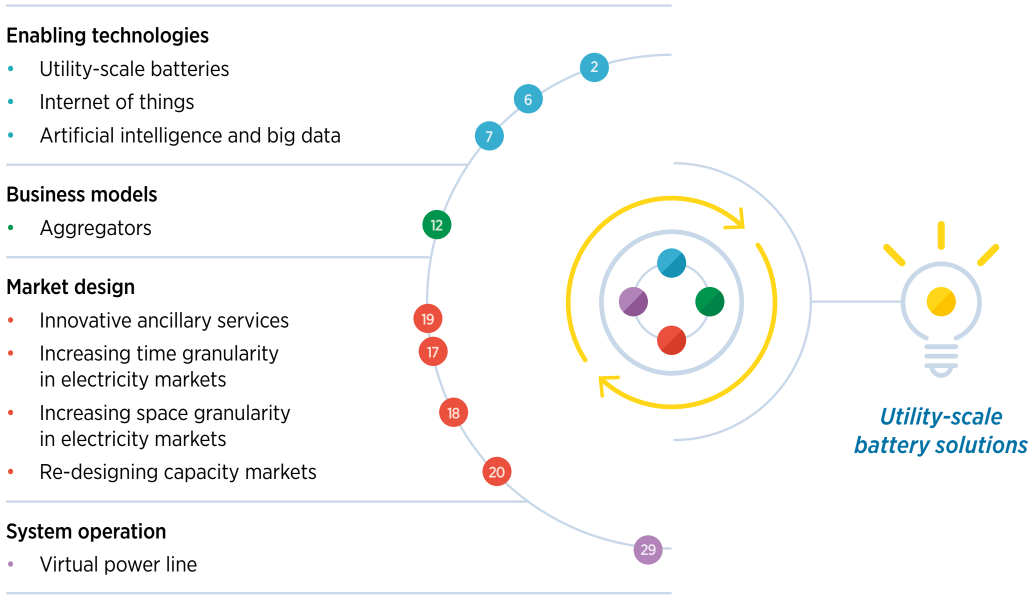
SOLUTION X

Utility-scale battery solutions

Figure: Synergies between innovations with utility-scale batteries



As **enabling technologies**, utility-scale batteries facilitate the integration of renewables from several fronts. First, they can help cope with the variability of renewables by storing energy in cases of excess generation, avoiding curtailment and supplying electricity to the grid when resources are scarce. Second, they are flexible and fast-responding technologies that help to maintain the balance in the system when sudden changes occur. Batteries provide stability and reliability services that become critical with the penetration of renewables, such as a need for faster frequency regulation and voltage control. (*Key innovation: Utility-scale batteries)*

In terms of **business models**, a utility-scale battery can, depending on its size, function as a single market player, or it can serve as part of an aggregator. *(Key innovation: Aggregators)*

Supply-side flexibility: Battery storage system coupled with VRE power plants

Coupling a specific VRE generation source with a battery reduces the variability of the power output at the point of the grid interconnection, thus facilitating better integration of the renewable energy into the grid. The battery storage system can smoothen the output of VRE sources and controls the ramp rate (MW per minute) to eliminate rapid voltage and frequency fluctuations in the electrical grid. Further, due to the smoothening of the generation, renewable energy generators can increase compliance with their generation schedules and avoid the payment of penalty charges for any deviation in generation output. Generation smoothening also would allow renewable energy generators to take better positions in the market-based auctions for energy/capacity, due to the increased certainty and availability of round-the the-clock energy. If a significant amount of renewable capacity installation is planned in an electricity system, the deployment of battery storage systems along with such renewable capacity also can be devised.

Furthermore, large-scale battery storage can be coupled with aggregated local distributed generation plants such as rooftop solar PV. These battery storage systems are connected to the utility network and can be controlled directly by the utility or by aggregators working on behalf of utilities. The stored electricity can be used later in the locality when the demand exceeds the supply. A pilot is being implemented in Walldorf, Germany, with a 100 kW battery system connected to 40 households (GTAI, 2018).

Grid flexibility: Battery storage systems providing services to the system

Battery storage systems can be used to provide services to the grid due to their fast-response capability. Ancillary grid services, such as primary (fast) frequency regulation, secondary frequency regulation, voltage support and capacity reserve, among others, will grow in significance as VRE penetration increases, although they have different dynamics in terms of performance, varying by the market and the time of year. Some applications require high power for short durations (*e.g.*, fast frequency regulation response), while others call for power over longer periods (*e.g.*, firm capacity supply). These different services imply various charge/discharge cycles. Each technology, therefore, is likely to find different market segments where it can compete on performance and cost (IRENA, 2018a).

The table below shows the suitability of various battery technologies for different applications, followed by details about some of these services.

- In terms of **market design**, a critical issue for electricity storage that will assist in its economics is the ability to derive multiple value streams by providing a range of services with one storage system. This will enable the "stacking" of the revenue streams and will improve the project revenues. In many countries, this will require changes in the market structure and regulations, or require the creation of new markets for ancillary grid services, and the introduction of more granular markets to reward individual services more directly (*e.g.*, primary and secondary frequency reserves, firm capacity, etc.). This will open up new opportunities for their deployment, given that battery storage will increasingly offer competitive services to these markets. At the same time, renewable capacity firming or time-shift services from battery storage technologies will also expand. *(Key innovations: Innovative ancillary services; Increasing time granularity in electricity markets; Increasing space granularity in electricity markets;; Re-designing capacity markets)*

Table: Suitability of various battery technologies for different grid applications

APPLICATION	TYPE OF BATTERY			
	Lithium-ion	**Lead acid**	**Sodium-sulphur**	**Flow batteries**
Load shifting – reducing excess renewable energy curtailment	Suitable	Suitable	Suitable	Suitable
Frequency restoration reserves	Suitable	Unsuitable	Unsuitable	Unsuitable
Capacity reserves	Suitable	Suitable	Suitable	Potentially suitable
Transmission and distribution system upgrade deferral	Suitable	Suitable	Suitable	Potentially suitable
Voltage support	Potentially suitable	Unsuitable	Unsuitable	Unsuitable
Spinning reserve	Potentially suitable	Suitable	Potentially suitable	Potentially suitable

Note: "Suitable" means that the battery type has been used for the respective application at the pilot or the commercial level. "Potentially suitable" means that the battery type has the potential to be used for the respective application, but with few or no installations. "Unsuitable" means that the battery type is unlikely to be suitable for the respective application.

Source: Adopted from HDR, 2017.

In many countries, the participation of energy storage systems in electricity markets is not allowed. A wide range of revenue streams for storage providers is enabled by clear regulations defining the ownership models and the operating models. This can include participation in wholesale electricity markets, the sale of frequency response services to system operators or participation in capacity markets. For example, in 2016 the UK grid operator awarded contracts for 201 MW of its first "enhanced frequency response" tender, which is directed towards storage systems.

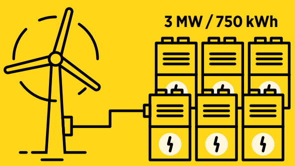
In the US the Federal Energy Regulatory Commission (FERC) voted to remove barriers to the participation of electricity storage resources in the capacity, energy and ancillary service markets operated by the regional transmission organisations and the independent system operators. This order will allow utility-scale batteries to help support the resilience of the bulk power system. In February 2018 FERC passed a rule to allow storage providers to participate in US wholesale electricity markets (FERC, 2018). Another recent FERC order allows energy storage systems to participate in capacity markets, mandating system operators to revise tariffs and establishing rules that recognise the physical and operational characteristics of energy storage systems (Walton, 2018).

Systems around the world are already including storage in their planning efforts. For example, in the Californian power system, the California Public Utilities Commission mandated that the three big utilities must have 1 325 MW of energy storage in operation by 2020. Similarly, Asia Pacific, North America and Western Europe are expected to be the leading markets for utility-scale energy storage capacity for ancillary services through 2026, accounting for more than 32 GW (Colthorpe, 2018).

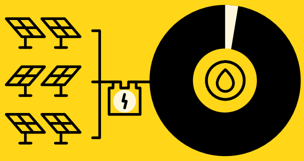
Battery storage system used for decongesting the grid

- To support **system operation**, large-scale storage systems can be deployed at different points in the distribution and transmission network to store excess power during non-peak hours. These systems can then be discharged to meet load requirements in the local area during peak hours, without the need for transporting electricity through congested grid lines, thereby reducing network congestion and creating "virtual power lines".

In this case, batteries are not merchant assets but network assets, owned by the grid operator and used exclusively for managing the grid. For example, Terna, a transmission system operator in Italy, is deploying a pilot battery storage project of 35 MW on part of its 150 kV grid in southern Italy for grid congestion management (Terna, n.d.). RTE, the French transmission system operator, is carrying out a similar initiative called the Ringo project. *(See Innovation Brief: Virtual power lines)*



8 MILLION kWh
ADDITIONAL WIND
integrated using batteries



97 %
FOSSIL FUEL USE REDUCTION in Hawaii with solar and batteries

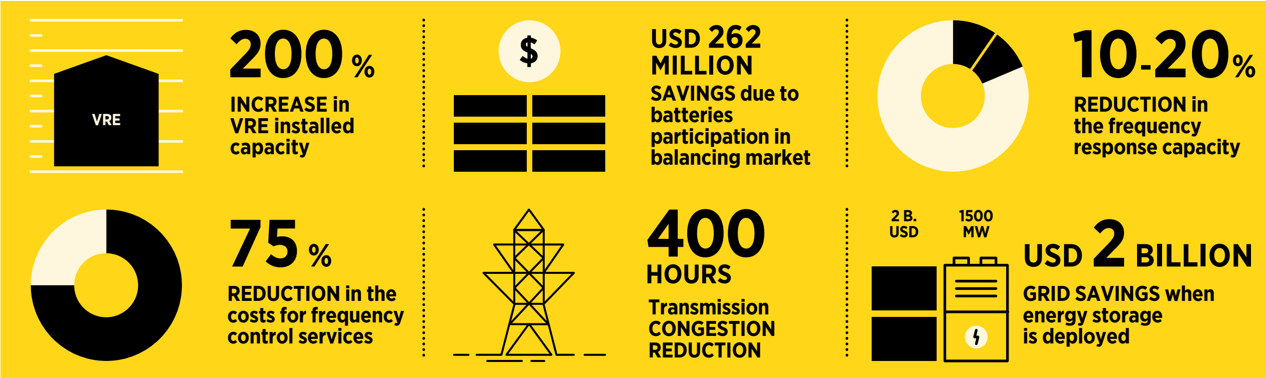
Impact on VRE integration:

- **8 million kWh of additional wind integration was enabled in Alaska using battery storage.**

In Alaska a local utility called Kodiak Electric Association, in collaboration with Berlin-based energy storage firm Younicos, has installed an advanced lead-acid battery storage system of 3 MW / 750 kWh with a 4.5 MW wind power project, resulting in additional wind integration of 8 million kWh (IRENA, 2015).

- **Solar and batteries are expected to reduce fossil fuel use by 97% on the island of Hawaii.**

In 2014 Aquion Energy, an energy storage system provider, completed installation of a 1 MWh battery system as part of an off-grid solar microgrid at Bakken Hale on the island of Hawaii. The system is designed to generate 350 MWh per year. This is expected to reduce fossil fuel usage by 97% and carbon dioxide emissions by more than 5 000 metric tonnes (ESA, 2014).



Impact on system operation:

- **200% increase in VRE installed capacity, 70% decrease in ancillary service procurement costs and 20% decrease in balancing market size in Germany.**

In Germany, alongside conventional generators, renewable energy generators, battery storage systems and industrial loads have been allowed to participate in the balancing markets since 2009. In the period 2009-2015 the balancing market size decreased by 20% (in GW), and ancillary service procurement costs by transmission system operators decreased by 70%, while in the same period the system stability increased and the installed capacity of VRE increased by 200% (Wang, 2017).

- **Around USD 262 million in cost savings for consumers** due to the deployment of the sub-second Enhanced Frequency Response by National Grid in the UK, which allows the participation of batteries in balancing markets. Contracts were awarded to more than 200 MW of battery storage in July 2016 (National Grid, 2017).
- **10% to 20% reduction in the frequency response capacity procurement expected by PJM.**

PJM, a power transmission operator in the US, has deployed energy storage systems that are providing cost-efficient frequency response, reducing the use of fossil fuel generation. PJM has forecasted that a 10% to 20% reduction in frequency response capacity procurement could result in USD 25 million to USD 50 million in savings for its consumers (HDR, 2017).

- **75% reduction in the costs for frequency control services from a utility-scale battery in Australia.**

Based on the first full month of trading in December 2017 the Tesla 100 MW battery resulted in about a 75% reduction in the costs being paid by customers for frequency control services (Frontier Economics, 2018).

Impact on transmission network:

- **400 hours of congestion reduced and savings up to USD 2.03 million on fuel costs per year.**

A high-level demonstration study for mitigating transmission congestion using a 4 MW / 40 MWh battery storage system with four hours of storage showed that the New York Independent System Operator (NYISO) can save up to USD 2.03 million in fuel costs and reduce almost 400 hours of congestion (IEEE, 2017).

- **USD 2 billion in savings when about 1 500 MW of energy storage is deployed.**

A draft study commissioned by the state of New York estimates over USD 2 billion in savings if the state deploys about 1 500 MW of energy storage in lieu of traditional grid solutions by 2025 (NYSERDA, 2018).

IMPLEMENTED SOLUTION

Large battery in Australia, coupled with a wind plant providing services to the system

● In 2017, the US company Tesla commissioned a lithium-ion battery storage capacity of 100 MW/129 MWh at the 315 MW Hornsdale Wind Farm in South Australia. The battery storage facility was installed to firm up the power generated from the Hornsdale Wind Farm and simultaneously provide ancillary services to the Southern Australia grid. A battery capacity of 70 MW is connected to the grid for providing grid services, and the remaining 30 MW is to be used for firming up the renewable power generated at the wind farm. The latter is designed to hold up to three-to-four hours of energy (McConnell, 2017).

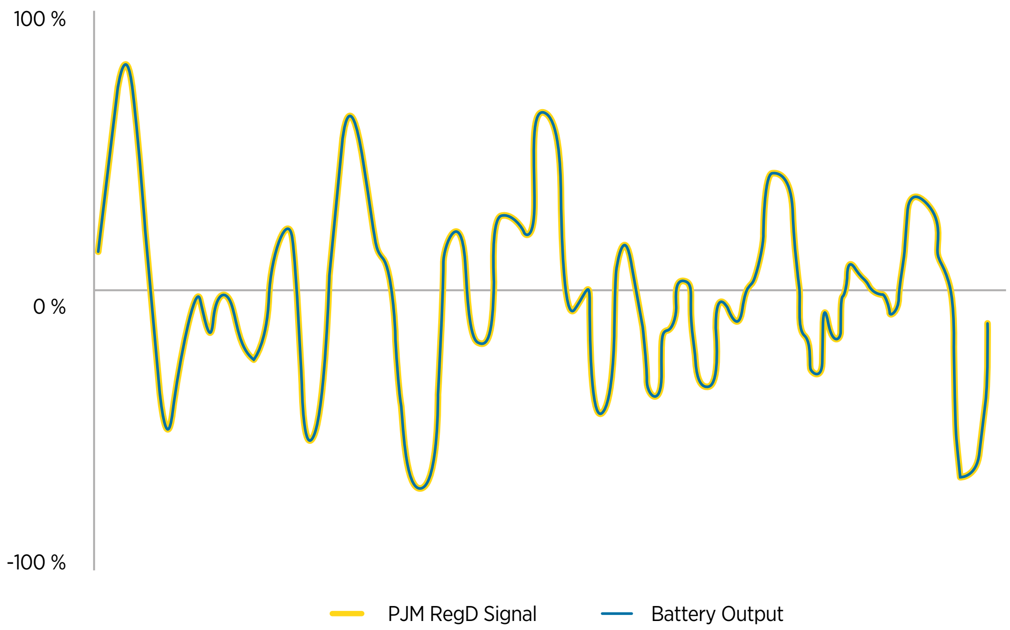
In addition the Australian Energy Market Commission changed the market rules, allowing energy storage to provide ancillary services and thus opening an additional opportunity for storage in the country (Stone, 2016).

Large battery provides ancillary services to PJM in the US

● Driven by FERC's mandate to independent system operators to pay for the performance of the frequency providers, Renewable Energy Systems (RES), a UK-based firm, built a 4 MW/2.6 MWh battery storage system that provides frequency regulation services to PJM, a regional transmission operator in the US (RES, 2016).

Frequency regulation is the injection and withdrawal of power on a second-by-second basis to maintain the grid frequency at the nominal level. The primary resources used for regulation – coal-fired steam plants and combined-cycle gas plants – are relatively slow at ramping and therefore cannot follow a fast-moving signal well. Realising this, FERC instituted Order 755, which requires the independent system operators to "pay for performance". This resulted in energy storage systems receiving much higher revenue per megawatt for regulation than that received by traditional resources (RES, 2016).

Figure: PJM regulation services signal and battery response



Source: RES, 2016.

PJM assesses the frequency regulation market participants largely on how quickly and accurately they can respond to a PJM-provided signal. The battery installed by the UK firm continues to earn a very high performance score, having been programmed and designed with maximum speed of response and accuracy when providing frequency regulation. Figure 32 shows the signal received from PJM and how accurately RES's storage system responds to it.

Batteries are flexible and fast-responding. They can cope with variable generation and help maintain the balance in the system

Solar PV – wind – storage hybrid solution for Graciosa Island, Portugal

Graciosa, a Portuguese island, has traditionally met its energy requirements through fossil fuel imports and diesel-based generation. However, the new Graciosa Hybrid Renewable Power Plant – comprising a 1 MW solar PV plant, a 4.5 MW wind plant and a 6 MW/3.2 MWh battery storage system – has helped reduce the island's reliance on imported fossil fuel while also reducing its greenhouse gas emissions.

The project's generated energy will be sold to the local utility, EDA. The project also uses the Greensmith Energy Management System (GEMS) software, which optimises energy generation based on various factors such as weather forecasts, load patterns, etc. Renewable energy consumption on the island is expected to increase from 15% to 65% of total energy consumption while eliminating the need for around 17 000 litres of diesel per month. The plant can currently meet 70% of local demand (Anteroinen, 2018).

SUMMARY TABLE: BENEFITS AND COSTS OF UTILITY-SCALE BATTERY SOLUTIONS

Utility-scale battery solutions	Low	Moderate	High	Very high
BENEFIT				
Potential increase in system flexibility				
Flexibility needs addressed	from seconds to hours			
COST and COMPLEXITY				
Technology and infrastructure costs	depends on scale and cost dropping			
Required changes in the regulation framework	send right incentives to the new player that can generate, store and consume electricity			
Required changes in the role of actors				
Other challenges	• Standards to be developed between DSOs and Battery providers			

This document is extracted from a longer report:

IRENA (2019), ***Innovation landscape for a renewable-powered future: Solutions to integrate variable renewables.*** International Renewable Energy Agency, Abu Dhabi (**ISBN 978-92-9260-111-9**).

The full report and related materials are available on the IRENA website (**www.irena.org**).