Wind energy and on-site energy storage

EXPLORING MARKET OPPORTUNITIES

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WindEurope

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1. EXECUTIVE SUMMARY

Energy storage is on the spotlight due to the growth of variable renewable energy and the fast decreasing costs of technologies, especially batteries. Whilst large pump hydro still represents over 95% of the energy storage market, there is a rapid growth of stationary utility-scale storage projects, mostly used as stand-alone installations. These include batteries, flywheels, power-to-gas, thermal storage and compress air energy storage. However, the number of projects used in combination with wind farms, the so-called co-located wind and storage projects is increasing too.

The commercial viability of co-located projects is still very limited. Most of the existing installations are pilot projects or demonstrators. This is because the generation overcapacity in Europe creates a small spread between electricity prices, which does not provide for incentives to invest in energy storage for arbitrage. In addition, there are regulatory barriers that constrain the uptake of such projects. Some of these are high network charges, lack of a legal definition for storage assets, unclear grid connection compliance and performance requirements and the lack of commercially viable ancillary service products. Furthermore, there are knowledge gaps in understanding the technical capabilities and limitations of co-located projects.

Co-locating wind energy and storage technologies could offer many benefits: It could reduce the amount of curtailed electricity at times of grid congestion or system instability. It could help maintaining generation schedules communicated to system operators, thereby reducing imbalance charges and avoiding penalties for not fulfilling the performance committed to the system. It could enable wind power to provide a wider range of ancillary services, such as frequency containment reserve (FCR), improve reactive power provision and even black start capability. In small power systems with stability issues, storage can support wind farms to reduce ramp rates, smoothing out electricity generation.

This paper discusses the possible functionalities of co-located wind energy and storage projects using examples from key ongoing projects. It uses information from WindEurope's online database of co-located projects developed specifically to improve the industry knowledge. Approximately 400 MW of co-located projects have been identified globally, with three quarters of them already operational.

Finally, the paper presents a number of policy recommendations to improve the market design for all storage projects and specifically for co-located ones. As industry gains more experience developing such projects, WindEurope will disseminate lessons learned on regulatory frameworks and incentive schemes.

1. ENERGY STORAGE MARKET

CONTEXT

Energy storage is not new. Having been used for over hundreds years, the main application of energy storage still remains to be *energy arbitrage* or *energy time shift*; storing electricity during low electricity demand and releasing it back into the grid during high demand, typically over a daily cycle, supporting the balance of the system. Given that in the past the electricity generation mix relied almost exclusively on fossil fuels, nuclear and hydro, and variability of generation was not a major challenge, the necessity for energy storage was more limited and less economically attractive.

However, as variable renewable energy resources (VRES) increase their share in the energy mix, supply becomes more variable and weather dependent. Therefore, energy storage could become more important by providing services across the existing energy, capacity and ancillary services markets. And it could enable new markets and services too. This has been reflected in the rapid increase of battery technologies (in particular lithium-ion) for stationary energy systems in the last years.

The services that energy storage systems can provide today compete against those from other sources of flexibility and adequacy, such as demand side management, flexible generation and electricity exchanges through interconnectors. Its success is therefore largely dependent on its cost structure, cost reduction potential and fundamentally, on how the energy market is designed and organised. This paper focusses on the potential value of energy storage systems for electricity grids and assess whether co-locating[1] it with wind farms can provided additional benefits.

STORAGE TECHNOLOGIES

A vast range of technologies is available for storing energy in all its forms (mechanically, electrochemically, electrically, and thermally). Other options exist to transform electricity into other energy carriers, such as hydrogen, which can be then stored in gas, liquid or even solid states. Figure 1 represents the various technologies.

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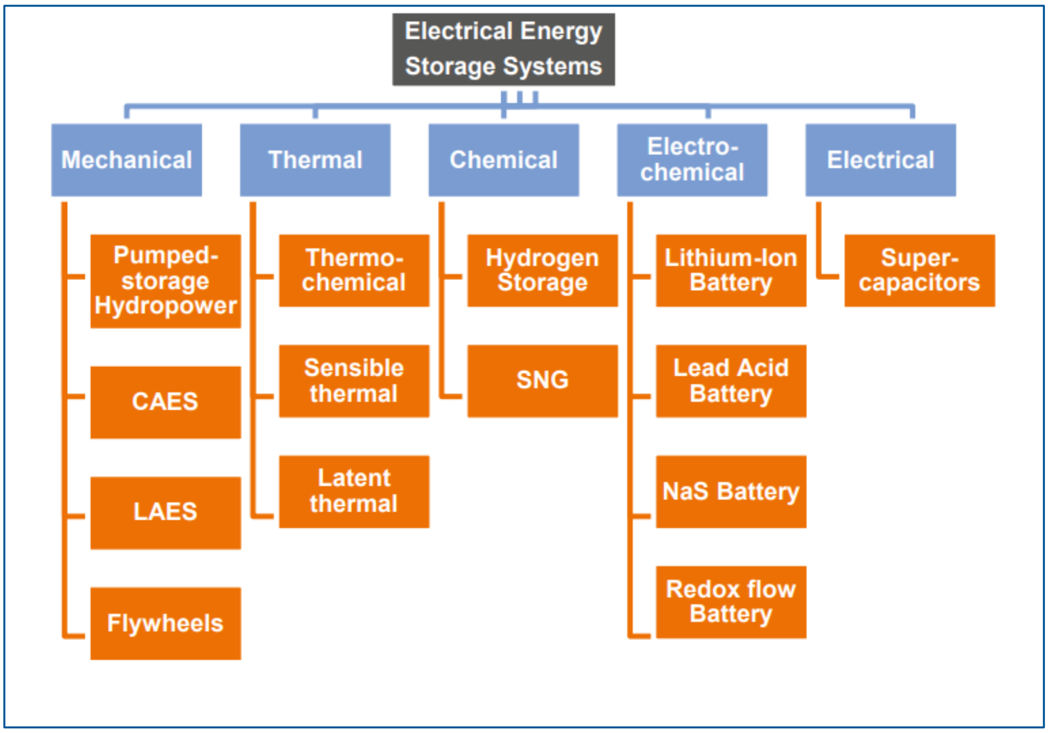
[1] In this paper, co-location refers to wind farms and storage systems that are connected to the same grid node/point, or for pump hydroelectric storage, hybrid projects combining the wind farm(s) and the storage facility in the same distribution grid or isolated electric grid (e.g. small islands)

Figure 1. Electrical energy storage systems. Source: World Energy Council

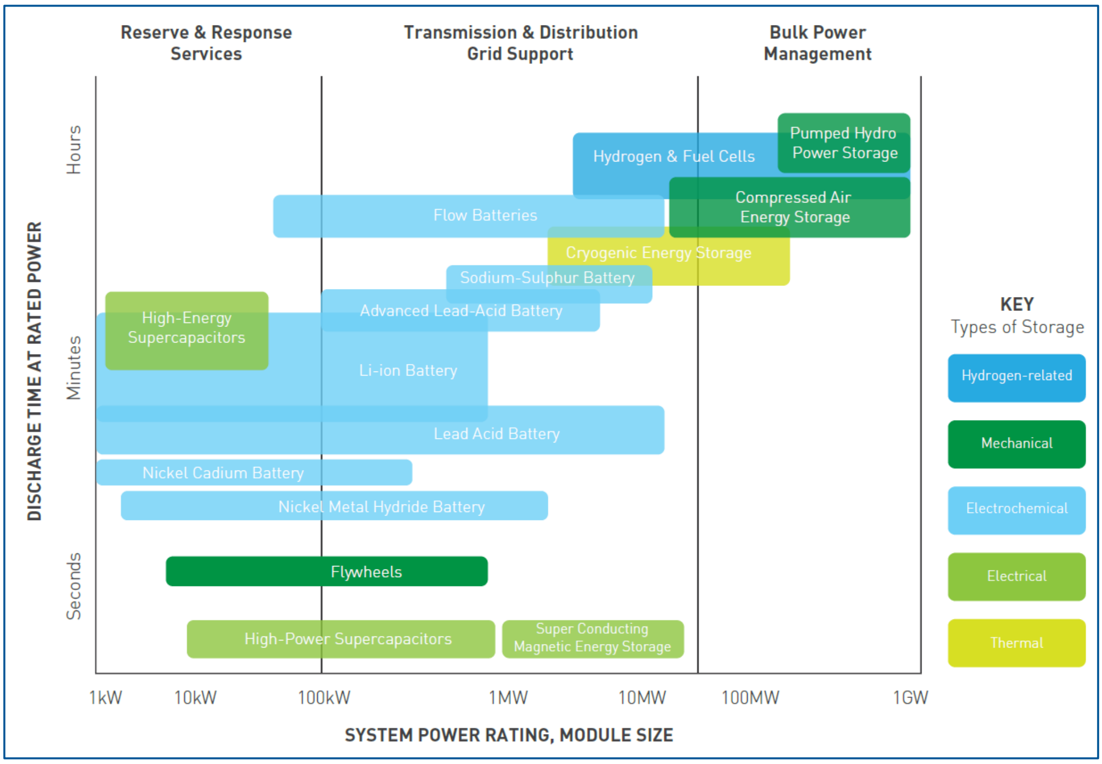


VALUE AND APPLICATIONS

The value of energy storage depends largely on the energy system needs. For example, smaller and isolated electrical systems are quite dependent of energy storage as it helps to balance supply and demand without relying on energy exchanges with other systems and can provide a wide range of frequency control services to maintaining grid stability.

Figure 2 represents the various technologies, classified on their type as well as on the time of discharge and the area of functionality where they are more effective.

Figure 2. Types of energy storage technologies Source: Pathways for energy storage in the UK. Lowcarbon futures, march 2012



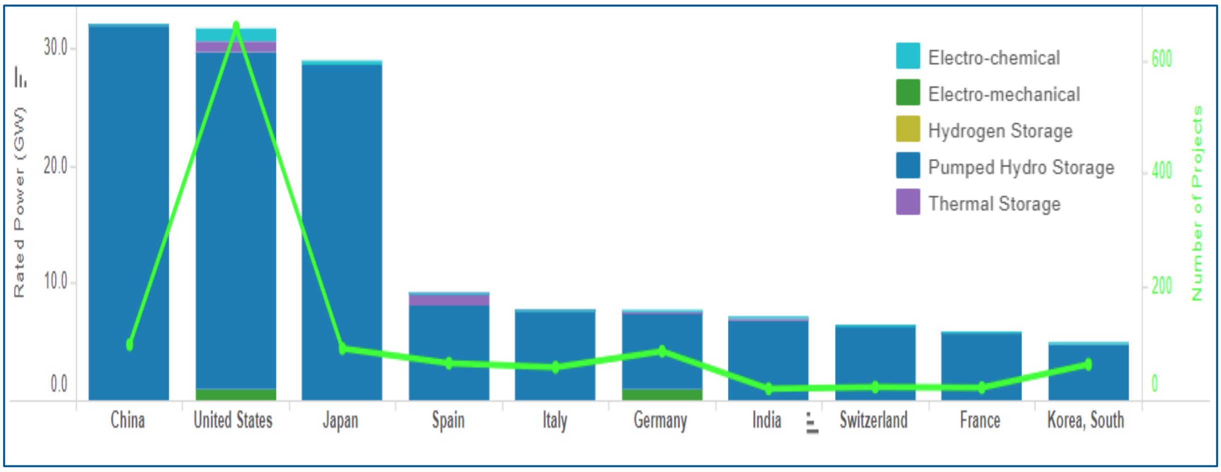
Based on their main functionality we can differentiate three type of storage technologies:

- Technologies with very fast discharge rates and generally a low Energy to Power ratio (referred in this document as E/P ratio; see explanation in section 0). These are well suited for very fast services, such as fast frequency control, frequency containment reserve, and dynamic voltage support. Examples are high-power supercapacitors, flywheels and most types of batteries.
- A second group of technologies characterised by a higher E/P ratio and discharge times in the range of a few hours. These are better suited to deal with grid bottlenecks, congestions, renewable curtailment and better renewable capacity firming. Within this category, a number of batteries are available; sodium-sulphur (NaS) batteries are the incumbent battery technology. Power to gas (P2G) systems, transforming electricity into hydrogen through electrolysis, as well as some small thermal storage systems could be included within this category.
- The third group of technologies belongs to large, centralised, bulk power management applications. These storage systems can store energy for multiple hours, days and in some cases even seasons as energy losses are negligible and capacity volumes are large. Within this category, we find pumped hydropower storage (PHS), compressed air energy storage (CAES), P2G, and thermal storage. These systems are well suited for energy arbitrage and balancing but they can also provide faster services such as frequency reserves. However, the potential to build new PHS and CAES installation is very limited due to unique geographical requirements and the associated environmental permits.

MARKET

Figure 3 shows the 10 largest electricity storage markets worldwide. Currently, there are over 167 GW of storage capacity installed and operational worldwide providing around 4.7 TWh of energy storage [2], 96% of which is PHS.

Figure 3. Cumulative Energy Storage capacity (operational). Source: DOE Energy Storage Database



In Europe (EU28, Norway and Switzerland)[3] , about 55 GW are installed, providing over 600 GWh[4] of energy storage. Most of the installed capacity is PHS too, with over 95% of the market. The rest is CAES, flywheel and various battery technologies.

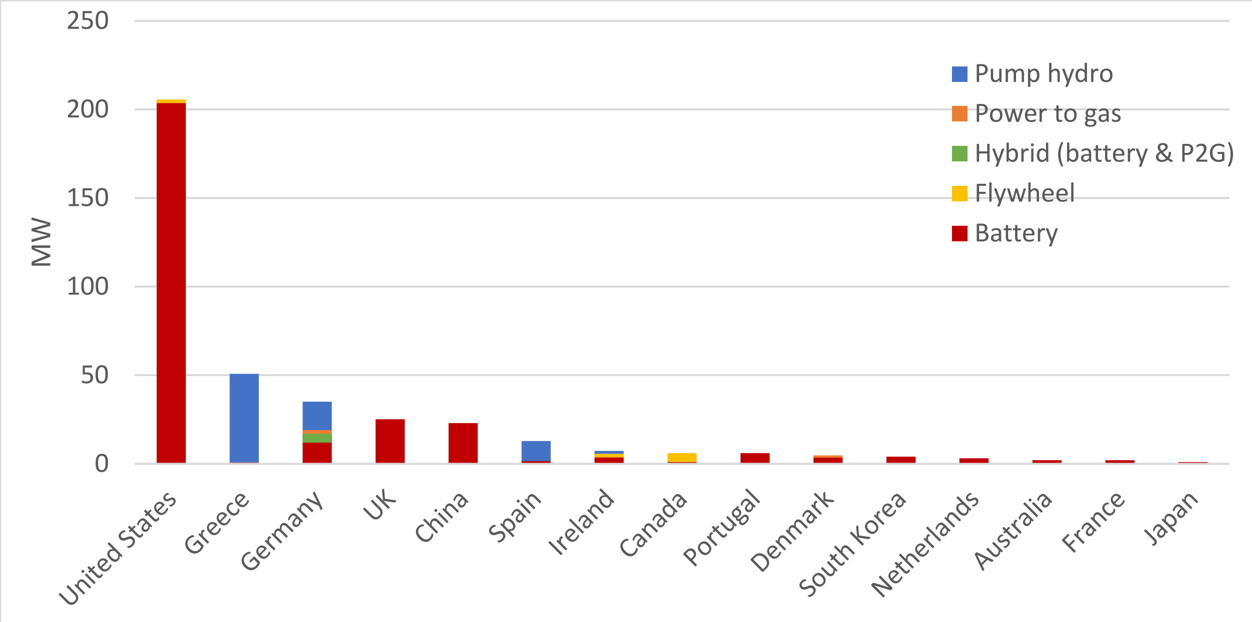
Global projections[5] estimate a tripling of energy storage capacity (in energy terms) by 2030, with battery storage increasing by a factor of 17 compared to 2017 levels.

WindEurope has compiled a database of existing and upcoming co-located wind energy + storage projects. Available online, this database[6] is publicly accessible and offer users the possibility to submit their own projects.

Up to October 2017, 388 MW of co-located projects have been identified globally, including those operational (64%), contracted or in development (22%) or announced (14%).

[2] Electricity Storage And Renewables: Costs And Markets To 2030, IRENA, October 2017 http://www.irena.org/DocumentDownloads/Publications/IRENA_Electricity_Storage_Costs_2017.pdf
[3] DOE Database on Energy storage projects, http://www.energystorageexchange.org/projects/data_visualization
[4] Valuing dedicated storage in electricity grids, EASAC policy report 33, May 2017 http://www.easac.eu/fileadmin/PDF_s/reports_statements/Electricity_Storage/EASAC_Electricity_Storage_Full_Report.pdf
[5] see footnote 2
[6] WindEurope online database of wind+ storage co-located projects, https://windeurope.org/about-wind/database-for-wind-and-storage-colocated-projects/

Figure 4. Co-located wind +storage project by country. Source: WindEurope



Most of the projects have been established under demonstration activities although some of them are developed or already operational under commercial terms. The largest market is the US, followed by several European countries and China. The use of batteries co-located next to wind farms has taken up mainly by the PJM[7] interconnector ancillary services market in the US (further explained in section 3.3).

Section 3 shows a selection of projects classified by their main functionality[8].

[7] PJM Interconnection is a regional transmission organization (RTO) that coordinates the movement of wholesale electricity in all or parts of Delaware, Illinois, Indiana, Kentucky, Maryland, Michigan, New Jersey, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia and the District of Columbia.

[8] Note that in most cases, storage systems at the wind power plant can satisfy more than one function. For instance, they can allow frequency response (in order to participate in Frequency containment reserves markets, while at the same time be operated to smoothen up deep up/down ramps.

3. SERVICES OF ELECTRICTY STORAGE

Energy storage systems can provide a large number of services. These services will have a different value depending on the user. TSO and DSO could use storage for the deferral of network expansion, to manage grid congestion or for the provision of ancillary services to maintain system stability (voltage support[9] in weak grids, fast frequency response (FFR), black-start capability). Asset owners could use stand-alone storage systems for energy arbitrage and they could provide firm capacity to system operators, thereby accessing capacity remuneration mechanisms. Conventional generators can integrate storage to optimise their electricity production and ancillary services provision. Variable renewable energy producers, such as wind and PV, could benefit from storage technologies to reduce the amount of curtailed electricity at times of grid congestion or system instability (like in Ireland where non-synchronous generation is limited). Energy storage could help them maintaining generation schedules communicated to system operators, thereby reducing imbalance charges and avoiding penalties for not fulfilling the performance committed to the system. Finally, energy storage could also enable variable renewable energy producers to provide a wider range of ancillary services such as FCR, FRR, FFR and reactive power provision even when wind is not available.

Table 1 presents an overview of electricity storage services, classified in four main categories: Energy arbitrage, ancillary services, grid adequacy and generation adequacy. Each of the services can help different actors and across various markets and mechanisms. This paper focuses on those services that could be provided onsite (highlighted in red[10]), co-located with or nearby wind farms. It is important to note that services can be combined (service stacking) to increase the value of the storage asset under co-location.

[9] Wind farms can and do support voltage in weak grids today without storage devices. In general storage energy is not need to provide voltage support, but the power electronics associated to the Energy storage system do give more capability to control voltage through reactive power management

[10] Assessment is based on experts opinion

Table 1. Services of electricity storage and its potential value for co-location

Category of service	Services of electricity storage	Typical User	Size	Potential Value of Co-location	Type of Market
Energy Time Shift	Energy arbitrage	Generators	Large	Low	DA, ID
	Self-consumption	Generators/ consumers	Small	**Low**	DA, ID
Ancillary services	**Frequency reserves**	Generators Independent storage operators	Small	**High**	FCR, aFRR, Fast frequency response, synthetic inertia
	Voltage control	Generators TSO,DSO	Small	**High**	Reactive power
	Black-start	Generators Independent storage operators	Large	**Medium**	Ancillary services
Grid adequacy	Network Upgrade deferral	TSO, DSO	Large	Medium	TSO/DSO investment
	Congestion management	TSO, DSO	Large	Low	Redispatching mechanism
	Curtailment Reduction/ congestion	Generator	small	**High**	Balancing/redispatch mechanism
	Ramping control/ smoothing	Generator	Small	**High**	New product?
	Capacity firming/ **Imbalance reduction**	Generator	small	**High**	Balancing, Frequency reserves
System adequacy	**Generation adequacy**	Generators Independent storage operators	Large	**Medium**	Capacity market
	Seasonal storage	Generators Independent storage operators	Large	Low	DA, ID, Capacity market, new product?

3. CO-LOCATING ENERGY STORAGE AND WIND FARMS

3.1. DEFINITION OF CO-LOCATION

Co-location refers to connecting a wind farm and energy storage to the same grid node (also known as point of common coupling). In this case, the asset owner has to comply with a set of connection requirements (grid code) covering the capabilities and functionalities of the combined facility.

However, in some small electrical systems (e.g. small islands), various distributed assets might not share the same connection point to the grid and still be referred as co-located projects. In some cases, these systems have PSH and high shares of wind power and other variable renewables (solar PV, run of river hydro). Such small systems lack a wholesale market and system operators manage the dispatch of all assets in a centralised and coordinated manner.

3.2. ENERGY TIMESHIFT

Self-consumption and dispatchable wind supply (islands)

Self-consumption supported with energy storage is an attractive solution for residential solar PV systems as the demand and generation profiles have a very stable pattern and repeat daily. Therefore, the owner can relatively simply size the energy storage system (i.e. a battery) to store excess energy produced during the day and discharge it during the evening. This generation-demand profile allows to charge and discharge the storage system on a daily basis, maximising the value of the asset with a relatively low E/P ratio. .

For wind power however, the resource availability does not follow a daily or weekly pattern. Periods of high wind can last several days and periods of low wind could extend for a couple of days too. In case of batteries, this would lead to a quick saturation of the battery capacity and a possible long period (days) of no usage. The use of HPS (especially in islands) and CAES (with large storage capacity) might be more appropriate for such use, allowing system to reduce their dependence from the use of back-up capacity such as diesel generators. This could allow small isolated systems to aim for 100% renewables supply. There is already a number of islands targeting this approach.

Open-loop Pumped Hydro Storage

El Hierro Hydro-Wind Plant
Endesa, REE, El Hierro, Spain

Wind Farm(MW)	Storage power rating (MW)	Storage capacity (MWh)	Main function
11.5	6 (pump) 11(generation)		Capacity firming/ energy shifting

Description: Operations started in 2015, aiming to provide 100% wind power to the inhabitants of the island. So far, the system still relies on diesel generators either for stability issues or to endure for very long period (10+ days) of no wind resources. Ongoing analysis is providing further evidence of the potential as well as of the challenges of 100% RES systems.

Battery: Lithium Ion Titanate

Graciosa project
Younicos, Azores Islands, Portugal

Hybrid plant(MW)	Storage power rating (MW)	Storage capacity (MWh)	Main function
5.5	6	3.2	Capacity firming/ Ramping control

Description: started operation by end 2016 in a hybrid plant (4.5MW wind, 1MW solar PV). The hybrid power system can immediately use up to 100 percent sun and wind power. The diesel generators will only be needed for back-up in weeks with very poor weather conditions. The plant is expected to cover an annual average of up to 70 percent of the island's power demand with renewables.

Battery: Lithium-Ion

Husahagi wind farm
ENERCON, Faroe Island

Wind farm (MW)	Storage power rating (MW)	Storage capacity (MWh)	Main function
12	2.3	0.7	Capacity firming/ Ramping control

Description: The goal of the system, which entered into operation by the end of 2015, is to enhance grid stability by smoothing ramp rates and providing ancillary grid services such as frequency control.

3.3. ANCILLARY SERVICES

FREQUENCY RESPONSE

Energy storage technologies are well suited to provide fast response to compensate for frequency variations in the energy system (e.g. due to a sudden loss of a large generator or forecast errors for load and supply). For instance, a number of storage projects are operational in the US in the PJM reserve market[11] providing system frequency balance. PJM has developed an advanced ancillary services market rewarding performance to suppliers and thus providing a clear business case for battery projects (see

[11] http://www.pjm.com/markets-and-operations/ancillary-services.aspx

examples in section 4.1). By 2017, about 265 MW of storage capacity was participating in this market, 151 MW of which (five projects) in co-location with wind farms. Since spring 2017, changes to the market rules have been introduced (restrictions in the use, changes in the length of products), reducing the demand for storage. This has affected negatively the business case for existing projects and those that were under development[12].

However, the suitability of fast-reacting energy storage assets to comply with requirement from frequency reserves is highly dependent of the product requested by TSOs. Reserves to provide energy for large periods of time (e.g. a couple of hours) are, for instance, not well suited to battery systems due to the need of oversizing. On the other hand, very fast products, such as the new *enhanced frequency response* requested by National Grid in the UK fit very well with battery systems, since they can deliver power extremely fast (below 1s) and the service is only requested for a few minutes or even seconds. 90% of the winning projects from the latest *enhanced frequency response* tender[13] are battery storage projects. One of them is co-located with an existing wind farm (*Vattenfall's Pen Y Cymoedd plant).*

Another potential service from storage devices at wind farms would be the provision of synthetic inertia. In principle, wind turbines could today provide synthetic inertia by advancing the kinetic energy available in the rotor to the generators, thus increasing temporarily their power output (e.g. approximately 10% of the output power during 10 seconds). After such power impulse, the turbine will need to recover that energy during a period (e.g. 1-2 minutes, depending on system specifications). This capability is well-proven, however no system operator requests this product yet. In the future, in systems with very high shares of converter-based technologies, such energy recovery time might demand additional fast frequency reserves or that the wind farms are equipped with their own storage device.

Many projects existing under this category. A few are shown below:

Battery: Lithium Ion Titanate

Lem Kær ESS Demo
Vestas, Ringkøbing , Denmark

Wind farm (MW)	Storage power rating (MW)	Storage capacity (MWh)	Main function
12	1.2	0.3	Frequency control

Description: The demo project has published (2016) a number of results when assessing the different functionalities of co-located battery system. Primary Frequency response being the most interested of the services as long as the product design and system needs are rightly provided.

[12] The latest market changes introduced have allowed the system operator to increase stability but they have harmed energy storage providers, who responded by filing two complaints against PJM. The complaints are currently under review by the Federal Energy Regulatory Commission (FERC). http://kleinmanenergy.upenn.edu/sites/default/files/Energy%20Storage%20in%20PJM.pdf

[13] http://www2.nationalgrid.com/Enhanced-Frequency-Response.aspx

Battery: Lithium-Ion

Barasoain experimental project
Acciona energia, Spain

Wind farm (MW)	Storage power rating (MW)	Storage capacity (MWh)	Main function
15	1.7	1	Frequency control

Description : Inaugurated in September 2017, the battery system is directly connected to 1 turbine out of the 5 of the wind farm. The battery can either provife Fast response at maximum capacity (1MW for 20') or a lower power for up to 1 hour (0.7MW for 60')

Battery: Lithium-Ion

Pen y Cymoedd Wind Farm
Vattenfall, South Wales, UK

Wind farm (MW)	Storage power rating (MW)	Storage capacity (MWh)	Main function
228	22		Frequency control

Description: Planning to enter into operation in February 2018, it will be the largest co-located wind-storage project in the UK. The system will provide fast frequency response under the recently developed market on Enhance Frequency response that National grid opened in 2017.

Battery: Lithium Iron Phosphate Battery

Beech Ridge Wind Storage
Invenergy, West Virginia, USA

Wind farm (MW)	Storage power rating (MW)	Storage capacity (MWh)	Main function
100.5	31.5	0.39	Frequency control

Description: Having started commercial operations in November 2015, the system provides fast-response frequency regulation to the PJM Interconnection ancillary services market. This project complements another 31.5 MW storage project in Illinois (Grand Ridge Storage), also operated by Invenergy and participating to the PJM market

VOLTAGE

As variable renewables increase their share and progressively displace synchronous generators, there is an increasing need for distributed resources to provide reactive power at the local level. Wind and solar power can be controlled to provide reactive power and thus control voltage levels in order to meet system needs. However, their capacity for providing reactive power at times of high load and low resources (wind, sun) is limited. This could create an incentive to deploy distributed storage, which is perfectly suited to provide voltage control. Both co-located at the wind farm and stand-alone systems could provide the right solution, depending on the local system needs and grid connection requirements. Too stringent requirements (grid codes) might lead to the need of having static compensators/ storage behind the meter in order to satisfy reactive power capabilities at times of low/no active power (when the wind is not blowing).

Overall, distributed storage is much better suited than centralised storage to provide voltage control, as voltage stability is a local issue and reactive power cannot be transmitted over long distance.

BLACK START

Black start is the capability to provide power after a partial/total shut down (of a power plant or a distribution grid) without the help of the transmission grid. Batteries are usually combined with diesel generators at hydro power plants to provide enough power to open the intake gates and to provide enough excitation current to re-activate the generator.

The wind industry is working to develop different black start capabilities that could substitute existing use of diesel generators. The first goal is to ensure that wind turbines can black start themselves and generate their own auxiliary power without relying on diesel generators, as these are a very expensive option in remote places (e.g. offshore wind farms), where fuel imports and operational costs are high.

In the future, the goal is it to provide enough power with the wind farm to re-energize the grid at which they are connected. An increasing number of battery-based projects[14] in combination with renewables are becoming active in the provision of these services. Two offshore wind farms[15] are also installing battery systems that might support them in the future to power their auxiliary services during downtimes.

Battery: Lithium Ion

Batwind
Statoil, Scotland, UK

Wind farm (MW)	Storage capacity (MW)	Storage capacity (MWh)	Main function
30	1	1	Frequency control Black start

Description: The project will be developed in the first commercial offshore floating wind farm: HyWind. The Batwind battery array will be installed on the coast, where the wind farm's export cable comes to shore, although Statoil exploring the possibility to add the storage devices at the wind turbine. Operations are expected to start in late 2018.

[14] Clean Technica article, February 2016, https://cleantechnica.com/2016/02/02/restoring-the-grid-after-a-blackout-using-batteries/

[15] Burbo Bank, Dong energy ; Hywind, Statoil

3.4. GRID ADEQUACY

Wind power plants tend to concentrate in areas of high wind resources, which do not always count with strong distribution and transmission infrastructure. In addition, the speed of grid deployment is in many cases lower than the deployment of renewable generation assets. This is leading to areas with regular congestions where wind energy needs to be frequently curtailed.[16,17] In this case, distributed storage might help to **reduce congestions** while increasing transmission capacity utilisation. The type of energy storage solution will depend on the profile of the congestions (frequency and duration). Battery storage could be quite suitable to solve short congestions (peak shaving for large solar installation). However, it might prove more difficult for areas with large wind power concentration if the period of strong winds remain for many hours but are not that often. Storage might also be used to over-dimension the power plant with regards the grid capacity. That could help to reduce transmissions costs by increasing the utilisation of the available grid capacity.

Other congestion mitigation options include transforming excess generation to hydrogen, to be later used in industrial, transport and/or heating applications. A recent comprehensive study[18] looks into the economics of such approach. A number of projects, co-locating wind farms and electrolysers are today in demonstration phase. As the cost of electrolysers is rapidly decreasing, the business case for such applications might improve significantly in the next years. Regulation regarding curtailment compensation and other redispatch measures will also affect significantly the viability of such approach.

Co-located wind and storage can also be used to **reduce imbalances**, which are caused by wind forecast errors. Reducing imbalances might prove economically interesting if it allows the wind farm to maintain schedules with a high level of accuracy (for instance, when providing automatic frequency restoration reserves), avoiding to pay high penalties associated with non-compliance. In some other markets where producers are exposed to very high imbalance charges and penalties, storage might also prove to be a viable alternative (e.g. Romania).


Flywheel Energy Storage System

Kodiak Powerstore
ABB, Alaska, United States

Wind farm (MW)	Storage power rating (MW)	Storage capacity (MWh)	Main function
9	2		Frequency control + Voltage control

Description: The ABB PowerStore units will provide voltage and frequency support for a new crane to be installed at Kodiak Island's port facility. They can also extend the life of the battery systems by up to 6 years, and provide renewables integration by helping to manage the intermittencies from a 9 MW wind farm on the island

[16] WindEurope position paper on priority dispatch and curtailment, June 2016 https://windeurope.org/wp-content/uploads/files/policy/position-papers/WindEurope-Priority-Dispatch-and-Curtailment.pdf
[17] In Germany, in particular the region of Schleswig-Holstein which account for about 60-70% of all the curtailed wind energy in Germany. See quarterly reports from the Energy regulator www.bundesnetzagentur.de
[18] Early business cases for H2 in energy storage and more broadly power to H2 applications, Tractabel, Hinicio, June 2017 http://www.fch.europa.eu/sites/default/files/P2H_Full_Study_FCHJU.pdf

Flow battery (vanadium redox flow)

Gigha community wind project
Redt, Scotland, UK

Wind farm (MW)	Storage power rating (MW)	Storage capacity (MWh)	Main function
1		1.68	Congestion relief/ Islanding mode

Description: Entering in operation by the end of 2017, the project aiming to increase 20% wind energy generation by allowing to generate electricity from a 4th turbine without constraints on the voltage (which is currently limited to 225kW). The second goal is to add islanding functionality when the interconnector with mainline (11KV Overhead line) is down.

Battery: Lithium-Ion

La Plana Wind Farm
Gamesa, Aragon, Spain

Hybrid plant(MW)	Storage Power Rating (MW)	Storage capacity (MWh)	Main function
2		0.5	Capacity firming/ Ramping control

Description: The offgrid Prototype hybrid power plant includes a 0.8MW wind turbine, complemented by 245KW of PV panels and 3 diesel genset (666KW). The battery aims to provide continues power to potential 4,000 housholds located in remoted areas. Thi

There are also projects based on Power-to-gas application, with electrolyser helping to provide a solution in areas that are frequently curtailed.

Power to hydrogen- PEM Electrolyser

Energiepark Mainz
Siemens/Linde,Hochschule RheinMain, Germany

Wind farm (MW)	Storage power rating (MW)	Storage capacity (MWh)	Main function
8	6.3		Congestion relief/ Frequency control (negative FRR)

Description: Demonstration project to prove the capability to transform wind energy that would otherwise be curtailed into hydrogen. While releasing local grid bottlenecks, it can also provide secondary control reserve. The system was successfully pre-qualified for the Frequency Replacement reserves in the German balancing market.

3.5. SYSTEM ADEQUACY

As conventional generation is progressively substituted by variable non-dispatchable renewables, there is an increasing need for system operators to develop mechanisms to ensure system adequacy (matching demand and supply). Wind energy contributes to system adequacy, but its contribution (known as "capacity credit") is relatively small compared to thermal and hydro generation. Demand response also contributes today to such adequacy, although its potential is much larger than today's use[19]. Finally, co-located dedicated storage might also contribute to system adequacy. This has been reflected in some capacity markets[20] where storage has been awarded capacity contracts.

The energy capacity of battery storage (as per their rated capacity) is quite limited. In situations of system stress (e.g. cold spell or large power plant outages), batteries might be of little adequacy help. This is an important aspect that has recently led the UK government and the regulator (Ofgem) to revise the prequalification criteria for their capacity auctions, in an attempt[21] to sort out storage technologies on the basis of their discharge duration at rated capacity (instead of just their capacity).

Other storage alternatives are also being explored. This is the case of an upcoming a pilot project[22] run by Max Boegl Wind using new prototype GE turbines. The concept combines the wind turbines with a pump hydro reservoir beneath and at the bottom of the wind turbine towers. Such concept would allow providing firm wind capacity for long periods, thus allowing generators to participate in capacity markets.

In the long term, with a very high share of variable renewable, seasonal storage is likely play an important role to ensure security of supply. So far the only viable solution would be to store hydrogen (produced from wind/solar power) in large quantities (e.g. underground storage in depleted gas reservoirs and/or salt caverns) to latter be re-electrified. Today, a business case for such solution does not exist partially due to the large (thermal) generation overcapacity and due to the high associated costs (and low round-trip efficiency) of this process. However, economies of scale are pushing down the costs for electrolysers and ongoing demonstration projects are showing increased efficiency levels.

Pumped Hydro Storage

Max Boegl Wind
Swabian-Franconian Forest, Germany

Wind farm (MW)	Storage capacity (MW)	Storage capacity (MWh)	Main function
16	13.6		Generation adequacy/ Congestion relief

Description: Start by the end of 2018, It will be the first wind farm with an integrated hydropower plant. The base of the turbines will serve as water reservoir. In addition, they will sit in another larger reservoir. When electricity is needed, water flowing downhill from the reservoirs will power the hydro plant. When the energy supply is high, the hydro plant will pump the water back up the hill to the reservoirs and will act as the giant battery.

[19] Explicit Demand Response in Europe, Mapping the Markets, SEDC, 2017 http://www.smartenergydemand.eu/wp-content/uploads/2017/04/SEDC-Explicit-Demand-Response-in-Europe-Mapping-the-Markets-2017.pdf
[20] 3.2 GW of winner capacity from storage system in the 2016 UK capacity auction, with over 500 GW being battery storage projects.

[21] Public consultation, summer 2017, https://www.gov.uk/government/consultations/capacity-market-consultation-improving-the-framework-detailed-proposals
(https://www.energy-storage.news/news/battery-storage-will-be-hit-by-uks-proposed-capacity-market-derating-change)

[22] GE Report, October 2016, https://www.ge.com/reports/unique-combo-wind-hydro-power-revolutionize-renewable-energy/

5. MARKET DESIGN IMPLICATIONS AND POLICY RECOMMENDATIONS

4.1. STAND-ALONE ENERGY STORAGE SYSTEMS

Stand-alone energy storage systems should be treated as any other technology that offer services to the electricity system. As a principle there should not be a preferential or differentiated treatment for technologies in the market. This includes prequalification criteria and procurement rules. TSOs should be able to procure services from storage technologies at a value that reflects system needs through competitive energy markets.

For example, if storage is to offer flexibility to the electricity system by offering balancing services, it should follow the same general principles on product and procurement rules than any other technology. Likewise, market rules should not preclude energy storage participation by ensuring that:

- Balancing capacity and balancing energy products should always be procured separately
- Upward and downward products are procured separately
- Balancing products are harmonized and shortened in the time frame of delivery
- Gate closure times are shortened and harmonized across balancing areas
- The lead time for the procurement of balancing capacity is as short as possible
- Aggregation of individual bids is possible
- Delivery-proof mechanism should be based on the available active power

In addition, **energy storage operators should not pay twice energy network charges.** Since storage devices consume and generate energy, they are subject of double charging in some Member States. In Austria, Belgium, France, Ireland, Portugal and Sweden operators pay both, load network charges and G-charges[23]. Moreover, these charges apply irrespectively of the time when the operators are consuming/generating.

Members States should remove the double charging from energy storage. This would reflect the system benefits storage provides to the electricity system and would set them on equal footing with other flexibility options. **In particular, governments should phase out G-charges in all European countries**[24] in order to avoid distorting electricity trading in the EU Internal Energy Market. OFGEM, the UK energy regulator, has recently removed such double charging from battery storage.

[23] EASE Position on Energy Storage Deployment Hampered by Grid Charges, May 2017 http://ease-storage.eu/wp-content/uploads/2017/05/2017.05_EASE-Position-Paper-on-PHS-Grid-Charges_final.pdf
[24] WindEurope position paper on Network tariffs, March 2016, http://www.ewea.org/fileadmin/files/library/publications/position-papers/EWEA-position-paper-on-harmonised-transmission-tariffs-and-grid-connection-regimes.pdf

Furthermore, **governments should adopt the definition proposed by the European Commission under the recast electricity directive for energy storage assets**[25]**.** This would be a first step towards addressing the diversity of national regulations applicable today to storage technologies. Moreover, adopting this proposed definition guarantees covering all energy carriers beyond electricity. For example, power-to-gas and thermal storage. Furthermore, this would ensure that ACER and ENTSO-E consider energy storage in the development of European Framework Guidelines and Network Codes and that national regulators and TSOs do the same in their national grid codes.

TSOs should allow energy storage operators to provide multiple services to the grid (service staking). For instance, storage could deliver congestion management services and voltage support to DSOs while offering frequency reserves to TSOs. They could participate in various frequency response products simultaneously while providing firm capacity under capacity markets too. In this sense, market operators should remove all barriers to the participation of energy storage in these services. Products and pre-qualification processes need to evolve too in order to foster technology deployment.

Finally, new capabilities required in Network Codes should be market-based and not mandatory. TSO should assess the system needs and procure the service to satisfy such needs through market-based mechanisms. Such approach would lead to overall lower cost for society and consumers. The current European Network Code Requirements for Generators (NC RfG)[26] contains mandatory capabilities that would mean that wind turbines might have to be equipped with energy storage devices. This would increase costs of wind energy under the current policy framework. These requirements include the delivery of *Fault-Ride-Through* (FRT) and reactive power capabilities in low frequency sensitive modes (LFSM), over and under frequency events (LFSM-O and LFSM- U)[27].

4.2. CO-LOCATION PROJECTS

Wind energy asset owners should not need to reapply for support schemes when adding energy storage to an existing wind farm. As most of the co-location wind energy with storage projects are on existing wind farms, these assets have already cleared all permitting and administrative procedures to obtain a support scheme. However, as soon as they incorporate an onsite storage device they need to re-apply for their support scheme. This is for example the case in Germany and in the UK. Regulators fear that operators claim electricity absorbed from the grid by the storage device as wind power-generated, hence receiving compensation from non-renewable electricity. Therefore, **regulators should clarify rules on metering** so that developers do not need to reapply for the support instrument.

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[25] *"Energy storage means, in the electricity system, deferring an amount of the electricity that was generated to the moment of use, either as final energy or converted into another energy carrier."*

[26] Network Code RfG, April 2016 http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32016R0631&from=EN

[27] The LFSM-U capability means that if the system frequency decreases below a certain pre-defined threshold, power plants will need to increase their active power output in line with the specifications. Generally, the change of active power needs to be started within 2 seconds. If this requirement becomes mandatory (now or in the future), wind power plants will need to operate below their maximum capacity (wasting free available energy), ensuring a head-room of power in case of system needs

ANNEX- TERMS AND ABBREVIATIONS

- ACER: Agency for the coordination of energy regulators
- aFRR: automatic frequency restoration reserve (equivalent to secondary frequency control)
- CAES: Compressed air energy storage
- DA: Day-ahead market
- DSO: Distribution system operator
- ENTSO-E: European network of transmission system operators
- FCR: Frequency Containment Reserve (equivalent to primary frequency control)
- FFR: Fast frequency response (frequency control faster than FCR)
- FRR: Frequency restoration reserve
- ID: Intra-day market
- LAES: Liquefied air energy storage
- NaS battery: Sodium-Sulphur Battery
- NC RfG: Network code *Requirements for Generators*
- P2G: Power to gas
- PHS: Pump hydroelectric energy storage
- RR: Replacement reserve
- SNG: Synthetic natural gas
- TSO: Transmission system operator

Energy to Power (E/P) Ratio

Energy storage modules are measured in (at least) two dimensions: their rated output or power rating, and their energy capacity.

Their **power rating, in MW**, measures the instantaneous demand requirement they are able to supply. If you add the power rating of all the demand appliances connected to an energy storage module, they need to total up to and no more than the module's power rating.

The **energy capacity, in MWh,** specifies the total amount of energy that the module is able to deliver over time.

If you divide the energy capacity (in MWh) by the power rating (MW), you get the duration (in hours, minutes or seconds) that the module can operate while delivering its rated output. This duration is the energy to power ratio (also referred as the discharge time).

In this document, we refer to the Energy to Power ration as the E/P ratio.