increased amount of self-sufficiency will lead to reduced revenue from the consumption charges, while the cost of operation and maintenance for the distribution grid may be increased due to age and deterioration. The increased cost should be allocated to the lower number of end-users that are not in a promising level of self-sufficiency, which means an increased charge of electricity from the utility side per existing customer. This will also give strong incentives for the reaming classic consumers to proceed to be prosumers or active consumers instead. Although this is a long-term overview of the electricity distribution network's role in the future power system, the policymakers should start continuous movements from now on to define the role of distribution companies, preserve their financial viability, and guarantee the required development in the distribution sector.

### Connection Issues

Grid connection policy is a major factor affecting the energy storage project expansion because this is the only way of accessing the market by the energy storage units. In addition, the level of competition, the generation mix, and the procurement of the required services supporting the carbon-free energy sector is affected by the grid connection policy. Based on the electricity act 1999, CRU may give direction to the distribution and system operator on the terms and conditions of the grid connection process. It was in 2018 that the CRU published the Enduring Connection Policy – Stage 1 [126], in which 400 MW out of 1000 MW 2018 batch was reserved for the DS3 service providers. In addition, the DS3 service providers that were mainly new technologies such as battery storage units were exempted from providing planning permission to apply for the grid connection. Based on the recent update (ECP-2) issued by CRU on 1th July 2021 [127], 115 connection offers were considered to be awarded. 85 connections will be offered to generation, storage, and other system service providers with more than 500 kW of maximum export capacity. 25 first largest renewable energy generation will be prioritized followed by the remaining part based on the planning permission grant date. It is remarkable that no more than 10 primarily storage and other system service providers could be granted in ECP-2. By primarily storage units the projects are addressed in which more than 50% of the maximum export, capacity is constituted by the energy storage. As is mentioned in ‎4.3, in 2021, more than 1400 MW of battery storage were in the planning permission phase, around 150 MW, in the pre-application phase, more than 300 MW submitted their application, more than 200 MW have also received their grid connection approval [54]. Considering these statistics published by unofficial bodies, it may be reasonable that CRU determines a cap (at most 10 connections offer) for the number of the projects with primarily storage and other system service technologies in each batch. It is stated in [126] that based on the CRU’s understanding, most of the storage projects with planning permission in hand gained that permission since 2017, and not limiting the number of such projects for the grid connection phase, would be an unnecessary prioritization of these projects.

### Aggregation of the BESSs

ESB provides an option for large electricity users to install BESSs. Based on the information provided on the ESB website [128], the scheme enables the users to store energy at the low tariff hours and consume the stored energy at the high tariff hours. This scheme reduces the energy cost, provides backup power in case of power supply interruption, and provided launching the Integrated Electricity Market in Ireland, enables the users to access to additional revenue stream by procuring demand response services. The optimum sizing of the battery storage will be done by the ESB and they will fund the battery costs therefore there is no need for any upfront investment by the customer. ESB estimates the required storage capacity, that enables us to store an average required energy in the all-island single electricity market in a sunny/windy day and inject it back to the network for PV and wind power energy shortfall, which would be equivalent to approximately 60 times the capacity of Turlough Hill pumped-storage hydropower plant [129].

Demand side management is defined as the electricity end-users that are capable to modify their usage from their current consumption (or normal consumption pattern). In addition to individuals (large electricity users that participate in the schemes operated by EirGrid[[6]](#footnote-7) for demand side management), participation of the medium and large end-users is possible via Demand Side Units or Aggregated Units in the demand side management [130]. One or more demand sites, that are able to reduce their demand within one hour of receiving the dispatch instructions from EirGrid or SONI and sustained at the reduced demand for two hours, are called DSUs. DSU is usually a third party that manage a number of demand sites and acts as an aggregator who receives the instructions at an aggregated level from the SONI and EirGrid, and coordinates the amount of instructed reduction in its demand sites. Storage technologies, on-site generation units, and shutdown of the industrial plant could be deployed to implement the required demand reduction. Aggregated Generation units is similar to a demand side unit but it consists of on-site generation units (fossil-fuel based generation [131]).

In EirGrid published document AGUs mentioned in adjacent of (fossil-fuel based generation) phrase [131]. To understand whether or not a battery storage unit could be aggregated under the definition of aggregated generating unit, some definitions should be reviewed.

**Aggregated Generator** [132]: “a collection of generators located at different generation sites each with a capacity of no greater than 10MW and which together comprise an aggregated generating unit within the meaning of the applicable Grid Code.”

**Aggregated Generating Unit** [132]**:** “An aggregated generator registered by a party in compliance with any of the relevant provisions of the applicable grid code.”

**Generator** [132]**: “**means a power plant or any similar apparatus that generates electricity (including all related equipment essential to its functioning as a single entity) with capabilities for delivering energy to the Transmission System or Distribution System and which is Connected to the Transmission System or Distribution System.”

**Generator Unit** [132]**:** “means one or more Generators, other item of Dispatchable plant or a notional unit registered as a Generator Unit under this Code. For the purposes of the Code a Generator Unit may be any one of the following types:

(a) physical: Aggregated Generator Unit, Demand Side Unit, Energy Limited Generator Unit, Hydro-electric Generator Unit, Pumped Storage Unit, Battery Storage Unit, Trading Unit, Wind Power Unit or Dual Rated Generator Unit;

(b) notional: Assetless Unit, which includes a unit registered by a SEM NEMO or a Shipping Agent under section B.8, an Interconnector Error Unit or Interconnector Residual Capacity Unit.”

Based on the definition of generator units, if a battery storage unit is registered as a generation unit, it could be aggregated under the definition of aggregated generating units. Considering the single electricity market decision, demand side units, aggregated generation units, and assetless supplier units can functions as aggregators in the SEM and there is no need to introduce an specific definition for the aggregators in the SEM [91].

Although in the EirGrid published document, the residual demand side unit has been mentioned [131], there is no official definition presented in the glossary document published by single electricity market [132]. It should be mentioned that the residential demand site units are not validated as a proven technology to procure services defined under DS3 program.

### Public Service Obligation

The PSO (Public Service Obligation) levy is mandated by the Government of Ireland and finally approved by the European Commission at the European Level. This levy will be charged to all electricity end-users in Ireland and the resulting monetary resources will support the electricity generation deploying the renewable energy resources. It was in 2019 that the CRU published an information paper clarifying the treatment with energy storage associated with the PSO levy payment [133]. Based on the current regulation, since a portion of the energy stored by the energy storage unit will be later injected into the electricity network and consumed by an end-user, the energy storage will be subjected to the PSO levy only for the portion of the energy that is consumed on-site which is called house load energy.

### Social Issues

Li-Ion batteries are the pioneering technology from the global share of installation point of view [21]. Thermal runaway of lithium-ion batteries, gas generation (mainly H2), and cell overpressurization lead to venting or rupturing the battery are the malfunctions reported for this family of batteries [134]. Although safety measures, such as shutdown additives, current cut-off tools, and separator materials, are taken in the structure of the Li-ion batteries, fires with the origination of primary lithium cells and lithium-ion batteries have been frequent happened [135].

Behind the meter batteries are one of the strategic technology that is expanding fast globally. Lack of information addressing the financial benefits of this technology for the household may have negative effects on the public acceptance of this technology. Self-consumption versus feeding the network option for the households owning rooftop PVs coupled with batteries should be clearly demonstrated for the society.

Automotive companies compare hybrid or full-electric vehicles with the fossil fuel-dependent option in terms of the fuel cost benefits. But for a household, just the fuel cost benefits may not be satisfactory. A clear vision of the time that should be spent on the charging station, the average time of access to the charging station in comparison to the conventional fuel stations, the average increase in the electricity bill for those who use home chargers, the average life cycle of the batteries in use and the cost and options of the replacement, are some other aspects that need to be demonstrated by the stake holders to increase the social acceptance of the EVs.

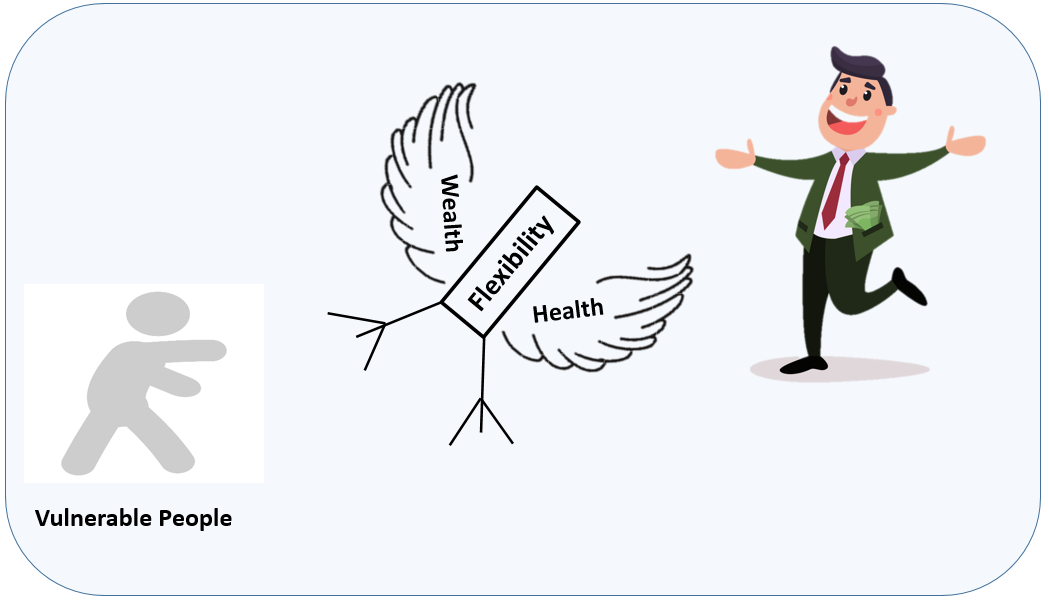


Figure Social Impact of inappropriate policies for supporting the BESSs

It should be noted by policymakers that to be flexible is tangled with wealth and health (see Figure 18). Time of use is one of the mechanisms that push the electricity end-users to be more flexible and provide a fertilized environment for the growth of residential BESSs. They can reduce the bill cost without affecting the pattern of demand at a household level. Instead of consumption time-shifting obligation for the householders, the battery could be charged in low price periods and discharged in the high price periods and reduce the negative impact of modified consumption behavior to the minimum level. However, this only enables the householders that can afford to have a BESS or an electric vehicle. So being flexible requires the wealth to be able to afford the flexibility requirement costs. Researches show that vulnerable occupants such as elders, families with young children and babies, patients who require constant heat and electricity-consuming medical care devices, could be hit by inappropriate designing of flexibility incentivizing mechanism [136]. Time of use could have an increasing effect on the request of medical attention related to heating for the low-income and other vulnerable consumers. Inappropriate policy makings may offset the benefits resulting from the deployment of renewable energies and the BESSs development to the rich peoples and have a negative impact on the quality of life for the vulnerable electricity end-users.

### Interconnections

As is addressed in section ‎4.4, in the future power system of Ireland, the interconnections have a vital role from the technical aspects, as well as they, bring up economic opportunities via the pan-European electricity markets [37]. It should be noted that due to the existing correlation between the wind regime in the whole Island and UK, the exporting of the excess wind energy to the GB might not be a promising option to manage the wind curtailment. Moreover, the international power transactions are subject to the prices obtained in the wholesale market. Considering the performance of the battery storage units, since the interconnectors can provide non-or partially regulating reserve (see section ‎4.5.5) and are able to participate in the capacity auctions, it deserves attention from the policymakers that the competition between the interconnectors and BESSs do not function as a barrier to the BESS deployment.

### Micro & small Generation Supporting Scheme

Similar to supporting schemes that are performed in Germany to promote the roof-top PV – BESS couples in the residential and industrial areas (it will be addressed in section ‎6.2.5), the government in Ireland decides to kick off the renewable-based energy generation by the electricity end-users. This is not only in line with the European level legislation [40], but also reduces the dependency of electricity on the political, social, and economical challenges that the government may face if the centralized generation remains the major source of supplying the energy demand.

So far, the Sustainable Energy Authority of Ireland (SEAI) has implemented various supporting schemes for the solar PVs – BESS projects. The scheme for the support of roof-top Solar Photovoltaic (PV) panels [137], enables the homeowners to install solar PVs and battery energy storage equipment. For the projects up to 2 kW, € 900 per Kw, € 300 for every additional kW up to 4 kW plus € 600 for installing the battery energy storage will be granted under this scheme. Better Energy Communities is another scheme stimulating the collaboration of different demand sectors such as public and private, or residential and non-residential sectors and provide funding levels up to 80% for fuel-poor private homes, 35% for non-fuel poor homes, and even up to 35% for private rented homes [138]. Other supporting schemes such as tax based incentives, VAT refund for purchasing the micro-generation equipment, and dedicated schemes for farm enterprises are also available for the eligible applicants [139].

Renewable directive II [40] entitled the renewable self-consumers to be remunerated for the excess energy that they may export to the grid. As is addressed in section ‎4.1, promoting the distributed generation under the micro-generation supporting scheme will lead to 260 MW renewable expansion at the low-voltage distribution level by 2030 in Ireland [41]. The micro-generation scheme will cover the generation units up to 50 kW that are connected to the low voltage distribution system. In addition, a small-scale generator support scheme will also be introduced for the farmers, and commercial consumers, enabling them to generate their own electricity and feed the extra energy to the grid. Community-based renewables account for at least 500 MW of supply by 2030 in Ireland. The small-generator supporting scheme will cover the generators with capacities above 50 kW and will not overlap the coverage domain of the renewable energy supporting schemes 1 and 2. The small-scale generator supporting scheme will be initiated in 2022 and will be available in 2023 [139]. Both of these schemes were committed in the climate action plan 2019 [44].

Addressing the identified challenges of micro-generation, the Department of Environment, Climate, and Communication (DECC) published a public consultation document on the micro-generation supporting scheme in January 2021 [140]. The main objective of the micro generation supporting scheme was to support the citizen to get access to the electricity markets, and enable the electricity end-users and communities to become active consumers, generate electricity, and be paid based on a fair price. The micro-generation supporting scheme has been approved by the government in December 2021 and the final design will be published in 2022 [139]. Leveraging the residential renewable- BESS projects under the micro-generation supporting scheme in 2022, it will replace the SEAI’s scheme for support of roof-top Solar Photovoltaic (PV) panels [137].

Based on the available data on the micro-generation supporting scheme, the clean export guarantee option has been adopted [139], among the other available options such as feed-in-tariff, feed-in-premium, investment subsidies or grants, and renewable obligation certificates [140]. The key futures of the scheme are as follows:

* A grant for the cost of installing equipment by sustainable energy authority of Ireland
* A clean export premium tariff for installed capacity between 6kW and 50kW based on a 15 years fixed rate while the payments will be limited to 80 % of the installed capacity to encourage the self-consumption.

### Other Aspects

In [37] the outlook of energy storage in Ireland has been implied by three main categories, namely, short term, medium-term and long term. In the short term, the gird services have been addressed which could be procured by Li-ion battery units but the issue of cycling and aging may put limits on the potential of the battery storage system to discharge for longer than 4 hours duration.

In the medium-term outlook, energy time-shift, arbitrage, and transmission/distribution system upgrade deferral, and behind the meter storage units have been addressed in [37]. The energy time-shift application needs the multi-hour capacity of battery storage as the primary infrastructure. To gain the maximum technical/ economic profit from this application, first, a reasonable difference between peak-low electricity prices should exist. The increasing penetration of renewables facilities that lower the electricity price in windy hours correlated with the low demand for instance in night overs during the winter. Although the redemption of dependencies on the expensive fossil-fuel burning peaking units, will decrease the electricity price for the consumers, it should be noted that the arbitrage opportunity, is one of the relying revenue streams for the energy storage units that should be taken into account by the policymakers. Utilizing energy storage in the high-density demand areas such as Dublin may mitigate the need for transmission/distribution system upgrade [37] and behind the meter battery storage unit could increase the utility of the existing transmission/distribution grid.

At the long term overview, [37] addressed the requirement of a high renewable penetrated power system to be integrated with long-duration energy storage technology such as pumped storage hydropower plant, compressed air energy storage, liquid air energy storage, and etc. Lack of the geographical requirements for this family of storage and the high capital costs associated with this project, [37] believed that they could not offer a sustainable solution to the energy storage requirement in Ireland. Hydrogen energy storage is proposed as an alternative to this family of energy storage units for Ireland.

Co-located battery storages are the most imperative solution to the SNSP problem in Ireland. Co-located storage units could absorb the excess energy at the point of generation and impose no additional burden on the grid. However, a number of regulatory barriers to co-locating energy storage with renewable energy generation projects are addressed by the existing reports. Dynamic sharing of maximum exporting capacity between units using the same grid connection could be a good example [37]. When the battery storage units were added to existing wind or solar farms, it is necessary to distinguish between the power injected by the renewable energy resources and the storage units enabling them to receive the relevant supporting remuneration subsidies. This in turn arises the sub-metering requirements for the co-located energy storage and renewable energy-based power generators.

# Energy Storage Value Streams/Benefits and Key Actors

## Benefits of the Battery Storages

### In the Generation Sector

In the generation sector, energy storage can provide multiple benefits related to diverse services in energy supply, ancillary services and renewable sources integration. More in general the energy storage can be used for the relaxation of system operating constraints (SOC) associated to the conventional generation units to maintain system stability and reliability of the power supply.

The storage offers a flexible means for energy supply (with zero-carbon emissions) especially when the demand is rapidly changing because so-called Peaker plants are either expensive or have a slow ramp-up. It can also be used in combination with power plants which have a costly down-ramping, such that they can ramp-down more slowly than the demand while the storage absorbs the excess of electricity generated. The electricity supply using storage may also defer the need for the construction of new conventional power plants therewith improving the environmental impact.

Energy storage can also be used to provide reserve services and frequency regulation at lower costs than conventional generation and with zero-carbon emissions and can respond to load variations.

The storage may be used for renewables integration because it can smooth out intermittent renewable sources (such as wind and solar) storing the excess energy not used for the load supply and releasing it when a renewable production lowers or a higher demand arises. It can also be used for energy consumption time shifting by storing and releasing energy such that the produced energy can be moved to a time-period to another, thereby providing more flexibility to the renewable generation.

Regarding SOCs relaxation, it is usually required that a minimum number of conventional generators are simultaneously online to maintain sufficient inertia for frequency regulation and reactive power supply. These SOCs also apply in Ireland where it is normally required to have 2/3 generation units always on in the Dublin area (day/night) and one generation unit always online in Northern Ireland. Moreover, additional generation units are required to be always online in the Republic of Ireland (five) and in Northern Ireland (three) to maintain system stability. SOCs can determine the curtailment of excess wind power. SOCs relaxation by requiring a lower minimum number of online generation units may potentially lead to a reduction of curtailed wind. In Ireland there is a potential of reducing curtailed wind from 8% to 4% by reducing conventional generation while maintaining system stability. When the SOC requiring two large generators in the Dublin area to be permanently online by day and three by night is relaxed, requiring only one by day and two by night, there is a total system cost reduction of 3.1%. Performed studies have considered the contribution of pumped-hydro-energy-storage. Availability of additional storage resources may contribute to convince the system operators that SOCs may be relaxed (thereby reducing the costs of energy supply by reducing the amount of wind curtailment even beyond the 4% in the energy mix), while maintaining reliability of energy supply [141]

Figure . Benefits of the battery storage systems in the generation sector

Battery storages system have abundant applications in the generation sector. We have classified the benefits of the battery storage systems in the generation sector into three main categories namely, the electricity supply, ancillary services, and the renewable energy integration. Although the categories may have some interdependencies, it will ease the understanding of the benefits associated with the deployment of battery energy storages in the generation sector.

### In the Transmission Sector

Figure . Benefits of the battery storage systems in the Transmission sector

Storage can provide multiple benefits to the transmission sector such as voltage support, enhanced grid operation and grid costs reduction (Figure 20).

Battery’s power electronics converter can provide fast and flexible voltage support and control services to mitigate voltage imbalances, improve the voltage profile, and correct power factors. It can support the increasing number of distributed energy resources better than traditional strategies being easier to coordinate and more scalable. Storage can also be used to improve the power quality mitigating voltage sags and swells as well as frequency transients and flicker; it can be used to improve the total harmonic distortion (THD).

Storage in the transmission sector can also help to integrate more renewable generation by making the renewable output more predictable and hereby simplifying the balancing of supply and demand. It can also relieve the congestion of transmission line which are operating very close to their thermal limits by injecting power downstream of the line to supply the power demanded by the loads. Following a similar approach, it can also defer upgrades of transmission capacity required by a growth in the energy demand by feeding the loads downstream of the undersized line. Finally, it can provide support to those transmission interconnections which are close to their end of life, to provide them a life-time extension.

BESSs have proven potential to provide various services after a major black-out and assist the power system controller to manage the system restoration process. Energy storage could provide the following services during the system restoration process [142]:

**Energizing the non-black-start generation fleet:**

From theoretical point of view, the energy stored in the BESS could be a promising energy source to energize the non-black start generation fleet that needs primary power supply to generate electric power. For these applications, additional parts are required to enable the battery storage unit to preserve the stability of frequency and voltage. In addition, combinatory use of renewable energy sources and BESSs could also provide a promising black start service for the power systems.

**Acting as a load:**

After a major black – out, large loads are disconnected from the system and there is a great potential for overvoltage in the transmission lines because of the limited amount of load available to be supplied. Battery energy storage. In such condition some transmission lines should be energized to supply the required start-up power for non-black start generation units. BESS could act as sufficient load to mitigate the capacitive current issues and the overvoltage problems for the transmission system during the system restoration process.

**Power Flow management:**

Since the topology of the system during the restoration process is changed, there may be uneven power flows across the power system. Optimised utilization of the BESS could be used as a tool to manage the uneven power flows in such condition.

**Provision of ancillary services:**

During the system restoration process, limited resources are available to provide the required system services. If BESSs could be deployed for the provision of the ancillary services in combination of the existing black-start generation fleet.

### In the Distribution Sector

The benefits achieved by the adoption of the storage in the distribution sector are similar to those related to the transmission sector (see Figure 21), and include: improved voltage and power-quality, utility system reliability, reduced power losses, and relieved distribution congestion. However, the scientific literature has highlighted the fact that connecting the storage in non-optimal locations of the distribution network can result in reduced benefits and network performances.

The capital cost of storage is an important factor to consider of when calculating the distribution grid's operating cost which depends on the payback period of the investment. On the other hand, the lifetime of the ESSs has a significant effect on the payback and it is determined by the number of cycles and the storage’s operating state-of-charge.

Figure . Benefits of the battery storage systems in the distribution sector

In the distribution sector (as well as in the demand-side sector) it is emerging the role of the aggregator which can coordinate a group of distributed ESS such that they can provide a power balancing service to the grid through joint charging or discharging of multiple storage units, to accommodate fluctuating renewables. Time-varying power imbalances and electricity prices can be included in control algorithms as well as finite battery size constraints, cost of using external energy sources, and battery life degradation.

The benefits of energy storage may be cumulated when the ESS is used to implement more than one service among those illustrated in Fig. 16 and the research is proposing new control algorithms, which can satisfactorily address multiple objectives. An open research problem is the joint optimization of storage self-charging and power balancing.

Optimal storage charge and discharge in distribution networks considers renewable sources, load fluctuations, and enables to achieve power losses reduction and peak demand mitigation while satisfying voltage limits.

Resembled to the other sectors, battery storage systems have a several applications in the distribution sector. We have classified the benefits of the battery storage systems in this sector into three main categories namely, the ancillary services by prosumers/aggregators, enhanced grid/network operation, and the electricity supply. Although the categories may have some interdependencies, it will ease the understanding of the benefits associated with the deployment of battery energy storages in the demand sector. Interdependencies may not be limited to the categories classified under this sector and some categories may implicates the applications in other sectors.

Benefits of the storage in the demand side sector (behind the meter) are mainly determined by services such are the time of use energy cost management, which enable to shift consumption considering the Time-of-Use (ToU) tariff by charging or discharging the storage. Furthermore, many of the current consumers will follow the pathway to become prosumers by installing renewable generation units (Fig. 18). Also in the case of prosumers, the storage will enable a better integration of renewable sources, for instance by maximizing the exploitation of the PV produced energy for own consumption and enabling the flexibility to provide services to other prosumers, such as the peer-to-peer energy trading and its emerging variants (prosumers to grid and organized groups of prosumers). New hybrid plants based on the integration of PV-panels and batteries will enable to optimize both energy consumption and energy purchase or sell to the grid, maximizing the benefits of both energy storage and PV generation.

Global attitude toward the deployment of renewable energy resources (23% of global electricity generation comes out of renewable energy resources in 2019 [143]), non-stop progress in the battery storage technology and their falling cost [144], recent progress in the smart meters [145], supports of the regulatory bodies and legislating favorable regulations [146], financial support of governmental bodies, and finally the social awareness of the citizens, altogether are implying a wide leap to the number of consumers, both in Europe and USA [147], that generate and/or store electricity at home using the solar panels coupled with battery storages or electric vehicles. Integration of residential batteries and the inclusion of electric vehicles bring customer benefits [148]. Although the car market experienced a 6% decline in 2020 due to the COVID 19, 3 million electric car has been sold in 2020 that manifest a 40% growth with respect to 2019 [149]. On-site or close to the customer distributed generation are encouraged by the utilities in USA [123], Germany, and Australia. As is lustrated in Figure 22, all of this indicators imply a reform on the demand-side of the electrical systems and in near futures, the consumers will be converted from a payer passive party to an active energy provider.

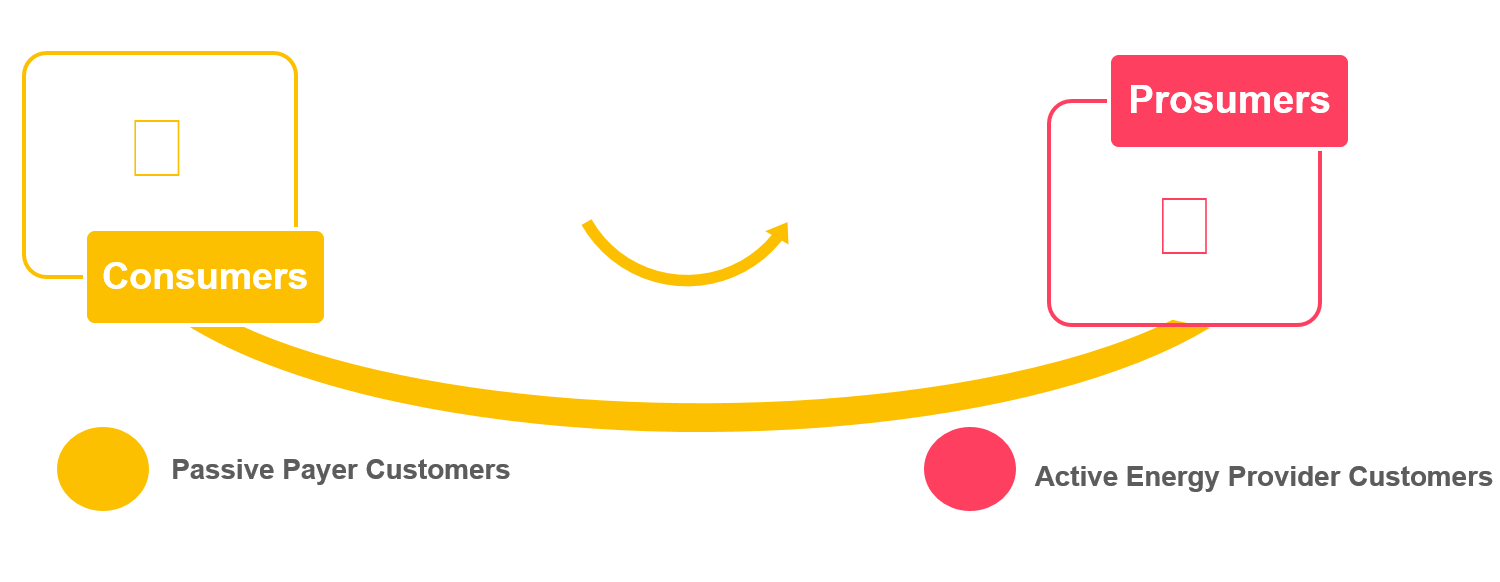


Figure . Moving toward prosumers

#### Data Centers & BESSs

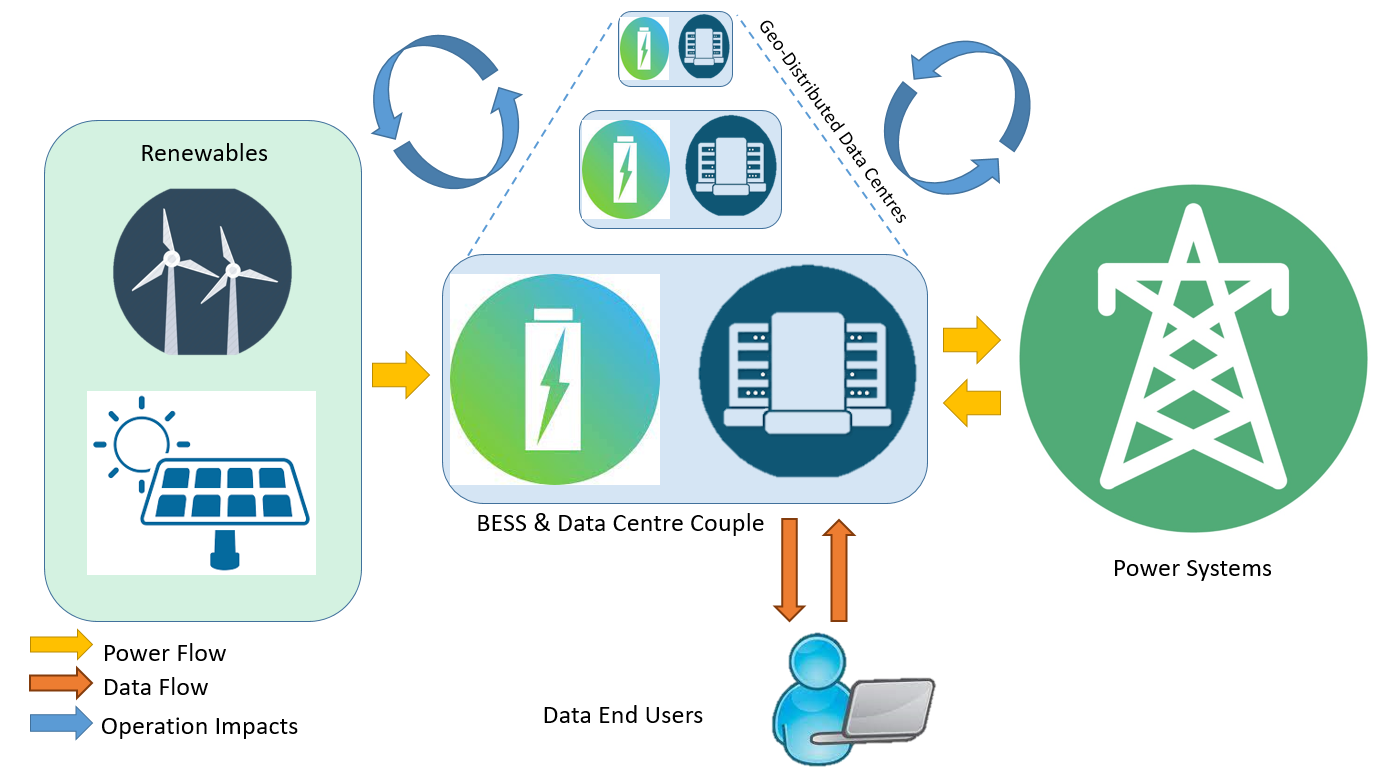


Figure . Data Centers, Renewables and Battery Storages

It is forecasted that the global electricity consumption of data centers make a leap forward until 2030 from its 2016 level (286 TWh) to 321 TWh [150]. Data centers are going to constitute a large part of demand in Ireland as well. Ireland acts as a hub for data centers hosting 70 data centers that are currently operating. One quarter of the all data centers in Europe are located in Dublin [151]. It is expected that 30% of the total electricity demand will come from the data centers by 2030 in Ireland. Based on the data provided in [42], the total electricity demand will be 56.6 TWh by 2030. Considering the realization of this scenario, the total demand of data center will achieve to 17 TWh in Ireland by 2030 which accounts for more than 20% of the total global consumption of the centers.

It is shown that, BESSs can have a proven effects on the cost minimization and energy management of the data centers [152]. Based on the maps published by SNOI and EirGrid in the “Shaping our Electricity Future” report, there are four main concentration points for the data center facilities by 2030 [42]. Two of these points are located near the Celtic and EWIC interconnectors. Beside the energy cost management issues, operation of the data centers could deeply affect power systems. Different computation request by end-users, impose different spatial electric demand in the geo-distributed data centers, which in turn affects the power flow, may arise voltage issues, and complicates the peak load problems [153]. Smoother load variation and reduced electricity costs for the data centers are addressed by [154] when considering the battery storage capabilities and the interaction of data centers with smart grids. Reduction of the grid losses could also be provided by the data centers coupled with battery storages [155]. The issue of placement planning for the data center has also been recently emerged in the research works [153, 156, 157]. For Ireland, the availability of high-speed fiber network to USA, and European countries, availability of large buildings in Dublin area, that are good fitted to host data centers, as well as the reliability of power supply, concentrate many data centers in Dublin area.

Figure 23 depicts the interaction of the data centers, renewable generation, and battery storage systems. Coordination of the data centers operation and the battery storage capabilities enables the data centers to provide grid services for the power system [158]. In the light of the aforementioned points, the issue of data centers and the coupled deployment with the battery storage in Ireland deserves the policy maker’s attention, especially, when we are going to feed a large number of data center in our future power system. Provision bi-directional data flows between coupled data center-battery storage systems along with the complementary function of the renewables provide a great potential for Ireland to manage the high demanding data centers as well as the provision of multiple revenue streams for the battery storage systems.

Feeding large electricity consumers like data centers could potentially provide a reasonable revenue stream for the battery storage units. In addition, adopting good policies can lead us to provide battery storage expansion incentives for the Data centers. It is remarkable that data centers as large electricity consumers could profoundly improve the SNSP level at a given time since it is proportional to the inverse of demand. As is explained in ‎4.5.4, constraints form the base part of the dispatch down volume and have a smooth trend during the 24 hours. However, the curtailment caused by SNSP level violation or minimum required conventional generation or high frequency problems, are an overnight problem in average[[7]](#footnote-8) [45]. Considering the coincidence of curtailment and high wind speeds during the night hours (0:00 to 8:00, and 22:00 to 23:00), data centers and the coupled battery storages have a good potential to mitigate the dispatch down problem. It could be simply managed by adjusting the consumption rates during this hours to provide enough incentives for this large consumers to shift their demand to night hours. Figure 24 schematically shows that how the coupled management of data centers as large electricity consumers with the battery storages could mitigate the dispatch-down problem.

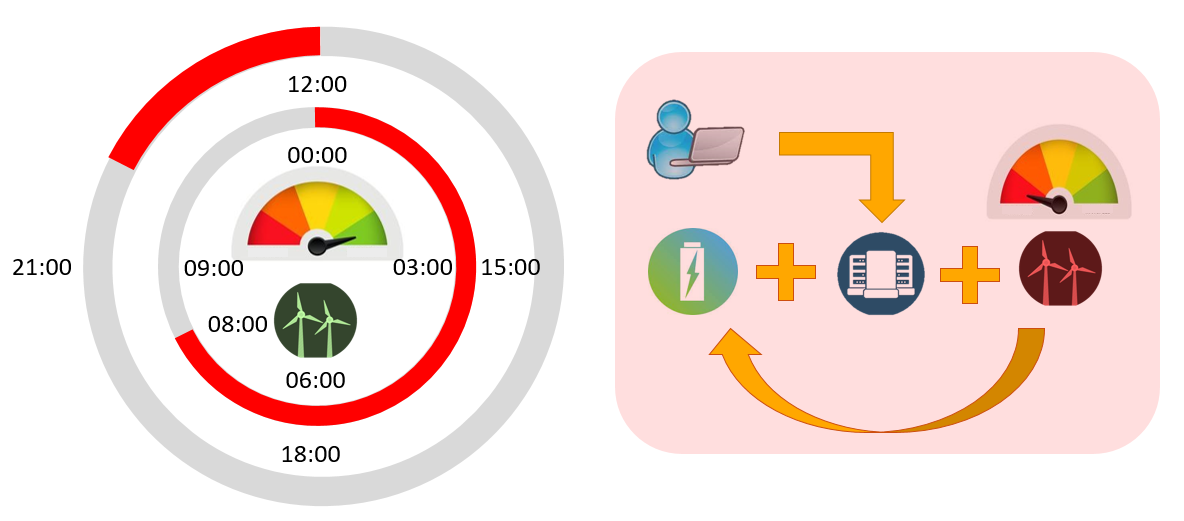


Figure . How Data Centers & Battery Storage can mitigate the Dispatch-down Problems?

### In the Regulatory Sector and Electricity Market Design

In the classic look into the electricity market design, the power system as a whole was integrated into a suite of constraints. The constraints associated with the security of the power system, continuity of the supply, stability and, controllability that normally classified as the transmission system constraints. Another suite of constraints was imposed by the technical and operational characteristics of the generation system. The demand side has no choice to incur the cost imposed by these constraints because it shows no elasticity with respect to the electricity price and has no other means of supplying the required electric power. These facts result in the classic way of wholesale electricity market design in which, an objective function (the social welfare) is maximized subject to the aforementioned suite of constrained (Figure 25). In this way of looking into the electricity market design, the constraint imposed by either the transmission system or the generation system fleet is considered as the playing field and all of the costs imposed by the constraints from these sectors should be beard by the demand sector and the electricity end-user.

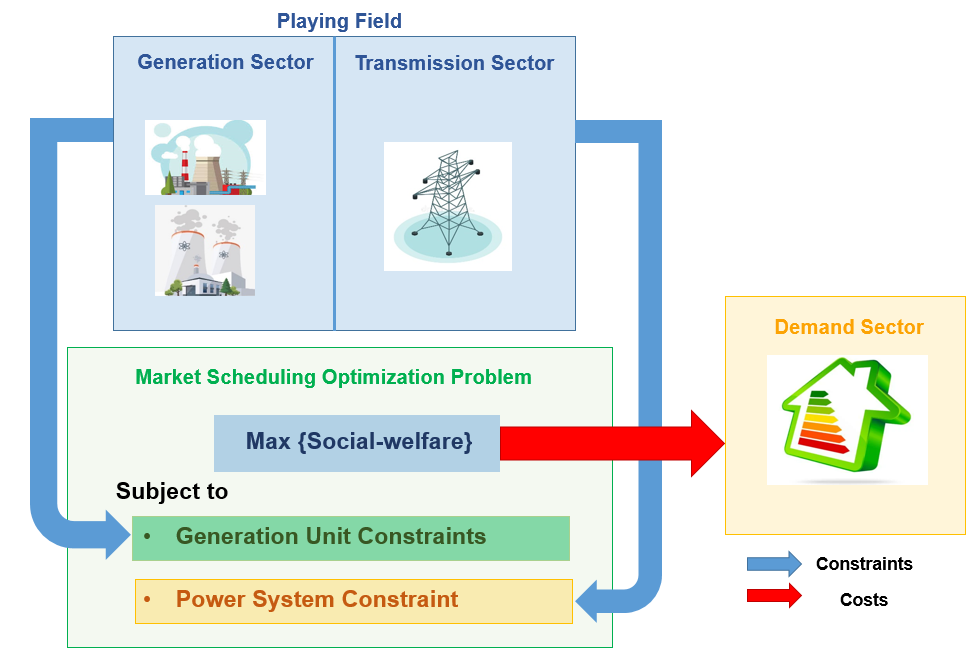


Figure . Classic wholesale standard electricity Market Design

Emerging the active consumers, the concept of prosumers, microgrid, and decentralized energy generation, peer to peer electricity market, distributed generation, demand response, active distribution networks, energy communities, and energy blockchain all are implying a new way of looking for policymakers and electricity market designers to the future of the power system. All of these evolutions are supported by the presence of energy storage in power systems. In this overview, the consumers are not price-inelastic importing-only players. They could actively be integrated into the power system, procure grid services, generate electricity, and have a level of self-sufficiency based on their own attitude. It is reasonable that such active consumers should not directly bear the costs imposed by the other sectors and their associated costs. The transmission system constraints should be satisfied and the associated costs are inevitable, for instance, the presence of a minimum number of conventional generation units in an operating mode in Ireland. But, the minimum power constraint that combines with this power system requirement is a technology-related constraint and the associated costs should not be directly beard by the demand sector. This idea draws a new look into the electricity market design and the definition of the playing field. On this ground, the playing field is the transmission system requirements to ensure the continuity of supply for the end-users, and prevent the negative effects of electric power supply interruption. In this era, the cost of the constraints imposed by the transmission system and the costs associated with the power system operation are acceptable to be paid by the end-users but the combinatory effect of the technology-related constraints such as minimum uptime, minimum downtime, minimum power, and ramp up/down rates will not be reasonable to be tolerated by the demand sector since there is enough capacity of the storage facility that could complementary relax the mentioned constraints.

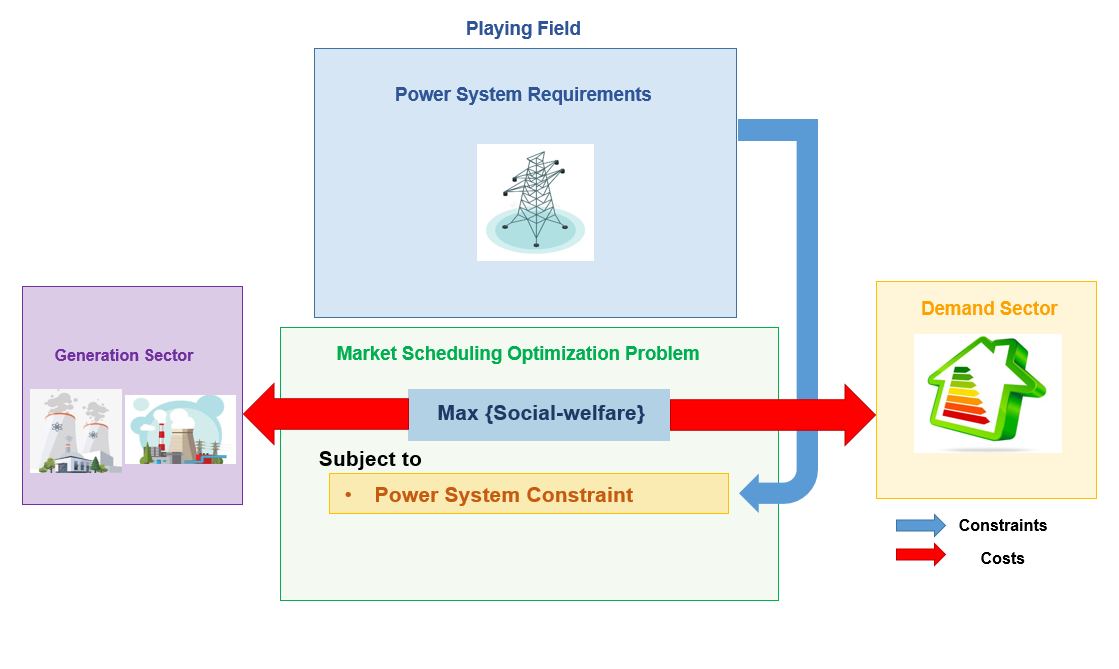


Figure . New definition of the playing field in the electricity market design

To mitigate the described problem, one option is that the Market operators drive the costs imposed by constraints associated with the generation sector. Although this scheme (Figure 24) could be implementable in the future, when there will be not necessary to integrate binary variables to drive an on-off implementable market schedule for the conventional generation fleet (ideally all of the constraints associated with the generation sector could be relaxed by the services provide by the energy storage units), in the current level of knowledge, there is not a strong mathematical method that could drive the shadow prices corresponding to integer-integrated constraints (such as minimum uptime) and treat them as the dual variables at the optimum solution point since the electricity market optimization problem is not a convex problem. A replacement to this scheme that could be achievable in near future with the presence of emerging technologies such as battery storage is the integration of the constraint-free conventional generation fleet into the electricity market. As is seen, the battery storage units as a representative of the energy storage technology are depicted in Figure 27 to sell constraint redemption services to the conventional generation fleet. As a result, the generation sector could be a constraint-free sector, imposing no additional cost to the electricity end-users and just submitting their price and quantity pairs into the electricity market.

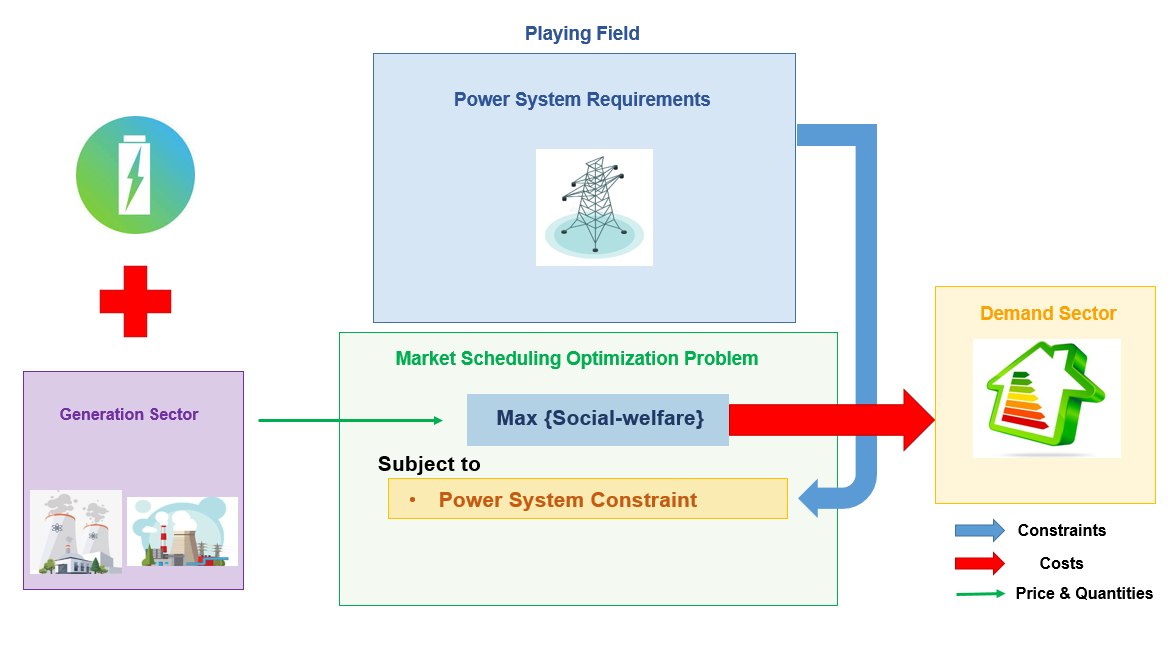


Figure . Constraint Redemption Service of the Energy Storage Units

**Constraint Redemption Arrangement:** Minimum power constraints of the conventional generation fleet not only is a source of economic distortion in the electricity markets, but also impose technical issues to the deployment of other technologies. A good example is happening in Ireland, the curtailment of the wind power resources, because the power system operation relies on the minimum number of conventional generation that should be kept in operating mode. It means, they must inject power at least at the minimum power constraint even if they are not at the top of the merit order list. Operation of the conventional generation plants at the minimum power means lower space for the renewable energies (or other technologies that have higher priority based on the merit order list) and the curtailment problem arises.

Other examples could also be mentioned in this regard. Although an optimization problem is solved to obtain the electricity market schedule, the constraints on each individual generation plant can impose additional cost to the objective function. For instance, one could consider the minimum up-time constraint of a typical conventional power plant. Whenever a conventional generation plant in the optimization process is awarded by a binary variable that is equal to one (corresponding to start-up of the unit), it should be remained on until the minimum up time of the generator will be satisfied. There is no doubt that if the constraints imposed by any technology to the electricity market scheduling optimization problem could be released, the final cost of the objective function could also be reduced. This means a reduced cost for the electricity end-users.

One of the fundamental characteristics of the model used in the European electricity market is its no-convexity. Most of the power exchanges accept multi-period energy products that are addressing the technical and operational characteristics of the bidders and allow them to internalize the variable and fixed costs in their offering strategy [159]. As a result, in the European electricity market scheduling optimization problem, the constraints associated with the generation plants are not directly modeled. This becomes possible by the bidding options given to the producers that are addressing the limitations associated with the conventional generation plant. The most common types of such bidding options are different kinds of block bidding such as parent-child blocks, energy flexible/inflexible block, and linked blocks that are having “fill-or-kill” nature and necessitates the use of binary variables for their explicit modeling. It is remarkable that internalizing the technical/operational characteristics in the bidding strategies does not mean the complete neutralization of imposing additional cost to the objective function. Therefore, regardless of the internalization of such constraints in the European electricity markets, the economic effects of the addressed constraints are not obliterated from the optimization problem and the associated costs are still incurred by the end users.

Innovative services such as minimum power constraint redemption could be delivered by the energy storage units coupling with the conventional generation plants. One solution to problems arising cue to the minimum power constraint is to use the consumption capacity of the energy storage to store the power generated by the must run units operating at the minimum power. This provides a redemption for the power system from the minimum power constraint of the conventional generation fleet. For the minimum up-time constraint example, one could think to deploy a storage facility to store the excess power injected by the conventional generation plant to satisfy its constraint once it is awarded the first integer representing its status to be on.

In the future power systems, the ***constraint redemption services*** could be procured by the energy storage units, to make a relief for the electricity market scheduling optimization problem from the imposed technical/operational costs associated with the technologies taking the role of producers. The more relaxed constraints, the more reduction on the objective function cost which in turn reduce the cost of electricity for the end-users.

In the meantime, regulatory bodies and policy makers are summoned to think about the economic and regulatory aspects of this proposition:

* Who should pay the additional costs imposed by the constraints associated with a specific technology to the electricity markets?
* What is the share of a constraint imposing technology on the system marginal cost and to what extent the system marginal cost is affected by technology specific constraint?
* Should a constraint imposer technology be paid by the system marginal cost for all of the power delivered to the system?
* How these additional cost enable the electricity market designer to devise new services deliverable by new technologies such as energy storage to make a relief from the technology specific constraints?

## Key Actors of the Energy Storages

The key actors of energy storages can provide different services based on storage which are incentivized or discouraged by multiple factors. They are summarized in table 5. Market drivers are the factors which will enable the storage to produce stable revenue streams. They will also determine the engagement of the various storage actors eventually fostering an even larger uptake of grid solutions based on energy storage. Improvements in storage technologies and the decrease of prices (mainly due to the scale economies achieved by electric vehicle manufacturers) are determining more installations of storage units and arousing a greater interest for storage solutions among the actors. The energy storage actors have diverse roles ranging from regulatory to generation, transmission, distribution, and utilization of energy, or provide energy services related to energy supply, energy trading, resource aggregation (including storage) and power system balancing. Regulators need to have a clear understanding of available technologies, ideally having knowledge of the competing technologies and the advantages/disadvantages of each of them. Local and national governments usually benefit from availability of European Directives or regulations to complete them or adapt to the needs of a specific country or region. Energy service providers have delivered energy supply as well as system balancing services, using the storage to compensate the differences between demand and supply which cause deviations in the system frequency. Other emerging actors relevant with energy storage are prosumers and communities of prosumers. These stakeholders aim at utilizing in an optimal manner their local resources for energy generation using renewable sources and energy storage units such as batteries. These actors provide services to the wider grid based on energy management and renewable integration, contributing to grid modernization, reduction of transmission congestion, and reduction of energy costs promoting a more competitive market among the energy producers through a peer-to-peer electricity trading between microgrids. Communities and housing corporations are organized groups of consumers or prosumers which strive to provide benefits for the community and its members (such as economic or environmental benefits) balancing shared resources between several smart buildings or homes owners. Furthermore, aggregators are providing an aggregate flexibility to various energy markets offering services which try to maximize its value.

Table Actors relevant with energy storage technologies

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Level** | **Actor** | **Activity** | **Services provided** | **Incentives and drivers** | **Barriers** |
| Government | Local/National government | political guidance on energy storage | completion and implementations legislative provisions related to energy storage | presence of clear European or National policy on storage | lack of clarity in energy storage policies and technical standards |
| Regulators | responsible for exercising autonomous dominion over energy storage deployment within the national grid | establish measures enabling to shift consumers’ demand, to increase self-consumption and storage, and to implement dynamic time-of-use tariffs | availability and decreasing costs of energy storage technology | competing with cheaper technologies |
| Generation & supply | Energy producers | gas, coal, nuclear,  solar, wind, biomass | bulk storage,  arbitrage,  Renewables  integration | price differences  between peaks in demand and  supply | possibility of  double grid fees |
| Transmission grid | TSO | energy transmission | Renewables  integration,  ancillary and  transmission | costs of  contracting flexible  capacity for  balancing | unclear whether  TSO is allowed to  own or control  storage |
| Industry/large consumers | co-generation | Energy  management  and integration | price difference  between peaks,  electricity can  follow heat  production |  |
| Energy consumption | Energy  management  and integration | Price difference  between peaks |  |
| Service company | Provision of energy services | All above | All above | Storage services  not mentioned in  Electricity  Directive. Double  grid fees |
| Distribution grid | Local energy producer | Solar, wind, biomass | Renewables  integration and  arbitrage | Price difference  between peaks in  demand and  supply | Grid priority and  feed in tariffs are  no incentives for  energy storage.  Double grid fees |
| DSO | Energy distribution | Renewables  integration,  ancillary and  distribution | Balancing costs | DSO is in most  countries not  allowed to own or  control storage |
| Communities, housing corporations | Energy consumption, system balancing | Energy management and integration. Efficient and dynamical management of their energy needs considering local balancing resources such as smart buildings/homes, and stakeholder needs | Price difference  between peaks and valleys in the electricity tariff.  Flexible demand. | Required technology not fully available, such as advanced controls and energy management schemes.  Integration and optimization of large amounts of data provided by community groups. Complexity of internal relations for the community and associated high transaction costs. |
| Business, industry, household | Energy consumption, generate demand for low-cost local energy | Energy  management  and integration | Depends on price  settings  Low or no  remuneration for  electricity supplied  to grid | Electricity prices  may not reflect  peak value differences. Feed in  tariff, net metering  are no incentive for  storage |
| Prosumers | Local energy generation, consumption, storage, trading | Reduction of energy cost with respect to the grid.  Reduction of environmental pollution thanks to increased renewable utilization | Incentives for storage and renewables installation. | Required technology not fully available, such as advanced controls and energy management schemes.  Cost of building and maintaining in operation of a distributed distribution network suitable for energy trading. |
| Aggregators | Maximize the value of flexibility in various energy markets | increase or reduce the electricity consumption of a consumers’ group according to total electricity demand on the grid | 1. well-functioning, transparent wholesale market 2. fair rules for cross-border electricity exchanges | absence of market signals for increased energy efficiency, RES, energy consumption  and discriminatory market access |
| Service company | Energy services provider | All above | All above | Unclear business  model for grid  related services.  Double grid fees |
| Off-grid | Business, household | Independent | Energy  management | No or low  remuneration for  supplying the grid | Grid connection  Obligations |
| Market & Technology | Local/global market operators | promote the adoption of BESSs for various grid-connected solutions | Provide solutions based on energy storage for a wide range of clients, from owners of residential properties to large industries | Grid modernization & increase in grid energy storage demand | High costs of storage technologies. Unfavorable regulatory framework. |
| Regulators | investigate market design and regulatory frameworks for energy storage | Provide adequate regulatory framework to implement storage applications in the grid | Expanding storage market, decreasing costs of technologies | lack of interest in storage, limited availability of storage technologies, availability of affordable competing technologies, |
| Technology providers | Manufacturing energy storage systems | Production and commercialization of energy storage technologies for various grid applications | Incentives for storage installation | Unfavorable regulatory framework, lack of incentives |

Based on the actors represented in Table 9, the list of the actors in the whole Ireland are reflected as follows.

**Governmental Level**

* Local/National Government:

The Energy Sector of the ***Department of Environment, Climate and Communication (DECC)***, is responsible for the security, sustainability, and competitiveness of the energy supply and its compliance with the international policies directing energy and climate change. It functions as the high-level policy-making body in energy-relevant matters.

**The Environmental Protection Agency (EPA)** functions to protect and improve the valuable asset of the people of Ireland, the environment. Their main responsibility is to protect the people and the environment of Ireland from the harmful effects of radiation and pollution.

* Regulators

The Commission for Energy Regulation (CER) has been established in 1999 and then changes its name in 2017 to the ***Commission for Regulation of the Utilities (CRU)***. It acts as the independent regulatory body in water and energy of Ireland and its scope of activities includes the economics of the energy and water and the responsibilities defined for customer protection and safety.

***The Utility Regulator (UR)*** in Northern Ireland functions as a regulator of the electricity, gas, water, and sewerage industry. It is a non-ministerial government department and protects the interest of customers in the mentioned industries.

***Sustainable Energy Authority of Ireland (SEAI)***, design and implement the supporting policies for renewable energies, and is in close contact with the communities, householders, businesses, and the government, to achieve *Ireland’s sustainability targets.*

**Market & Technology**

* Local/global market operators

**Single Electricity Market Operator (SEMO)** is responsible for the balancing & capacity market settlement in the whole Island, as well as administration and updating the trading and settlement code.  SEMO is regulated by CRU, UR, and SEMC.

* Regulators

Following the initiation of the single electricity market, the **Single Electricity Market Committee (SEMC)** was established in 2007 to protect the interests of electricity customers. It functions as a decision-making body for the relevant matters to the single electricity market. The committee consists of three representatives from CRU, two representatives from UR, one independent, and one deputy independent member.

* Technology Providers:

**Energy Storage Ireland (ESI)** is an association established in the industry sector and acts as the representative of its members, which are active in the development of the energy storage industry in the whole Island.

**Irish Energy Storage Association:** The Irish Energy Storage Association (IESA) was established to support the growth of energy storage and promote the benefits of energy storage on the whole island.

**Transmission grid Level**

* TSO

**EirGrid and SONI** (called transmission system operators TSOs in this report) are the system operators on the whole Island. Valuable knowledge and experiences regarding the system operation and requirements, accommodating the high renewable penetration in Ireland’s power system, monitoring and preserving the adequacy of the electricity supply, managing and implementing the transmission networks are the main responsibilities of these TSOs.

**Distribution grid Level**

* DSOs

In 1927 the **Electricity Supply Board (ESB)** was established 1927 as a statutory corporation in the Republic of Ireland based on the legislated Electricity (Supply) Act 1927. ESB is majorly owned by the Irish Government and manages the distribution networks in the Republic of Ireland.

**Northern Ireland Electricity Networks (NIE Networks)** is the owner of the electricity networks (transmission & distribution) in Northern Ireland.

Private Sector:

**Generation & supply**

**Energia:** Energia Group is active in energy generation from renewables, operation of and purchasing energy from the conventional generation plants, and finally in the retail electricity market.

**Lumcloon Energy:** Lumcloon Energy has the largest fleet of battery storage under construction in Ireland.

**RWE Renewables Ireland:** (Former Innogy) is one of the biggest renewable energy producers across Europe.

**ScottishPower Renewables:** as a part of Iberdrola is one of the biggest wind power producers in Ireland and the UK and one of the winners in the volume-capped DS3 auction.

**Renewable Energy System Limited:** it is active in the power production from wind resources across the world and invests in energy storage projects.

**Wind Energy Ireland:** It acts as a representative body for the Irish wind industry and aims to promote wind energy in the whole Island of Ireland**.**

**Demand Response Association of Ireland (DRAI):** DRAI encompasses a total of 600 MW industrial and commercial loads that are actively participating in capacity markets, energy markets, and DS3 program.

**Micro Energy Generation Association of Ireland (MEGA):** MEGA cultivates the relationships between the communities and experts, who are making the clean energy solution available to all.

Retailers:

**Bord Gáis Energy:** it is active in the retail energy market, especially residential gas and electricity.

**Electricity Association of Ireland:** It functions as the representative of the retail sector in the gas and electricity industry that are active in SEM.

Collaboration of the Different Levels

Collaboration of the key actors in all levels will have a profound effect on the development of energy storage in the electricity industry since the BESSs are multi-functional equipment taking different roles and procuring different services. In Ireland, this important aspect is reflected in the structure of stakeholders and enables them to cooperate in a coordinated manner. To this end, communities have been introduced gathering all of the stakeholders and enabling them to share their points of view and experiences, seeking an efficient solution to the problems, and supporting the development of the BESSs. Currently the **FlexTech** (see section ‎4.7) initiative and one future actor have this important responsibility.

Based on the climate action plant 2021, DECC will establish a **National Climate Stakeholder Forum (NCSF)**. It will act as a consultative forum on climate-relevant issues, with administrative support being provided by the EPA. A broad range of stakeholders is the participants of NCSF including politicians; government departments, local authorities; state agencies and national organizations; academics; representative bodies; community, local and voluntary groups; and representatives of stakeholders and communities most affected by the climate change or influenced by the movements toward a carbon-free country. It will inform the participants by the latest scientific and policy developments, along with functioning as a core mechanism facilitating inputs into the Climate Action Plan and sectoral policies relating to climate change [160].

# Policy International Initiatives and Strategies

## Worldwide Status of the Storages

In 2020, around 40% increase is reported for total investment in battery storage (around 5.5 billion USD). Integration of the energy storages with the renewable energy systems causes a significant share for utility-scale BESS. Although the Covid-19 invasion reduce the household sector investment on behind – the – meter storage by 12%, the utility-scale BESS shows a 60% growth due in no small part to the hybrid auctions of renewables integrated with storages [21].

China doubled the additional capacity of BESS in 2020. It was in July 2021, that China unveiled an ambitious plan to install more than 30 GW of storage until 2025. It is remarkable that in the intended plan, the capacity of pumped hydro storage was excluded. It means that China is going to expand its storage capacity almost ten-times to the existing capacity in 2020.

Utility–scale storage capacity expansion in the United States manifests a fourfold increase by 2020.  Federal support for the deployment of the solar integrated storage is enhanced by congress's approval of 900 billion USD Covid-19 relief bill authorizing an extension of two years for the solar investment tax credit. In addition, the Better Energy Storage Technology Act allocates 1 billion USD during five years to conduct researches on storage technologies.

Europe compensates for the drop in utility-scale storage capacity expansion by a significant increase in the installation of storage by households and in the residential areas. Germany has the leg up and doubles behind the meters installations.

Following the sharp decline in deployment of storage in 2018 and 2019 by South Korea, a 6% increase is observed by 2020. Due to the phasing out of the federal subsidy scheme in January 2021, which was adopted in 2018 to make Korea the storage market leader, a drop is expected in storage deployment in Korea in the near future.

Australia remains a key market for behind-the-meter storage. Virtual power plants are quickly gaining popularity as a way to aggregate distributed assets. The additional revenues from aggregation could accelerate deployment in Australia, which already ranks fifth in the world for market size. Co-located storage capacity also expanded in 2019, and over 200 MW of capacity is under construction around the country. Although Australia represents a significant achievement in behind-the-meter storage, it is expected that over the next years, utility-scale storage will be dominated. As is planned by Japan, behind-the-meter storage installations achieved to almost 300 MW in 2020.

Cumulative installed battery storage capacity achieved almost 17 GW at the end of 2020. 50% growth has been experienced compared to 2019. Looking into the worldwide scope, the battery storage capacity is increased by 5 GW in 2020. Leading countries were China and the United States that contributed to the total global share in the gigawatt scale. Dominant installations were registered by Utility-scale that possess almost two-thirds of total installed capacity. European countries, Japan and South Korea represent significant additional capacity in the statistics. Germany has also contributed a great share in cumulative installed battery storage capacity statistics.

## Energy Storage by Countries

### China

#### Energy Policy

China is going to be completely carbon neutral until 2060, and by 2030, it will reduce the carbon intensity more than 65% from the level of 2005. The share of non-fossil fuels in the primary energy consumption should increase to 25%. To do so, China aims to add 1200 GW of PV and wind power generation capacity until 2030. Major energy goals of China and the millstones of 2025, 2030, and 2060 are illustrated in Figure 28 based on the ambition provided by the state of council, china [161].

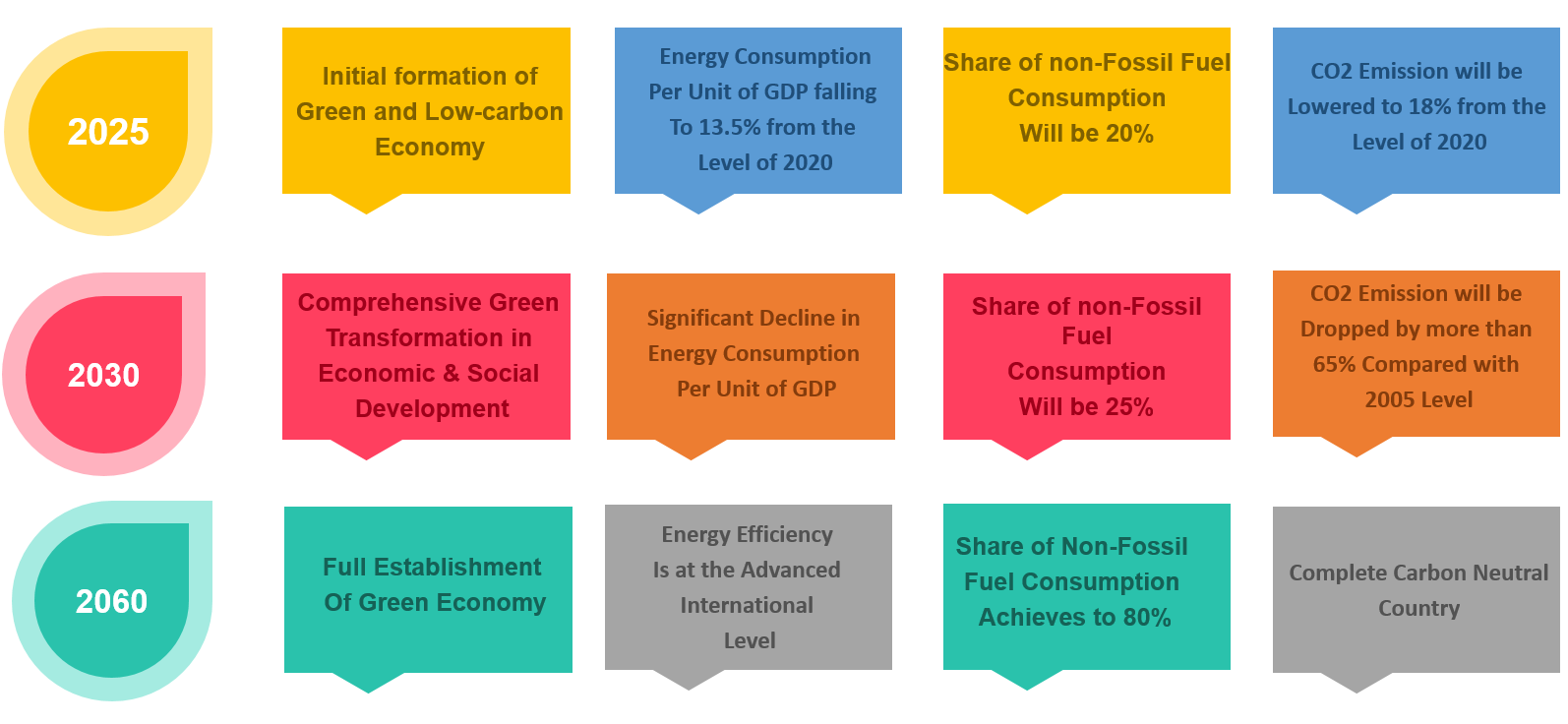


Figure . China’s major energy overview

#### Generation Mix

Based on the data provided in [162], the electricity generation mix of 2020 is illustrated in Figure 29. Total energy generation was more than 7600 TWh that is almost 250 times than that of Ireland. As is seen in Figure 29, fossil fuels account for 68% of total electricity generation and renewable energies contributed to 27% of the total generated electricity. China has currently 534.9 GW of installed solar and wind energy capacity.

Figure . China electricity generation mix 2020

#### Storage Mix and Overview

In 2020, co-located battery storage-renewable generation units contributed to 40% of total battery storage installation in China [162]. Accordingly, different provinces mandates the co-located installation of the battery storages and renewable energy based power plants. The mandate requires that at least 10-20% of the total generation capacity must be coupled by the battery storages. This requirement arises criticism in the industry sector since it will increase the capital cost by 8-10% while there is no financial support offered by the governments [163]. Based on the data provided by China energy storage alliance [164], Figure 30 illustrates the share of different energy storage technologies in total installed capacity. The total capacity of energy storages achieved to 35.6 GW while the pumped hydro storage accounts for 89.3% and the electrochemical batteries contributed to 9.2% of the total energy storage capacity. Li-ion leads the electrochemical technology by 8.16% from the total installed energy storage technologies.

Figure . China Energy Storage mix 2020

Considering the under construction plants, pumped hydro storage capacity in China will achieve to 650 GW until 2025 [164]. In 2020, China has installed 1559.6 MW new battery storage capacity that achieves 145% growth compared to the previous year. The cumulative battery storage installed capacity was 3269.2 MW by 2019 and in the conservative scenarios, china will achieve to 35519 MW of installed battery storage capacity until 2025 [164].

#### Regulations, Barriers & Policy Recommendations

Energy storage industry encounters problems in China including the high costs associated with this technology which Impedes its commercialization, incomplete technical standards, that have negative effects on the commercialization of the battery storage systems, the lack of benefit evaluation system, that avoids the comprehensive cost-befit analysis in China, and finally the lack of incentivizing polices are the main problems reported by the literature [165]. Time of use pricing mechanism could be helpful for the energy storage to evaluate arbitrage opportunities between peak-valley prices but there is a lack of implementation of peak-valley tariffs in China that could negatively affect the battery storage investment incentives [166]. There is no subsidies that directly support the energy storage investment in China. While it is acknowledged that excessive direct subsidies may distort the competition in the market, [165] suggested that reasonable subsidies can orderly manage the progress of battery storage in China. A series of national level policies have addressed the energy storage in China.

* the 13th five year plan in 2016, that recognize the energy storage as a strategic resource
* the 13th five-year plan for renewable energy development in 2016, that bolded the potential of energy storages to improve the power system stability and accommodating higher penetration of renewables,
* guiding opinion on the promotion of the energy storage and the associated industry development in 2019,
* guiding opinion on the promotion of orderly development of battery storages in 2019.

Considering the aforementioned policies, it is acknowledged that the price arbitrage and demand charge reduction will not adequately recover the capital cost for behind the meter storages in China [167]. Figure 31 summarized the polices recommended to support the energy storages in China [165, 167-169]



Figure . China recommended policies to support energy storages

### USA

#### Energy Policy

Leading by solar and wind power the share of renewable energy resources increased from 9% in 2008 to more than 19% in 2020 while the total electricity demand has remained relatively constant [170]. Renewable Portfolio Standards (RPS) are defined to set minimum levels for the electricity, sold by utilities, that should come from renewable resources [171]. Some states have legislated Clean Energy Standards (CES) to address zero carbon energy resources which may not be necessarily recognize as renewable energy resources[[8]](#footnote-9) [172]. Most of the states set RPS target to be at least 40%, while the recent legislation paved the way to achieve to 100% clean or renewable by 2050. Different states may have a combinatory targets of RPS and CES. Based on the data provided by national conference of state legislatures (NCSL) [173], the RPS/CES targets of the jurisdiction areas are illustrated in Figure 32.

Figure . Different RPS/CES targets of the states in USA

Supporting schemes for main renewable energy resources, namely solar and wind power are based on the tax credits. For solar, the main supporting policy is a 30% investment tax credit (ITC) for all sectors such as residential, commercial and utility-scale solar installations. For wind power, it is in the form of the renewable electricity production tax credit (PTC) [170]. Excluding the hydropower, it is planned to add 3561 additional renewable capacity the generation fleet by 2024 [174].

#### Generation Mix

Based on the Data provided by U.S. energy information administration, the generation mix of USA in 2020 is illustrated in Figure 33 [175]. Fossil fuels account for 60% of the total electricity generated in 2020. Renewable energies contributed to 19.8% of the electricity generation. Total electricity consumption in USA is around 143 times that of Ireland [176].

Figure . USA electricity generation mix

#### Storage Mix and Overview

The declining cost of the utility-scale battery storages project a significant capacity installation expansion (around 10 GW of new utility-scale capacity) in the USA between 2021 and 2023 [177]. Currently USA have the largest utility-scale fleet of battery storages. At the end of 2020, the battery storage capacity of united states achieved to 1650 MW [178] which grew by 35% compared to 2019 and has been tripled in the last five years. For less than 1 MW battery storage which is known as small-scale in USA, 400 MW of installed capacity was reported in 2019. United states has installed 22 GW of pumped hydro storage and plans to add 50 GW of new capacity until 2050 [179].

It is planned to add 14.5 GW of battery storage between 2021 to 2024. 9.4 GW of this additional capacity (63%) will be co-located battery storages with the solar power plants, and 1.3 GW will be co-located by wind farms [180]. The remaining part will be located on stand-alone sites. Since the RTOs/ISOs announce clear legislations to provide multiple revenue streams for the battery storages, as is illustrated in Figure 34, 97% of incoming stand-alone located utility-scale and 60% of the co-located battery storages are in RTOs/ISOs territory [180].

#### Regulations, Barriers & Policy Recommendations

In USA, the Federal Energy Regulation Commission’s (FERC) dictates the high-level policies to clear the pathway for the system operator in different states. Order 841 removed the barriers of participation for the battery energy storages in the wholesale electricity markets operating under the tutelage of the FERC. According to this order, the Independent system operators and regional transmission operators are obliged to make a revision on their participation model, if required, to ensure the hassle free provision of the services, capacity, and energy by the energy storages, if they are technically eligible to provide them [181]. It mandates the participation of the energy storage in the wholesale electricity market taking the role of sellers and buyers. Based on this order, the TSOs and RTOs were capable to set out minimum operation time for the energy storage, but the energy storages were also allowed to de-rate their capacity. It means that if the required minimum operation time was 2 hours, a 300 kW battery with 300 kWh capacity is able to bid for 150 kW. In addition, make-whole payments compensate the unfavorable dispatch instructions that may be obliged the energy storage. For instance, if the battery storage is dispatched as a load while the market price is higher than its energy purchase bid, the difference will be covered by make-whole payments.

One of the outstanding policies adopted in USA to promote the deployment of BESS is the align prices with the dispatch instructions. Order 825 required that the settlement in real-time markets happen with the similar time interval as dispatch instructions. As a result, in most of the markets, the financial settlement moved from an hourly basis to 5-minute prices. This decision provide a promising trading environment for the energy storages to make the arbitrage profit more than doubled compared to the electricity markets adopting hourly time intervals for the settlement [182].

One of the interesting attitudes in USA treating with the battery storages is the provision of multiple revenue streams. Figure 34 shows that in all RTOs/TSOs territories, battery storage are opt to participate in capacity, wholesale, and ancillary service markets. ERCOT is an energy-only market so there is no capacity market to allow the battery storage to participate.

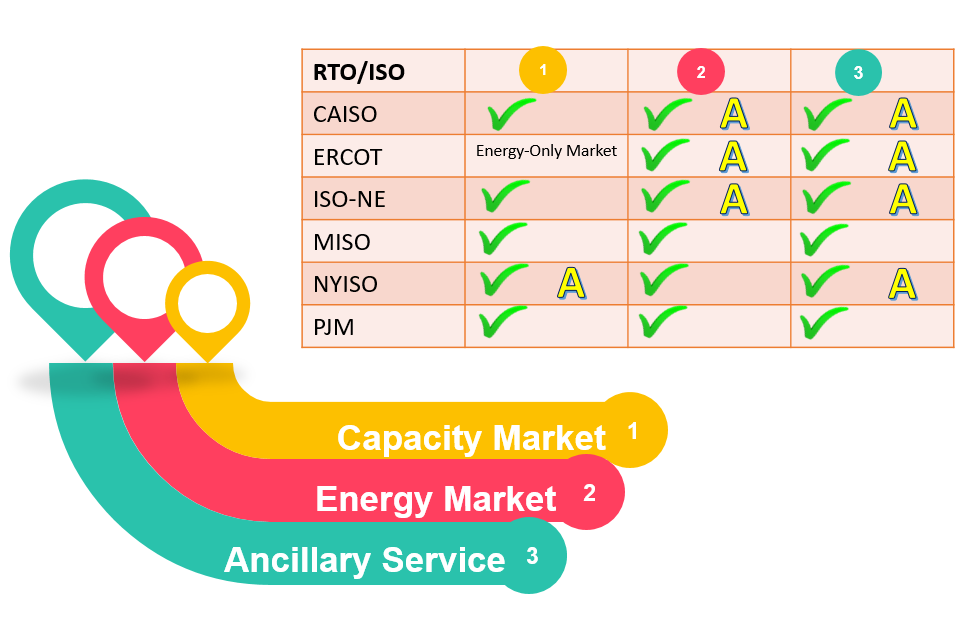


Figure . Multiple revenue stream for energy storages

In USA, aggregators are allowed to procure grid services and this point could unlock the potential of the smaller capacity storages to access to the multiple revenue streams. In Figure 34, the yellow “A” symbol indicates that aggregators are allowed to participate in specific market.

Generation, consumption, and transmission/distribution network investment deferral complicates the definition of the energy storage in USA like every other countries in the world. CAISO defines a Non-generator resource category that refers to “ resources that operate as either Generation or Load and that can be dispatched to any operating level within their entire capacity range but are also constrained by a MWh limit to (1) generate Energy, (2) curtail the consumption of Energy in the case of demand response, or (3) consume Energy” [183]. Other RTOs/TSOs have also addressed the whole or a part of the storage capability by different terminologies and definition. ISO-NE used “Alternative Technology Regulation Resource” enabling battery storage to participate in the ancillary services market, MISO designate the “Stored Energy Resources”, MISO adopts “Limited Energy Resources”, and PJM refers to the storage by defining “Capacity storage resource” for the capacity market and “Energy Storage Resource” for the energy market [184].

### South Korea

#### Energy Policy

By 2030, the renewables will account for 20% of total electricity generation in South Korea, leading to 30-35% target of 2040. South Korea’s 9th basic plan that dictates the long-term electricity supply and demand accounts for 40.5% of renewable energy share by 2034. This target requires the uptake of renewable energies from 16.1 GW in 2019 to 51.7 GW by 2034 [185]. In addition, Korea set out a target to be carbon neutral by 2050, deploying the renewable energy sources and gradually phasing out of coal power plants as a significant source of energy and emission in South Korea. So a coal power plant installed capacity reduction from 35.8 GW to 29 GW is expected by 2030. The nuclear power plants will also be decommissioned from 23.3 GW in 2020 to 19.4 by 2034.

#### Generation Mix

Based on the data provided by Korean Electric Power Statistics Information System [186], the generation mix of South Korea in 2020 is illustrated in Figure 35. Fossil fuels account for 66.9% of the total electricity generated in 2020. Renewable energies (including the pumped storage hydro power plants) contributed to 12.7% of the electricity generation. Excluding the pumped hydro storages, solar PVs are the main source of renewable energy in South Korea. Total electricity consumption in South Korea was around 19 times than that of Ireland in 2020 [187].

Figure . South Korea Generation Mix 2020

#### Storage Mix and Overview

Based on the data provided by [185], the total installed capacity of battery energy storages in 2019 was 1605 MW. In addition, 4700 MW of pumped storage hydro power plants [186] are the dominated storage fleet in South Korea. Based on the South Korea’s 9th basic plan, 1.8 GW additional pumped hydro storage capacity will be installed by 2034. The storage mix of South Korea is illustrated in Figure 36.

Figure . South Korea Storage Mix

Behind the meter units have the largest contribution in the battery storage fleet and account for 57.8 % of total battery storage volume in 2019 [185]. The applications of the battery energy storages in South Korea are illustrated in Figure 37. 35.5% of the BESSs are co-located with the renewable energy resources. 23% of the total installed battery energy storages are designed for contribution to the frequency control but only 2.2.% of the total MWh has been dedicated to this application in 2019.

Figure . Battery Storage Applications in South Korea Source [185]

Based on the South Korea’s 9th basic plan, 970 MW additional battery storage capacity will be installed until 2034, and the peak shaving capacity of the behind the meter units will also be 16 times than that of 2019 [185]. Based on this information, Korea plans to install around 6 GW additional capacity of battery storage until 2034.

Excluding china by 32.6 GWh, Japan by 2.3 GWh and South Korea by 1.2 GWh will comprise the biggest part of the stationary storage market in Asia [26].

#### Regulations, Electricity Markets & Storages

#### Policy Recommendations

Renewable energies are supported by the electric utility act that guaranties the dispatch priority and purchase assurance for renewables. Based on the MW rating the renewable resources are opt to participate in wholesale electricity market or go through the power purchasing agreement. Renewable energy certificates (REC) are another revenue stream for the renewables. Power producers are obliged to increase their share of renewable energies to 10% by 2022 whether by their own generation asset or by purchasing the renewable energy certificates. Assigning weighting factors to different technologies is the corner stone of the REC mechanism in Korea. The implication of REC mechanism for battery storages lies also in the REC weighting factor since the maximum weighting factors were assigned to coupled energy storage systems with solar PVs or wind power generators.

TO support behind the meter battery storages for peak shaving and energy arbitrage, Korea deploys tariff discounts. This scheme shorten the duration of the payback period of upfront costs from 10 years to 4.6 years [185].

It is interesting that while 23% of the storage fleet are able to provide frequency services by design, only 2.2% of the installed storage volume have contributed to the frequency control in 2019. This is due in no small part to the remuneration scheme for these services which is based on the avoided fuel cost for conventional power plants that don’t provide a promising revenue stream for the battery storage fleet. It is reported that only battery storages owned by KEPCO participated in the frequency control service provision [185].

To support the battery storage expansion, public owned entities that have consumption more than 1 MW are obliged to install battery storage system in their buildings. In South Korea by gradually phasing out the out of market supporting schemes until 2034, the battery storage will rely on the multiple revenue streams based on their various capabilities.

### Japan

#### Energy Policy

As is declared by the prime minister of Japan in 2020, Japan will reduce its greenhouse gas emission to net-zero in 2050, an announcement that defines Japan’s future energy prospect. The most pertinent movement toward this aim is recommissioning the nuclear power plants and the expansion of renewable energy resources. Japan’s greenhouse gas emission experienced a peak in 2013 following the accident that happened in Fukushima that increased the fossil fuel consumption to compensate for the sudden shut down of the Fukushima power plant. Because of the mentioned movements, in 2018, the greenhouse gas emission was reduced up to 12% in comparison to 2013. Japan’s energy is heavily dependent on the import of fossil fuels.  To have a clear vision, fossil fuels contributed to 88% of the total primary energy supply in Japan in 2019.

In December 2020, the “green growth Strategy in line with Carbon Neutrality in 2050” was presented by Japan. The government relies on large expansion in the renewable energy sector and developing new technologies to recover nuclear power. Renewable energies are to account for 50% - 60% of the electricity demand. The nuclear and other thermal power plants along with the carbon capture utilization and storage will supply 30% - 40%, and the remaining part will be procured by hydrogen & ammonia-based generation. Hydrogen will have a predominant role in Japan’s green energy transition.

Japan plans to increase the contribution of renewable energies from 8% of the total primary energy supply in 2019 to 13% by 2030. To do so, renewable power generation should be increased from 19% in 2019 to 24% by 2030. Thanks to the feed-in-tariff mechanism, japan experienced ample expansion in PVs. It has also a great potential to utilize wind and geothermal energy as well.  In 2030, nuclear energy will account for 11% of the total primary energy supply which significates a huge expansion from its 4% share in 2019 [188]. Japan plans to add 100 GW of solar [189] and 10 GW of offshore wind power until 2030.

Although the share of fossil fuel will decline by 2030, it accounts for 76% of the total primary energy supply and correspondingly more than 50% of electricity generation in 2030 vision. To achieve the ambitious goal of Zero-net emission by 2050, zero-emission power sources should be significantly supported.

#### Generation Mix

Based on the data provided by [190] the 2020 electricity generation mix of Japan is illustrated in Figure 38. The total electricity consumption of Japan (by 2019) was around 1000 TWh and is almost 33 times than that of Ireland [191]. In 2020, 69.14% of the electricity generation came from fossil fuels and renewable energies account for 26.29% of the total generated electricity.

Figure . Japan 2020 Generation Mix

#### Storage Mix and Overview

Japan has already installed 243.4 MW of battery storages based on the data provided by [53]. Behind the meter storage capacity is not included in this DOE report while Japan achieved to 300 MW behind the meter storage capacity by 2020 [21]. Battery storages account for less than 1% of the total installed storage capacity in Japan (0.9%). Pumped hydro storage constitutes 99% of the total storage fleet in Japan. The capacity is around 27.4 GW by 2020 and may achieve to 35 GW by 2050 [192]. Japan is the world leader in manufacturing Nas battery energy storages and achieves to the world second rank for Pb-Acid energy storage systems. Nas and Li-ion batteries are the main technology of the batteries that are currently being used in Japan. Japan is among the countries that are projected to have the largest market for stationary storages by 2.3 GWh in 2030 [26].

#### Regulations, Barriers & Policy Recommendations

It was in 2012 that ministry of economy, trade and industry (METI) of Japan formed a battery storage project team cooperating with the Agency for Natural Resources and Energy, the Commerce and Information Policy Bureau and the Manufacturing Industries Bureau. The mission of the team was to devised and implement polices to create the future battery storage market, enhance the industrial competitiveness, and standardize the technologies associated with the battery storage. The goal was defined to capture 50% of the global battery storage market by 2020 [189].

Between 2012 and 2013, METI heavily subsidized the Li-ion battery storage that covered a third of the total cost. Another program subsidized coupled renewable energy battery storage projects that covered one-half of the associated costs. Japan Ministry of Energy lunched a subsidy program to cover one-half of the cost associated with the more than 1 MW battery storage co-located in renewable energy plants [189]. In August 2013, METI started movements to stimulate the large-scale battery storage projects and another program to support the installation of Li-ion batteries in the residential areas and households. Battery manufacturers in Japan are teamed-up with METI to develop solid-state batteries within a program defined for 2018 to 2022. Under this program, the automakers and battery manufacturers received a budget to commercialize their R & D battery storage projects. The supporting policy of the Japan’s government are mainly based on the subsidy programs.

### Germany

#### Energy Policy

In 1980, the institute of applied ecology issued a program called “Energiewende – Wachstum und Wohlstand ohne Erdöl und Uran” that means the energy revolution, growth and prosperity without crude oil and Uranium [193]. In 2000, the renewable energy act[[9]](#footnote-10) open the windows to the renewable energies in Germany. It was in 2010 that the energy concept set out renewable energy targets for all sectors power generation. Consistent with the EU target, the share of renewable energy in total gross consumption achieved to 18 %. By 2030 and 2050 Germany will account for 30% and 45% of renewable energies respectively. For the electricity sector, renewable energies has contributed to 35% of gross electricity consumption by 2020 but this goal had already been overtaken in 2018 by 38% of renewable share. For 2030, 2040, and 2050 Germany will account for a share of 50%, 65% and 80% for the renewable energy in the electricity sector respectively. Based on the Energiewende (means energy revolution) Germany aims to phase out are nuclear power plants by 2023 [194] and replace them by renewable energies [195]. Germany will have more than 150 GW of renewable energy capacity until 2025 [196] .

#### Generation Mix

Based on the statistics provided in [197], Germany’s generation mix in 2020 illustrated in Figure 39. The total electricity consumption in Germany was 536.5 TWh by 2019 [198] which is around 18 times that of Ireland [199]. Renewable energies account for 47.4% of the total share of renewable energy in Germany.

Figure 2020 Germany Generation Mix [195]

#### Storage Mix and Overview

Germany adopts to deploy three kind of energy storages, namely residential storages, Industrial storage, and utility-scale storages. Figure 40 illustrate the battery storage status from the installed capacity point of view in Germany until 2020 [200].

***Residential storages:*** in addition to 185000 residential storage which had been installed in Germany with an output power of 750 MW and capacity of 1.42 GWh, 60000 new storage have been installed in 2019 that is estimated to add 250 MW with the capacity of 490 MWh. It is remarkable that around 40% of the new residential storage is operating in combination with heat pumps.

***Industrial storage:*** more than 700 industrial storage have been registered in Germany until 2020 which accounts for 27 MW and a capacity of 57 MWh.

Utility-scale energy storage: In 2019, nine new utility-scale storage have been commissioned by 54 MW of rated power and 62 MWh of capacity. The accumulated rated power achieved 460 MW of rated power that procures 620 MWh of capacity. This kind of storage is mainly active in frequency containment service. It is planned to have two 100 MW/ 100 MWh projects and one 250 MW/250 MWh project in operation by 2022. Germany plans to have 20 GW energy storage by 2030 and BESSs will contribute to 9 GW of the determined target [201]. Moreover, the pumped storage hydro power plants will grow from 9810 MW in 2020 [202] by 1.4 GW additional capacity until 2030 [203].

Figure BESSs status in Germany

#### Regulations, Barriers & Policy Recommendations

In Germany, the feed-in tariff for PVs is lowered below the average household’s electricity price. In addition, self-consumption of PVs is excepted from tax and network tariffs. These regulations make incentives for on-site consumption of the PVs. It was in 2013 that BMU granted €25 million to boost the deployment of PV integrated battery storage for the households that covers 30% of the total cost. The remaining 70% were covered by low-interest loans [204]. By using the roof-top PV integrated battery storage the self-consumption PV share will be increased from 35% of the current share to more than 70% [194].

By the end of 20 years of guaranteed feed-in tariff support for the older PVs, they become a customer for the battery storage and expand the battery storage market. Utilities are offering battery storage systems with discounted electricity tariffs to their customers. This will facilitate the formation of VPPs in Germany that in turn support the grid. Even after 6 hours of negative electricity prices, the renewable energy subsidies continue to support oversupplying the renewable generation. This may impede the incentives for installing the battery storage [205]. Germany support both behind the meter and in front of the meter battery storages by exempting them from the network charges and levies. German Federal Ministry for Economic Affairs and Energy support new roof-top PVs integrated with the battery storage by giving low interest loans (utilizing the development bank KfW). Old PVs could also supported by this scheme if they have been installed after 2012 and the rated power were below 30 kW [206]. Germany aims to deploy 14 Million electric vehicle until 2030. To this end, national platform for future transportation[[10]](#footnote-11) has been established to consult the government regarding the integration of EVs to the grid [207].

### Australia

#### Energy Policy

It was in 2001 that the Australia announced its renewable energy target for 2020 that sets out 33 TWh for electricity to be generated by the renewable energy resources [208]. Australia is going to increase the penetration level of the renewable energies in near future. As is seen from 91174 MW total expansion plan, 68% of the total electricity generation will come from renewable energy resources. Battery storages will also contribute to 21% of the total expansion plan.

Figure Australia ten years plan for generation expansion

The renewable energy target in Australia have two pillars, namely the large-scale renewable energy target (LRET), and the small-scale renewable energy scheme (SRES) [209]. LRET obliges the energy users to feed a predetermined portion of their electricity consumption form the renewable energy resources. They should secure large-scale generation certificates, that can be supplied by large-scale renewable power plants, to meet their LRET obligations. Heat pumps, solar water heaters, and rooftop PVs are supported via SRES. Small-scale technology certificates will be issued for the owners and the energy users are obliged to supply a fixed portion of their total consumption from this sector. To this end, they should secure small-scale technology certificates that could be purchased from the owner of these technologies.

#### Generation Mix

Electricity Sector is the most pertinent source of emission in Australian Industry by contributing to more than 30% of total national emission [210]. Based on the available data in national energy market database [211], from 30 Nov 2020 to 5 Dec 2021, Australia generation mix is illustrated in Figure 42 . As is seen, more than 63% of total electricity generation comes from Coal power plants. In this period, between 25.1% to 37.2% of electricity generation was based on the renewable energy resources. 0.09% of total electricity consumption came out of the battery storages. Australia total electricity consumption in 2019 was almost 8 times than that of Ireland [212].

Figure Australia generation mix for the period of 30 Nov 2020 to 5 Dec 2021

#### Storage Mix and Overview

By 2021, there are five utility-scale battery storages in operation that procure 260 MW of battery storage capacity for the Australian power systems [146]. Based on the data provided by Australian Energy Market Operator (AEMO) [210], from the rated power point of view, the smallest one is Dalrymple BESS with 30 MW capacity and 0.27 hour duration and the biggest is Hornsdale Power Reserve Unit 1, a 150 MW unit with 1.25 hour duration. In terms of duration, Lake Bonney BESS1 with 25 MW rated power has 2.08 hours duration. It is planned to add 85 new utility-scale battery storages with 18664 MW rated power [213]. Based on the data provided by Sandia-lab, USA department of energy global storage database [53], in addition to the above mentioned battery storage, Australia has around 66 MW ranging from 2kW Remote Off-Grid Container - Regional Queensland unit to two 20 MW battery storages (Lakeland Solar and Storage - Lyon Group, and Cape York Solar Storage 20MW / 80MWh - Lyon Group). Based on the data provided in [214] Australia has currently installed 314 MW of battery storages. Australia has currently installed 3.6 GW pumped storage hydro power plant including the Tumut 3 and Shoalhaven power stations [215].

#### Regulations, Barriers & Policy Recommendations

Australia is going to reform the electricity market design by the inclusion of several new markets, to capture the full potential of the battery energy storage. It means that the battery storage units can access to multiple revenue streams. In addition, governmental funding bodies such as Clean Energy Finance Corporation (CEFC) and Australian Renewable Energy Agency (ARENA) and drive direct investment to the utility scale battery storages. Figure 43 illustrates the services that are currently being provided by battery storage units in Australia.

Figure Services that are currently being provided by Battery Storages in Australia

Energy storages are simultaneously categorized as generation asset and load asset [146]. Introduction of a new participant category (named integrated resource providers [216] ) for integrated battery storage with renewable energy resources has been proposed to facilitate the efficient entry and operation of the storage units. It also accommodates aggregators of small renewables and batteries to promote the competition in the provision of the required services.

Considering that many participants have currently bi-directional energy flows, the non-energy cost framework associated with the non-energy services that AEMO procures to ensure the safe and satisfactory operation of the power system, is proposed to be changed in a manner that do not impose disadvantages to the energy storages [146].

In order to foster higher penetration levels of renewable energies, two services have been defined under the tutelage of the Frequency Control Ancillary Services market (FCAS), as very fast raise and very fast lower” service [217].

It is acknowledged in Australia that the firming capacity are required but contracting with conventional generators to meet the adequacy requirement impede the clean energy transition. To mitigate this problem, it is proposed to deploy battery storages to enhance the adequacy of supply but the implications depends on the market design [218].

AEMO is capable to contract the reliability and emergency reserve traders to procure the required emergency short and medium notice reserve, which is currently secured mainly by demand-side response. Battery energy storages has a great potential to be deployed for such services [146].

It is recommended to deploy the potential of the battery storage devices to postpone the transmission and distribution network upgrades [146]. It relies on the provision of the revenue models for congestion relief ability of the battery storage units.

### GB

##### Energy policy & Generation Mix

In January 2021, the generation mix of the GB is illustrated in Figure 44. Based on the available statistics, 41.2 % of the generation mix has been decarbonized in GB [219]. The total renewable energy installed capacity was 47813 MW by the end of 2020 [220]. The carbon intensity has been reduced by 66% between 2013 and 2020. Considering the way paced from 2016 to 2020, the wind electricity generation has been three folded. The record of wind electricity generation achieves to 17.7 GW. GB achieved to 9.7 GW solar generation record that covers the charging of over 1 million electric vehicles. GB aims to operate a zero carbon grid by 2025 and become net zero carbon in all sectors by 2050. GB total electricity generation fleet will achieve to 290 GW and will host 68 GW of electricity storages and interconnectors. To meet the 2030 targets, GB requires between 34 GW and 77 GW of new wind and solar electricity generation capacity, reinforced with 16 GW capacity of interconnectors [221].

Figure GB generation mix-January 2021

#### Storage Mix and Overview

Until 2020, 25.513 MW of battery storage capacity has been installed in UK in various voltage from distribution to transmission levels (230 v – 275 Kv), using different technologies (Li-ion, NaNiCl2, PbAc, and VRF), and for different applications [222].

* Consumption: time shift, electric bill management,
* Distribution: distribution system upgrade deferral,
* Grid Services: frequency regulation, reserve services, voltage support, reliability and quality enhancement, transmission congestion relief, transmission system upgrade deferral, Peak Shaving, load following, load leveling
* Generation: renewable capacity firming, renewable generation shifting

It is reported that GB has utilized the energy storage for transmission/distribution system upgrade deferral[[11]](#footnote-12) [222]. To accommodate the huge growth of renewables by 2050, GB require 13 GW of electricity storages [221]. Based on the current reports, 8.3 GW of battery storages are pre-qualified by T4-capapcity market [223]. GB has installed 2828 MW of pumped storage hydro power plant [224].

#### Regulations, Barriers & Policy Recommendations

Based on the current market structure in GB, electricity storage could provide a limited number of services to the electricity grid. Figure 15 depicts the intended services.

Figure Services that could be provided by energy storages in GB

Energy storages are defined as generation asset in GB [225]. It is controversial since the energy storage could not inject a positive net flow of electricity by considering both of both of charging and discharging modes.

One of the key barriers in GB to release the potential of energy storages is the double distribution system charges on the energy storage taking the role of generator and consumer. In case of higher installed capacity (more than 100 MW) which is way far from the current installed capacity of a single storage unit, the storage unit will be doubly charged for the transmission system usage.

The ownership and operation of the energy storage in the restructured power system is also a controversial issue. Due to the unbundling of the generation, transmission, and distribution sectors, a system operator is not allowed to own any kind of generation system and vice versa [226]. On the other hand, owning energy storage by other parties may avoid the efficient deployment of their potential because of the imperfect information. One of the good example is the transmission and distribution system upgrade deferral by using the potential of energy storage. However, the electricity sectors are unbundled and law prohibits moving toward vertically integrated system.

The absence of ancillary service markets is also an important barrier to attract the attention of investors into the storage technologies. Most of the ancillary services such as replacement reserve reactive power and frequency responses are procured based on the bilateral contracts or mandatory service agreements [227].

To enhance the reliability and security of supply, GB held T-4 capacity auction to secure the required capacity between 2020 and 2035. From the total 3.2 GW commitment, storages secured 500 MW of capacity (around 15%). The barrier is the open – ended time duration of energy provision in the times the network is under stress. Figure 46 illustrates the main barriers for the deployment of energy storages in GB [225].

Figure Main barriers for the energy storage devices in GB

Careful definition of the energy storage devices to address their ability to time control of import and export, consider their net zero power injection (neglecting the losses), and avoiding the double network charges is the very first recommendation in GB to host the electricity storages. Updating the ancillary service requirement to reflect the wide characteristics and potential of the energy storage devices is recommended as a key point for deployment of energy storage devices [228]. In T-4 capacity market outcomes, it is recommended to define time limits for the exercising of capacity obligations and avoid the risk of open – ended discharging duration for the energy storage devices. Rewarding the energy storage for their non-energy based benefits such as avoiding emission or facilitating the renewable energy integration. GB government are not going to put direct subsidies for supporting the deployment of energy storage, however, they are actively obliterate the barriers confronted the energy storage development. Long duration storage are preferred over short duration storages in the T-4 capacity market auction since they provide more liable resources in the short fall of the capacity [229]. To do so, de-rating factors are introduced that scale the payment to the battery storage in which longer duration battery storage gain up to 5 times the short duration ones [230].

## Key Point for the Policy Makers

Figure Illustrative target diagram for the deployment of Energy Storage for the Leading Countries

Figure 47 illustrates the total installed generation capacity (per unit of China). The red round marks refers to the current ratio of the renewables to the total installed generation capacity, the violet bars show the current ratio of the installed energy storage fleet to the renewable installed capacity, and the red bars depict the target ratio of the storage capacity to the renewable target capacity. China represents the biggest leap forward and aims to uptake this ratio from 6% to 41% followed by USA that aims to increase the ratio from less than 12% to more than 30%. The third rank belongs to Australia followed by, Germany. The lowest Increase manifested by South Korea. Based on the available data, Japan[[12]](#footnote-13) and South Korea show a decrease on this index by the target year. This is because of the expansion of the renewables and current high share of energy storage units in their portfolio. The green rectangles represent the ratio of renewable energies in the target year with respect to the current level. As is seen, Australia, followed by Japan, China, South Korea, GB, Germany, and United States possess the highest to lowest values of this index.

Figure Ratio of the Battery storage to the Renewable Capacity in Current/Target year

Figure 48 depicts the ratio of the battery storage to the renewable capacity for the current and target year. Australia aims to have the first rank in the expansion of the battery storages followed by South Korea, GB and USA. Germany, Japan, and China have the next ranks based on this index.

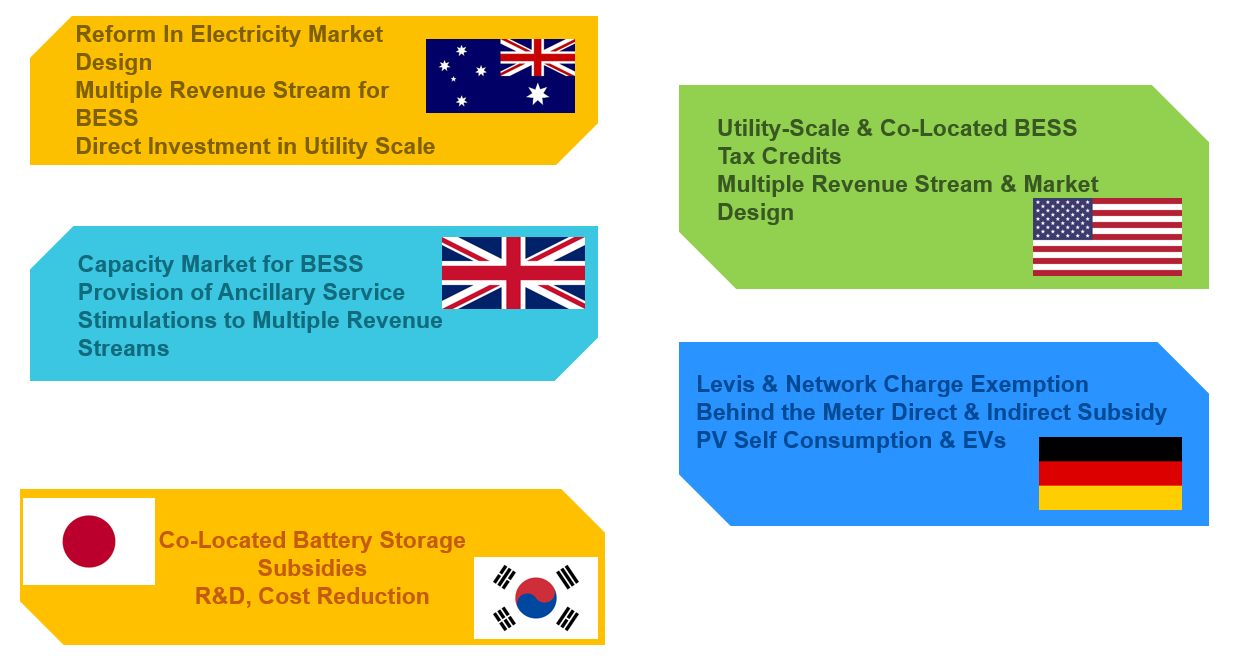


Figure Review of the Policies in the leading Countries

Figure 49 summarizes the high-level adopted policies leveraging the uptake of energy storage units in the BESS leading countries. As is seen, one of the most important polices to adopt is to establish the market mechanisms supporting multiple revenue streams for the BESS.

# EU Policy Initiatives on Storage Technologies

## European Energy policy and the energy storage deployment

As is addressed in [231], the energy sector accounts for 79% of European gas emissions among other emitting resources such as Industrial processes, livestock, land use, waste management, and etc. In the energy-related emitting sources, the biggest share is possessed by the energy supply and transport. Figure 50, , illustrates the share of electricity/heat production, transport sector, and road transport in the total emissions caused by the energy sector [232]. As is seen, the road transport individually caused more emission than the whole heat/electricity production sector. Figure 51 illustrates the trend of emitting sources in the energy sector. It represents that in 2019, the electricity/heat production emissions go below the transportation sector for the first time [232].

Energy storages are an important source for the provision of flexibility for the power systems that are required to manage the variable behavior of the renewable-based generation system. Renewables facilitate green fuel production such as hydrogen, which in turn could reduce the transportation sector emission. In addition, a mature energy storage technology will support the conformity of the electric vehicles fleet with the transportation system requirements. In the light of these facts, the European-level initiatives on renewable energies are also important in the energy storage framework.

Figure The share of Transport, Road transport, Electricity, and heat production in the emissions caused by energy sector

Figure The Trend of Transport, Road transport, Electricity, and heat production emissions

One of the main drivers for supporting energy storage was the European target for reducing the CO2 emission up to 95% from the level of 1990. In 1997, a target had been set for a share of 12% for renewables by 2010 at the European level [233]. In 2009, Renewable Energy Directive I [234], set a 20% share for renewable energy resources in the final energy consumption by 2020. In the directive, it was stated that “There is a need to support the integration of energy from renewable sources into the transmission and distribution grid and the use of energy storage systems for integrated intermittent production of energy from renewable sources”. This was the first time that energy storage was supported in the official legislation of the European Union.

Following the determination of twelve prioritized trans-European energy infrastructures by the Commission In 2013, that includes the smart grids integration, the electricity highways and interconnections, electricity transmission system, energy storage units, transmission and storage in the gas sector, infrastructures facilitating the production of liquefied or compressed natural gas, Transportation of the CO2, and oil infrastructures) energy storage units were recognized as a strategic energy infrastructure [55]. To prioritize the projects of common interest, [55] determined a minimum required capacity equals 225 MW (and annual  250 GWh energy capacity) for the electricity storage. In the same year (2013), to promote the investment in trans-European networks, Connecting Europe Facilities was established and brought significant financial support [235]. Underpinning the energy storage units, Connecting Europe Facilities allocates more than 5,000,000,000 to support them as a strategic element in the energy sector.

Paris agreement approved at the conference of parties in 2015 [235] and became legally binding in 2016. It aimed to enhance the global response to the climate change and agreed to hold “the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels”.

In 2015, following the determination of the Energy Union Strategy [236], the Commission revised the Integrated Strategic Energy Technology Plan (SET-Plan) of 2007. The Set-Plan had 10 key actions that four of which were relevant to the energy storage [237]. The mentioned actions are as follow:

“

* development and operation of resilient, reliable, and efficient energy systems, able to integrate variable renewable sources;
* continue efforts to make EU industry less energy intensive and more competitive, e.g. by developing thermal energy storage technologies
* batteries for electric mobility and stationary energy storage
* bioenergy and renewable fuels for sustainable transport”

The first relevant actions addressed the ability of energy storage to enable the power system for accommodating high penetration levels of renewable energies. The other relevant actions directly address a specific energy storage technology, namely, thermal, batteries, and hydrogen.

In 2016 a document was published by the Commission that reports the agreement achieved between representatives of the European Commission on the implementation of the actions addressed by the 2015 SET‐Plan [238]. Based on the agreement, “the European member states will aim at developing and demonstrating technologies, manufacturing processes, science‐based standards, and regulations, to increase performance and safety and reduce the overall cost of battery systems used for storage purposes in the automotive and other sectors. “

Although the SET-Planaimed to make a consensus on the required BESS researches, the European battery alliance did not focus on the new technologies and there is a risk for not achieving the European ambitious plant for battery storage. As a result, in terms of manufacturing, Europe is behind its rivals [231]. Another risk is that the EU has not provided sufficient support for the innovative energy storage solutions to be deployed by the market.

Since the battery energy storages were a strategic part of Europe's energy transition and also a key enabling technology for the automotive sector, the Commission decided to support battery manufacturing through Europe. In the light of this decision, the European Battery Alliance has been established in 2017 that aims to create a competitive, sustainable battery-manufacturing value chain in Europe  [239].

Following the goals of the European battery alliance, the strategic action plan was set for the battery energy storage by the commission in 2018 that includes six main priority areas:

        Securing access to raw materials for batteries

        Supporting European battery cell manufacturing and other investments

        strengthening industrial leadership through accelerated research and innovation programs

        securing a highly skilled workforce along the whole value chain

        supporting a sustainable EU battery cell manufacturing industry

        Ensuring consistency with broader frameworks

In the same year, to adjust the European targets for the energy sector (electricity, cooling/heating, and transportation), the targets have been changed for the share of renewable energy resources in final energy consumption (20% by 2020 and 32% by 2030) [40] based on the Renewable Energy Directive II. To be more specific for the transport sector, the share of the renewable energies in the transportation sector that had been set to 10% by 2020 [234] was changed to 14% by 2030 [40].

For battery energy storage, the year 2019 was an important year. Serious movements have been started in 2019 to promote the battery industry in the whole of Europe. The stimulating step was a report to the European Parliament in 2019 [240]. The report estimated the annual worth of the battery markets to achieve EUR 250 Billion in 2025 and addressed the limited 3% share of the European countries compared to the 85% share of Asian rivals in the global battery energy storage market. The reports warned the policymakers that if no action is taken by the European countries, the consequences will be irreversible and the European battery industry will be left behind the rivals permanently. The strategic role of the battery industry in supporting the European automotive industry was also emphasized in the report. Construction of the 20-30 Giga battery energy storage manufacturing factories in the whole of Europe was suggested to the Commission. Job creation, accessing to skilled human resources, and promoting the battery energy storage industry was mentioned as the strategic goals for the European member states [240]. As a result, Battery Europe as the technology and innovation platform of the European Battery Alliance has been launched in 2019. Its main goals were to develop the European battery industry in the global market and to drive research activities related to battery storage technology [241].

In addition to the movements commenced in 2019 to promote the battery manufacturing industry, the regulations experienced a revolution in 2019 concerning the electricity market integration of the energy storage units. The very first problem at that time was the definition of energy storage that caused regulatory problems around the world and was reported frequently by the literature [146, 217, 225, 242, 243]. A clear definition has been devised at the European level that resolves the coverage of the storage domain to the various technologies and considers the non-generation capabilities of the energy storage units, while not limiting them to be classified as transmission, or demand assets. As is addressed by [244] “energy storage means, in the electricity system, deferring the final use of electricity to a moment later than when it was generated, or the conversion of electrical energy into a form of energy which can be stored, the storing of such energy, and the subsequent reconversion of such energy into electrical energy or use as another energy carrier”.

In 2019, a European level directive put an end to the continuous debates regarding the ownership of the energy storage units by the transmission and distribution system operators [244]. Respecting the unbundling of the ownership principle in the electricity markets, the European level regulation prohibited the transmission and distribution system operators to develop, own, operate, and manage the energy storage facilities. But there is enough room for these entities to derogate from this directive if some regulatory conditions are met provided to the approval of the domestic regulatory authorities. Based on this directive transmission and distribution authorities are able to own or operate the energy storage units if:

* A transparent tender is initiated under the supervision of the regulatory authorities and no other parties have awarded to own, operate, and manage the energy storage facilities,
* No other entities have the capability to procure the intended services cost-effectively and timely,
* The energy storage units were vital for the transmission/distribution operators to meet the obligations attributed to them in the same directive

Efficient dispatch/re-dispatch of the energy storage units, provision of the market-based incentives for the investment in the energy storage units, prohibition of discrimination against energy storage by the network tariffs, and definition of the appropriate products facilitating the participation of the energy storage units in the electricity markets were presented at the European level regulations [117].

To accelerate the deployment of renewable energy sources, an amendment is proposed for the Renewable Energy Directive II. It aimed to raise the renewable energy share set by Renewable Energy Directive II from 32% to 40% by 2030 [245]. In addition to the renewable targets amendment, the proposed directive emphasized the aggregation of the energy storage units, revision of the regulations of building construction and their associated retrofits, utilizing the small-scale BESSs to provide the system services concerning the connections issues, tariffs, and commitment times. Figure 52 illustrates the main European initiatives supporting energy storage technology, especially the battery storage fleet.

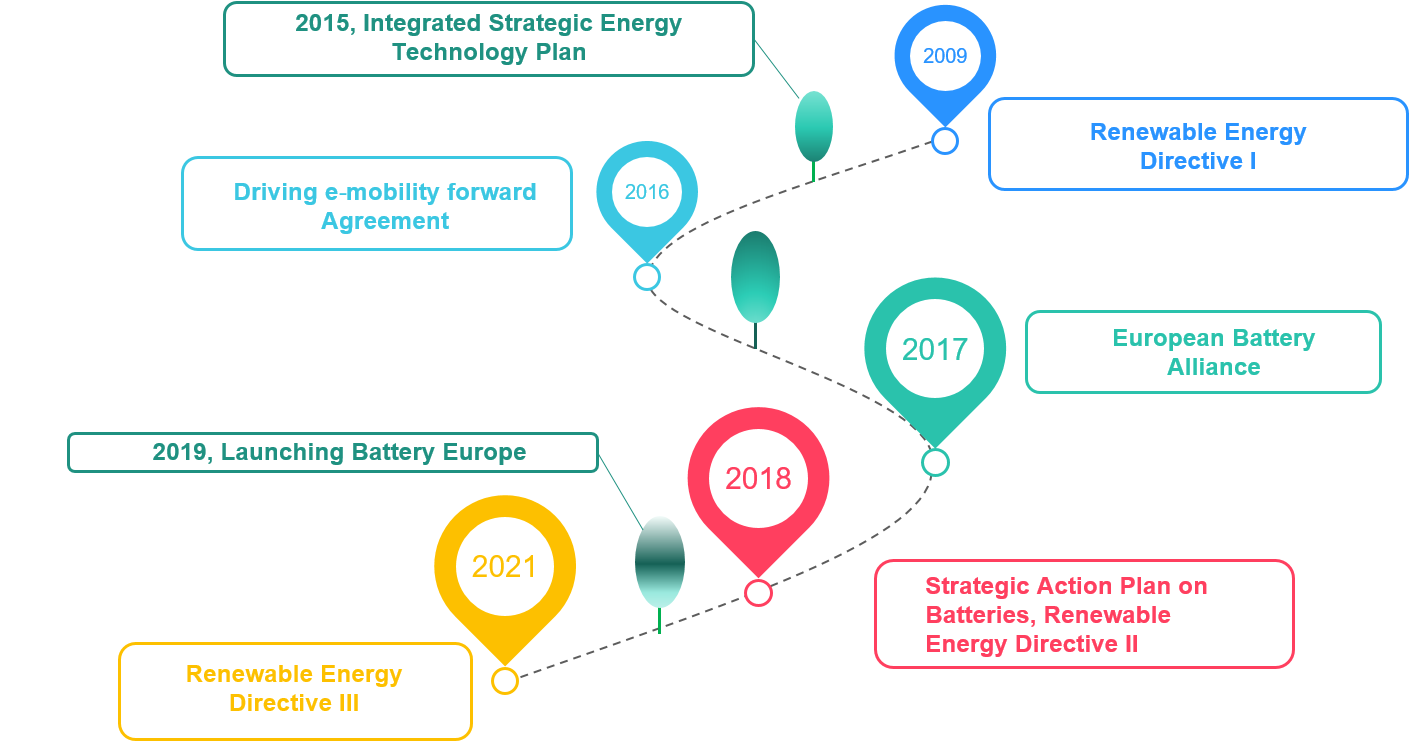


Figure The time-line of European Initiatives Addressing the Deployment of Energy Storage Technologies

## European Generation Mix

Figure European Countries Generation Mix

Based on the data available in [246], the European electricity generation mix for the first six month of 2021 is illustrated in Figure 53. As is seen, excluding the hydropower, 26% of the total electricity generation comes from renewable energies. In 2019, total electricity generation in the whole Europe was 2778 TWh [247] which is more than 75 times that of Ireland.

## European Storage Mix and Overview

Figure European Countries Storage Mix

Based on the data provided by the U.S department of energy [53] and some local data sources for Ireland [54] and Germany [200], the energy storage mix in the European countries is illustrated in Figure 54. The most dominated technology is the PSH and Germany possess the greatest share of installed energy storages. Spain has the largest thermal energy storage fleet among the European Countries.

Table BESS Installed Capacity by European Countries

|  |  |
| --- | --- |
| **Country** | **Installed Capacity [MW]** |
| Austria | 0.128 |
| Czech Republic | 0.07 |
| Denmark | 1.29 |
| France | 1.164 |
| Germany | 1487 |
| Greek | 2.4 |
| Hungary | 1 |
| Ireland | 122.547 |
| Italy | 133.611 |
| Netherland | 7.42 |
| Portugal | 12.01 |
| Slovenia | 0.01 |
| Spain | 4.906 |
| Switzerland | 1.03 |

To be able to meet the targets for 2050, the energy storage fleet should be expand up to six-folds in comparison to the level of 2018 [248].

Similar to the other leading countries on the deployment of battery storage, PSH account for 88% of the installed storage capacity in the whole Europe. Challenges such as geological limitations, public opinions and acceptance, and environmental issues may prevent form further expansions on this kind of energy storages.

## Regulations, Electricity Markets & Storages

The main topics that had been addressed by different parties [230, 231, 242, 249-251] regarding with the regulations accommodating the energy storage facilities in the power system at the European level are as follows:

* Consistent treatment mechanisms with the energy storages among the member states [249]
* Diversity in the grid fee regulation [230, 231, 242, 249, 250]
* Consistent cost-efficient use of the energy storages [231, 251]
* The definition of the energy storages [230, 242]
* Supporting research & innovation activities by the member states [231]
* Ownership of energy storage facilities by the TSOs/DSOs [231, 242]
* Connection to the distribution & transmission grid [231]
* Accessing to the market opportunities by the energy storages [230, 249]

Based on the most recent ratifications and directives at the European level the aforementioned issues are addressed to support the energy storage uptake for the future sustainable and carbon-free energy system.

**Ownership:** At the European-level regulation, the borders are crustily clear that whether the storage facilities could be owned by the transmission/distribution network operators or not. In [173], it is there is enough indication that the third parties are able to own, operate, expand, and manage the storage facilities with a satisfactory level of the associated costs, the regulatory authority must ensure that all activities of the DSO/TSOs will be phased out within 18 months. In such a case, the regulator should also have clear mechanisms to compensate the residual value of the investments done by the DSO/TSOs in the storage facilities. It is stated that the energy storage facility could be owned by the TSO/DSOs where can be recognized as the ‘fully integrated network components’. This refers to the components (including the energy storage facilities) that are integrated into the transmission or distribution system, and are solely deployed for providing a secure and reliable operation of the transmission or distribution system, and not for balancing or congestion management [173].

**Access to the Market:** Integrated electricity markets must ensure competitiveness and provide non-discriminatory access for the entire market participant including the energy storage to the opportunities of the electricity market. In addition, market rules must provide investment incentives for the provision of a sustainable energy system in which energy storage is one of the strategic components. Based on the internal electricity market design regulation at the European level [244], TSOs under the supervisor of the regulatory authorities, or the regulatory authority itself, must determine the specification of the non-frequency ancillary services, and standardized market associated with the mentioned services, at the national level. DS3 program In Ireland could be a good example of this regulation at the national level. This specification must ensure the non-discriminatory participation of the market participants including the energy storage. Facilitating the market development, the distribution and transmission operators must be coordinated and exchange all necessary information to this end [244]. As an example, the FlexTech program adopted in Ireland could be considered as the reflection of this European-level regulation at the national level, in which DSOs, TSOs, and the industry are functioning to support the utilization of the energy storage in the power system. It is stated that the pre-qualification process of the balancing market must be organized in a manner that ensures the non-discriminatory adoption of different technologies including the energy storage facilities. In addition, the product size in the day-ahead and intraday market should be sufficiently small, a minimum volume equal to 500 KW, to allow the effective presence of the energy storage facilities [117].

As is reflected in programs such as FlexTech in Ireland, DSO/TSOs must cooperate to achieve coordinated access to resources such as energy storage facilities that may support specific requirements in both DSO/TSO levels [117].

**Consistent cost-efficient Use:** Market rules must ensure the efficient dispatch for all of the resources including the energy storage facilities. In addition, market rules must function in a manner that no obstacle prohibits the energy storage facilities from entering/exiting to/from the electricity markets based on their operational financial viability [117]. Energy storage facilities are enabled to be re-dispatched based on a transparent and non-discriminatory manner unless it is not technically feasible for them to be treated as re-dispatchable facilities [117].

**Connection Issues:** Transmission system operators must facilitate the non-discriminatory and transparent process for the market participant including the energy storage facilities to have access to the transmission system. Moreover, transmission system operators are prohibited to refuse the connection of the market participants including the energy storage because of the possible future limitations on the available transmission capacity [244].

**Definition of the energy Storage:** The definition of storage has also been clearly addressed at the European-level regulation. Based on the definition in [244] “ ‘energy storage’ means, in the electricity system, deferring the final use of electricity to a moment later than when it was generated, or the conversion of electrical energy into a form of energy which can be stored, the storing of such energy, and the subsequent reconversion of such energy into electrical energy or use as another energy carrier”, the energy storage facilities are not limited to a specific technology. The definition reflects the time-shifting capability of the energy storage facilities and does not limit them only to the generation activities.

**Grid fee Regulations:** The issue of network tariffs and the associated challenges with the energy storage facilities are fully addressed at the recent European-level regulation. In order to provide a competitive and non-discriminatory playing field for the market participants, it is declared that the network tariffs should not be applied in a way that does positively or negatively discriminate between the producers connected at the distribution level and production connected at the transmission level [117]. In addition, it is stated that the network tariffs should not discriminate the energy storage and must not impose limitations on the demand response. The European-level regulations state that network charges must not discriminate either positively or negatively against energy storage or aggregation and must not create disincentives for self-generation, self-consumption, or participation in demand response [117].

At the European level there exits some long-term recommended actions obtained from the previous funded research works. In [242], supporting of the large-scale, continuing the basic material research to improve the manufacturing, and enabling the storage assets to contribute in the load shifting services were recommended. Removing the obstacles for the investors, supporting the research and innovation activities, market uptake of the energy storage and deployment of the innovative services are also addressed by [231] to be reflected to the policy makers.

# Storage Technologies

Different types of energy storage are designed and used for various applications [252-254]. Figure 55 depicts the classification of the energy storages based on their structural materials and storage mechanism.

Figure . Technology Classification of Energy Storages

## Electrochemical Storages

### Batteries

Electrochemical energy storages are structurally made from electrolytes and electrodes (positive: anode, and negative: cathode). Electrolytes could be solid, liquid, or paste.  Electrochemical reactions occurring between two electrodes in the electrolyte environment generate electric flow in an external circuit. Within the deployed battery storage technologies, the electrochemical reaction is reversible by applying a voltage across the battery terminals enables the battery storage to recharge frequently [255]. Excluding the hydrogen storage which consists of electrolyzer and fuel cells, different kinds of electrochemical batteries that currently have commercial application in power systems are as follows:

* Metal-air batteries

The metal-air batteries have a simple operating concept. The chemistry fundamental is that during the discharge, the anode is oxidized consuming the air oxygen, so the air takes the role of the cathode. Although this kind of battery storage have attractive characteristics (for Li-air) such as high specific energy (energy per unit of weight), greater than petrol and about 100 times of every other type of battery,  and high energy density (energy per unit of volume), one of their draw is the high reactivity of the Li with air and the danger of fire along with some other technical challenge are the main barriers for commercialization of this kind of batteries. Other metals such as zinc could be used instead of Li but with one-tenth of the specific energy compared to the Li-air batteries [253].

* Lead-acid batteries

The oldest technology that is also currently in use is Lead-Acid batteries.  Lead metal electrodes and lead oxide in an electrolyte of 37% sulfuric acid make the main structure of the lead-acid batteries. While discharging, the electrochemical reaction converts the electrodes into lead sulfate, and the electrolyte converts to water. Low cost, high efficiency, limited charging-discharging cycle life, and low energy density are the main specifications of the lead-acid batteries  [253].

* Sodium-sulfur batteries (Nas)

As is seen in Figure 46, NaS batteries consist of two molten Electrodes. The anode is molten sulfur and the cathode is molten Sodium. The electrodes are separated by a ceramic electrolyte (Sodium beta Alumina). Electrolytes cease the negative ions and only the positive sodium ions. In the discharging mode, sodium ions pass through the electrolyte and the negative ions flow through the external circuit. By applying a voltage across the terminal, the formed sodium polysulfide sets the sodium ions free, and returning through the electrolyte, they will be absorbed by the sodium element.  Long charging/discharging life cycle, preferable built-in terminal voltage for power system application, high energy density, fully recyclable materials except for sodium, emission-free, instant full discharging response (1 ms), and independent operation from the ambient temperature are the main characteristics of the NaS batteries.

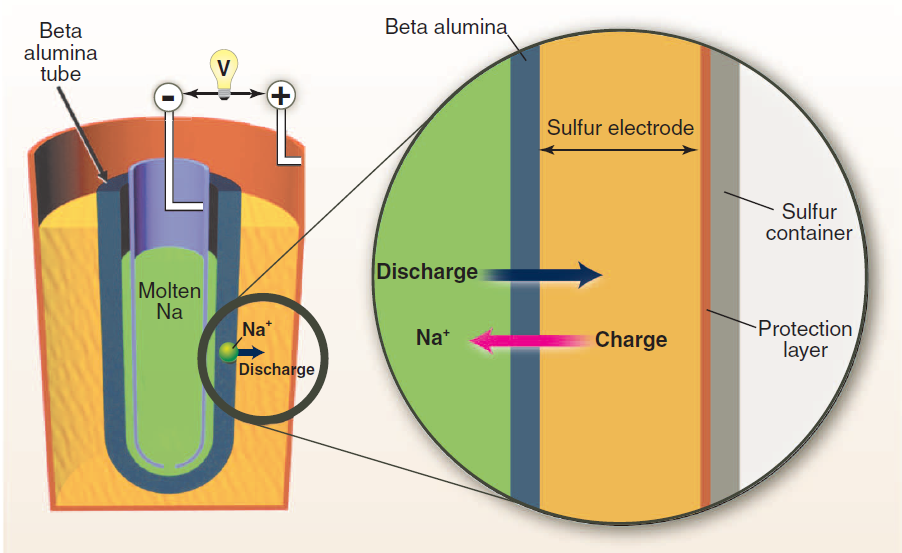


Figure . Schematic of NaS batteries [256]

* Nickle-cadmium Batteries (Ni-Cd)

The Anode of the NiCd batteries is nickel hydroxide and the cathode is made from cadmium hydroxide. A separator is used to isolate the electrodes from direct contact and they include an alkaline electrolyte. High energy density and low maintenance requirements make them an ideal option for portable devices. High cost associated with the manufacturing process and the toxicity of the cadmium are the disadvantages of NiCd batteries.

* Lithium-ion Batteries (Li-ion)

Li-ion batteries are widely used in the power system application. In this kind of battery, the anode is made of lithium compounds and the cathode is made of graphite that is capable to host lithium-ions in solid-state.  Since water violently reacts with Lithium, non-water-based electrolytes should be used in this family of batteries. Ionizable organic solvents such as propylene carbonate embedding sufficient lithium salts in solution. During the charging mode, ionized lithium atoms released from the anode move toward the carbon-made cathode and are reduced by the electrons to be deposited into the electrode atomic structure. During the discharging mode, this process is reversed. This family of batteries is one of the most efficient kinds of battery storage with an efficiency of almost 100%. The main drawback is the high manufacturing cost [255] which has a declining trend.

* ZEBRA (Sodium Nickel Chloride Batteries-Na-NiCl2)

This kind of battery is similar to the NaS battery since it is operating In high temperatures. A beta Alumina electrolyte separates two electrodes (Sodium and Nickel Chloride). The electrolyte is capable to pass the sodium ions. The advantages over NaS batteries are higher cell voltage, withstanding against overcharge and over discharge, and offering better safety characteristics [257].

* NiMh

In this kind of battery, the anode is made from nickel hydroxide and the cathode is a metal hydride electrode. The flexibility in the cell size, high voltage safe operation, satisfactory specific energy, maintenance free nature, and fully recyclable material make NiMh batteries as an idea option for the electric vehicles [258].

### Flow Batteries

Redox flow batteries and their simplified name flow batteries have a similar structure to the other kind of batteries except that the anode and cathode in the redox flow batteries are two circulating soluble redox couples [259]. Various materials can be used as electrolyte Such as ZnBr, VBr, PsBr, and NaBr [252]. When the battery is discharged, the catholyte is oxidized and the anolyte is reduced, to releasing the energy. The process is reversed while charging. The. Because of the nature of the anode and cathode in redox flow batteries, they are called Anolyte and Catolyte. A schematic of the redox-flow batteries is depicted in Figure 46.  As is seen, the electrolytes are pumped through the active cell area, and the ion exchange membrane enables the battery to exchange the required ions during charge and discharge. The energy capacity of the flow batteries depends on the electrolyte tanks and the quantity of the electrolyte, which could be theoretically unlimited. The power ratings of the flow batteries are the limiting factor and depend on the active area specifications of the cell [253]. Pumping the electrolytes through the active area solves the problem of the limited charging/discharging life cycle.

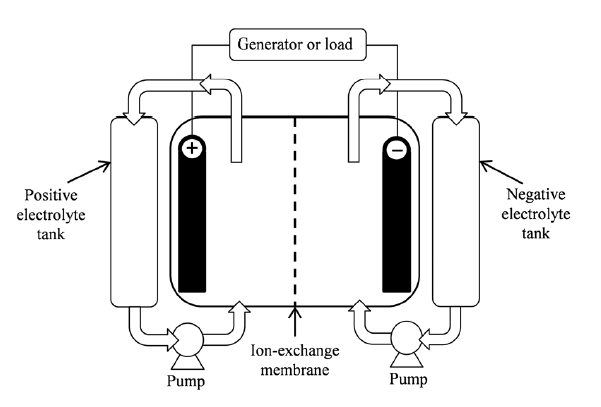


Figure . Redox flow batteries [256]

### Supercapacitors

Based on the mechanism of charge storage and the materials used in the electrode structure, electrochemical capacitors fall within three different categories namely, double-layer capacitors, pseudo-capacitors and, a combination of the mentioned types. By attracting the electrolyte solvated ions by the electrode, two layers are formed that are connected by the electrolyte in series. This process establishes the double layer electrochemical capacitors. Different materials such as metal oxides, conducting polymers, and carbon are used to make the electrodes [254]. The operation of the pseudo-capacitor is based on the Faradic charge transfer in the vicinity or on the surface of the electrodes.

Capacitators suffers from self-discharge problem and limited voltage range in comparison to the battery storage systems. Specific energy of the batteries is 30 times that of supercapacitors [254], however, supercapacitors are able to charge and discharge thousands of times since unlike the batteries the supercapacitors do not store the energy in the bulk of the material and instead deploy the surface adsorption reactions of charges and the electrodes. Due to this fundamental difference, volume changes caused by redox reactions are not associated with the supercapacitors and they can be cycled more than the batteries. The efficiency of the supercapacitors are satisfactorily high (>95%).

### Hydrogen Storages

Hydrogen can be stored using mechanical methods based on high pressures and low temperatures, as well as chemical methods which consist in embedding hydrogen in chemical compounds and releasing it upon demand. There are five storage possibilities for hydrogen:

* Geological storage of hydrogen in salt caverns or natural formations, including depleted oil and gas fields and aquifers.
* Compressed cylinders or tubes
* Cryogenic tanks
* Chemical storage in solid materials
* Chemical storage in liquid carriers

Geological storage is attractive for large scale production and utilization of hydrogen which may involve applications to all the sectors (heating, transportation, and electricity). This type of storage is also the most economically viable for large scale grid application.

Hydrogen can be stored in the form of compressed gas or cryogenic liquid, and transported using cylinders, tubes, and cryogenic tanks for use in the chemical industry or as propellant in space applications. Storage in gaseous form requires high-pressure tanks (350-700 bar), whereas storage in liquid form requires very low, cryogenic temperatures since boiling point of hydrogen at atmospheric pressure is -252.8°C [260]. Another potential solution for hydrogen storage is embedding it within solids (or on their surface), possible solutions include metal hydrides and hydrogen adsorption in porous materials such as metal-organic frameworks (MOFs), zeolites, carbon nanotubes (CNTs), and graphene [261]

Furthermore, hydrogen can be stored in liquid organic hydrogen carriers (LOHC) systems, with the advantage of enabling the use of the existing fuel infrastructure for hydrogen storage and transportation. Hydrogen storage in LOHC systems requires an exothermic hydrogenation chemical reaction and an endothermic dehydrogenation reaction, which are carried out at the same temperature level. LOHC charging through catalytic hydrogenation occurs at high hydrogen pressures (above 20 bar) which can be provided by electrolysis or methane reforming. LOCH discharging (release from the LOHC system) occurs at low hydrogen pressures (less than 5 bar), hydrogen takes place. Guaranteeing the stability of the LOHC system over several charging/discharging cycles conflicts with achieving a high power-density of hydrogen production [262].

Hydrogen production and storage can be seen as a flexible load from the grid point of view; therefore, electrolysers and storage sites offer a solution to store energy at grid scale by converting electric energy into hydrogen and then converting back hydrogen into electricity using a fuel-cell, when required. It is foreseen that hydrogen can be used for all the services requiring power balancing of demand and supply at grid scale. Demonstration of such systems has already begun at a small scale in stand-alone power systems. A hydrogen-based system is currently in operation is currently in operation at Neo Olvio of Xanthi, Greece [263]. This stand-alone system includes a photovoltaic array and wind generators. It uses water electrolysis to store the excess of energy produced by renewable energy sources (RES) converting it into hydrogen, as well as a polymer electrolyte membrane (PEM) fuel cell to convert hydrogen back into electricity. This type of systems will require the development of power management strategies to enable the capacity to meet the load demand and to effectively use the electrolysers and fuel cells taking into account the variable energy production from solar and wind generators.

## Mechanical Energy Storages

### Pumped Storage Hydro Power Plants

Pumped storage hydro power plants deploy the elevation difference between two water reservoirs to generate electric power. In charging mode, electric pumps feed the upper reservoir picking water from the lower reservoir. In the discharging mode, stored energy in the form of hydro potential turn the hydro turbine – generator by going through the pipelines connecting the upper and lower reservoirs. By applying vale control, the output power could be controlled like ordinary hydro power plants. It is possible to deploy drive system to enable the pumps to procure demand response services such as regulation service. The efficiency of the PSHs depends on the efficiency of the pumps/generators and the amount of water loss caused by evaporation in the free air, and it lies normally between 70-80% [254]. The main advantage of the PSHs over the batteries are the long life time (50-100 years) while the high required capital cost, availability of the natural reservoirs, and the environment impacts of the PSHs projects are attributed to their disadvantages. It is remarkable that the capital cost per unit of energy is not high since the power rating of the PSHs is typically 1000 – 3000 MW [255].

### Flywheel

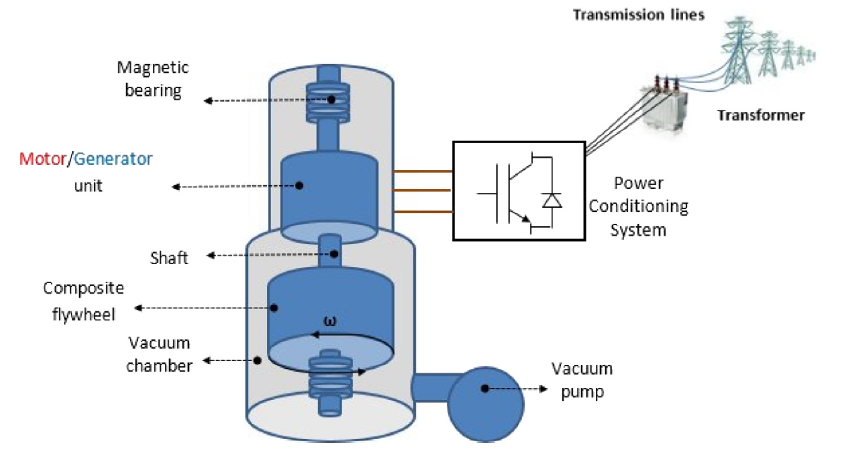


Figure . Flywheel energy storages [252]

Flywheels deploy simple physics concepts, the stored energy in the angular momentum of a rotating mass. In the charging mode, a motor rotates a rotor shaft, driving a flywheel in a vacuum chamber (Figure 48). In the discharging mode, the prime mover is the kinetic energy stored in the rotating mass in the vacuum chamber, and the motor converts to a generator injecting the electric power into the network. The energy rating of the flywheel depends on the size of the rotating mass and the speed of the rotor while the power rating depends on the motor/generator specifications. Flywheels are commonly used for high-power short-duration purposes. This characteristic makes the flywheels an ideal option for power quality problem mitigation and as a bridge to switch between the power supplies.

The efficiency of the flywheel storage is highly dependent on the storage time. The average efficiency of the flywheels are around 85% that could significantly drop to 45% after 24 hours [252]. Efficiency issues make the flywheels not suitable options for long–term energy storage purposes. Metal rotor flywheels suffer from high standby losses while the composite flywheels improve the efficiency [255]. By the deployment of magnetic levitation, superconductor magnetic bearings, and some other new technologies [254], manufacturers aim to improve the efficiency of the flywheels. In comparison to the BESSs, lower power density, high manufacturing cost, noise pollution, and maintenance requirement, are the disadvantages of the flywheels. Long cycle and operation life, low environmental impacts are attributed as flywheel storage system advantages over battery storage systems.

## Thermodynamic Energy Storages

### Pressure (Compressed/liquefied Air Energy Storages)

In this family of energy storages, natural caverns such as aquifer strata, underground natural gas/crude oil fully extracted resources, or artificially made reservoirs such as abandoned mine caverns could be used to store compress air when excess energy is available. When such geographical privileges are not available, huge tanks that can resist high pressures are buried underground and used instead of caverns, naturally with increased project cost. The other option is to used liquefied air keeping its temperature between -150 to -273 °C that requires moderate pressure reservoirs. The liquefied air energy storage are more efficient than the compressed air family [264]. Similar to the PHSs, the CAESs are also bulk energy storage systems and has low cost per unit of storage capacity. Long operation life, long duration discharge, and large capacity are the main advantages attributed to the CAESs.

CAESs comprises a motor that drive a compressor when excess energy is available and store the compressed air in the reservoir. In the discharging mode, the compressed air goes through an expander, which in turn drives a generator to generate electric power. Early CAESs were diabatic and subject to high losses in terms of heat during the compression process. In addition to the heat loss in the compression stage, cooling down the turbine during decompression requires additional thermal energy consumption that causes the whole storage system to have very low efficiency (around 42-54%). Newer generation of CAESs are adiabatic and use the heat energy released in the compression process to decrease the heat energy requirements in the decompression process. In advanced CAESs, heat storage are used to make this possible [265].

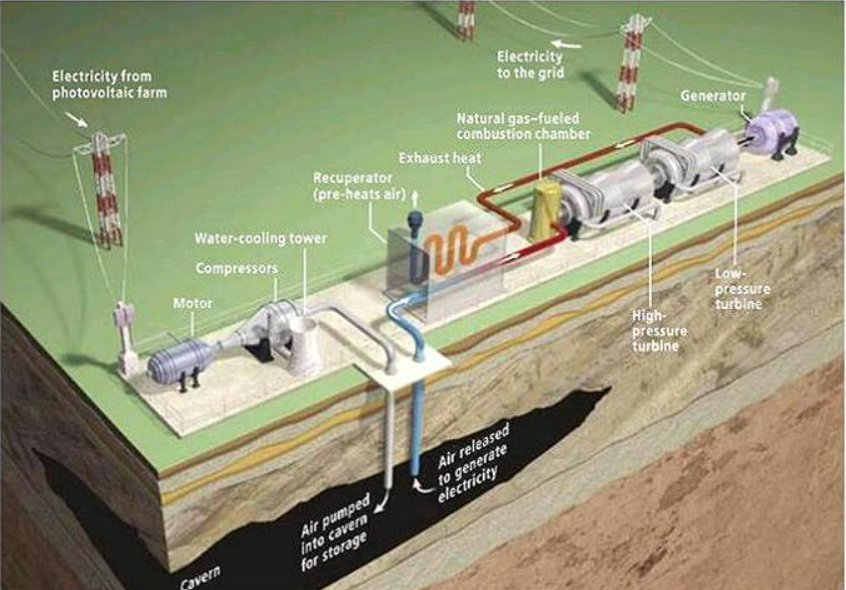


Figure . Schematic of a Typical Compressed Air Energy Storage [266]

### Thermal Energy Storages

Thermal Energy Storages are used for a vast amount of applications. Containing the materials that are capable to be kept at low/high temperatures, the stored heat/cold could be extracted and applied for electricity generation by using the heat engine cycles. Typical thermal energy storage has low efficiencies (60-70%).

Low-temperature thermal storages have two main categories, aquiferous and cryogenic Energy Storages. In the first one, water is converted to the ice during off-peak hours using a refrigerator and the stored ice will be later used (in peak hours) to supply the cooling demand. In the latter, the cryogen which is normally liquid nitrogen or liquid air is produced during the off-peak hours and during the peak hours, electricity is produced using a cryogenic engine. Cryogenic energy storages have low efficiency (40-50%) [255]. Early high-temperature energy storages were in the form of sensible heat that means to increase the temperature of a material. In contrast, latent thermal energy storages are based on changing the phase of material (for instance from liquid to gas) since the phase changing is isothermal (no need for temperature change). This family of energy storages are fitted to energy management in the buildings [252].

## Magnetic

By using cryogenic materials, the temperature of a coil is preserved in the cryogenic temperature where the electrical resistance is diminished and the coil becomes a superconductor. Flowing DC current through the coil, a magnetic field is established in which the energy could be stored. This is the fundamental idea of superconducting magnetic energy storage (SMES). The core advantage of the SMES is the ability to discharge instantly and deliver a large amount of power for an unlimited life cycle. Magnetic energy storages, based on the accompanying converters and the control concepts have various implementable applications in the power system  [267]. Due to the cryogenic vessels required to preserve the cryogenic temperature, there is some energy loss but the SMES are highly efficient (more than 95%). High power capacity, the fast response time (less than 100 ms), high efficiency, no environmental impact, no noise, and deep charge and discharge capability are attributed as the advantages of the SEMS while cooling requirements, high cost of raw materials (titanium for the coil), and design complexity open up the windows for further researches in this field  [252, 267].

## Hybrid Energy Storages

Combining different technologies, hybrid energy storages are trying to improve the advantages and mitigate the disadvantages of the individual technologies. Researches are conducting in this filled to make hybrid energy storages suitable for specific purposes [268]. The following subsections briefly introduce the hybrid energy storages in use.

### Thermo-chemical Energy Storages

This family of energy storage deploys chemical reactions in a forward-backward direction that release/require thermal energy. The operating stages are endothermic dissociation, storing the products of the reaction, and finally, the exothermic reaction of the dissociated products. At the final stages, the primary materials are recreated and make the whole process repeatable. Whit respect to the ordinary latent or sensible thermal storage, thermo-chemical energy storages have a higher energy density and lower energy loss [254]. Thermochemical energy storages are fitted for the applications that require low space and it is undergoing of research and development.

### SMES-Battery Energy Storages

Battery energy storages have proven application for make the power flow smoother. The main drawback of the battery storages is that they could not tolerate deep charging and discharging cycle frequently. Combining the SMES and battery storage can mitigate the cycling problem of the battery storage and smoothing the power flow simultaneously [269].

### Flywheel-battery Energy Storages

Flywheel – battery hybrid energy storages are proposed to improve the life-cycle of the electrochemical battery storages. The high-power short-duration nature of the flywheels enable the hybrid flywheel battery storages to avoid deep discharge of the battery energy storages during the peak load demand and hence increase the life time cycle of the included batteries. Proposed to use the hybrid flywheel-battery storages In the microgrid and showed that the life-time cycle of the li-ion batteries could be increased up to 3.6 compared to the individual utilization of battery energy storages [270].

## Comparison of Different Technologies with BESS

Levelized cost of energy (LCOE) has been calculated for different storage technologies in [271]. LCOE for an energy storage technology is defined as the economic resources that a storage technology

requires to charge the storage system and it is calculated per unit of energy that the storage device delivers. To address the capital cost, operation and maintenance cost (both of fixed and variable costs), and the replacement/recycling/disposal costs, the total life cycle cost of Storage (LCCOS) storages are calculated to give a yearly estimation of the total costs and it is expressed in an annualized form €/kW-year. The life cycle costs depend on many factors such as the efficiency of the technology, charge and discharge duration, and the supplied energy costs. A sensitivity analysis has been performed to evaluate the life cycle cost for different energy storage technologies in

[271]. Table 11 contains the LCOE and LCCOS of each energy storage technology.  The lower bound of the LCCOS corresponds to maximum efficiency, minimum discharge time, and maximum lifetime/cycle of the intended technology while the upper bound represents the associated costs to the minimum efficiency, maximum discharge time, and minimum lifetime/cycle. In [254] a number of papers were reviewed to obtain the Power density, energy density, cycle efficiency, and life time cycle of different energy storage technologies and the associated ranges were reported via a reference based approach. The most five right columns of Table 11 contains the upper and lower bounds reported by the references reviewed by [254] for the aforementioned specifications. Figure 60 illustrates the advantages and disadvantages of the different technologies with respect to the battery energy storages based on the review has been done in this section.

Table comparison of different energy storage technologies

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Technology** | **LCOE**  **€c/kWh** | **LCCOS**  **€/kW-year** | **Power Density (kW/m3)** | **Energy Density**  **(kWh/m3)** | **Energy Density**  **(Wh/kg)** | **Cycle Efficiency (%)** | **Life time**  **(Cycles)** |
| PSH | 15.67 | 240-520 | 15-100000 | 1-35 | 0.2-1.5 | 60-100 | 104-106 |
| Underground CAES | 22.82 | 260-700 |  |  |  |  |  |
| CAES | 24.43 | 260-730 | 0.04-10 | 0.4-20 | 3-60 | 41-90 | >104 |
| NaS | 28.98 | 48-340 | 1-180 | 150-350 | 100-250 | 65-90 | 1000-4500 |
| SMES | 36.92 | 32-98 | 300-4000 | 0.2-14 | 0.5-75 | 80-99 | 104->105 |
| Hydrogen [271] | 44.28 | 150-540 | >500 | 500-3000 | 800-10000 | 20-66 | 1000-20000 |
| Flow Batteries (VR) | 44.41 | 75-900 |  |  |  |  |  |
| Flow Batteries (ZnBr) | 46.64 | 55-514 | 0.5-2 | 16-70 | 10-50 | 60-90 | 800-1.6x104 |
| Supercapacitors | 54.03 | 14-70 | 15-100000 | 1-35 | 0.05-15 | 60-100 | 104-106 |
| Lead-Acid | 58.68 | 60-890 | 10-700 | 25-90 | 10-50 | 75-90 | 100-2000 |
| Flywheel | 50.02 | 28-105 | 40-5000 | 0.3-400 | 5-100 | 5-200 | 104-107 |
| Li-ion | 61.1 | 90-1310 | 60-10000 | 90-750 | 6-300 | 85-98 | 250-104 |
| NiCd | 64.11 | 90-640 | 60-700 | 15-150 | 10-75 | 60-80 | 500-2500 |

*Figure 60 Qualitative Comparison of Different Technologies with Battery Energy Storages*

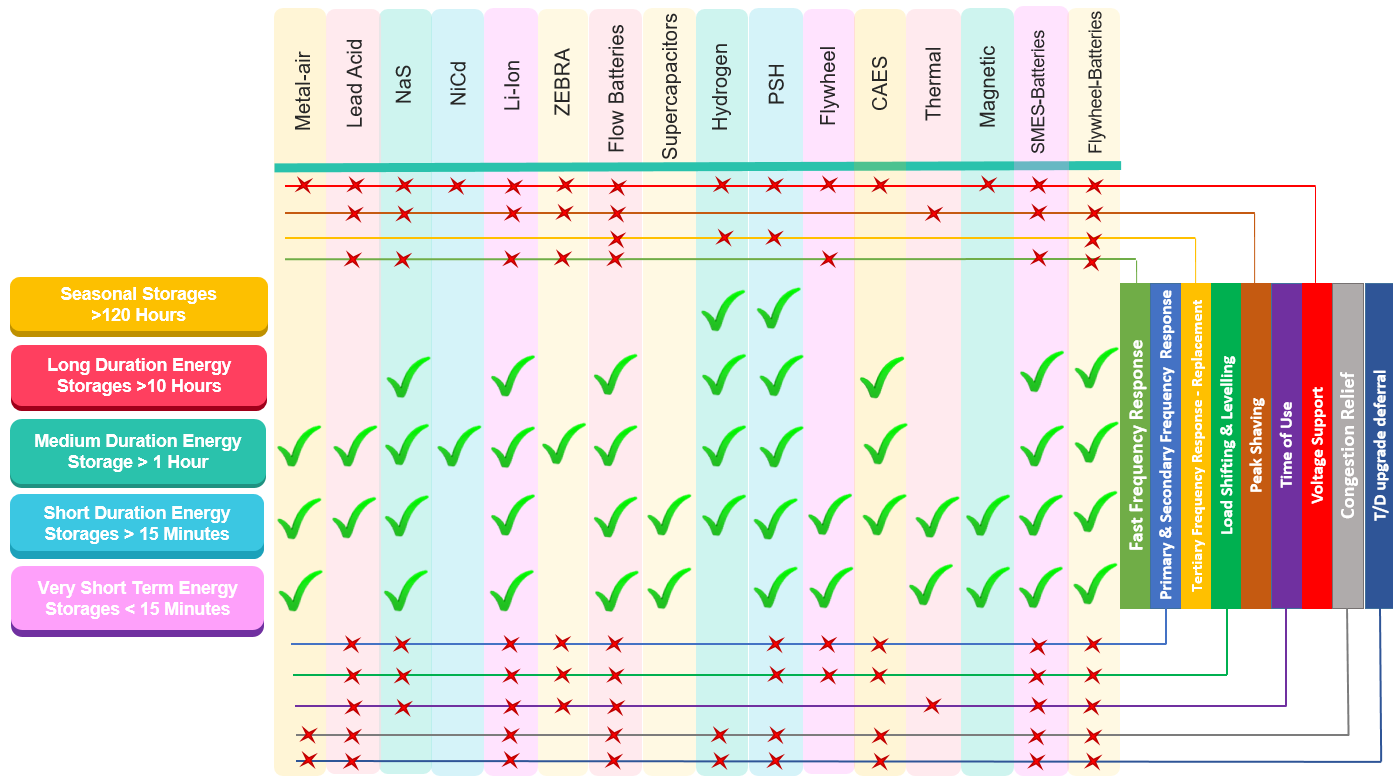


Figure Classification of energy storage based on the discharging duration and their applications [26, 254, 271],

## Dominant Storage Technologies and Key Points for The Policy Makers

Pumped hydro storage has the highest installed capacity (around 94% of the total installed energy storage capacity) among other storage technologies and globally is able to provide 9000 GWh of energy [272]. Based on the information presented in Table 11, PSHs have the lowest levelized cost of energy in comparison to all other storage technologies [271]. Maturity of the technology, reputation as long as history, proven ability to serve the power system in case of need, and low LCOE are the most pertinent factors that achieve the PSHs to the first rank of installed storage capacity.

Considering the international energy agency statistics, this is the fifth subsequent year that the dominated installation capacity for the storage is registered by the Li-ion batteries [21]. It should be noted that these statistics exclude the installation of the PSHs.

Looking into the information presented in Table 11 discloses that the LCCOS of the PSHs is comparable or in some cases multiples of the other existing technology. A closer look reveals that the energy density per volume and energy density per weight of the PSHs in most of the cases is dominated by the other technologies. Li-ion and NaS electrochemical batteries storages possess the top ranks from the energy density point of view. This implies that the battery storage is pushed by the industries that the volume and mass matter, for instance, the EVs and portable electronic devices such as Notebooks and Laptops.

Based on the information reviewed in this report ([192], [185], [203], [179], [164]) until 2050, the total amount of planed PSHs capacity by the leading countries deploying BESS is more than 636 GW while the total planned battery storage fleet to be installed is 94 GW (see Figure 62). It is notable that china and the united states plan to install 620 GW [164] and 50 GW [179] of PSH by 2050. As a result, they will have more than 677 GW of PSHs.

It is remarkable that based on the IEA storage report, Japan, Australia, and the whole of Europe (as is emphasized in this report, Germany) is expanding the residential (behind the meter) battery storage fleet. Moreover, as is mentioned in section ‎‎6.2.3 for South Korea, behind-the-meter battery storage units have the largest contribution in the battery storage fleet and account for 57.8 % of total battery storage volume in 2019 [185]. For the future plan in Korea, the peak shaving capacity of the behind the meter units will also be 16 times that of 2019 [185].

This high-level analysis makes the interpretation of the information presented in Table 11 (associated with the energy density per volume and weight) more understandable. Behind the meter battery storage will be installed in the residential areas where the volume and the weight of the battery storage matters and this is the point in which policies of the automakers and BESS supporters are lined up. It clearly shows that the main policy lines of the BESS expansion should not be only rummaged in the electric power industry.

Figure Comparison of planned BESS & PSH Capacity Installation until 2050 by the Leading BESS user Countries

Based on the available data from international energy agency, the transport sector contributes to nearly 25% of global energy-related CO2 emissions [273]. As is seen from Figure 63, 40% of the total CO2 emission came from transportation sector (in 2018) that necessitates the importance of electrification in this sector [274].

Figure Ireland’s CO2 Emission by Sector, 2018 [274]

Considering the analysis has been done in this section, one of the most important drivers that integrate electricity industry in the deployment of battery energy storages could be the requirement of automotive industry to develop specific family of battery storage. This fact has been reflected even in the location in which the battery storage are used in the electricity sector, namely the behind the meter and residential battery storage systems. It is notable that the end-user electricity price will be affected by any kind of policies supporting any kind of technology in the electricity industry. Although the electrified transportation system users will be the electric power end-users, in the transition phase, policy makers are recommended to pay enough attention that supporting the electrification of the transportation sector should not only stressed the current electric power end-users.

Based on the available data Ireland plans to install 1.11 GW new PSHs [48, 49] while it aims to install 2.5 GW of BESS [54]. Figure 64 compares the planed energy storage mix for the leading battery storage user countries and Ireland.

Figure Comparison of Ireland’s planned storage mix and the leading battery storage user countries

Ireland[[13]](#footnote-14) is one of the European countries that has the lowest potential for the expansion of PSHs. In Ireland, the realisable potential for the PSHs with a maximum of 20 km distance between the upper and lower reservoirs is reported to be equal to 94 GWh (the overall European is 33 TWh). It represents meaningful difference with the other European countries such as Sweden (3081 GWh), GB (5292 GWh), and Spain (9363 GWh) [275]. Considering the limited potential for the PSH in Ireland, It is recommended to assess that whether the deployment of this minimum potential could reduce the energy cost for the end-users at least in the next ten years planning horizon.

# Barriers to Storage Deployment

## Non-efficient Dispatch/re-dispatch of the Energy Storage Units

As is addressed in sections ‎4.10.10 and ‎4.10.11 the energy storage units should be available by their full capacity (have zero physical notification) for the provision of the DS3 services. It is obvious that the contracted battery storage capacity should be available at the time of system requirement. In addition, the inherent characteristic of these services is their time uncertainty and real-time operational dependency. Keeping all these in mind, complete prevention of the storage fleet from active participation in the ex-ante markets is a discriminatory manner. To conform to the European level legislation, that addresses the efficient dispatch and re-dispatch of the energy storage unit should only be subjected to the technical feasibility [117], the current instruction in Ireland requires a reconsideration.

It should be noted that the real-time operation of the power system completely occupies the capacity of the system controllers and there will be no room for the economic efficiency concerns of their decision. This is the point that the electricity market tools start their services and could help the system controllers by the provision of efficient merit order lists. Although the security-constrained unit commitment and the security-constrained economic dispatch are employed by the TSOs to balance the real-time system requirements [90], and the production and consumption schedules will be determined based on an economic ground [276], the follow PN rule prevents the energy storage units to be dispatched efficiently since they will be dispatched irrespective of their bids [111]. This manner is clearly addressed in [118] by the following sentences “The Providing Unit would be expected to bid into the Balancing Market in line with their TSC obligations. However a “Follow PN” rule would be put in place in the scheduling software to ensure that they are not scheduled to generate or consume differently to their PNs, and their scheduled generation would therefore be equal their PNs – i.e. it would be 0 MW if the Providing Unit submits a PN of 0 MW. This would be irrespective of their submitted bids.” (see section ‎4.10.11 for more information).

For any reason, if it is required to deviate from the physical notification of an energy storage unit in the balancing actions , the dispatch will not be based on an economical ground as is stated in [118] with the following sentences “Any decisions taken to dispatch the Providing Unit differently to their PN would only be triggered manually by the system controllers, rather than economically through the schedule”. However, the unpredictability is an inherent characteristic of the real-time operation and these deviations are inevitable. Efficient dispatch will be only possible if the service providers are allowed to actively participate in the electricity markets. Considering the increasing available capacity of the BESSs, the current situation requires reconsideration.

## Ambiguous Vision of the Energy Storage as a Replacement/Deferral for Network Expansion

As is addressed by national development plan [104] (see section ‎4.10.1) energy storage units could act as a complementary approach for network reinforcement. The energy storage has technically proven and practically experienced contribution on the network expansion deferral [222] (see section ‎6.2.7). In addition they reduce the operation/maintenance cost of the network. Considering these abilities, there is not a clear evaluation mechanism for the energy storage units, the services could be defined, and the revenue stream should result from this potential for the energy storage units in Ireland.

As is addressed in [120] (section ‎4.10.17), CRU aimed to review the tariff structure for the DTUoS at the transmission level. The losses could be affected by the energy storage operation in the distribution and transmission level. In light of this fact, the costs associated with the losses should also be reviewed by the regulatory bodies in a coordinated manner. The same discussion could be raised for the distribution network as well. Based on the multi-role functions of the energy storage units, the balanced and efficient decisions on the different parts of the network tariffs could be achievable by comprehensive coordination between the regulatory bodies. Considering this fact, it could be a potential barrier if the regulatory bodies solely focus on the DTUoS review.

## Dealing with the Charging Mode of the Energy Storage Units in the Electricity Market

Based on the SEM trading and settlement code, all units above 10 MW must be recharged via a dispatch instruction. To prevent cycling issues for the battery storage units, a maximum number of 10 dispatches per year, in addition to the normally less than 20 minutes frequency event responses, is approved by the TSOs. This limit does not include the charging dispatch instructions [118]. It is also stated that by removing this annual maximum limit for out of frequency response dispatch orders, the energy storage unit will be treated as a normal service provider and the follow PN rule will not be applied for them anymore. Therefore, based on the current instructions, the energy storage units should desist from their cycling concerns to be treated normally in the ex-ante electricity markets.

The abnormal treatment with the BESSs is explained in this section. As is addressed by [118], a negative physical notification is essential for the BESS to be able to be recharged by dispatch instruction. The negative physical notification should be reflected to the TSOs as well. Follow PN rule obliges that the market schedule will not differ from the submitted negative physical notification and they will be able to recharge their asset. Although the BESS can have a negative physical notification [116] and the physical notification itself, is a power profile extended over a specific time period, it should reflect the position of the energy storage units in the ex-ante markets [90]. In addition, based on the obligations of the trading and settlement code, the BESS should submit zero price-quantity pairs in the ex-ante markets [116], which means that they will have a zero physical notification. Considering this obligation, the only tool in the hand of BESS to be scheduled in the charging mode is the target charge level at the end of trading day that should be submitted by them as a commercial offer data. Based on the instructions, the market scheduling software takes it as a minimum charging target for these units. By using this option, the BESSs could not affect the duration of their charge, while they could be penalized if they will not be recharged and be available within 8 hours after a frequency event (see section ‎4.10.12 for more information). Another inefficient option is to rely of the non-scheduled dispatch instructions in the balancing markets which will not be issued on an economic ground and will be triggered manually by the system controllers (see section ‎9.1 for more information).

This treatment is discriminatory in comparison to the conventional generation fleet since no reduced payment for the energy storage units is subjected to not existing the security issues. For instance, a combined cycle gas power plant will not be subjected to any financial penalties because of their minimum downtime constraint and instead, they will be treated in a manner that the market schedule covers their technical/operational constraint. This is done by enabling them to submit complex bids in the pan European day-ahead electricity market or directly modeling the generation fleet constraints in the market scheduling optimization problem (see section ‎5.1.4, Constraint Redemption Arrangement).

Another discriminatory aspect arises from the procedure adopted for constraint payments (see section ‎4.10.13). As is addressed by [116], in case of any difference between the dispatching production cost and electricity market schedule production cost, compensative payments will be made to the affected units. These payments are made regardless of the causes of difference and are called constraint payments [116]. However, as is clearly stated in the trading and settlement code, “There shall be no constraint payments in respect of pumped storage units or battery storage units” which reflects an unfairly discriminatory manner dealing with different technologies in the electricity market. Consider a situation that a battery storage unit submitted a negative physical notification. Therefore, conforming to the follow PN rule, it has a negative scheduled power, but due to a security issue such as a frequency deviation, it should automatically respond to procure the required frequency services. In such conditions, no constraint payment will be made to the battery storage unit. In addition, even if it is capable to provide the required services, it will be subjected to a reduced payment because of the reduced performance availability scalar[[14]](#footnote-15) (see section ‎4.10.13). As an example of the treatment with storage units in case of unfavorable dispatch, the method in the USA could be mentioned that covers the costs associated with unfavorable dispatch by use of make-whole payment for the battery storage (see section Regulations, Barriers & Policy Recommendations ‎6.2.2.4).

## Budget Limitations and the DS3 Program Payment Rates

There is an expenditure limit determined by the regulatory bodies on the DS3 program services purchased by the system operators. As is addressed in section ‎‎4.10.7, by increasing the capacity of fast-acting service providers, the payment rate should be decreased. It is in line with the economy of scale, while the cost of a product will be reduced by increasing the capacity of the production but the question is, in the expansion phase of the BESSs, does this mechanism generate the efficient economic signal for the investors? This matter exacerbates when it comes to a more necessary reduction in the payment rate by encountering high wind scenarios, which necessitates a 50% more reduction in the intended services payment rate in comparison to the normal wind scenarios[113]. As the matter of fact, this mechanism does not conform to the basic concepts of demand and supply interactions where an increasing demand causes higher prices, results in more earning for the service providers, and facilitates more investment in the limited capacity of the services.

## Proper Definition of the Black Start Services

It is mentioned in section ‎‎4.10 (black start) that the pumped-storage hydropower plant has already been contracted for the provision of the black start service[109]. Although the current capacity of the battery storage may not be sufficient for the provision of the required services during the power system restoration process (TSOs should comment on this matter), the expanding battery storage fleet may bring them to the ring of suitable candidates for the provision of such services in near future. BESSs have proven potential to provide various services during power system restoration (see section ‎5.1.2). BESSs can provide the following services [142] during the system restoration process and deserve revenue streams for these capabilities if the pricing mechanism and remuneration methods are determined for these services.

* Energizing the non-black-start generation fleet,
* Provision of sufficient loading for the transmission system to prevent overvoltage during the system restoration process,
* Balancing the power flow by optimized utilization of the battery storage units during the restoration process,
* Provision of ancillary services during the power system restoration process

## Single Revenue Stream

Full potential of BESSs will be deployed if they have access to the following revenue streams:

1. Energy arbitrage
2. Ancillary services including the system restoration services
3. Capacity markets
4. Transmission/Distribution system upgrade deferral

Considering the DS3 program, the contract holders are only active in the ancillary service provision while this reflects only a small corner of the potential energy storage capabilities. Based on the reviews that have been done in this report on the current electricity market procedures applicable to the energy storage units, there is not a clear opportunity for them to actively bid in the day-ahead and balancing market for the purpose of energy arbitrage. Zero physical notification and follow PN rule that is applied to the energy storage units (see section ‎4.10.10) prevents them to unlock their potential in energy arbitrage and abandons them from an important revenue stream. The capacity market schemes have also not attracted the BESSs to a satisfactory level.

## Side-payments to Generation Technologies

Based on the trading and settlement code of the SEM [116], the start-up cost recovery of the convention generation fleet should be guaranteed. As it is mentioned before (see section ‎4.10 and ‎7.1.4 for more information), side payments due to the start-up recovery is a problem originated from the electricity market design and the minimum power constraint of the conventional generation fleet. Briefly, an inherent specification of specific technologies, along with the market design issues, cause to make side payments in favor of those specific technologies in the electricity markets. Cycling problem of the energy storage is also an inherent specification of the energy storage, which is treated differently in the electricity market procedures. As is mentioned before, side payments in favor of a specific technology are currently a common measure in the electricity markets. It may be reasonable to assess the cost-benefit analysis of the required expenditure to cover the aging and cycling costs of the BESSs within a market-based approach and utilize their services to reduce the final electricity cost for the end-users instead of putting 10 dispatch limits and subjecting them to inefficient dispatch during the charging mode. As is addressed in [90], if a wind power producer is subjected to the output power limit due to the SNSP or other constraints, it will be compensated. It should be noted that although this manner is a supportive policy for the wind farms, it may affect the incentives to deploy the co-located BESSs in the whole Island.

## Transmission Network Charges- the Interim Solution

As is addressed in section ‎4.10.17, CRU proposed an interim solution dealing with the transmission network charges for the energy storage units. Based on the proposed solution, the CRU ceased the doubly charged regime of the storage units and decide to apply the DTUoS charges to the energy storage unit [120]. Although this is a good step forward, it should be noted that the GTUoS constitutes only 25% of the total collectable revenues from the network costs in the 2020/21 tariff year, while the DTUoS contributes to 75% [120]. It means the energy storage units that are not inherently the electricity end-users, are classified to be treated as the demand side and pay three-quarters of the transmission costs. The mechanism is not clear for different kinds of energy storage that will be installed in near future. For instance, a co-located battery storage unit that provides capacity firming and generation time-shift services for the renewable energy resources is also subjected to pay the DTUoS?

## Connection Issues

CRU adopts  ECP-2 to manage the connection offers to different submitted requests (see section ‎‎4.10.19). Based on the published document [126], no more than 10 primarily storage and other system service providers could be granted in ECP-2 based on the understanding that most of the storage projects with planning permission in hand gained that permission since 2017 and not limiting the number of such project for the grid connection phase, would be an unnecessary prioritization of these projects. Although the position of the regulatory bodies could be true by preventing unnecessary prioritization of the energy storage projects, a lack of information about the size and duration of the energy storage may affect the efficient investment. If there is any preference for specific characteristics of the energy storage project that could meet the power system requirement, it should be reflected in the procedures adopted for grid connection. For instance, the co-located battery storage unit will not put an additional burden on the grid and could be excluded from the determined limit. In order to have a flexible power system and experience less curtailment of renewable energies, the seasonal energy storage units will be needed for very high renewable penetration rates (more than 80%) [26].

## Lack of Clear and Long-term View for the Investors

Although the DS3 program establishes a good environment for the growth of storage projects (see section ‎4.6), especially the battery storage units, there is not a clear vision for the investors after the effective period of the DS3 volume uncapped contracts (2023). There are various uncertainties regarding the payment rates that affect the attainable revenue from the volume uncapped armament for the provision of the system services (see section ‎9.4 for more information). The window of volume-capped arrangement has also been opened to the investor just for one time (October 2019) and there is no indication for reopening. In addition, it brings some obligations (it puts some limits on the ability of the contracted units to actively participate in the ex-ante markets; see section ‎9.1 for brief and sections ‎4.10.10 and ‎4.10.11 for comprehensive information) that can impair its attractiveness for the investors. As is addressed in ‎4.10.3, the capacity markets have also not attracted the new or existing BESSs as active participants. However, the investors require a clear and continuous overview to be able to conduct cost and benefit analysis on the energy storage projects and receive financial support from banks. Discrete supporting programs will not satisfy this requirement. The issues associated with the connection offers can also baffle the investors about the timely decision making about their investment on the energy storage projects (see section ‎9.9 for brief and section ‎4.10.19 for comprehensive information).

## The Role of Distribution System Companies in the Future Power Systems

As is mentioned before, consumption charges account for the largest part of the DUoS (see section ‎4.10.18) and DUoS, in turn, contributes a quarter of the customer’s bill [122]. Deployment of the energy storage units accelerate the movement toward prosumers’ era where the distribution companies will not be the main electricity supplier at the distribution level. The increased amount of self-sufficiency causes to reduce the revenue collectable from the consumption charges, while the cost of operation and maintenance for the distribution grid may be increased due to the age and deterioration. In that era, the number of end-users that are not in a promising level of self-sufficiency will be lowered, which means an increased charge of electricity from the utility side per existing customer. As a self-fueling process, this could be taken as a strong signal for the reaming classic customers to convert themselves to an active consumer. In the light of these facts, the regulatory bodies should determine the role of distribution companies and assess the financial viability of the DSOs in the implied future. The lack of movement from the regulatory bodies in this direction is a potential barrier for the expansion of the battery storages as the cornerstone of the future carbon free power system in which the active customers play a vital role since the distribution system is one of the environment that the energy storage units could be developed in.

## Aggregation and BESSs

As is addressed in ‎4.10.20 , if a battery storage unit is registered as a generation unit, it could be aggregated under the definition of aggregated generating units provided to a capacity limit (it should have less than 10 MW power capacity [132]). There is no registering obligation for the aggregation of the batteries as a demand-side unit. The minimum acceptable demand reduction capability to function as a DSU is 4 MW [130]. Demand sites having greater than 10 MW demand reduction capacity could be registered as an individual DSU. It is understandable that the 10 MW threshold in the definition is set respecting the dispatchability requirements and the “De Minimis” definition (and its associated obligations) but it may limit the functionality of the storage units as DSUs especially for the time aggregation purposes that will be addressed in this section.

By the current level of technology, the BESS performance will be costly (due to cycling issues) for medium- and long-term discharging duration. Aggregated operation of the energy storage could be effective to compensate for this weakness. Time aggregation means to allow the energy storage units to procure the aggregated amounts of energy during time periods longer than that is possible by considering their individual energy capacity limits. For instance, if 50 MW power is required for 10 hours to meet a specific service requirements, time aggregation enables 5 individual energy storage units having 100 MWh energy capacity to operate consequently in 2-hour spans. Therefore, the time aggregation of the energy storage units differs from the normal power aggregation. Power aggregation means the simultaneous deployment of energy storage units during a certain time span.

Knowing the meaning of time and power aggregation, the following questions should be answered to adopt a good policy for the energy storage units.

1. Which type of aggregation would be more beneficial for the energy storage units? time aggregation or power aggregation.
2. What type of the energy storage units could be benefited from aggregation? Utility-scale or small-scale energy storage units.

Power aggregation could be effective to achieve high power capacities in the residential distribution sector. It should be noted that since the residential demand-side units are not approved for delivering the DS3 services [131] or participating in the capacity market, the power aggregation would not be beneficial for them. Currently, the demand side units can only cover the industrial or commercial demand sites. Because the deployment of the residential BESSs via aggregation is provided to the installation of the smart meter devices [277]. Therefore, both of the questions are answered for small-scale energy storage units. In the short-term, neither kind of aggregation would be beneficial for the residential energy storage units since the required infrastructure such as smart meter devices have not been developed yet. In contrast, for the commercial/industrial energy storage units, the power and time aggregation could be beneficial. However, it should be subjected to their convenience since the time-shift may not be preferable for some of the commercial/industrial loads because of the specific pattern of their consumption (see Figure 65).

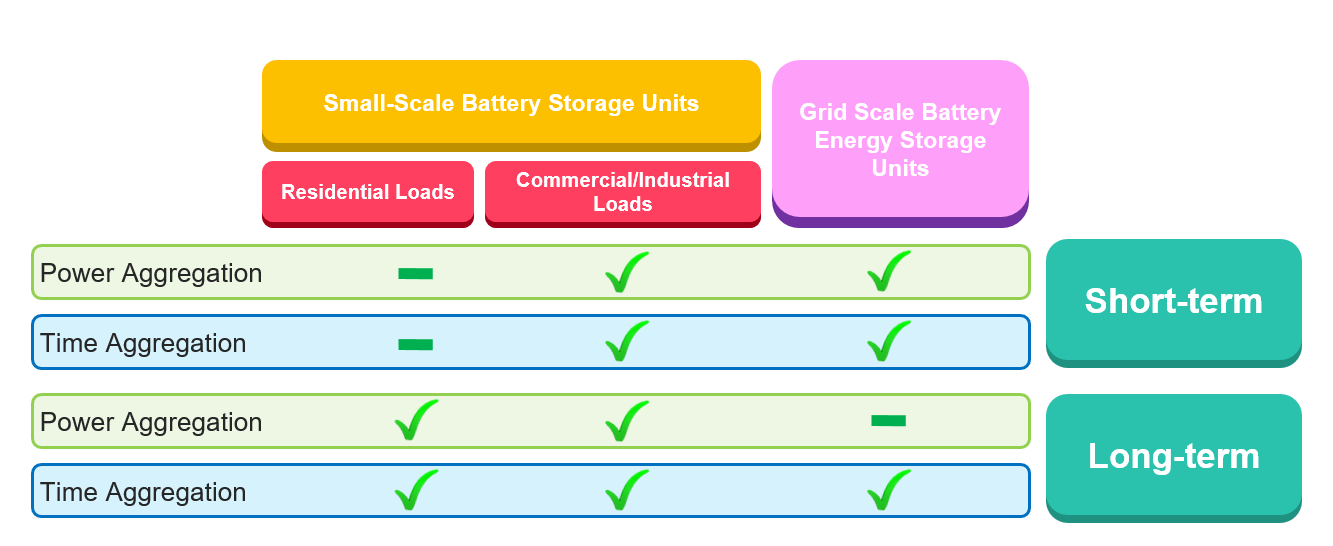


Figure Power-aggregation VS time-aggregation for BESS technologies

For the utility-size energy storage units, the power aggregation is not as important as the time aggregation because this is not the power capacity of the energy storage units that is limited by the current level of the technology but the energy capacity is limited. Currently, the costs may prevent the BESS to have enough power capacity for some potential services so the power aggregation could be a choice for the short-term as well. In the long-term, when the technology achieves to the level that the cost was not a pertinent factor to limit the power capacity, the power aggregation will not be a good choice.

Similar to the storage units, DSUs and AGUs are approved to provide POR, SOR, TOR1, TOR2, RRS, RRD, RM1, RM3, and RM8. Therefore, at the first glance, both of them could be good options for time aggregation of the utility-scale battery storage units that cannot individually discharge for a long duration of time. However, if a battery storage unit has more than 10 MW capacity, it could be aggregated neither as DSUs nor as AGUs since there is no other option for the aggregation. This treatment can put serious limits on the development of BESS in Ireland. This is the exact point where the time-aggregation can enable the utility-scale battery storage units to provide services necessitating medium- and long-term discharging time. As is seen in Figure 65, the time aggregation of the utility-size energy storage units could be beneficial and enable them to procure the services that required longer discharging time such as TOR2, RM1, RM3, and RM8.

Power aggregation could also be beneficial for the BESSs where the required services nictitate higher power capacity than the power capacity which could be provided by an individual battery storage unit.

## Behind the Meter BESSs

In section ‎4.10.24, it is explained that the approach for accommodating behind the meter energy storage will be reformed commencing by the micro-generator supporting scheme in 2022 and will be followed by the small-scale generator supporting scheme that will be available to implement in 2023. For the first phase, the SEAI’s scheme for the support of roof-top Solar Photovoltaic (PV) panels [137], will be replaced by the micro-generator supporting scheme in early 2022. This would be the first step toward a market based supporting scheme, and increase the social awareness about prices in the electricity markets. This scheme functions based on the clean export guarantee tariffs under the regulations devised by CRU to increase the competition between suppliers in terms of determination of the clean export tariffs [139]. Similar evolution is expected for the other SEAI’s supporting schemes targeting the communities and outer sectoral collaboration between public, residential, and nonresidential demands. For instance it is likely that after design and approval of the small-scale generator supporting scheme, it will replace the Better Energy Communities scheme.

As is addressed in [140], the document that published by DECC to summon the public consultation about the micro-generation supporting scheme, “micro-generators will always optimize their investment through achieving the lowest cost installations with the highest possible level of self-consumption which increases the savings against the retail rates that would otherwise be paid.” The assumption made for the economic assessment was that 70% of the total generated energy by the micro-generators will be consumed on-site, which constitutes the major part of the economic benefit for these project, since they will not be exposed by the retail tariffs for most of the times. Leaving the major part of the costs to be recovered by not paying the large amounts to the electricity bills could be a good starting point but it should not be taken as the main goal. The scheme determines a maximum share of 80 % for the installed capacity to be supported by the clean export premium tariff to encourage the self-consumption. Considering the total expected capacity of micro and small generation (760 MW as is expected by clime action plan 2021[41]), and assuming that a similar scheme will be designed in order to cater the small-scale generators, by 2030, 0.3 times 760 MW (almost 230 MW) renewable capacity will be injected to the grid and should be paid by the clean export tariff. Looking to the overview of the renewable expansion plan by 2030, (at least 5 GW offshore, up to 8 GW onshore and up to 2.5 GW of solar PVs) this excess capacity will account for 1.5 to 2 percent of the total renewable generation capacity. Although at the first glance, this portion is not significant, it could be problematic by considering the SNSP problems and the curtailment that may prohibit the electricity end-user to capture the whole benefits of the low cost renewable energy based electric system.

## Economic Barriers

Some economists argued that whether or not it is welfare maximizing to integrate the BESSs into the wholesale electricity markets. They have raised the issue of market power and the attitude of the storage investor to sell in the high prices and maximize the arbitrate benefits in the wholesale electricity markets [278, 279]. Some others argued that beside the probable behaviour of the storage owners, the storage will reduce the congestion and ramping costs imposed to the end-users [280]. Some realized observation approved the counter results to these studies. For instance, in Australian electricity market, the participation of the battery storage leads to lower peak prices due to the displacement of the gas peaking units by the battery storage [146]. These concerns should be kept in mind by the electricity market monitoring groups if the active participation of the BESSs in the ex-ante markets and utilizing their arbitrage potential will be permitted in the future.

## Non-technology Neutral Market

Although energy storage can provide ancillary service faster and more accurately than traditional generation units, and this is not reflected on the market compensation methods, which do not sufficiently reward the quality of the service provided. In fact, ancillary services are valued considering the asset’s availability and utilization rather than response time and accuracy of the service provided. Therefore, the current market design is more favorable to flexibility providers relying on traditional technologies. The market design is a barrier for the storage operators which hinders the full exploitation of the unique characteristics of storage for some ancillary services because some of the potential benefits achievable cannot be properly monetized. Examples of services that often are not remunerated are the black start (i.e., the system recovery after an outage) and the voltage control, since there is no reward for the service provider while voltage stays within its normal range. Other services that are poorly priced are those based on the ability of storage to reduce generator ramping and cycling [281]. Moreover, storage can be used to balance variable renewables’ fluctuation relieving strains on conventional generators. Finally, in the markets that were designed for traditional providers there can be minimum requirements for market participation which hinder the utilization of storage systems with low power capacity or short duration as stand-alone service providers, making it necessary to combine them with other assets through aggregation [282].

## Uncertainties about Ownership and Operation of ESS

Traditionally TSOs are not allowed to own and operate any generation asset; if storage is considered a kind of generation asset, then TSOs would not be allowed to own it. The on-going debate within the European Commission on whether DSOs/TSOs should be allowed to own energy storage assets may generate additional uncertainty for new investments in the storage technologies in Ireland. The system operators are the best placed actors for optimizing the utilization of storage assets for system balancing purposes, because they enjoy perfect information ownership about electricity demand. This unique position cannot be easily transferred to an independent storage operator. In the worst case, it could be argued that storage operators would not be able to timely sell enough storage services because only imperfect information would be available to them. This issue could make storage a less competitive technology and therefore could also have a negative impact on investments [225]. Based on the European level legislation [244], provided to regulatory authority approval, the TSOs and DSOs are allowed to develop, own, operate, and manage the energy storage facilities but there is no clear regulation at the national level to address this issue and alleviate the market distortion concerns.

Even in the case where TSOs or DSOs would be allowed to own energy storage units, they would be obliged not to distort competition in the electricity market when buying and selling energy to charge and discharge the storage. Energy trading required for the storage’s operation may interfere the energy trading in the wholesale market. The system operators may require a third-party operator with a license to participate in the wholesale market on behalf of the DSO/TSO to operate the storage. The addition of an additional actor makes the business model more complicated, generates additional transaction costs, and requires that each player produces a return such that the arrangement is worthwhile [282].

## Storage Wear Costs are too High to Ensure a Profitable Operation

The storage life is limited by its throughput (expressed in kWh) and a storage bank requires replacement when its total throughput equals its lifetime throughput. Storage throughput is determined by the cycle lifetime [283]. The storage wear cost is the cost of cycling (i.e., charging and discharging energy through the storage unit). The high wear cost of storage compared with its installation cost is the main technological barrier for the uptake of grid-connected storage applications. If the cost of degradation is high, then other technologies with lower marginal generation cost will be preferred to storage especially in highly rewarding services such as energy arbitrage [284].

## Lack of Incentives for the Optimal Placement of Storage in the Distribution Networks

In Ireland, electricity suppliers purchase the energy and sell it with various retail prices at the distribution level. However, the retail prices do not essentially reflect the technical issues such as congestion, losses, and the electric power value at a certain connection point. For this reason, there are no incentives for the optimal placement of the storage assets within the distribution network. Intervention of the policymaker, along with a more widespread adoption of smart grid technologies might promote the development of relevant business models, such as the one where the utility owns the storage which is installed at the customer site [281].

## Electricity Market Design and the Integration of the BESS

Although it is reported that The utility-scale BESS coupled with solar plants are now a feasible economic solution to replace gas peaking units [285], typically, the energy storage technologies are currently capital intensive. The competition of capital intensive and non-capital intensive technologies can arose some problems. Since the wholesale electricity markets use uniform pricing mechanism, if the capital intensive technology become the marginal provider, all of the auction participants will receive the market-clearing price which would be the offered cost of the marginal provider. This results in high rewards for the non-capital intensive technologies. Although from an economic point of view, it would be a strong incentive for the capital intensive technologies to reduce their costs, which in turn improve the technology, it will unnecessarily increase the cost of electricity for the end-users. In addition, if a non-capital intensive technology becomes the marginal provider in an auction, the revenues resulting from the uniform price mechanism may not be sufficient for the BESS to recover their long-run marginal costs (affected by the cycling issues). Policy intervention may be required to adjust the market within the technology transition phase of the BESSs especially when they are allowed to deploy their arbitrage capabilities.

In the other electricity market platforms such as capacity and real-time markets, the foot prints of employing other pricing mechanism such as pay-as-bid have been already observed. This will smoothen the technology transition of the BESS while not resulting in unnecessarily high rewards for

# Policy Recommendations to enable the Development of the Irish Energy Storage Market

## Short-term Concerns

### Inconsistency with the European Level Regulations

The Energy Sector of the DECC, is responsible for the compliance of the national level regulations with the international policies directing the energy and climate change. As is addressed in Table 12 (section ‎9), there are some non-compliances between the national level procedures, instructions, and regulations compared to the European level ones concerning the following main issues:

* Non-discriminatory participation/deployment of the energy storage units in the ex-ante markets (Day-ahead and balancing markets)
* Efficient Dispatch/Re-dispatch of the Energy Storage Units
* Grid connection issues of the energy storage units
* Network Charges for the energy Storage Units

### Multiple Revenue Streams for the BESSs

So far, the battery storage units rely on the revenue streams collected from the DS3 program which mainly focused on the provision of the ancillary services (see section ‎4.6). The capacity market is also another option for the battery storage units to provide a sustainable revenue stream that could not attract the new and existing BESSs. As is reviewed in section ‎6.3, one of the common procedures among the leading countries in the deployment of the energy storage units is the provision of multiple revenue streams (see Figure 49) which should also be noticed by policy makers in Ireland.

Storage owners could increase utilization and profitability of their assets stacking multiple services among those available in the market-remunerated group (ancillary services, energy services, capacity services) and the regulated group (investment deferral in network infrastructures). Due to the lack of a clear regulatory definition of energy storage (see also section ‎9.8), a too narrow classification of grid assets (such as generation, transmission, or distribution) not considering the peculiarities of storage could generate uncertainties in Ireland on whether storage assets can be used to provide both regulated services and market-remunerated services simultaneously. These uncertainties prevent the full utilization and profitability of the available assets or may eventually introduce additional costs to procure multiple licenses to provide multiple services [286].

#### Arbitrage and Aggregative Operation:

Arbitrage is the dark aspect of the revenues streams for the BESSs in the whole Island that are not accessible by the current procedures directing the electricity markets (see sections, ‎4.10.10 and ‎4.10.11). DSUs and AGUs definition do not comprehensively meet the aggregation requirements of the BESSs in Ireland especially in the technology transition phase.

#### System Restoration Services

In spite of the fact that the BESSs have proven capabilities to provide various services during the system restoration process [142] (see sections ‎5.1.2 and ‎4.10, Proper Definition of the Black Start Services), among the energy storage family, only the pumped-storage hydroelectric power plants have been contracted to provide the restoration services [73].

#### Non-event Reserve Requirements

It is explained in ‎4.5.5 that non-event reserve requirements are mainly procured by synchronous generation units in the whole Island. As is addressed in that section, the summation of the non- or partially regulating reserve procured by the demand side and energy storage units are currently less than the amount that is procured by EWIC and Moyle interconnector in Ireland and Northern Ireland respectively. The interconnectors are able to participate in the capacity auction as well. The competition of the interconnectors and BESSs as capital intensive technologies deserves significant attention from the policy makers (see section ‎9.19).

### Electrification of the Transportation Sector

As is addressed in section ‎7.1.1 one of the key drivers of supporting the BESS at the European level [238] is the requirements and strategic programs that already exist in the automobile industry (see section ‎8.7). The strategic role of the battery storage technology in the automobile industry is frequently mentioned at the European level legislation and the importance of emission reduction in the transportation sector is also justified (see section ‎7.1.1). Based on the analysis has been done in section ‎8.7, behind the meter battery storage is where the requirement of battery storage in the automobile industry has been lined up with the specifications that suit the application of battery storage in residential areas. Considering the country-based analysis has been done in this report (see sections ‎6.2.3.3, ‎6.2.4.3, ‎6.2.5.3-residential storage) and the dominant energy storage technologies studied in section ‎8.7, It is remarkable that the leading countries supporting behind the meter energy storage technologies are among the automobile industry leaders as well. In the light of these facts, it should be noticed that the financial stress of supporting the automobile industry should not be completely put on the shoulder of the electricity end-users. Although the electricity end-users may be the same as electrified transportation system users, the matter is in the transition phase, how the supporting costs are balanced between different sectors.

### Unclear long-term Overview for the Investors

Ambiguity in the DS3 program services after 2023 (see section ‎4.10), the reduction in the payment rates of volume uncapped arrangement (see section ‎9), discontinuation of the volume-capped arrangement, capacity obligations of the T-4 capacity market auction winners, and limited publication and reports from the FlecxTech Program may affect the incentives of the investors for entering to the energy storage market.

## Medium-Term Concerns

### Energy Storage Mix

As is addressed in section ‎8.7, 1.11 GW of PSHs is going to be installed in Ireland while 2.5 GW of BESSs are in the pipelines. Figure 64 represents the comparative energy storage mix in Ireland and the BESS leading countries in total. Figure 66 makes it possible to conduct a case-by-case comparative analysis. Considering the ratio of BESS to the capacity of renewable energies (depicted by grey and orange triangles in Figure 66 respectively), and comparing them to the progress span between violet and red bars that include the PSHs capacity in the mentioned ratios, it is obvious that the overview of the energy storage mix in Ireland is completely different from the BESS leading countries. As is seen, almost for all of the leading countries (except Australia), the orange triangle lies outside of the progress span between the violet and red bars. It clearly indicates that even the BESS leading countries rely on long and seasonal duration energy storage technologies at the target year.

It should be noted that Ireland will be one of the world leaders in the deployment of renewable energies and this exacerbates the flexibility requirements of the power system. The interconnections linking Ireland to the neighboring power systems with non-correlated wind regimes are currently zero (GB has a highly correlated wind regime to Ireland) and will be very limited after the energization of the Celtic project (see section ‎4.4.3). These facts increase the reliance of the Ireland power system on domestic flexible resources. The limited potential of Ireland in deploying the PSHs is mentioned in section ‎8.7. This deprives the whole Island from one of the important source of power system flexibility (Considering Figure 61, PSHs are one of the two main seasonal storage technologies.)

Figure Ireland Vs Battery Storage leading Countries

Figure 67 represents an informative diagram of the power system requirements for different penetration levels of renewable energies [26]. As is seen, the renewable target of Ireland (climate action plan 2021 [41] set 80% target for renewables) necessitates the deployment of the energy technologies that fall within the long and seasonal energy storage units (see Figure 61). Necessity of long duration energy storage systems deployment in Ireland for 2030 and beyond has been acknowledged by the Irish TSOs [42]. Based on the studied scenarios, the average duration of 100 hours energy storage systems should be available to meet the renewable targets by 2030 [287]. In the medium term, the deployment of energy storage technologies tolerating the discharging periods from days to a week at the rated power is required. Based on the information provided in Table 11, other BESS technologies such as flow batteries and NaS batteries have much LCCOS than the Li-Ion batteries. These kinds of electrochemical battery energy storage are not suitable for automotive industry application, since they have high operating temperatures or low energy density. Although the cost of Li-ion batteries are declining due to high demand, technology development, and the possibility of re-used as residential batteries, they could be the most economical solution while keeping a multisector look into this technology (namely automotive and electricity sector). The policy makers should consider the best individual sector based solution as well. To this end, the deployment of NaS and flow batteries could be considered for the electricity sector.

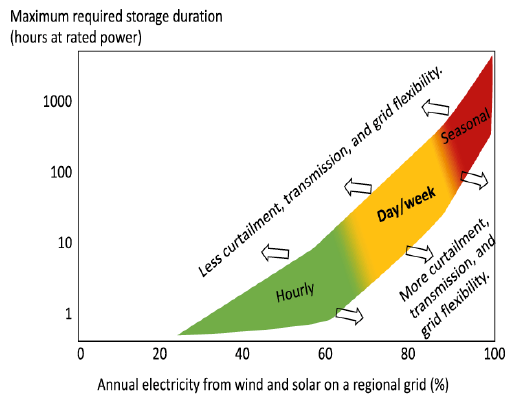


Figure Required Energy Storage technology (storage duration) Vs Renewable penetration [26] (USA department of Energy)

### DS3 Program Payment Rates[[15]](#footnote-16)

Table 8 in section ‎4.9 contains the purchasing rates of different services under the DS3 program volume uncapped arrangement. For the period of October 2020 – September 2021, the purchase rate for FFR has been significantly increased (305%), followed by RRD (68%), RM1 (53%), RM3 (37%), Rm8 (35%), SIR (24%), POR (18.7%), and TOR1 (0.64%) in comparison to the previous year. SOR purchase rate has been decreased by 1.5%, followed by TOR2 (-12%), RRS (-23%). Since the ancillary services constitute the main revenue stream for the BESSs in Ireland, enough attention should be paid to the economic signals resulting from the purchasing rate for the intended services. FFR possesses the highest increase rate and the battery storage have been contracted for this service addressing the short and very short duration energy storage units (see Figure 61). Neglecting DRR and FPFAPR, BESS has not been contracted for RR, RM1, Rm3, RM8 and this could be a result of technical requirements that necessities a longer duration of discharge for the BESSs. In spite of the fact that the purchase rates of longer duration services addressing the long- and medium- duration energy storage units (see Figure 61) have been increased, DS3 program cannot absorb the potential of the existing energy storage units for these services (if any). In addition, as is explained in section ‎9 the expenditure limitation for the DS3 program and the approach used to reduce the payment rate may distort the economic signals required by the investors to develop the BESSs with the required duration of discharge to meet the power system requirements.

### BESS and the Network Upgrade Deferral

The national development plan [104] (see section ‎4.10.1) recognizes the energy storage units as a complementary measure for network reinforcement and the practical examples of this application is also reported [222] (see section ‎6.2.7). There is not a clear evaluation mechanism for the effect of the energy storage units tackling the financial, social, and environmental benefits achievable by the network upgrade deferral, the services could be provided by the energy storage units, and the revenue stream accessible by the energy storage units because of this function in Ireland.

### Social Issues

As is addressed in section ‎4.10.22, vulnerable peoples may not afford the costs of being flexible and because of that, the time of use schemes may have a negative impact on the quality of life for this part of the society. On one hand, the cost associated with rooftop PVs, BESSs, and electric vehicles are not affordable for all parts of the society, and on the other hand, one of the efficient incentive-based mechanisms for the development of BESSs in the household level is the deployment of time of use schemes (such as night saver schemes introduced by ESB). It should be noted that the policies should not exacerbate the non-symmetric distribution of wealth among the members of the society (see Figure 18).

### Behind the Meter BESSs

It is addressed that due to the micro-small generator supporting schemes, almost two percent of the total installed renewable capacity by 2030 (and even beyond sine the duration of the mentioned schemes are 15 years starting by 2022) will be injected into the upper-level grid with priority and be paid by clean export tariffs (see sections ‎4.10.24 and ‎9.13). Considering the SNSP problem and the efforts that have been made to improve it through the DS3 program (and the future plans for achieving 90% by 2030), more efficient management for this excess energy should be devised by the policy makers.

## Long term Concerns

### Financial Viability of the Distribution Companies

The financial viability of the distribution company as the distribution system owner and operator in the future power system is a long-term concern due to the emerging technologies facilitating the development of the prosumers. Since more than half of the collectable revenue of the distribution company comes from the consummation rates, considering the movement toward the active consumer era, policymakers should play an active role to preserve the financial viability of the distribution companies (see section ‎4.10.18).

### The Updated Look into the Playing Field of the Electricity Markets

Fair definition of the playing field for the electricity market participants and careful consideration of the costs imposed by different sectors to the electricity end-users. By the classic look into the electricity markets, the electricity end-users have no choice but to incur all of the costs imposed on them by the constraint associated with different technologies in the generation sector since they could not rely on any other sources to supply the required electric power. In the future, the active consumers achieve a level of self-sufficiency and not only are not completely dependent on the generation fleet; they could provide grid services for the upper-level systems. In this condition, the classic look into the electricity market design and considering the generation sector technology-specific constraints to add to the cost of electricity for the end-users will not be a reasonable choice anymore (see section ‎5.1.4).

### Seasonal Energy Storage Deployment

The seasonal energy storage technologies are required to accommodate the renewable penetrations of more than 90 % in future power systems. Considering the applications of different energy storage technologies (see Figure 61), currently the PSHs and hydrogen storage can provide such long-lasting storage capacities. Research and innovation should develop the battery storage technology to fit them for future power system requirements since Ireland have limited potential to deploy PSHs (see section ‎8.7).

### Catering 760 MW of Micro & Small Generation Coupled with BESSs

It is addressed in section ‎4.10.24 that the micro-generation supporting scheme will be initiated in early 2022 and will be followed by the consultation on small-scale generation supporting scheme, which in turn will be implemented by 2023. Based on the climate action plan 2021, these schemes will lead to 760 MW of renewable-based micro energy generation (mainly solar PVs) that 70% of the total energy generated should be consumed on-site and the remaining part will be injected into the upper-level grid. It means that around 2% of the total installed capacity of the renewable by 2030, should have dispatch priority and there is no way but to accommodate by the upper-level grid which is at the distribution level.  It is addressed in section ‎9.13 that it would be problematic. The policymakers should think about the electricity market designs that facilitate the efficient management of these amounts of energy in an efficient manner. Peer-to-peer electricity market design [124], could be one of the promising solutions to this problem.

## Recommendations

### For Short-term

Resolving the inconsistencies with the regulations at the European level will help the development of the BESSs in Ireland. The first five policy recommendation increase the conformity level of the Ireland’s national level regulations and instructions with the European ones.

* Non-discriminatory Participation of the Energy Storage Units In the Ex-ante Markets (Day-ahead and Balancing Markets)

It is recommended that the barriers for participation of the energy storage in the day-ahead/balancing markets should be removed. Looking ahead, the capacity of battery storage units will be increased and they should have access to the various market based trading mechanisms. Deployment of BESS for the provision of ancillary services, as well as, participation in the capacity markets, should not put limits on the potential ability of the BESSs for energy arbitrage in the ex-ante markets such as day-ahead and intraday markets. Active participation of the BESSs will facilitate the efficient dispatch/re-dispatch of the energy storage units.

Currently, the block orders provide a good opportunity for the BESSs to catch the maximum profit from the arbitrage in the day-ahead market. Provided that the peak/off-peak hours could be recognizable for the battery storage owners, they could submit block bids to charge their asset during the off-peak and discharge during the peak hours. However, as is addressed in this report, the BESSs that provide ancillary services are prohibited to actively participate in the day-ahead market.

Charging of the BESSs

Considering the capacity expansion of the BESSs in near future, especially the presence of utility-scale projects with hundreds of MW power capacity, the current instructions of charging will not efficiently work. Provided to the power capacity, most of the battery storage units will be classified as dispatchable units and charging their assets should be based on the dispatch instructions. Removing the barriers for BESSs to actively participate in the ex-ante markets, not only increase the liquidity of these markets, but also result in more efficient dispatch/re-dispatch of the BESSs. Non-zero bidding in the ex-ante markets let the BESSs to affect their duration of charge, facilitate the arbitrage, and open the windows to competitive ancillary service markets instead of the current bilateral contract scheme between the TSOs and the service providers.

* Network Charges

The regulatory bodies are recommended to clearly define a mechanism that addresses the allocation of network charges to the BESSs located in different power system sectors. For instance, a co-located battery storage unit that provides capacity firming and generation time-shift services for the renewable energy resources could not be treated similar to a storage unit that is installed at the distribution level and provides load-leveling services in terms of network cost allocation. Considering the current instructions, both of the mentioned storage units are subjected to DTUoS charges.

* Grid Connection

Considering the European level legislation, the transmission system operators are prohibited to refuse the connection of the market participants including the energy storage because of the possible future limitations on the available transmission capacity. CRU put a maximum of ten grid connection offer limit on the primarily storage projects in ECP-2. This is done on the ground that that not limiting the grid connection offers would be an unnecessary prioritization for these projects. It should be noted that grid connection is the primary step of accessing the market opportunities for the energy storage units. If there is any consideration on limiting the number of energy storage projects, it should be clearly announced on the primary phases of such projects. A maximum of 10 limit could not address the type, size, and specifications of the battery storage units that will be required by the power system during the effective period of ECP-2. From an energy capacity point of view, a 100 MW storage unit with 250 MWh energy capacity could be replaced by twenty-five distributed storage units with 10 MW capacity and 10 MWh energy capacity while these two arrangements could have completely different effects on the available network capacity. Therefore, putting a limit on the number of projects cannot generate efficient economic signals to the investors about the required storage power and energy capacity. In addition, some energy storage projects such as co-located battery units will not put an additional burden on the grid and can be excluded from the maximum limit.

* Non-frequency Ancillary Services

System restoration services (referred by black-start) are non-frequency ancillary services and conforming to the European level legislation, the TSOs/Regulatory bodies at the national level must determine the specification of these services and the associated markets. The energy storage units have technically proven capabilities on the provision of black start services. Considering the future of the power systems, the available capacity of the energy storage will be significantly increased and they can be reliable sources for system restoration services. As the first step, the required services should be recognized by the TSOs and then a market-based mechanism should be designed for competitive provision of the intended services by capable technologies.

Resolving the inconsistencies with the European level directives open up the windows to implement the other recommended policies.

* Interconnectors and the BESSs

Considering the Brexit, meeting the interconnection level obligations with the European countries could be a serious problem for the whole Island. Existing interconnectors are linking the whole Island to the GB. Therefore, there is no link between the whole Island and the European countries until the energization of the Celtic project. Considering the development of the interconnectors (see section ‎4.4.2) and the operation policies for the provision of non-event reserve requirements, enough attention should be paid by the policy makers on the regulations of such services that could be provided by the interconnectors. Currently, the summation of the non-event reserve services procured by the demand side and battery storage units are less than the amount procured by the interconnectors in the whole Island (see section ‎4.5.5).

Based on the current proven technology list for the DS3 program services, interconnectors can provide, FFR, POR, SOR, TOR1, and TOR2 regardless of the HVDC technology. In addition, voltage source converter scheme for HVDC links enable them to provide SSRP, DRR, and FPFAPR as well. In addition, interconnectors are able to participate in the capacity markets. Considering these overlaps with the BESS capabilities, interconnectors could be a serious potential rival for the domestic BESSs. Regulatory bodies are recommended to design the mechanisms in such a way that the probable discriminatory preference of the system operators for the provision of the required services could not limit the potentials of a technology that is able to provide a certain service.

* DS3 Services

As is acknowledged by SONI and EirGrid [131], BESSs are able to provide FPFAPR and DRR (see section ‎4.6.7) while these services have not been contracted in the DS3 program so far. In addition, the BESSs are not recognized as a technology that can provide SIR while they have proven capabilities for the provision of the synthetic system inertial response as well [94]. High-frequency problems are one of the main sources that limit the improvement of SNSP and result in wind resources curtailment. Using the energy storage capacity as power loads can mitigate this problem provided to recognition of power load capability as a frequency service. Currently, most of the services are focusing on under-frequency problems.

* Aggregation of the BESSs

In the technology transition phase, the utility- and small- scale energy storage units may not be able to individually procure long-duration discharge capacity (see Figure 65) but the time-aggregation (see section ‎9.12) of the energy storage units could be a promising solution to this end. Time aggregation requires technical structures to be determined and approved by the TSOs and market instructions and remuneration mechanisms to be devised by the regulatory bodies. Neither time- nor power aggregation is permissible for the utility-scale energy storage units (energy storage with more than 10 MW power capacity) based on the current possible options for aggregation, namely the demand side units, and the aggregated generation units. Neglecting the cost factor, the power aggregation may not be reasonable choice for the utility-scale energy storage in the long-term since there are no technical limits on the power capacity of the energy storage system. It is addressed in Figure 65 that as a short-term recommendation, the power aggregation allows the current utility-scale BESSs to access the revenue streams that requires higher levels of power capacity.

* Electrochemical Batteries and Multisector Benefits

It is explained in section ‎8.7 that behind the meter battery storage technology is the crossing point for the specifications of the battery storage used in the automobile industry and in residential areas. If the electricity sector solely supports this technology, the electricity costs for the end-users will be increased while the developed products (energy density efficient batteries) will not be used only in the electricity sector. Similar to the public service obligation levy supporting the electricity generation deploying the renewable energy resources, levies could be applied to charge the fuel-burning automobile end-users to support the development of battery energy storage technology in the electricity sector, especially behind the meter energy storage technology.

* Side/Constraint Payments

It is explained in section ‎‎9 that currently different kinds of side-payment have been made to different technologies in the generation sector. For instance, the start-up cost recovery of the conventional generation fleet should be guaranteed and the curtailment of the wind resources should be compensated. When it comes to dealing with the cycling deterioration of the BESSs, the proposed treatment becomes completely different (putting 10 dispatch limits and abandoning them from arbitrage opportunities). It is recommended to assess the cost-benefit analysis of the required expenditure to cover the aging and cycling costs of the BESS in the electricity market and utilize their services to reduce the final electricity cost for the end-users. Direct compensation of the curtailment for the renewable energy resources may weaken the incentives for the deployment of co-located BESSs. Such payments should be made in a manner that incentivizes the renewables to install co-located BESSs. Reducing the uncertainty of the renewable energy resources is one of the services that could be provided by the energy storage units. Competitive market should be designed to enable the BESSs to provide these services.

* Business Case for Improving Co-located BESSs

Although the scheduling and dispatch of the renewable generation is prioritized by the Control Centers, sometimes all the renewable power cannot be accommodated while maintaining the power system operation safe and secure. In 2020, more than 13700 GWh of wind energy was generated in the whole island, while 1909 GWh was subjected to the dispatch-down [45]. Therefore, a recommendation for the policymaker is to evaluate the business cases for installing energy storage units at the wind farms (especially those at which the produced energy is curtailed the most, in concertation with storage manufacturers, renewable power plant operators, network operators and storage associations. The payback period associated with storage installation can be evaluated considering the investment costs, the amount of curtailed energy that can be stored, the levelized cost of energy stored (which in turns determines the selling price for the energy stored). Storage technologies need to be identified through a comparative study among those currently available and those which will be available in the future.

* Incentives for Renewable Energy Time Shifting Service Using Energy Storage

In 2009 a carbon tax carbon tax was introduced in Ireland to lower carbon emissions proportional to the tones of carbon dioxide (CO2) emitted from the burning of fossil fuels. The tax has been introduced on a phased basis and was increased in 2012, 2020 and in 2021 to the current amount of €33.50 per ton of CO2 emitted [288]. This tax contributes to increase the cost of the energy produced with conventional power plants using fossil-fuels. In the liberalized electricity market, the suppliers purchase energy on the wholesale market and sell it on the retail market to the end-users. If the share of energy produced with conventional generators is high compared to the share of electricity produced using renewables, then the carbon tax will contribute to increase the energy price paid by the suppliers to the generators and also the price for the end-user in the retail market will be higher. The Energy storage has the potential of increase the renewable utilization by storing the excess of electricity produced using renewables which is not used to supply the current consumption, such that it can be used in a different time period thereby lowering the need of burning fossil fuels to generate electricity. The renewable power plant owners have an opportunity to secure an additional revenue stream by operating energy storage units such that they can supply a higher fraction of the energy demand by storing the energy produced when there is abundance of wind or sun and shifting the renewable supply to the time periods when the demand is high by discharging the storage.

* Legal Requirements for Unbundling Network and Non-network Activities

Although the Directive 2009/72/EC concerning common rules for the internal market in electricity has clearly established that network activities should be fully separated from supply and generation activities, there also a few possible exceptions to this general rule [289]. Examples of such exceptions are the possibility for the network operators to own energy storage systems of capacity less than 100 MW in the UK, and the possibility to own and operate storage to implement transmission network congestion relief projects in Italy [290]. The regulatory uncertainty around unbundling and ownership of storage is generating uncertainty in investment decisions for the DSO and TSO. The storage ownership by network operators could be acceptable in exceptional circumstances in relation to the provision of grid services such as the congestion relief, the transmission & distribution (T&D) upgrade deferral or the T&D life extension.

### For Medium-term

* Energy Storage Mix

As is illustrated by Figure 67, the power system requires medium- and long-duration energy storage units to accommodate the renewable energy resources in the level that is determined by climate action plan 2021. All of the policy adoptions should be lined up to direct BESS development meeting this requirement. Based on Figure 61, all of the BESSs are able to provide medium-duration discharging capacity. Table 11 contains the levelized cost and the life cycle cost of energy for different battery energy storages technologies. A comprehensive economic analysis is required to select the best option for Ireland among the following options:

* Import the required battery energy storage until 2030,
* Manufacture one or some of the battery storage technologies
* Rely on the existing pumped storage hydro power plant capacity and making progress in the construction of the planned projects
* Develop the hydrogen storage in the medium term
* An optimum combination of the above choices

Although the global trend is to rely on the Li-ion battery energy storage for the electricity sector, it may be a result of economic studies that consider multi-sector benefits, namely the electricity and automotive industry sectors. NaS and flow batteries are not applicable in the automotive industry (because of high operating temperature and the structure requirements-see section ‎8) but they have attractive characteristics for power system applications. It is recommended that especially for Ireland, the policymakers should pay enough attention to the other existing technology that may not be useful in the automotive industry but well suited to the electricity sector such as NaS and flow batteries.

* Expenditure Limitations and The DS3 Program Payment Rates

It is explained in section ‎9 that there is a conflict between a basic economic concept (the interaction of demand and price for specific merchandise in case of limited availability) and reducing the payment rates for different services in the DS3 program (because of expenditure limit) especially in high wind scenarios (as is proposed by TSOs). This treatment generates wrong economic signals for the investors. If the root cause of proposing the payment rate reduction is not excess capacity problems, it is recommended to revise the expenditure limit in a manner that does not distort the economic signals for the investors procuring the required services.

It is explained in section ‎4.6.7 that the temporal scarcity scalar directly affects the payment of DS3 system services. This scalar is expected to reflect the situation of the system in terms of SNSP level but the clusters should be revised in order to cover the recent changes of the SNSP level (75% trial and 90% in the future) .

* Energy Storage and Network Expansion Deferral, a Business Model

It is addressed in section ‎4.4.1.1 that based on the European level legislation, all of the member states should achieve an interconnection level at least equal to 10% of the installed electricity generation capacity by 2020. It is also mentioned in section ‎4.4.5 that a number of national-wide transmission expansion projects in the whole island are capitally approved and planned to be delivered before 2030. Although the national development plant recognized (see section ‎4.10) the energy storage units as a complementary approach for network reinforcement, there is no serious movement to evaluate the financial and technical benefits of energy storage units on the network upgrade deferral, congestion relief, and life cycle extension. It is recommended that the research program should determine the services that could be provided by the energy storage units to this end. In addition, market and pricing mechanisms for these services should also be proposed.

It is mentioned in section ‎4.1 that the total power loss in distribution and transmission level in Ireland is 7-8%. It is explained in section ‎4.10.17 that CRU aimed to review the tariff structure for the DTUoS at the transmission level excluding the losses that could be affected by the energy storage operation in the distribution and transmission level. Considering the technical effects of energy storage units on the transmission and distribution networks, balanced and efficient decisions on the different parts of the network tariffs could be achievable by comprehensive coordination between the regulatory bodies. It is recommended that the regulatory bodies, in addition to the DTUoS, conduct a comprehensive review on all of the pertinent factors affected by the presence of energy storage units. For instance it is addressed by Table 1 that the transmission system upgrade deferral and transmission congestion relief are the services that could be procured by the energy storage. The mentioned services can affect the costs associated with the transmission system operation and maintenance.

The legal requirements for unbundling will be the starting point to establish the business models which will allow the DSOs to effectively implement services for the transmission & distribution (T&D) upgrade deferral or the T&D life extension. Three business models have been described in the literature: the DSO merchant, the DSO contracted and the contracted services [290]. The DSO merchant model provides that the DSO procures and operates the storage equipment to deploy the storage services based on the needs arising on its network. This model cannot be applied if the unbundling requirements will be strengthened in Ireland. The DSO contracted model provides that the DSO procures, owns and operates the storage equipment but will use it only partially, while a storage operator will use commercially the storage having a contractual agreement with the DSO. The contracted service model provides that a storage operator company procures, owns and operates the storage equipment, selling the services to the DSO. It is recommended to initiate a public consultation involving the policymaker, the DSO, the storage operators and the storage associations to debate the most advantageous regulatory framework and the applicable business models in Ireland, given the status of the market for network services based on storage and the legal requirements for unbundling the network activities and supply and generation. A complex contractual agreement which involves more actors will reduce the overall revenue because each actor involved with the DSO will need to make a profit.

* Social Issues

Since the cost of flexibility equipment (rooftop PVs, electric vehicles, and BESSs) are not affordable for some parts of the society, supporting policies should be considered for vulnerable peoples enabling them to be benefited from the results of decarbonisation in the energy sectors. Unless the deliberated incentives, that changes the consumption behaviour of normal society members, can increase the cost of electricity for the vulnerable peoples or they may be forced to be flexible at cost of their health.

* Data Centres , a Solution to the SNSP, an Opportunity for the BESS Development

Data centres are going to be a major part of demand in Ireland. The consumption pattern of these recently emerging loads depends on the computation requests of the end-users. This may be a potential operation challenge, while it could be utilized as an opportunity for the development of BESSs in Ireland (see section ‎5.1.3.1). BESSs have significant effects on the cost minimization and energy management of the data centers [152]. Smoother load variation, reduced electricity costs for the data centers, and reduction of the network losses, are the byproducts of the data centers – BESSs couples.

Power quality and continuity requirements of the datacenters, make them suitable customers for the markets delivering electricity with specific characteristics that differ from the normal electricity end-users requirements. This may open new windows to define new products, based on the power quality and continuity, for supplying the data-centers. BESSs can deliver the required services alleviating the quality and continuity requirements of the datacenters and get access to revenue streams resulting from delivering these services.

### For Long-term

* Defining the Role of Distribution Company

It is explained that, currently, more than half of the collectable revenue of the distribution company comes from the consummation rates. Emerging technologies such as smart metering, rooftop PV integrated with BESS, active distribution networks, and energy communities are implying a new era in which the prosumers have an adjustable level of self-sufficiency. This may reduce the revenues of the distribution company, but the costs will not reduce and even may increase due to the aging of the network elements. This should be compensated by higher consumption rates for a limited number of remaining traditional consumers. This in turn is a strong incentives for the remaining consumers to become prosumers. In this self-fuel process, defining a new role for the distribution company is essential to preserve its financial viability, the movement that should be started by the policymakers.

* Who Should Pay the Cost Of In-Flexibility in the Generation Sector?

It is explained in section ‎5.1.4 that the constraints imposed by the inflexible generation sector increase the cost of the energy supply for the end-users. A fair definition of the playing field for the electricity market participants necessitates that the cost of constraints should not be solely beard by the demand sector. The constraint redemption services proposed in section ‎5.1.4 may increase the costs in the generation sector. It is obvious that any increase in the generation sector costs will be reflected in the electricity price they will offer in the electricity market. Therefore, the demand sector finally pays the costs but the only effect of the constraint redemption services is not to increase the generation sector costs. The constraint redemption services affect the total electricity costs for the end-users by increasing the possibility of commitment for the generation plants based on their more pure economic legitimacy. By the presence of constraint redemption services, the cheaper generation plants (in the merit order list) such as wind power producers, which were normally curtailed or limited because of the interactions of power system requirements and the generation sector associated constraints, will be committed. In other words, from the final electricity cost for the end-users point of view, constraint redemption services have two main effects:

* Increasing the cost of electricity production for the generation sector since they have to buy constraint redemption services and pay the associated costs
* Reducing the cost of electricity purchased in the electricity market because of the relaxed constraints

It could be an interesting subject of research to understand which effect would be stronger and what would be the resultant effect of the constraint redemption services on the electricity costs for the end-users. Even if the constraint redemption services cannot reduce the costs of the electricity for the end-users, what is proposed in section ‎5.1.4, is in fact a proposition to rearrange the cash flow, aiming to provide a revenue stream for the energy storage units and generate true economic signals regulating the flexibility in the future power systems.

* Durable Energy Storage Units

As is explained in section ‎8.7, most of the leading countries in the deployment of BESSs, plan to achieve a satisfactory level of the seasonal energy storage capacity (see Figure 62) while they will not have more than 90% penetration level of the renewables (see Figure 67 and section ‎10.2.1 for more explanation). Since the potential of pumped storage hydro power plant is limited in Ireland, the remaining choices are power to gas technologies such as hydrogen energy storage, conducting research and innovations to procure longer-duration energy storage units from other technologies such as BESSs, and facilitating the aggregation. Seasonal energy storage units can also deliver long duration services but as an alternative, the time aggregation of the BESSs could be a promising solution for the policy makers.

* Electricity Market Design, Leveraging the Deployment of Energy Storage Units in the Distribution Sector

Behind the meter energy storage systems, co-located with the renewable energy resources are going to be developed in Ireland. Based on the climate action plan 2021, the micro and small generators will account for 760 MW of capacity until 2030. The current policies are designed to encourage self-consumption but the excess energy has no choice but to be injected into the upper-level network (see sections ‎4.10.24 and ‎9.13) and be paid by the clean export tariff. Managing the excess energy injected from these prosumers to the upper-level grid could be done more efficiently if the technical structures and regulations establish a framework for them to deal with their internal power mismatches cooperatively. Peer-to-peer electricity market design can enable the community-based and aggregated residential prosumers to efficiently manage this excess power.

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1. MAREX Organic Power Energy Storage [↑](#footnote-ref-2)
2. neglecting the small portion of thermal, flywheel, and ultra-capacitors, the energy storage volume excluding the pumped storage hydro power is assumed to be the capacity of battery storage in Ireland [↑](#footnote-ref-3)
3. The volume of the contracted FFR has also been increased. [↑](#footnote-ref-4)
4. For those energy storage units that have been contracted thorough volume capped arrangement. [↑](#footnote-ref-5)
5. In page 23 of the refereed document it is stated that “The current DUoS tariff structure, designed to be cost-reflective, includes a day/night rate and it is noted that network … ” and “It is also noted that the CRU is currently undertaking a full review of the network tariff structure, therefore this is an interim decision taken within the current DUoS structure and will be superseded when the new tariff structure has been implemented, which may or may not include a time-of-use component [↑](#footnote-ref-6)
6. Short-term Active Response (STAR) and Powersave [↑](#footnote-ref-7)
7. Please see Page 14, Figure 5, of the referred Report. [↑](#footnote-ref-8)
8. Nuclear energy is categorized as a clean energy resource while it is not renewable. Similarly, biomass, in spite of its carbon emission, is recognized as an eligible renewable energy in RPS. [↑](#footnote-ref-9)
9. Erneubaren Energien Gesetz [↑](#footnote-ref-10)
10. Nationale Platform, Zukunft der Mobilität [↑](#footnote-ref-11)
11. 6 GW Leighton Buzzard Li-ion 11 Kv, 250 kW Milton Keynes NaNiCl2 11 Kv, 2.5 GW Rise Carr Li-ion 6.6 Kv, 100 kW Denwick Li-ion 20 Kv, 50 kW Wooler Li-ion 20 Kv, 50 kW Maltby Li-ion 230 v, 50 kW Rise Carr Li-ion 6.6 Kv, 100 kW Rise Carr Li-ion 6.6 Kv [↑](#footnote-ref-12)
12. For Japan, It is assumed that the annual battery capacity addition remains constant until 2030 to the value of 400 MW. [↑](#footnote-ref-13)
13. Poland, Belgium, Luxemburg, Slovakia and Ireland have either minimum existing capacity or minimum potential for further expansion of the PSHs [↑](#footnote-ref-14)
14. This is a descriptive interpretation from the current version of the trading and settlement code. [↑](#footnote-ref-15)
15. For the technical requirements of the mentioned services please see sections ‎3.5.5 and ‎3.6 [↑](#footnote-ref-16)