California ISO

Renewables Grid Initiative

ENERGY STORAGE

Perspectives from California and Europe

Discussion Paper – October 2019

California ISO

Renewables Grid Initiative

California ISO:

The California Independent System Operator Corporation (CAISO) operates about 80% of the bulk of the state's wholesale transmission grid. The nonprofit, public benefit corporation provides open and non-discriminatory grid access, supported by a competitive energy market and comprehensive planning efforts. Partnering with about 160 entities, the CAISO is dedicated to developing and operating a modern grid that benefits consumers.

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The Renewables Grid Initiative is a unique collaboration of environmental NGOs and Transmission System Operators from across Europe. We promote transparent, environmentally sensitive grid development to enable the further steady growth of renewable energy and the energy transition.

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Foreword – Storage: the game changer

In recent decades, energy storage systems have undergone significant advances, both in the volumes of capacity added and the expansion of innovative technology. More storage is being used now than ever before, in grid-scale and local applications. Key storage technologies have been fine-tuned to the point of being economically viable, with significant cost reductions for some technologies. Batteries, for example, now represent one of the most commercially viable storage options available in many markets.

Manon van Beek, Chair of the Executive Board and Chief Executive Officer of TenneT Holding B.V – the company that manages the high-voltage grids in the Netherlands and large parts of Germany, highlights the already significant use of storage:

> *"With economic and technical (r)evolutions, storage will be the game-changer which is needed for the acceleration of the successful energy transition. Our company is already incorporating energy storage and its usage as a source of flexibility in our grid planning and operation. We also actively develop solutions for a higher utilization of our grids enabled by fast reacting storage assets, for example grid booster, as well as long-term storage solutions like power-to-gas."*

Accelerating the spread of energy storage will propel a renewables-based energy system – alongside increased flexibility options and a better use of (existing) infrastructure – and subsequently help reach ambitious Paris Agreement climate targets.

Steve Berberich, President and Chief Executive Officer for the California Independent System Operator (CAISO) – one of the world's largest transmission organisations, managing the electric grid and wholesale power markets for 30 million Californians, highlights the important role storage will play in the upcoming energy landscape:

> *"Economical grid-scale and distributed storage has the potential of completely transforming the electric industry. Planning processes, operations, markets and the role of utilities will all be impacted by large-scale deployment of storage."*

In Europe, this message is echoed by Luigi Ferraris, Chief Executive Officer and General Manager of Terna – the company responsible for managing the Italian high-voltage transmission grid:

> *"Global warming and the explosive growth of humanity's demand for ecological resources call for a resolute action to drive a profound (r)evolution of the entire energy system. The electrical system has a crucial and central role as an enabler of such a transformation; in order to ensure the quality of service and security of supply, storage systems and flexibility resources are key "ingredients" of the energy transition, both for frequency regulation services and for the containment of structural overgeneration from renewables."*

However, there are challenges to the further deployment of energy storage. More effective regulatory and market schemes are needed to incentivise and sustain the continued development and integration of a diverse portfolio of electrical energy storage technologies. It is and will remain extremely difficult to deploy new utility-scale storage based only on volatile spot prices, due to the high upfront cost of some storage technologies. By ensuring that a diverse portfolio of storage technologies are available to the market, the suite of services that are ultimately needed to further integrate renewables can be better provided. In this context, grid services can be an important enabler for deploying new storage, because they allow storage operators to complement their revenues from energy markets with revenues from ancillary services markets for electricity grids ("revenue stacking").

There is a lot for Europe to learn from California. RGI Members have therefore teamed up with CAISO to develop this report.

> *Collaboration across geographies is essential to learn from each other and develop robust solutions. TSOs play an essential role in developing, testing and scaling solutions necessary for integrating increasing shares of RES in a safe and reliable way. Understanding and facilitating applications of storage-led services is a fundamental contribution to the energy transition"*, says Antonella Battaglini, CEO of RGI.

This report highlights the key main trends in electrical energy storage between the European and Californian/U.S. regions. Contained in this report are also a number of recommendations with regard to storage for decision and policy makers that must be addressed moving forward. These recommendations represent the voice of power grid operators and NGOs: who share a common interest in facilitating high shares of renewables on the grid.

Executive Summary

Energy storage is essential in enabling the large-scale deployment of renewables, which are in turn needed to support the energy transition and achieve Paris Agreement climate targets. Energy storage can be integrated at different levels of the electricity system, including at transmission and distribution levels. It can provide flexibility and balancing services, frequency control, voltage control in addition to acting as a back-up for variable renewables generation.

Energy storage includes a range of technologies, some of which have been utilised for decades across different geographies and markets. Pumped hydro storage is the predominant technology in use and represents over 96% of tracked storage capacity worldwide. Developments in other storage technologies such as batteries (stationary applications and battery electric vehicles – BEVs), flywheels, hydrogen and other chemical applications continue, contributing to their commercial viability.

Energy storage resources are currently deployed in a limited capacity but are expected to more than double in the 2030-2040 decade. California leads the U.S. in installed energy storage capacity, and the U.S. is expected to remain the leading global market for energy storage deployment until at least 2022. In Europe, Spain leads in terms of operational, grid-connected energy storage capacity.

The costs of some energy storage technologies, including lithium-ion batteries, are declining. This represents a key incentive towards their deployment. Moving forward, however, increased revenue streams including from ancillary services, policy support and market incentives will be crucial to guarantee growth and deployment of storage technologies. In California, the CAISO has initiated several wholesale market and infrastructure policy initiatives to remove barriers and increase the operational usefulness of storage resources. Similarly, electricity markets across Europe are expected to see continuous refinement of their policies and mechanisms, aimed at supporting the deployment of energy storage systems. For example, adaption of the regulatory and market frameworks to enable Vehicle-to-Grid (V2G) services will be needed soon in view of the anticipated annual addition of millions of BEVs. Efforts are also needed to make re-financing options available, especially in case of insufficient market schemes or in the presence of market failures.

Energy storage must be capable of providing essential grid services, including voltage and frequency control, ramping capability (i.e. active power management) and other services. These are essential in integrating higher levels of renewables into electricity grids.

Energy storage will also increasingly contribute to shifting load and providing peak services (i.e. when demand is high), which is beneficial in supporting the continued integration of renewables. Grid visibility and the operability of storage resources will become increasingly important in maintaining a reliable grid. These have to be provided to ensure that optimisation of all grid connected resources can take place. Transparent collaboration and coordination between the transmission and distribution levels can support this, as well as further our understanding of the role behind the meter storage will play.

Moving forward, it is crucial that the complexity and diversity of energy storage as a resource is grasped. This will better permit the design of adequate reward mechanisms for energy storage resources.

1. Introduction to energy storage

1.1 Overview

Energy storage has in the past played an important role in balancing supply and demand on electricity grid networks. Moving forward, it will be an increasingly important component of modern energy systems. Energy storage enables the storing of electricity, particularly from variable, non-dispatchable renewable energy sources (RES) such as wind and solar PV. When electricity production from RES falls below consumption levels, this stored electricity can then be fed back into the grid to provide needed load. As some RES generation is heavily dependent on weather conditions, times of high energy demand do not necessarily correspond to times of high generation. Safely integrating increasing shares of variable RES therefore requires a more flexible power system. Energy storage is an essential element to balance supply and demand and provide important grid-stability services, such as voltage and frequency control.

The combined trend of decreasing costs for RES and some storage technologies will continue to influence and speed up decarbonisation efforts. Grid integrated storage services will be fundamental to achieve the decarbonisation targets set in the Paris agreement.

1.2 Energy storage benefits

Energy storage provides a number of benefits, both directly for energy systems and also more broadly. Some key benefits are highlighted below.

Storing and smoothing renewables generation – enabling the integration of variable renewables: Storing excess solar and wind generated electricity and supplying it back to the grid or to local loads when needed can reduce RES curtailments, negative wholesale power prices coincident with wind/solar over-generation, and price spikes related to evening peak ramping needs. Also, co-locating batteries with solar and wind allows generators to meet reliability requirements in place and system owners to more predictably manage the power supplied to the grid.

Reduce greenhouse gas emissions: Enabling the continued integration of RES into electricity/energy systems, displaces the need for fossil fuel electricity generation sources and supports the electrification of other sectors (such as vehicles/mobility). Storage can provide the needed flexibility to maintain system security. Today, most of the flexibility is still provided by fossil fuel sources, mainly gas. Under the right regulatory conditions, storage can increasingly take over the supply of flexibility services. Additionally, storage applications, as for example “Vehicle to grid” (V2G), can reduce curtailment of wind and solar power.

Improve the reliable operation of transmission and distribution grids, particularly when operating with a higher proportion of RES: Energy storage technologies can provide essential reliability services, including frequency regulation, voltage support and ramping needs in addition to time-of-use bill management.

Balancing grid supply and demand: Energy storage systems can help balance electricity supply and demand on multiple time scales (by the second, minute, or hour). Fast-ramping batteries are particularly well-suited to provide ancillary services such as frequency regulation, which helps maintain the grid’s electric frequency on a second-to-second basis.

Defer or substitute costly investments in transmission, distribution or generation infrastructure: Local pockets of growing electricity demand sometimes require expensive new grid infrastructure, such as upgraded substations or additional transmission/distribution lines to handle the higher demand. Installing energy storage at strategic locations, at potentially lower cost, enables utilities to manage growing demand while deferring large grid investments.

Reduce demand for peak electricity generation: Presently, peaks in electricity demand are typically satisfied by increasing generation (commonly from fossil fuel 'peaking plants') or reducing consumption at fairly short notice. In place of these fossil fuel peaking plants, energy storage can be used to supply electricity during peak demand hours. This further supports decarbonisation of the electricity sector.

Lower wholesale electricity prices – peak shaving and price arbitrage opportunities: By buying power and charging during lower-price (or negative price) periods – generally when generation is high and load is low – and selling power and discharging during higher-price periods, batteries can flatten daily load or net load shapes. This would reduce the amount of higher cost, seldom used generation capacity needed to be online. In some regions such as California, this can deliver overall lower wholesale electricity prices.

Reduce end-use consumer demand charges: Large power consumers such as commercial and industrial facilities can reduce their electricity demand charges, which are generally based on the facilities' highest observed rates of electricity consumption during peak periods, by using on-site energy storage to remove or reduce peak demand times.

Provide back-up power: Energy storage can provide back-up power to households, businesses, transmission and distribution grids during outages or to support electric reliability. As part of an advanced microgrid setup, batteries can help keep power flowing when the microgrid is 'islanded', or temporarily electrically separated, from the rest of the grid.

1.3 Energy storage technologies

Some energy storage technologies, such as pumped hydro storage systems, have been utilised for decades across markets and regions globally. Currently, pumped hydro storage is the predominant storage technology. As of September 2019, the United States (U.S.) Department of Energy's Global Energy Storage Database reported that pumped storage accounts for over 96% of all tracked storage technologies worldwide, with a rated power capacity of over 181 GW[i] (1).

Other storage technologies such as lithium-ion batteries are continually developing, which has contributed to some interesting cost reductions. In order to provide the crucially needed flexibility and other services for power grid systems operating under a higher proportion of RES, a more diverse portfolio of storage technologies and services must be deployed (along with non-storage service options – primarily demand response). There is thus a pressing need to continue development and implementation of alternative storage technologies, including in both decentralised (such as electrical vehicles, heat pumps, batteries) and centralised applications (i.e. the storage of molecules such as hydrogen). These technologies must be able to cope with energy supply fluctuations on timescales ranging from seconds – 'frequency restoration', to months – 'seasonal storage'.

i) This includes approximately 13 GW of pumped hydro storage as either announced, contracted or under construction/repair.

Figure 1. summarises the common electrical energy storage technologies currently in operation across various markets and regions globally.

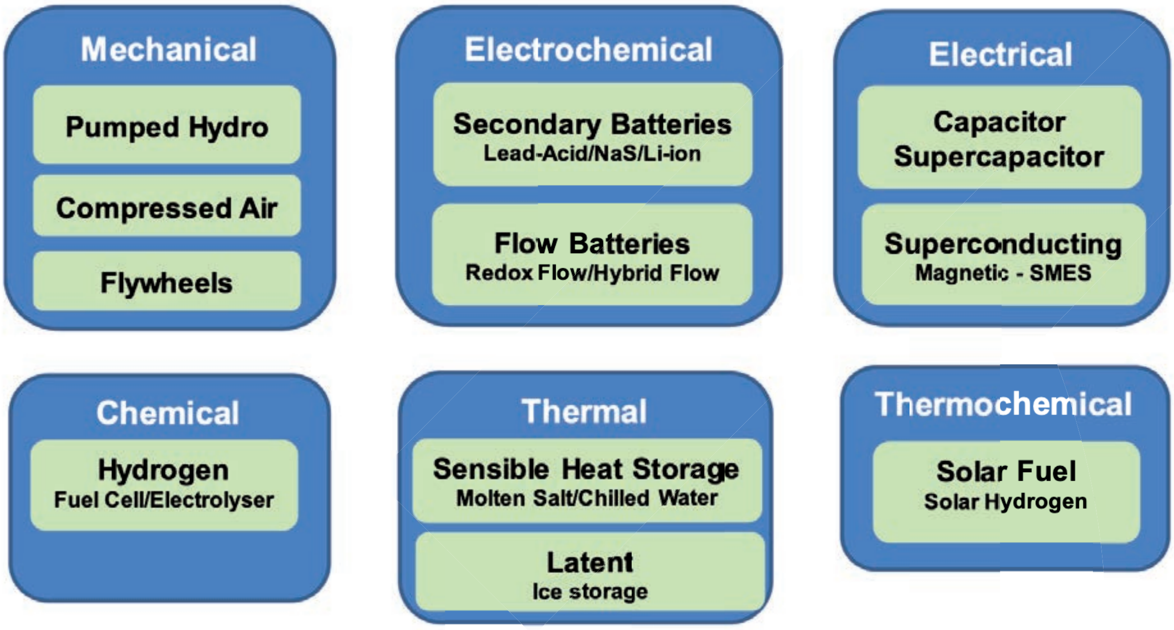


Figure 1: Common electrical energy storage technologies by form of energy stored. Source: Science Direct, Applied Energy (2)

Mechanical storage: The most common types of mechanical storage systems include pumped hydro-storage, compressed air energy storage and flywheels. These use kinetic energy technologies to store energy when the demand for electricity is low and transform that kinetic energy back to electricity when demand is high.

Electrochemical storage: Electrochemical technologies include batteries that have been used to power consumer electronics for decades. Lithium-ion batteries are lighter and significantly more energy-dense than their alkaline counterparts (3). Flow batteries do not use electrodes but instead uses two circulating electrolyte fluids which exchange electrons directly across a shared membrane. Flow batteries are well-suited to grid-scale storage due to their relatively low energy density and power output.

Electrical storage: Electromagnetic energy storage systems store energy in the form of an electric field or a magnetic field, the latter created by the flow of direct current through a superconducting coil. Their primary advantage compared to other types of energy storage is their very short reaction time and ability to provide high power for short periods. Because they can be switched on with virtually no time delay, superconducting magnetic energy storage (SMES) systems can counteract abrupt changes in demand for applications where even the shortest interruptions are unacceptable.

Practical electrical energy storage technologies include electrical double-layer capacitors (or ultracapacitors) and SMES. Both are characterised by high power density, low energy density, high efficiency and little or no degradation due to charge/discharge cycling.

Chemical storage: Chemical energy storage systems store energy in chemical fuels (such as hydrogen) that can be used for power generation, heating and transport. Chemical fuels can be readily converted to mechanical or electrical energy.

Thermal storage: Thermal energy storage systems store energy in water, rock, concrete, phase change materials, molten salts or other fluids, which can be later used to generate heat or electricity. Thermal storage also includes freezing water at night using off-peak electricity, then releasing the stored cold energy from the ice to help with air conditioning during the day. Conversely, using excess solar power to heat up water during the day, which can be used at a later stage, is another example of thermal storage. Additionally, using the thermal mass of buildings to pre-heat or pre-cool by means of a heat pump, is another form of thermal energy storage.

Thermochemical storage: Thermochemical energy storage is a chemical reaction process whereby thermal energy from the sun is stored as chemical energy, and when needed, a reverse reaction recombines the chemical reactants and releases energy. The main advantage of thermochemical storage compared to 'phase change material' storage is that losses only occur during charging and discharging, but not over time, making these systems preferable for long term storage.

Moving forward, storage technology developments over the medium to long term look promising. Many technologies are competing to gain a competitive position across markets. These include advanced pumped hydro (variable, ultra-fast reacting generation), fly wheels, compressed air, batteries (of different types, including from BEVs) and super-capacitors – all which aim to store and provide electricity. These storage technologies have differing properties (i.e. capacities, ramp rates, reaction times and costs) and will ultimately cater for differing services. If properly incentivised, industry can play a significant role in their advancement (4).

2. Energy storage – installed capacity and forecast

2.1 Global overview

As of September 2019, global tracked energy storage totalled nearly 188 GW, which includes approximately 1,300 operational grid energy storage projects. An additional 11 projects are under construction. Of these, 40 percent of operational projects and 27 per cent of projects under construction are located in the U.S. In Europe, Spain leads in terms of operational grid-scale storage capacity, followed by Italy and Germany (1). Energy storage is, however, currently deployed in a limited capacity. Across the U.S. and European energy systems, energy storage deployment is at approximately 2 percent and 5 percent of total installed generation capacity, respectively (5) (1).

According to Bloomberg New Energy Finance (BloombergNEF), global battery energy storage installations alone[ii] will increase significantly to 1,095 GW or 2,850 GWh by 2040 (see Figure 2). This is expected to attract at least a further $662 billion in investment until then (6). This is a significant uptake, and according to the International Renewable Energy Agency (IRENA), a tripling of current storage capability is required to double renewables in the energy system by 2030 (7).

The U.S. is expected to remain the leading market for energy storage until at least 2022. China's storage market is set to expand significantly and will eventually lead cumulative energy storage installations. Continuous refinement of policy and market mechanisms will be needed to encourage energy storage. This includes for RES integration, time-of-day-based PPA structures, competitive market redesigns, retail rate reforms, urban and remote microgrids, and distributed resources for grid services and as virtual power plants. As a result of these initiatives and energy storage system improvements, the annual global energy storage market could reach 8.6 GW and 21.6 GWh by 2022 (8).

ii) BloombergNEF's definition includes stationary batteries used in eight applications. It excludes pumped hydro storage.

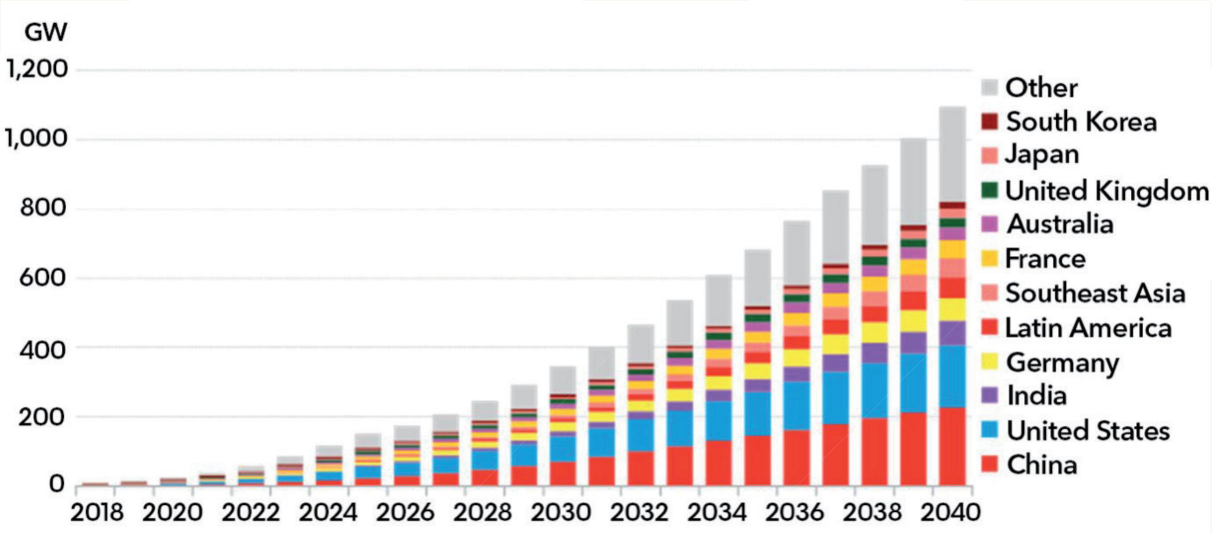


Figure 2: Global cumulative energy storage installations. Source: BloombergNEF (6)

2.2 United States overview

As of 2019, the U.S. has approximately 24 GW of operational electrical energy storage (1) compared to 1,097 GW of total in service installed generation capacity (5). A further 7 GW of energy storage has either been announced or is under construction (1). From 2013 to 2018, the number of U.S. energy storage projects increased by 174% (9). Approximately 94% of operational energy storage in the U.S. is from pumped hydro storage, equating to 22.5 GW as of September 2019 (1).

Looking forward, there are optimistic RES deployment projections across the U.S. In 29 states, RES portfolio standards will require electric load-serving entities to meet a minimum portion of their load with eligible forms of renewable electricity. Figure 3 shows this breakdown by state.

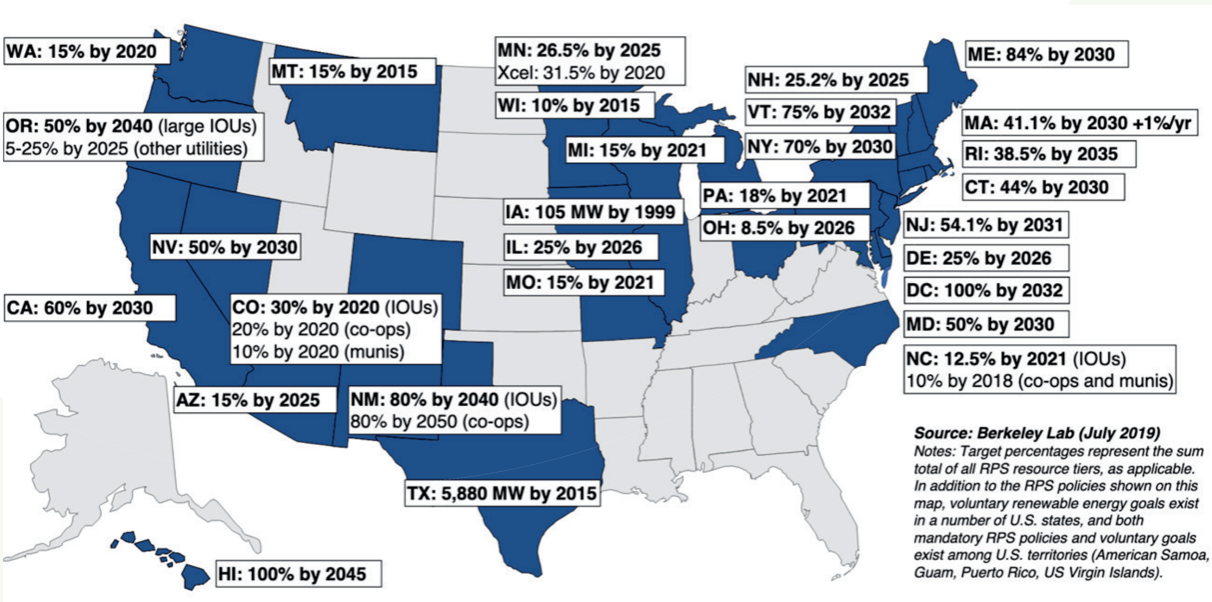


Figure 3: U.S. States with RES portfolio standards. Source: Berkeley Lab (10)

Energy storage deployments across the U.S. are subsequently increasing as states implement these RES standards in an effort to transition to a greener grid. According to an extrapolation of Bloomberg's data, it is projected battery energy storage technologies alone in the U.S. will reach more than 70 GW or nearly 200 GWh by 2030, as shown in Figure 4. These values will more than double during the 2030-2040 decade.

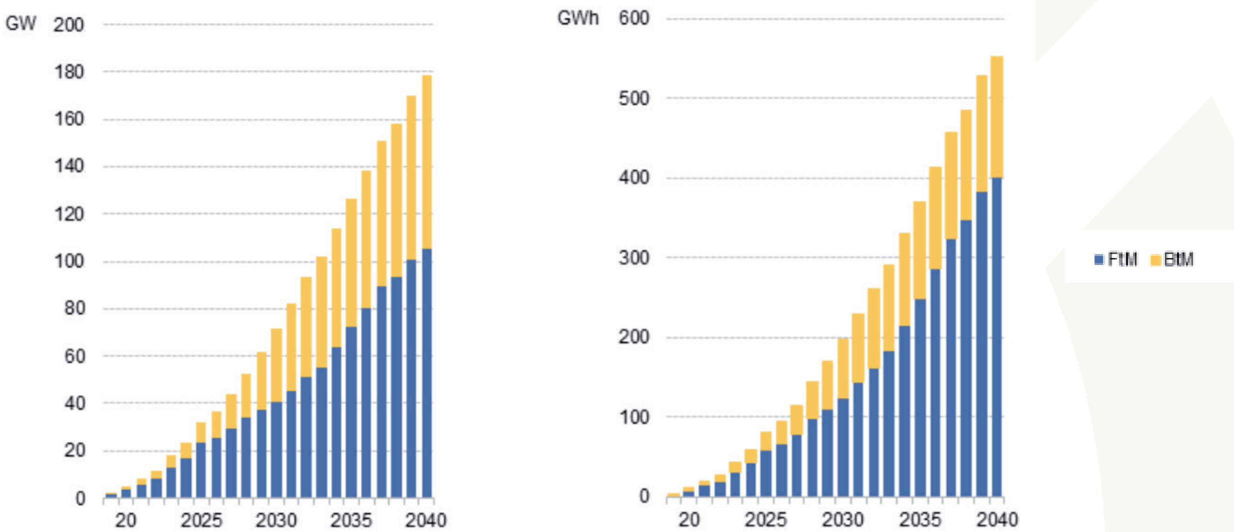


Figure 4: Electrical energy storage forecast – United States. Source: BloombergNEF (11)

Figure 4 also indicates the important role storage currently and will increasingly play in the U.S. at different levels of the energy system, including both the transmission and distribution levels (represented under FtM – "Front of the Meter"). Effective collaboration and coordination between the two levels, will be important in integrating further storage resources and maintaining a reliable overall power system.

› California

California leads the U.S. in energy storage with 4.2 GW of installed capacity (220 operational projects), followed by Virginia and South Carolina (9). California has ambitious environmental and energy policies to eliminate fossil fuels from its energy sector, which would require energy storage technologies in order to be achievable. The state is targeting serving 33 percent of its demand from renewable resources by 2020, and 60 percent by 2030 (see Figure 3). Also, California's Senate Bill (SB100) mandates that 100 percent of electric demand in California must be served from carbon-neutral resources by December 31, 2045 (12). Hawaii was the first state to adopt a 100 percent carbon-free goal for retail electricity.

Similarly, California had previously committed to reducing greenhouse gas emissions to 80 percent below 1990 levels by 2050. Its previous Governor, Jerry Brown, announced an executive order directing California to achieve carbon neutrality, meaning it would remove as much carbon dioxide from the atmosphere as it emits, by 2045. In order to meet these goals, energy storage must play a key role in the state's resources mix.

The California Public Utilities Commission (CPUC) has imposed energy storage procurement targets, the largest in the U.S., for each of the investor-owned utilities (IOUs) in California, totalling 1,325 MW to be completed by the end of 2020 and implemented by 2024 (13). In 2017, the California Legislature passed AB 1405, which established a standard requiring a portion of the peak hour demand be met by clean resources. Storage that can shift the available supply from non-peak production hours to peak demand hours provides a solution for meeting the clean peak standard.

Additionally, the CPUC provides funding programs including Permanent Load Shifting and the Self Generation Incentive Program that provide incentives for adoption of customer-side energy storage (14). Also, the California Energy Commission continues to fund critical research to advance energy storage as a viable grid resource through the Electric Program Investment Charge. At the national level, the Federal Energy Regulatory Commission (FERC) provides clarity through its direction to transmission providers to define electric storage devices as generating facilities enabling these resources to take advantage of generator interconnection procedures (15).

Pilot and demonstration projects in California

The following provides a selection of storage technologies, either tested or operating as a pilot or demonstration programme (16).

Thermal energy storage with ice: This storage technology produces ice at night when demand for electricity is low and uses that ice during the day to efficiently deliver cooling directly to a building's existing air conditioning system, thereby decreasing total energy usage. The technology can also qualify for clean energy incentives such as the Federal Investment Tax Credit (ITC) and the Self Generation Incentive Program in California. The developer, Ice Bear, indicates that efficient cooling technology can reduce overall energy use by taking over an air conditioning system for up to six hours a day. Also, adding Ice Bear batteries to an air conditioning system can cut cooling costs by up to 40% and reduce a building carbon footprint without compromising comfort. The lead project partners to this project include Pacific Gas & Electric (PG&E), NGK Insulators and S&C Electric Company.

Vehicle-to-grid demonstration project (V2G): The V2G project uses a fleet of 34 light and medium-duty plug-in electric and hybrid vehicles (PEVs/PHEVs) and their bi-directional charging stations, to provide normal daily vehicle capabilities and reliability to the grid. Located at the Los Angeles Air Force Base, vehicles use the grid to recharge the batteries, and the battery-stored energy on board the vehicles becomes an available power grid asset. This project represents the first large-scale, market-integrated project to demonstrate full vehicle-to-grid capability, which allows PEV/PHEV owners to earn revenue by making stored energy available to the power grid. The demonstration is comprised of five vehicles at power capacity ratings of 50 kW and 29 vehicles at 15 kW.

Molten sulfur energy storage used for back-up power: This project, an initiative of PG&E and installed at the Hitachi Global Storage technologies facility in San Jose (California), is a utility-scale sodium-sulfur battery energy storage project. Its objective is to mitigate fluctuations and enhance power reliability for customers on distribution networks. It has a 4-megawatt capacity and can store more than six hours of energy. The sodium-sulfur battery uses molten salt that has relatively high energy density, good efficiency, and a long cycle life, but generally must be operated at high temperatures and with additional protections for corrosion.

Grid-scale demonstration of zinc battery technology: This project demonstrates the viability of a rechargeable zinc hybrid cathode battery ("Eos") to cost-effectively provide the grid with peak shaving, ancillary services, load following and frequency regulations. Eos demonstrates a 125kW/500kWh AC integrated energy storage system employing Eos Znyth™ battery technology. This system, located in San Ramon, California, is integrated with intelligent control software to enable economic evaluation of grid services under simulated conditions in a representative grid-connected environment. The project will illustrate the technology's ability to achieve the Energy Commission's performance and financial targets of keeping costs under $200/kWh when manufactured at scale.

Integrated solar photovoltaic energy storage: This project, located in San Diego, demonstrated integrating multiple renewable energy technologies with energy storage to support power grid reliability. San Diego Gas & Electric (SDG&E) installed a 1.5 MWh solar photovoltaic system, integrated with a battery storage system at the Borrego Springs township substation as part of a broader distributed energy storage plan. The 6 MW of substation-connected battery energy storage system and nearly 5 MW of customer-owned battery energy storage is designed to improve local power grid reliability for the town, both in normal conditions and outage events. The demonstration intended to prove the effectiveness of integrating multiple renewable energy technologies, energy storage, feeder automation system technologies, and outage management systems with advanced controls and communication systems to improve power grid reliability.

New life for electric vehicle batteries: This project, led by the University of California, San Diego, and BMW, reuses electric vehicle batteries to demonstrate stationary energy storage. Located in San Diego, the project stores up to 108 kW of electricity for 2-3 hours inside each battery. Although batteries used in electric vehicles (EV) have a usual-vehicle lifetime of 8-10 years, they still have significant capacity left for alternative uses. Demonstration of this technology will help to prove the feasibility of using second-life EV batteries for stationary energy storage. If the project demonstrates that used batteries from EVs have a viable second use, the overall cost of owning an electric vehicle could be offset.

Rechargeable electrolytes: An initiative of the Primus Power Cooperation (PPC), this project demonstrates the storage of energy from RES generation in Zinc Bromide “EnergyPod®” batteries. Located in the Modesto Irrigation District in the Central Valley of California, the objective of this demonstration is to show the primary and secondary application benefits of this technology, including renewable firming, strategic local peak shaving, automated load shifting and other ancillary services. PPC uses a 1 MWh EnergyPod® battery to support the integration of RES into the power grid. Primus Power Cooperation has a new 25 MW solar photovoltaic system and the EnergyPod® will reduce variability created by the resource on their power grid.

Capturing wind: The Tehachapi Wind Energy Storage Project, led by Southern California Edison, Southern California’s primary electrical supply company, uses more than 600,000 battery cells to store energy and integrate RES generation into the power grid. Located in the Tehachapi Wind Resource Area, the project tests an 8 MW, 4-hour (32 MWh) lithium-ion battery that stores energy from more than 5,000 existing wind turbines and any future additions. The project will demonstrate the performance of the lithium-ion batteries in actual system conditions while testing the capability to automate the operations of the battery energy storage system and integrate it into the power grid.

Lithium-Ion battery supports renewable energy integration: The SMUD Galt Advanced Feeder Demo ESS project, an initiative from the Sacramento Municipal Utility District (SMUD), is demonstrating a 500 kW/125 kWh advanced lithium-ion battery energy storage system developed by Mitsubishi Heavy Industries to evaluate the technology’s ability to support the integration of a solar photovoltaic system into the power grid. Located in Galt, California, the battery tests for its ability to provide solar photovoltaic firming, peak electricity demand shaving, ramp rate control, and simulated frequency regulation support. It is envisioned that SMUD will apply the results of this demonstration project to use similar battery energy storage technologies to reduce the costs of serving peak electricity demand and the integration of more renewable energy.

2.3 European overview

By the end of 2018, Europe had a total installed RES generation capacity of 536 GW (17). For gross electricity production within the EU, this represents a 32.3 percent share from RES (18). Looking forward, the upward trend in RES adoption will continue. This is partly driven by the EU Clean Energy Package, which sets a binding renewable energy gross final consumption[iii] target of at least 32 percent by 2030 – with a possible upward revision in 2023 (19). This increase in RES is expected to be largely driven by wind and solar.

As in the U.S., there is overall limited storage in the EU energy system, at roughly 5% of total installed generation capacity (20). According to the European Association for Storage of Energy, the EU member states have approximately 45 GW of energy storage capacity (21). This is almost exclusively from pumped hydro-storage and mainly in mountainous areas (the Alps, Pyrenees, Scottish Highlands, Ardennes and Carpathian Mountains). Other forms of storage technologies such as batteries, electric cars, flywheels, hydrogen and chemical storage are either minimal, or at a very early stage of development.

However, given the increased RES target implemented by the EU, the demand for energy storage is expected to grow rapidly over the coming years. The third edition of the European Market Monitor on Energy Storage of EASE and Delta-ee (EMMES 3.0) provides an overview of the development of energy storage in Europe, indicating a large market growth in the near future (see Figure 5).

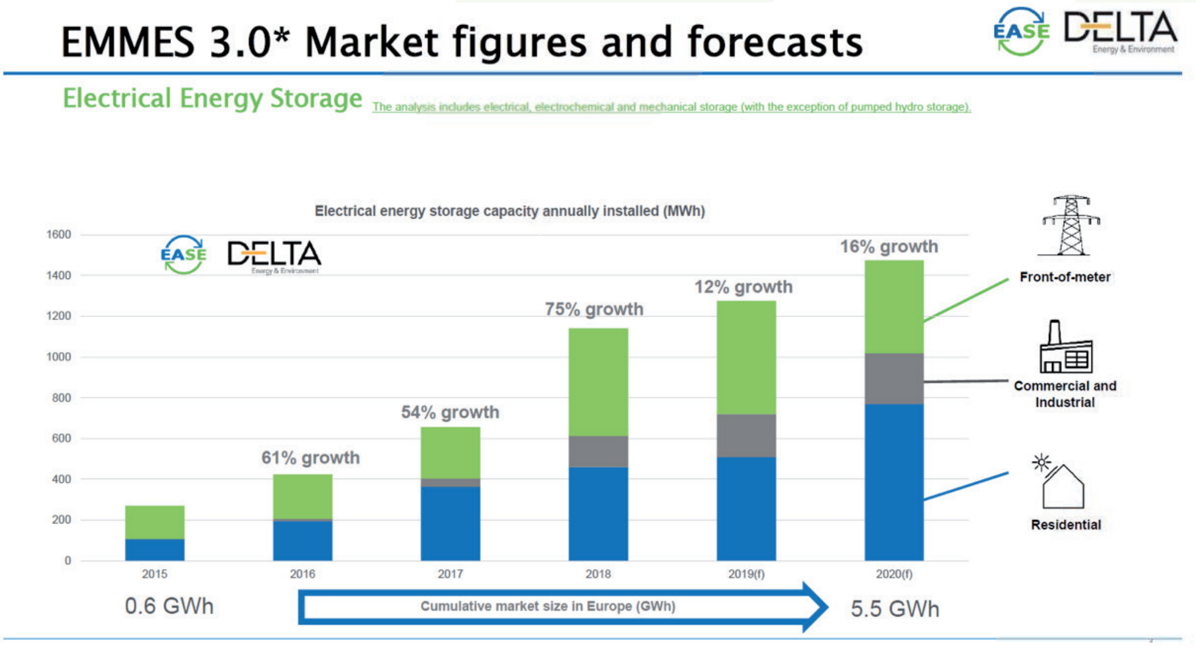


Figure 5: Electrical energy storage capacity installed in Europe. Source: EMMES 3.0 (22)

This increase in energy storage capacity in Europe can partly be attributed to the capacity growth in Great Britain, where electrical storage is expected to grow from 3.3 GW in 2018 to 6 GW in 2020.

Furthermore, according to an elaboration of Bloomberg's data, Europe's projected battery energy storage values alone are expected to reach more than 100 GW or 260 GWh by 2030, as shown in Figure 6. These values will more than double during the 2030-2040 decade.

iii) According to the EU, 'gross final consumption of energy' means the energy commodities delivered for energy purposes to industry, transport, households, services including public services, agriculture, forestry and fisheries, the consumption of electricity and heat by the energy branch for electricity, heat and transport fuel production, and losses of electricity and heat in distribution and transmission.

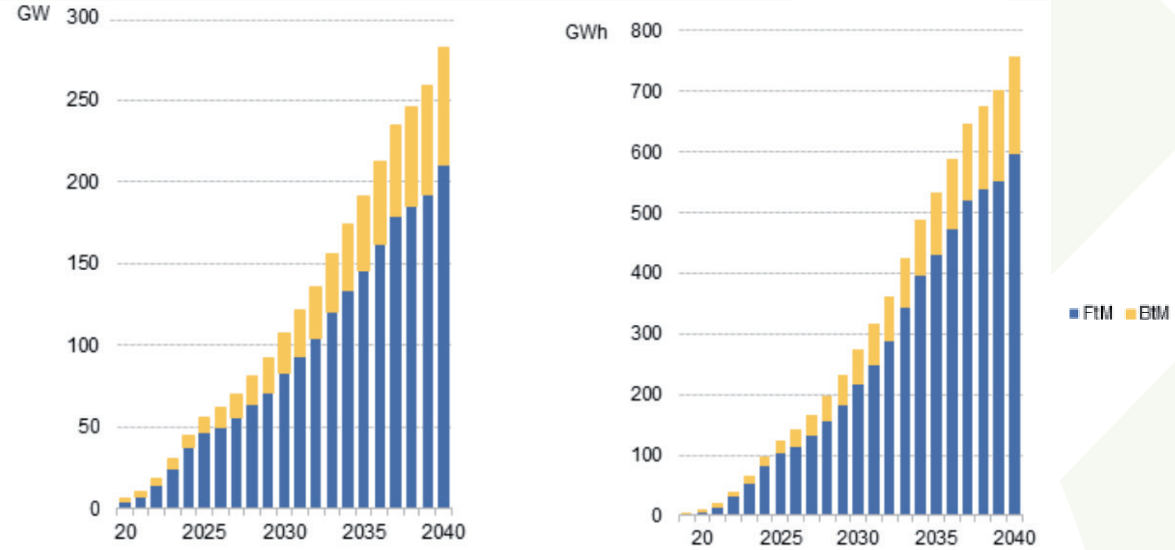


Figure 6: Electrical energy storage forecast – Europe. Source: BloombergNEF (11)

As indicated by Figure 6 and similar to the U.S., storage currently does and will increasingly play an important role at different levels of the energy system in Europe. For transmission and distribution levels (represented under FtM – "Front of the Meter"), there are distinct technology trends between the two. For example, pumped hydro storage systems are almost exclusively connected to the transmission grid. Additionally, electro-chemical storage systems (primarily batteries) are more often connected to the distribution grid rather than the transmission grid, with Italy as an exception. Likewise, hydrogen storage in Europe (primarily in Germany), is mainly connected to the distribution grid. As in the U.S., effective collaboration and coordination between the two voltage levels will be important in integrating further storage resources and maintaining a reliable overall power system.

According to the NGO Transport & Environment, there will be a surge in BEV models coming on the market from 2020. The annual sale of BEVs will reach 3.2 million units in 2030, based on a conservative base-case scenario (23). If used smartly, these BEVs can offer a great energy storage resource for Europe.

There are ultimately significant differences in RES and storage deployments and forecasts across Europe. Below we provide a snapshot of Italy and Germany.

› Italy

Already today, the electricity mix in Italy is dominated by renewables and natural gas. In 2018, renewables accounted for 35.6 percent of the Italian generation mix, with a total of 56.5 GW of installed capacity, mainly consisting of hydroelectric plants (22 GW, including pumped hydro), solar (20 GW) and wind (10 GW). In terms of installed capacity, natural gas comes second after renewables with a total of 47.5 GW. The participation of storage in energy and ancillary services markets is relevant, considering the roughly 7 GW of pumped-hydro storage plants. However, the battery storage market size is still relatively limited and can be attributed to two use cases: residential energy storage (deployed next to PV) and utility-scale, front-of-the meter storage (see: *Storage pilot projects in Italy*).

According to EASE and Delta-ee, battery storage was deployed next to roughly 25% of new rooftop PV systems installed in 2018 (see Figure 7). The cumulative market size in 2018 was about 23,700 units, which translates into 120 MWh in terms of energy that can be stored. Second only to Germany in Europe, towards 2020, the Italian market for residential storage is expected to reach 230 MWh. It is evident that this is a sizeable, relevant source of flexibility.

To enable the participation of distributed energy storage and distributed energy resources in general, the Italian transmission owner and system operator, Terna, has launched several pilot projects, including the so-called UVAM pilot project (see: *Distributed Energy Resources in the Italian Ancillary Services Market*).

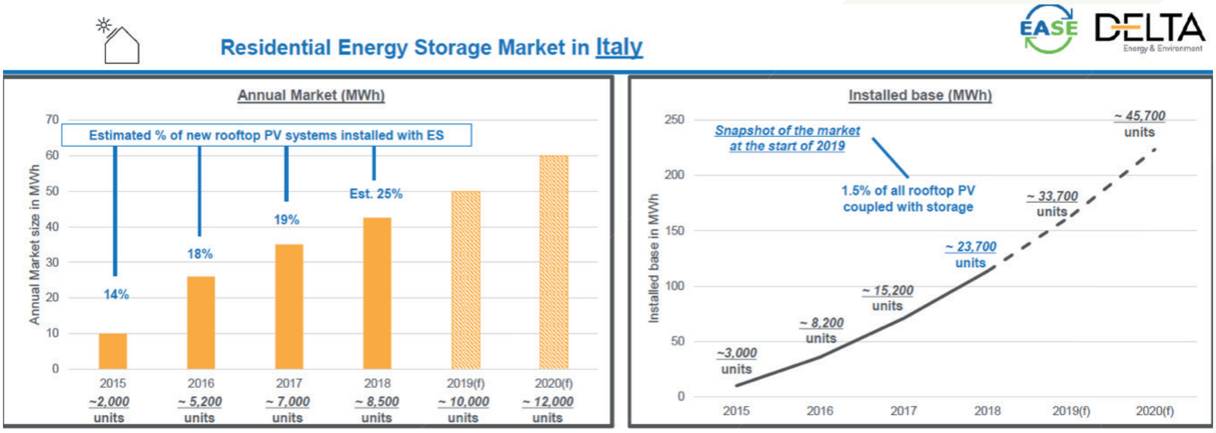


Figure 7: Electrical residential energy storage capacity installed in Italy. Source: EMMES 3.0 (22)

In December 2018, the Italian Government submitted its draft Integrated National Energy and Climate Plans (NECP) to the European Commission, which lays out how the country intends to contribute to the union-wide target of decarbonisation through the progressive increase of renewables and efficiency. The plan envisages a transition to a low-carbon economy, covering all energy sectors, from electricity to transport as well as heating and cooling.

The NECP describes a profound transformation towards a more efficient and more electrified energy sector, combined with a progressive increase of renewables especially in the electricity sector. In terms of gross final energy consumption by 2030, renewables are expected to cover at least 30% of final energy consumption as well as at least 55% of electricity consumption. Finally, it defines a target of phasing out coal-fired power plants by 2025.

By 2030, according to the NECP scenario (see Figure 8), wind power will reach 18 GW of installed capacity (up 80 percent compared to 2017), while solar will grow substantially by about 31 GW, reaching 51 GW (up 155 percent compared to 2017). Other RES, in particular hydroelectric, are expected to remain at today's values. In order to manage a power sector dominated by variable renewables, in line with the current adequacy and security standard, Terna has identified a set of enabling factors to improve system flexibility, the central ones being the deployment of new storage facilities and the redesign of electricity and ancillary services markets. Specifically, markets should enable and incentivise the participation of new resources including demand-side response and distributed storage, thus diversifying how Terna procures flexibility (see: *Distributed Energy Resources in the Italian Ancillary Services Market*).

With the current solar PV penetration and the expected addition of some 31 GW, storage becomes a fundamental asset to manage the increasingly steep morning and evening ramps. It will also play an increasingly larger role in limiting curtailment of variable renewables. In total, Terna expects that **6 GW of new utility-scale storage systems** are required until 2030, which could be a mix between new pumped hydro power stations and new electrochemical battery systems, which have been tested successfully in Terna's storage pilot projects (see: *Storage pilot projects in Italy*). In line with the regulatory requirements defined at EU level in the Clean Energy Package, this new storage capacity is expected to be developed by third parties.

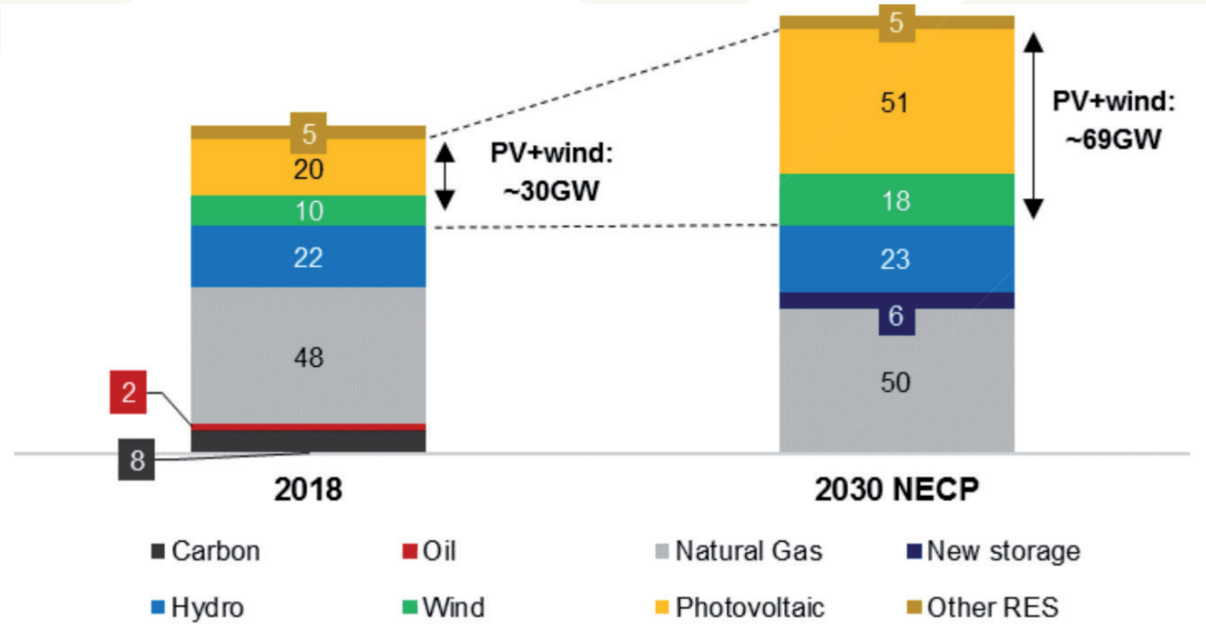


Figure 8: Evolution of installed capacity in Italy, according to the Integrated National Energy and Climate Plans – NECP (PNIEC). Source: Terna

Storage pilot projects in Italy

In recent years, the growing increase in electricity generation plants using variable renewable sources, especially in the Southern regions of Italy and on the two biggest islands, have had tangible impacts on the dispatch of electricity and the safe operation of the National Electricity System. In order to limit the curtailment of renewables and at the same time ensure increased security management of the electricity system, Terna has decided to install new storage technologies connected to the national electricity transmission grid (see Figure 9). The innovative nature of using new storage systems has led Terna to embark on an experimental phase, to test and validate the use of electro-chemical storage at the "utility-scale" level. The following two projects are currently being tested.

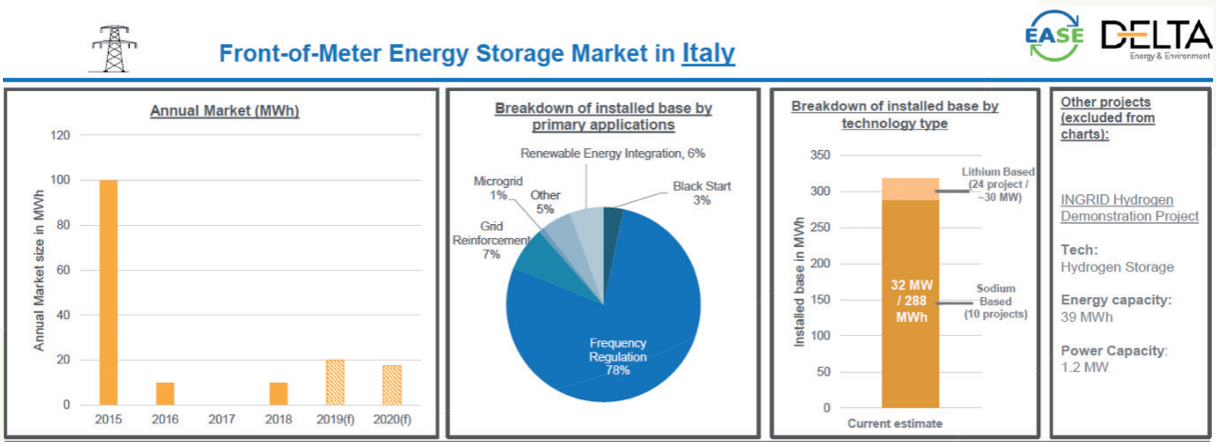


Figure 9: Front-of-Meter energy storage capacity installed in Italy. Source: EMMES 3.0 (22)

Storage Lab project: Under the Defence Plan for the Security of the Italian Electricity System 2012-2015, Terna has developed a 16 MW storage-system installation programme, to exploit the potential offered by the rapid response times of storage systems to increase the operating security margins of high voltage (HV) grids, on the islands of Sicily and Sardinia. The project involves installing approximately 16 MW of various storage technologies, divided into approximately 8 MW in Sicily and 8 MW in Sardinia. The individual storage units are lithium-based (9.2 MW, 5 types), ZEBRA type (3.4 MW, 2 types) and flow-tech (0.8MW, 2 types). Terna is currently integrating the projects with "supercapacitor" technologies.

Large Scale Energy Storage: Terna has developed and is currently operating large scale energy storage projects on portions of the 150 kV grid in Southern Italy. This is critical in managing the high frequency of grid congestion, caused by the increased deployment of variable RES. With the primary focus on reducing such congestion, Terna has planned an innovative project based on the use of energy intensive electrochemical storage technologies – selecting NAS battery technology (a sodium/sulphur technology). The total 35 MW storage programme is divided across three locations: Flumeri, Ginestra and Scampitella. Each site is connected to a 20/150 kV substation, which is then connected to the national transmission grid. After a temporary operating and tuning phase with on-site monitoring throughout 2015, the three plants are currently operating under remote control. By providing services to the grid, the storage project has mitigated congestion caused by RES and also contributed significantly to maintaining grid security (for example, by providing primary frequency regulation).

Distributed Energy Sources in the Italian Ancillary Services Market

Today, the main suppliers of flexibility services are large fossil-fuel power plants that continually guarantee the real-time balance between electricity consumed and supplied. With progressive decarbonisation of generation facilities, new flexible resources are required to guarantee the adequacy and security of an increasingly heterogenous electricity system which is far more complex than the current one (see Figure 10).

In this context, Terna recently launched a pilot project known as the UVAM (Virtually Aggregated Mixed Units). The objective is to support the progressive opening of the ancillary services market ("Mercato dei Servizi di Dispacciamento", MSD) to distributed resources, including storage behind-the-meter.

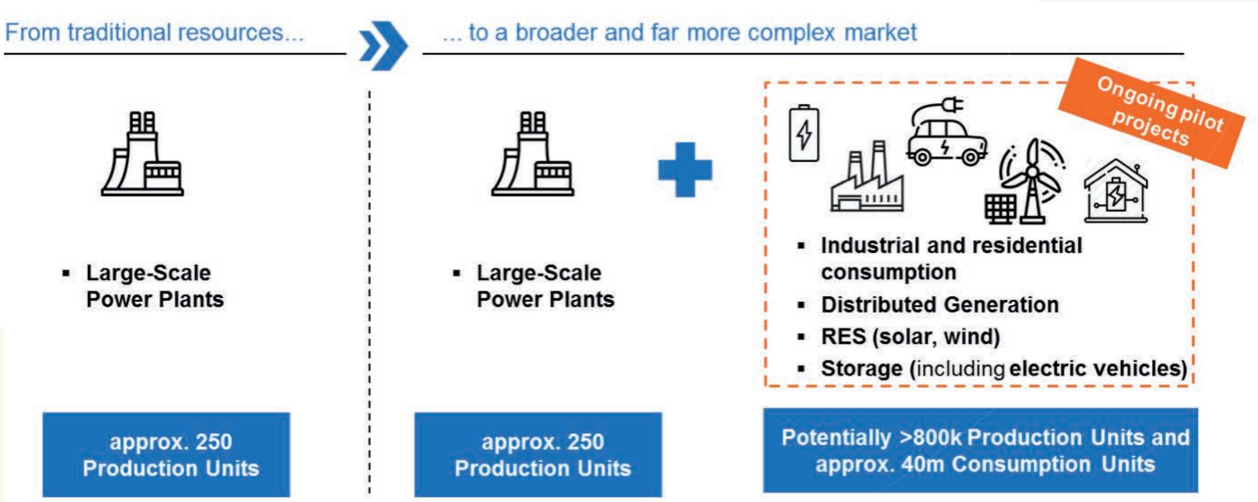


Figure 10: Complexity of future electrical systems. Source: Terna

The success of the pilot project can be measured by the capacity of distributed resources qualified for, and participating in, the ancillary services market during the two years of testing. In June 2017 it started with around 100 MW of virtually aggregated mixed units (UVAC) and it reached a peak of 830 MW UVAC in June 2019, with 83% of this capacity subject to contracts that remunerate the dispatchability of these resources.

It is important to note that the remuneration mechanism for the pilot project is different to that of large-scale power plants, as it foresees remuneration linked to both energy activated (€/MWh) and availability (capacity, €/MW). This capacity is allocated through auctions on the fixed premium with a cap of 30,000 €/MW/year, with pay-as-bid allocation.

The UVAM can include electrochemical storage alone (minimum size of 1 MW) or aggregated together with other resources. Initial results of the pilot projects are very encouraging, making Italy one of the leading European players in enabling DRs on the dispatching services market.

› Germany

Germany has a high demand for flexibility due to the vast share of mainly variable renewable energy sources. The installed capacity for renewable electricity generation in Germany continues to increase. 6.6 GW of capacity was added in 2018, resulting in 118.3 GW of total installed capacity. The participation of energy storage in the German market is, however, still rather low. Nevertheless, an increasing, even exponential trend is observable. Figure 11 shows the installed capacity of utility scale battery and power-to-gas storage technologies in Germany, from 2013 through to 2019. Presently, this represents nearly 300 MW of capacity.

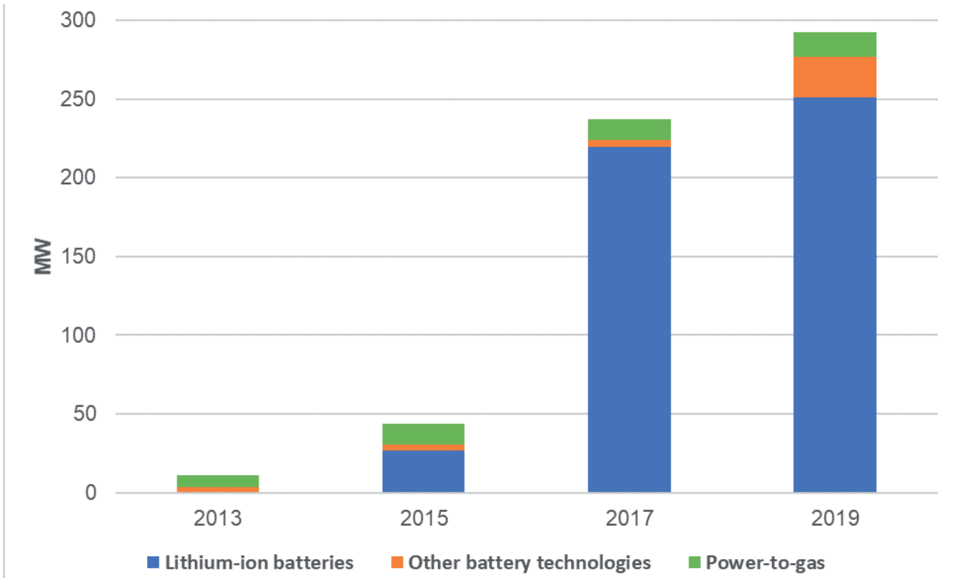


Figure 11: Historical development of energy storage in the German market. Source: TenneT Market Review (24) & RGI calculation as of October 2019 based on U.S. DOE Energy Storage Database (1)

The majority of utility-scale storage systems consist of batteries, which is primarily intended for providing frequency containment reserves (FCR) to the balancing market. However, both the installed battery and power-to-gas capacity are still relatively small compared to the installed capacity of pumped hydro storage in Germany, which is currently 6.7 GW (25).

Pumped hydro storage is likely not to increase further due to limited geographical possibilities, the massive impact on the landscape and acceptance issues. Due to the high number of small-scale PV installations in Germany there is also a high share of small-scale storage units.

There is uncertainty regarding the future expansion of energy storage capacity/volumes in Germany. Varying projections differ substantially as the development depends on factors such as energy policy, energy market frameworks, potential subsidy schemes, innovations and resulting technology/cost developments. For example, BloombergNEF is projecting that there will be 5.5 GW and 15 GWh of energy storage installed in the German market by 2040. In a more attractive policy framework setting however, BloombergNEF indicates that up to 100 GWh of storage volume could be installed. Policy frameworks which support the deployment of storage technologies are therefore crucial.

Pilots/innovative projects in Germany

Connecting electrons and molecules – ELEMENT EINS: The climate targets set out by the Paris agreement, along with the increase of renewables in the German electricity system, fostered a discussion on technological options to decarbonise energy sectors other than electricity (such as heating, mobility and some industry). TenneT, Thyssengas and Gasunie plan to integrate a ~100 MW electrolyser into the grid, to push power-to-gas (P2G) technology as a technology to support the integration of RES into the broader energy system, thereby achieving ambitious climate targets. The main aims of this initiative are making the first steps with P2G by:

- Stabilisation of the electricity grid
- Creating flexibility for system operation
- Limitation of curtailment of wind energy
- Reduction of future need for grid expansion, and
- Using the gas grid as a storage unit.

This is part of the TenneT vision towards an integrated energy system. The power-to-gas technology is seen as a promising option as it enables the use of renewable energy in different sectors, either in direct or indirect means. The project ELEMENT EINS will be accompanied by a research project to gain in-depth insights on the relevance of power-to-gas and its interactions in an integrated energy system. It has been awarded as one of the projects to submit an application for the research fund "Reallabore für die Energiewirtschaft" by the German Federal Ministry for Economic Affairs and Energy.

Use of unexploited transmission capacities – Grid-Booster: The goal of the pilot project is to implement and test a concept of automated grid operation by installing two spatially separated storage systems in the North and South of the main congestions. In contrast to the classic preventive approach, the Grid-Booster ensures a n-1 secure grid operation reactively, i.e. after fault occurrence. Therefore, the power load of existing power lines can be increased beyond presently valid stability thermal limits, saving preventive redispatch.

Storage and the Blockchain Technology: In two pilot projects with sonnen (a supplier of energy storage systems for private households and small businesses) and Vandebron (a company which delivers green electricity to individual and business customers), TenneT is using a private blockchain to provide system services. In cooperation with sonnen, household batteries are providing redispatch services, whereas with Vandebron (with this project located in the Netherlands), a pool of charging stations for electric vehicles is delivering automated secondary control reserve. The flexibility is managed by TenneT via an IBM blockchain solution and used to balance the grid.

3. Going forward: policy and other initiatives for incentivising energy storage

In contrast to significant schemes for promoting and supporting RES, dedicated storage incentives and/or remuneration schemes are less common. This raises the question whether market prices alone can provide sufficient incentives for investments in storage systems. For small-scale storage systems, indirect benefits like circumventing levies and taxes seem to be attractive options, amongst others. However, there is certainly room for policies which provide clarity on refinancing long-term investments in storage systems, in order to balance periods with over and under production of energy. As storage system providers are only very occasionally remunerated, a positive business case for large storage systems seems to be unrealistic under the current framework. Some energy storage technologies, such as hydrogen storage systems, are continuously improving however are far from being economically viable. In any policy measures introduced, it will be important to encourage a broad portfolio of technology options, given the differing services and capabilities needed.

› California: removal of market barriers

In the short term, a key driver of the energy storage market in California is a 30 percent federal tax credit for solar investments. Developers who integrate batteries into their solar projects can take the tax credit on their entire investment, including the cost of the batteries. However, the 30 percent tax credit will begin phasing down after 2019.

Additionally, the CAISO has initiated several market and infrastructure policy initiatives to remove barriers and increase operational usefulness of storage resources in the operation of the wholesale market. The "Regulation Energy Management" for Non-generating Resource (i.e. for storage and demand response) is an important market enhancement that enables new types of resources to participate in regulation markets (26). The implementation of Non-Generator Resources will create the initial model for energy storage devices to fully participate in ISO markets. The "Energy Storage and Distributed Energy Resources (ESDER)" is an initiative of the CAISO, and has addressed rules related to the accounting, visibility and control requirement for energy storage (including storage that is interconnected to the distribution system) (27). The "Storage as a Transmission Asset (SATA)" is a policy developed to clarify how storage that is justified based on being a transmission asset can also have opportunities to participate in the wholesale market, at times that do not impede the storage resources ability to provide its primary purpose of transmission support (28).

› Italy: storage as an enabling factor to coal phase out

Italy aims to totally phase out coal by 2025, as originally announced in the 2017 National Energy Strategy and confirmed in 2018 in the Integrated National Energy and Climate Plan, submitted to the European Commission. This is a challenging task, because coal-fired thermal power generation capacity amounts to 8 GW and is the primary source of electricity in Sardinia, the second-largest island in the Mediterranean Sea. Different and parallel actions must take place to guarantee the adequacy and security of the electrical grid. One enabling factor to phase out coal is the deployment of new storage capacity. The loss of synchronised generators like coal-fired power plants implies a loss of rotating masses which are needed to contain frequency drops or increases, that occur when a power line or power plant trip but also when there are forecast errors on the demand-side or from renewable energy generation. The effect of losing rotating masses can partly be offset by deploying new electrochemical batteries which can react swiftly to frequency changes and thus help stabilise the grid. This is of even more relevance on Sardinia and generally on islands where frequency containment can be challenging. Moreover, storage technologies like pumped hydro are needed to shift RES production from noon hours to evening hours. Overall, Terna has identified a need for 3 GW of new storage capacity by 2025 to support the phase-out of coal in Italy.

It is important to note that the deployment of 3 GW of new storage capacity is just one measure and will have to be complemented by the following measures:

- Deployment of new synchronous compensators, to complement voltage regulation from power plants with voltage regulation from synchronous compensators, and
- Increase of gas-fired capacity and the conversion of oil-fired generation to gas.

Full implementation of Terna's National Development Plan 2019 foresees a total investment volume of more than 6 €bn over the next five years. A significant portion (3.3 €bn) is dedicated to grid development, including realisation of SACOI3 – which links the Italian Peninsula, Corsica and Sardinia and several new lines to reduce congestion between North and South Italy.

› Germany: behind the meter storage

There is no dedicated scheme to incentivise investments in energy storage systems in Germany. Like every other unit, storage systems shall refinance themselves by interacting with electricity markets. However, due to the early stage of maturity, investments in energy storage systems seem unable to be refinanced by merely placing bids on the wholesale and/or balancing markets. Most of the recent projects in Germany were financed at least partly by research programs. Without R&D financing no investments would have taken place. TenneT has developed an online storage tool in order to help market actors identify revenue potential.

However, a large number of applications are connected to PV installations as behind-the-meter systems. This investment scheme was incentivised by a subsidy scheme of the German KfW bank.

There are a large number of small-scale solar PV installations in Germany. Initially stimulated by a generous feed-in remuneration scheme, currently, solar PV systems are deployed due to the high savings gained through consuming self-generated solar electricity and bypassing levies and grid connection costs. About 40 to 50 percent of the household electricity bill (29), representing roughly 30 €ct/kWh, comes from levies, taxes and grid fees. There is therefore a high incentive to increase self-consumption via behind-the-meter energy storage systems in Germany.

Additionally, in the period 2013 to 2018, the German state-owned KfW bank had a special programme to foster investments in batteries. The program consisted of a subsidized loan and additionally redemption of loans (up to 25 percent in 2013). To be able to access the scheme, some technical requirements had to be met, as for example, a maximum feed-in of 50 per cent of the PV capacity into the public grid.

Most of the early decentralised, small-scale energy storage systems in Germany were incentivised by this program. From the beginning of 2016, however, there has been a shift towards investments without making use of the KfW program. Until the end of 2017 (the end of the KfW programme), about 30,000 energy storage systems were subsidized, amounting to 200 MWh of storage volume. In total, in Germany about 85,000 decentralised, small-scale energy storage systems have been deployed, summing up to 600 MWh of storage volume.

TenneT has developed a storage tool that allows users to analyse business cases for energy storage in the Netherlands and in Germany. There are a variety of possible products from which storage systems may gain revenue, such as day-ahead and balancing markets.

Users can define their own projects or start with one of the example cases and change and/or see the impact of key technical and economic parameters. The example cases include several technologies, with current performance, costs and projections until 2026. The tool is publicly available through the TenneT website: https://www.tennet.eu/electricity-market/dutch-market/electricity-storage-tool/.

› Important considerations for incentivising storage

Improving project economics

Some storage technologies, such as electrochemical lithium-ion applications, have reached a mature technology level. This has contributed to improved project economics (primarily decreasing costs) for a number of these applications in recent years. As costs have come down, particularly for shorter duration lithium-ion applications, returns have incrementally improved year-over-year[iv]. However, revenue streams for storage resources have not developed to the same extent and remain largely dependent on local market dynamics or utility tariffs. Many storage technologies, including lithium-ion batteries, still largely remain capital-intensive – and difficult to realise as utility-scale projects on volatile spot prices alone. Among the currently identifiable revenue sources available to energy storage systems, ancillary system service products (such as frequency regulation, spinning reserves, etc.), demand response and demand charge mitigation represent potentially attractive revenue opportunities in selected geographies (30). Ultimately, an appropriate market strategy is needed to push forward technologies such as lithium-ion batteries – which are in themselves capable of providing many of these grid-services.

Combining solar PV and storage

Combining energy storage with solar PV can create value through shared infrastructure (e.g., inverters, interconnection), reducing curtailed production by delaying the dispatch of electricity onto the grid and/or by capturing the value of “clipped” solar production. As indicated by Figure 12, the economics for solar PV + storage systems are most attractive for commercial use cases (including in California), but remain modest for residential and utility-scale projects (30).

iv) A June 2019 report by Transport & Environment ‘Batteries on wheels’ highlights the opportunities of giving the batteries of BEVs a second life. Such repurposed batteries will reduce the cost of battery storage for the end consumer to about ~ $ 40.4/kWh in 2030 (40 percent cheaper than a new battery) (35).

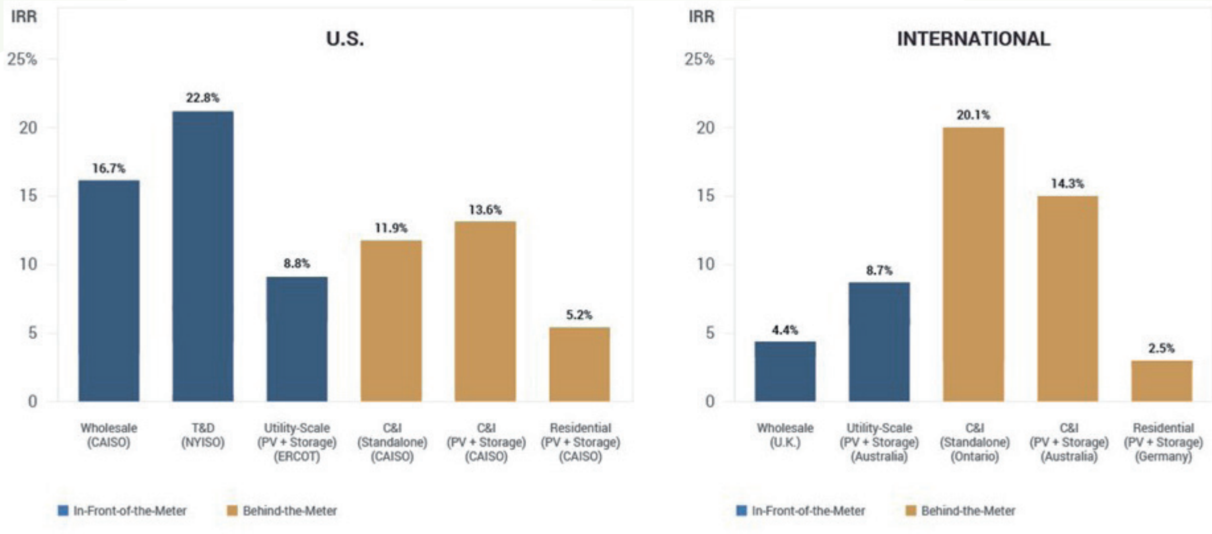


Figure 12: Internal Rate of Return for combined solar PV and energy storage – sectoral analysis. Source: Lazard's LCOS 4.0 (30)

4. Technical requirements of energy storage resources

The following section takes a look at reliability services that storage technologies can provide in order to maintain a reliable grid. It is expected that many lessons can be learnt between the European and North American regions. Below are three essential reliability services, as identified by the North American Electric Reliability Council (31):

- Voltage control
- Frequency control, and
- Active power management (ramping capability).

Over the years, advances in smart inverter technology have allowed variable renewable energies (such as wind and solar power) to provide these essential reliability services, which are similar and, in some cases, better than what was provided by conventional resources. In other words, variable renewables with the right/smart operating characteristics are required to displace conventional resources and decarbonise the grid.

› Voltage control

Voltage control is a fundamental need for a secure and stable electricity system. With increasing RES shares storage technologies must take over the capability to provide voltage control in various modes of operation, these include:

- Maintaining a scheduled voltage at the point of interconnection or another agreed upon station on the grid
- Operating between minimum and maximum reactive power capability
- Maintaining voltage control at zero real-power output
- Operating at a constant power factor
- Providing a constant reactive output, and
- Upward and downward active power control independent of voltage control.

› Frequency control

As more conventional generation resources are being replaced by renewable resources combined with energy storage, maintaining frequency control will be crucial. The system must be capable under low-inertia conditions, to arrest frequency decay and avoid involuntary under frequency load shedding after a large generator trip.

Storage devices must also have the capability to respond to high and low frequency events on the grid. They should be able to control the speed of frequency response and provide fast frequency response to arrest frequency decline in systems with high levels of variable renewables. Similarly, the system must be capable under low-inertia conditions to arrest frequency increase for the loss of a large load.

› Active power management (ramping capability)

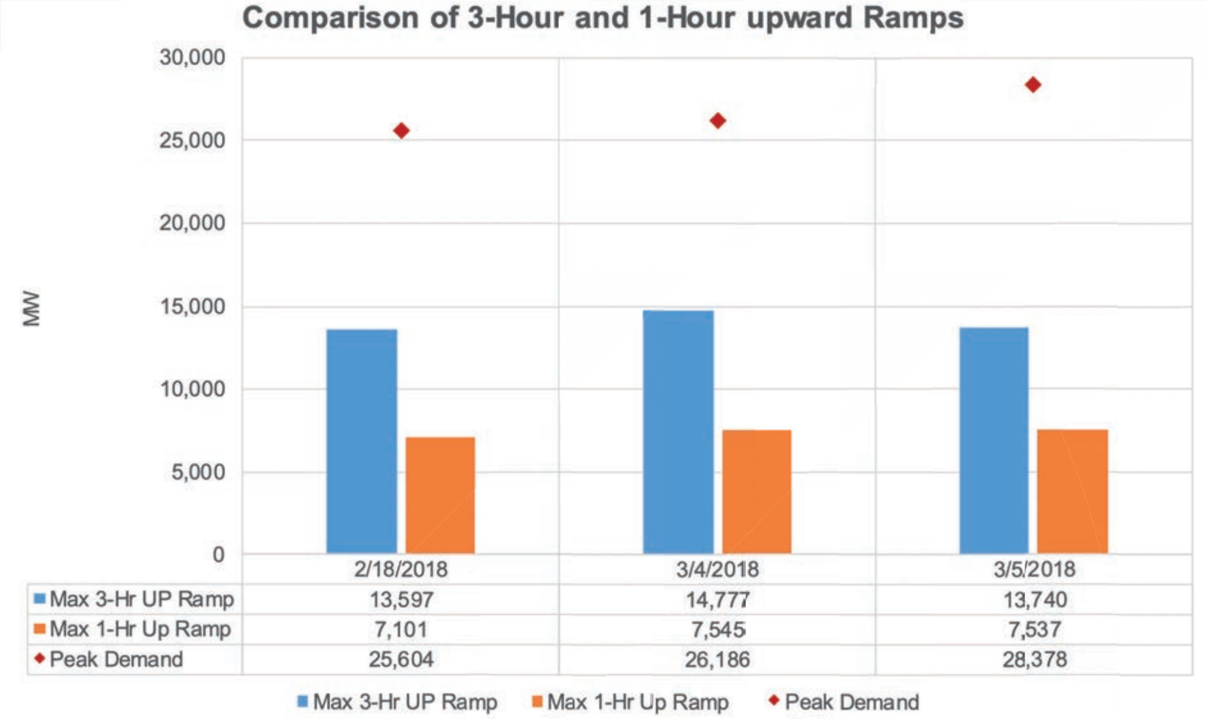
Similarly, as more variable renewable sources are integrated into grid systems, some grid operators including the CAISO are experiencing ramping challenges. This is occurring primarily during sunrise and sunset in addition to oversupply operating conditions during the middle of the day. This is especially the case on weekends when the demand is low and renewable production is high.

In California, the diverse generation resource mix is comprised of some base load renewable resources such as geothermal, biomass, qualifying facilities and run-of-the-river hydro. High penetrations of these base-loaded or non-dispatchable resources meet a large portion of California's energy needs, during certain times of the day, resulting in the need for additional flexibility and ramping. This is not a totally new concern for Balancing Authorities (BAs), as some resources and imports have had output levels that are not easily altered through the dispatch process to meet system ramping needs. Additionally, newer resources may or may not be incorporated into the dispatch process or they may be considered "must take" resources, so these resources can significantly contribute to increasing ramping needs for some BAs.

The combination of all such factors can result in increased periods of over generation, ramping scarcity and other situations that cause an overreliance on the interconnection for balancing. There are many ways to mitigate ramping and balancing concerns including the curtailment of renewable production. Other mitigation methods may take significant time and effort. As a best practice, BAs should regularly examine their fleet make-up to determine if changes are needed in their supply procurement and unit commitment practices, to adequately balance generation and load to help meet the shared responsibility of supporting interconnection frequency, and to meet their frequency response obligation following a contingency[v].

Within the CAISO's footprint, daily ramps are becoming a reliability concern and storage could help in addressing this. For example, as shown in Figure 13, over 50% of the daily peak demand must be committed and available to system during sunset, which occurs across a three-hour period. Figure 13 also shows that the ramps are not evenly distributed across three hours, but the one hour ramp could be greater than 50% of the three hour ramp.

v) NERC glossary of terms defines a contingency as the unexpected failure or outage of a system component, such as a generator, transmission line, circuit breaker, switch or other electrical element.



	2/18/2018	3/4/2018	3/5/2018
Max 3-Hr UP Ramp	13,597	14,777	13,740
Max 1-Hr Up Ramp	7,101	7,545	7,537
Peak Demand	25,604	26,186	28,378

Figure 13: Comparison of 3-hour and 1-hour upward needs of the system. Source: CAISO

Figure 14 shows areas of opportunities within California whereby storage could be used to mitigate the ramping needs during sunset. The vertical axis on the right of Figure 14 shows the 5-minute energy prices averaged across an hour of the system while the vertical axis on the left shows the load (blue curve) and net-load (red curve). Net-load is defined as load minus wind production minus solar production. As shown, when the solar production is high during the middle of the day, the 5-minute energy prices are typically low, which creates an opportunity for storage devices to charge. Similarly, just before sunrise and just after sunset, storage devices could discharge when the 5-minute energy prices are typically high.

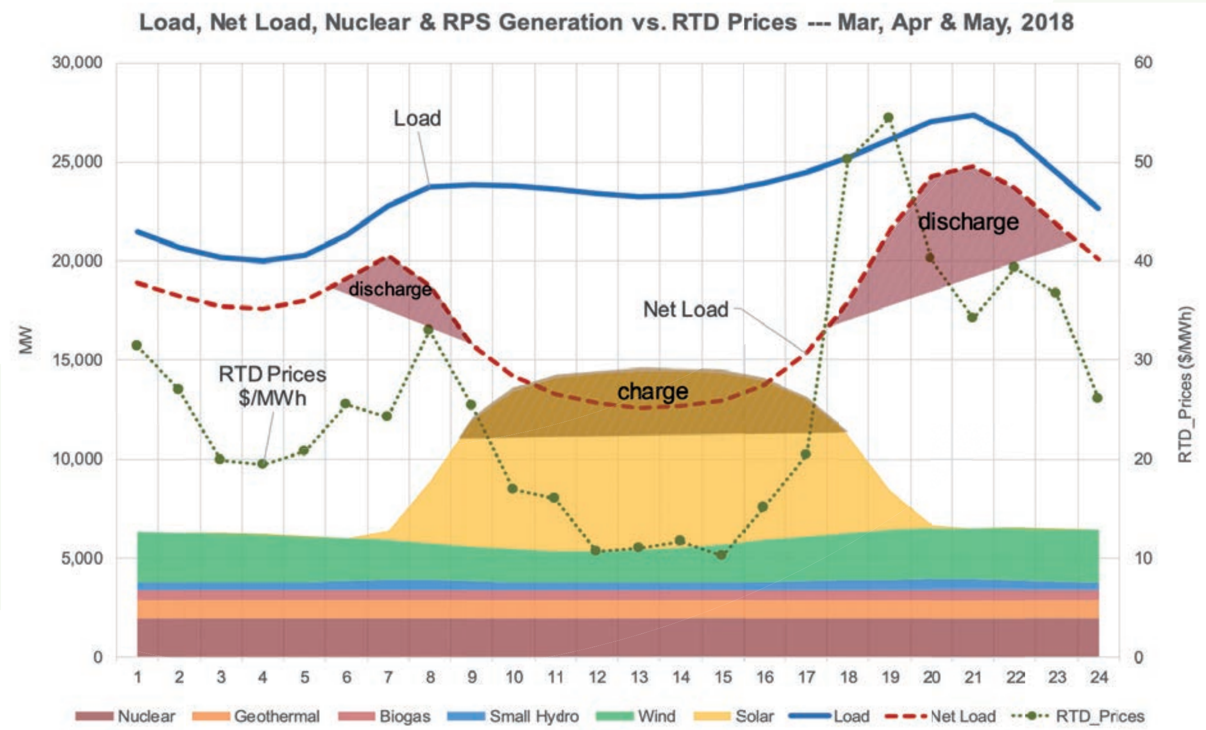


Figure 14: Potential opportunities for storage technology to enhance reliability. Source: CAISO

5. Barriers to further development and deployment of energy storage

› Key challenges for energy storage technologies:

- Market and regulatory – ensuring there are appropriate market signals to incentivise the building of storage capacity and provision of storage services. A significant difference between the areas of California, Italy and Germany is the market design model and the geographical resolution of price signals. In contrast to Germany which applies a single price zone model, California has a locational marginal pricing system with prices on a nodal resolution. Italy is somewhat in between, as it has several bidding zones implemented. In principle, incentives for energy storage systems are higher, the more granular the geographical resolution of the price. This is because of more volatility compared to an "averaging" of prices if a bidding zone is large.
- Technological – this is particularly related to increasing capacities and efficiencies of existing technologies; developing new technologies for local (domestic), decentralised or large centralised applications; and market deployment of new and existing technologies.
- Strategic – developing a holistic approach to storage development and deployment is important. By doing so, it is thereby possible to ensure that technical, regulatory, market and policy advancements complement one another and are not developed in isolation.
- Grid integration – energy storage is not a stand-alone technology and will compete with and/or complement other mechanisms to improve the grid flexibility (such as demand response services). A whole package of integrated measures is needed, including large centralised and small decentralised storage applications, flexible generation systems (similarly both centralised and decentralised systems) and back-up capacity.
- Above all, however, the economics of energy storage is the main challenge in its development. The economic and therefore business cases differ significantly, in part due to where the storage is needed (i.e. at the generation, transmission, distribution or customer level). The following uncertainties also strongly affect the value assessment of energy storage:

  - The existence of compensation schemes for storage: a key issue when some stakeholders are part of the regulated market (such as TSOs in the EU) and the other are part of the deregulated market (such as producers and end customers in the EU).
  - The potential to develop new and innovative business models: energy storage studies in both Europe and U.S. demonstrate that the provision of a single service (e.g. KWh) was not sufficient to make the storage scheme cost effective; services such as frequency stabilisation and voltage stabilisation (excluding Germany as is not presently being remunerated) have a much higher commercial value.
  - Ownership of the future energy storage systems, whatever the location and the grid connection (transmission or distribution): conditions under which storage can be owned by utilities or TSOs must be considered and clarified (4).

Energy storage safety standards, social acceptance issues and environmental considerations

Recently, in some locations including Ireland, social acceptance issues have arisen in relation to energy storage installations and their associated safety standards. Consequently, there has been a growth in local groups opposing energy storage projects. There are particularly fears of battery energy storage systems exploding or catching on fire, with opposition to new projects now considered a standard response when being proposed

(32). Further effort is therefore needed to understand what safety standards exist or are being proposed, across differing jurisdictions. Working with local opposition groups on understanding these safety standards will also be crucial.

Additionally, there are environmental impacts associated with some energy storage technologies. For example, battery energy storage systems can have potential impacts on freshwater eutrophication and also result in the consumption of limited natural resources during the production stage. Moreover, the construction of new pumped-hydro projects can have significant impacts on virgin landscapes and bio-habitats – which are often fiercely opposed by local opposition groups (33). There is therefore also the need to better understand and mitigate environmental impacts of differing energy storage technologies.

As in the case of grids projects, energy storage projects will need to consider meaningful and inclusive stakeholders' engagement processes. A regulatory framework or guidelines for public participation are likely to be soon needed.

6. Recommendations

The below recommendations have been prepared in collaboration with power grid operators from across Europe and California, and European NGOs.

1) Energy storage should be capable of providing essential ancillary grid services, including voltage control, ramping capability, frequency control and others. These services should be guaranteed and can be remunerated either via grid codes or regulated/market-based mechanisms, depending on the local situation. These remuneration methods should permit the integration of generation overcapacity, and over time develop the services needed to meet demand in times of low supply.

2) With increasing shares of renewables, including decentralised generation, grid visibility/observability and operability will become increasingly important in maintaining a reliable grid. These have to be provided at both transmission and distribution grid levels, to ensure that optimisation of all grid connected resources, including electrical energy storage technologies, can take place.

3) With increasing deployment of variable renewables in the system, curtailment can increasingly become an issue in some regions. This is one of multiple challenges that can be answered with additional storage investments, the volume of which is dependent on local situations.

4) The complexity and diversity of storage as a resource must be grasped, barriers to its deployment removed and adequate reward mechanisms designed to incentivise its usage.

5) With the likely addition of millions of battery electric vehicles on the road, there is a need to design grid codes, market incentives and supporting policies to enable load shaping. If properly designed, electric vehicles could become an important storage resource for the system – contributing to load shaping, peak shaving and load shifting.

6) In a well-functioning market were system services are adequately rewarded, re-financing should not be a problem. However, special attention is needed and alternative schemes designed in case of insufficient market schemes, or in the presence of market failures.

7) More research is needed to understand the role of behind-the-meter storage in the energy transition. While increased self-consumption offers some system security opportunities, there is uncertainty on how the massive expansion of residential solar PV combined with storage will impact system security.

8) R&D in long-term storage applications should be intensified (including power-to-X) and the integration of other sectors should also be facilitated. In some geographies, improved regulatory frameworks are also needed to better-incentivise its deployment. To overcome periods with low infeed from renewables (mainly in winter when demand for electricity is highest) or in countries where fossil-fuel and nuclear sources have been phased out, long-term storage technologies will become increasingly important for ensuring security of electricity supply.

9) Energy storage safety standards, societal acceptance issues and environmental impacts must also be considered and addressed. By properly mitigating any issues relating to these, deployment delay risks for energy storage projects can be more effectively minimised.

10) Particularly in Europe, storage data availability should be improved to support decision making.

Glossary of key terminology

- **Balancing services:** the services (commonly as 'products') which are provided in order to balance electricity supply and demand close to real time.
- **Battery electric vehicles – BEVs:** electric vehicles that exclusively utilise chemical energy that is stored in rechargeable battery packs to drive an electric motor.
- **Behind the meter:** energy storage interconnected behind a commercial, industrial or residential customers utility meter, commonly providing bill savings (e.g. demand charge management).
- **Concentrated solar power:** a system which uses mirrors or lenses to concentrate a large area of sunlight, or solar thermal energy, onto a small area – thereby generating solar power.
- **Demand response – DR:** a change in the power consumption of an electric utility customer to better match the demand for power with the supply.
- **Electrical energy storage (EES):** refers to the process of converting electrical energy into a stored form that can later be converted back into electrical energy when needed.
- **Fast-ramping:** a measure of how quickly a generator (also including energy storage technologies) can add power to the grid, or reduce its output when demand reduces.
- **Flexibility:** the capability of the power system to maintain balance between generation and load under uncertainty.
- **Front of the meter:** energy storage interconnected on distribution or transmission networks or in connection with a generation asset.
- **Grid code:** a technical specification which defines the parameters a facility connected to a public electric network has to meet to ensure safe, secure and economic proper functioning of the electric system.
- **Grid visibility and observability:** the need for system operators to know production levels of all on-line resources (including storage) connected to the system, in order to balance supply and demand in real-time.
- **Load shifting:** the moving of electricity consumption from one time period to another. By shifting load to another time, the returns generated through energy cost savings are greater than the loss of production.
- **Peak load/demand:** the maximum of electrical power demand.
- **Peak shaving:** shifting portions of electricity demand from peak hours to other times of day, reducing the amount of higher-cost, seldom used generation capacity needed to be online, which can result in overall lower wholesale electricity prices.
- **PPA:** a power purchase agreement is a legally-binding agreement between an electricity generator (provider) and a power purchaser (typically a utility or large power buyer/trader).
- **Price arbitrage:** buying power and charging during lower-price (or negative price) periods and selling power and discharging during higher-price periods. Batteries can flatten daily load or net load shapes.

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