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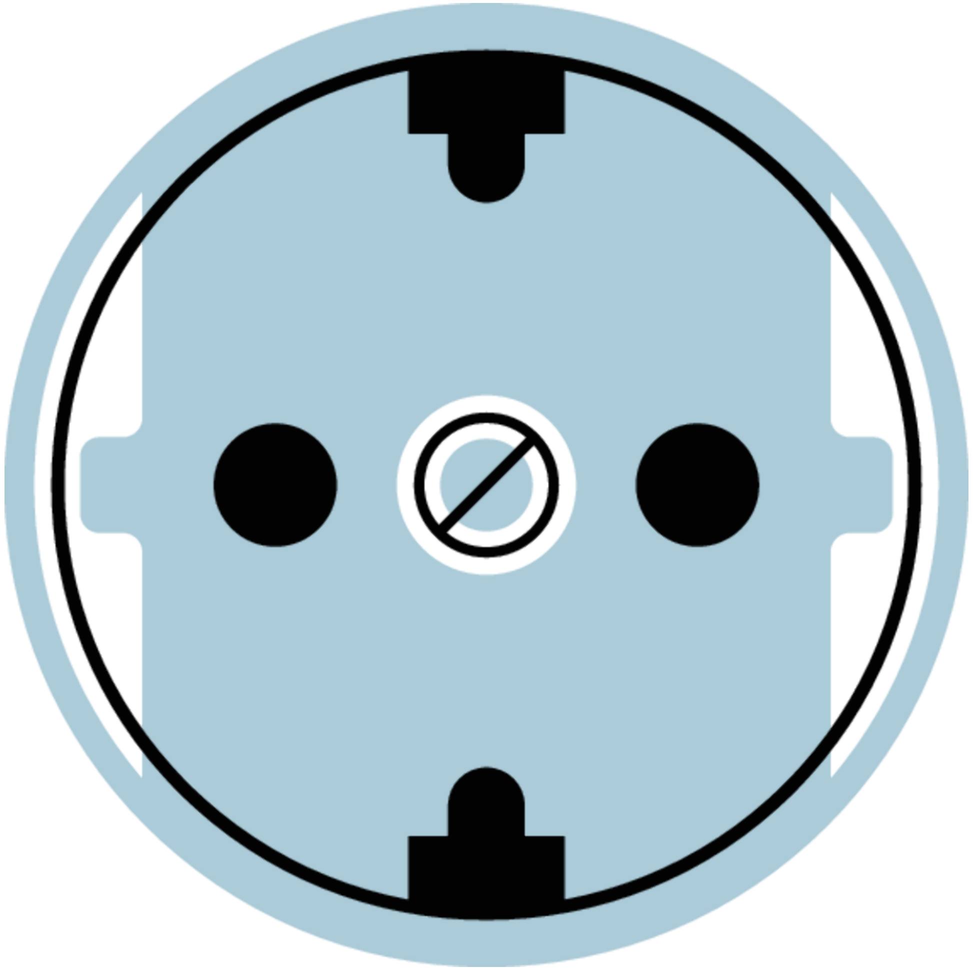

The Future of Energy Storage in the Energy Transition

Discussion paper

February 2021

Future confident

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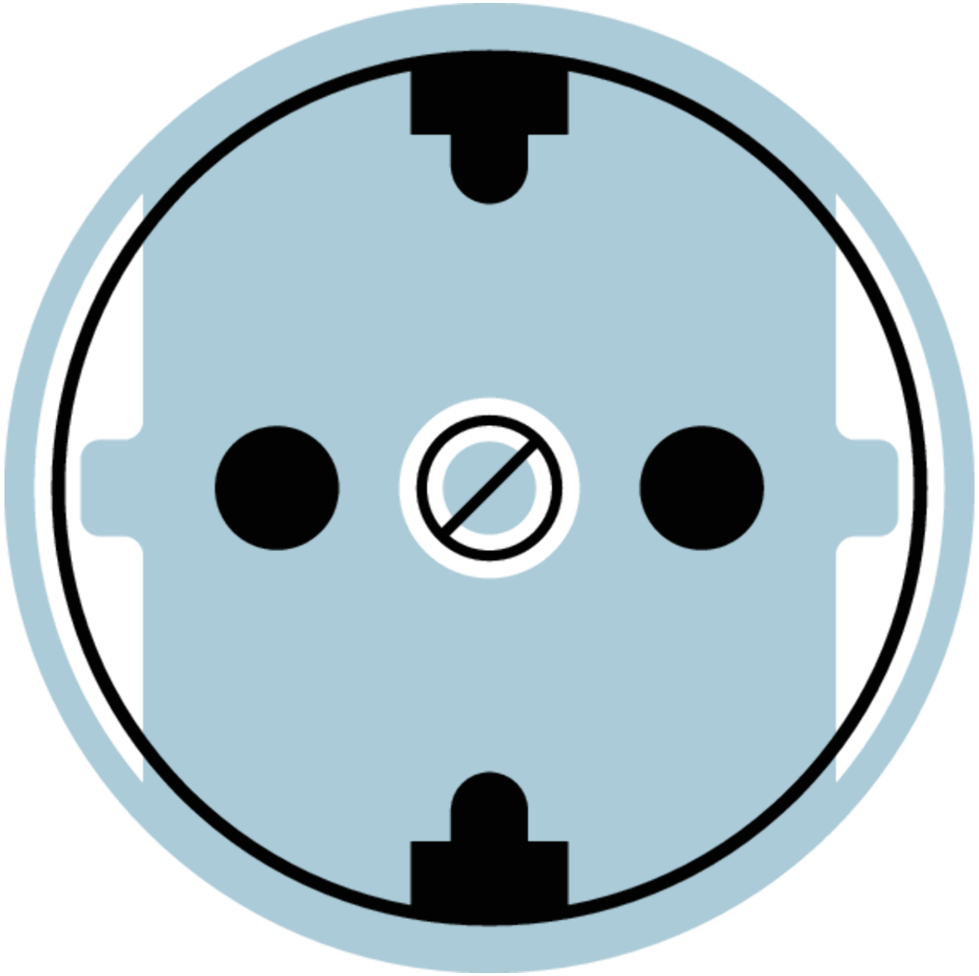

Energy storage is already being used across the power sector supply chain

Revenue sources for storage applications

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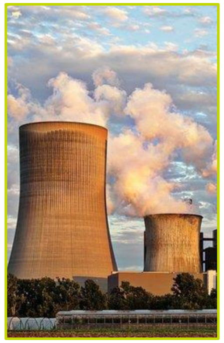
Utility-scale | *Behind the meter*

	Centralized generation	**Power grids (transmission and distribution)**	**Retail**
Applications	• **Flattening the demand curve**, taking advantage of the spread between peak and off-peak prices • **Integration of renewables** (intermittency problems) • Conventional technologies **utilization ratio increase** • **Reduction of investments in new peaking** power plants • Improve **power plants stability**	• **Balance services** (e.g., black start applications, operational reserve) • **Stability** and **quality** of the transmission grid • **Deferral of grid investments** • **Interconnections management** when there is an excess of renewable production	• **Potential savings** (in markets with high electricity market prices or with high differences between peak and valley prices) • Client **independence from electricity grid increase** through self-consumption facilities (PV + storage) • EV penetration and its storage flow utilization
Technologies	• **Hydrogen** • **Batteries** (lithium-ion, lead-acid, etc.) • Pumped hydro • Thermal storage • Compressed air	• **Batteries** • Super capacitors • Flywheels • Compressed air • Super magnetic capacitor	• **Batteries**

Source: IEA; Sandia National Laboratories; UBS; Lazard; Monitor Deloitte

Before 2030, three trends in the energy system will cause problems that energy storage can help mitigate, becoming a business opportunity

		Issue caused	Energy storage helps	Estimated year
Increase in renewable generation		• **Increase in renewable non-dispatchable generation** to meet EU and national targets will **increase variability of generation** (daily and seasonal) • **Curtailment will increase** as renewable generation increases	Providing **daily, weekly and seasonal storage** depending on the technology used	2025
Phase-out of synchronous generation		Phase-out of synchronous generation will reduce the system's inertia and **cause frequency unbalances in the grid** as most remaining generation will be non-synchronous	Stabilising the grid by **injecting power when required to keep the system inertia**	2027
Rise of widespread demand-side management		Once distributed generation and demand-side management become mainstream, **micro-grids will become more relevant and voltage unbalances** inside and between the micro-grids **will be common**	**Providing stabilise voltage inside micro-grids** by balancing load (reactive power)	2030

Energy storage technologies are improving fast and costs tend to decline. Pumped hydro, flywheel, batteries and H2 storage will be the leading technologies

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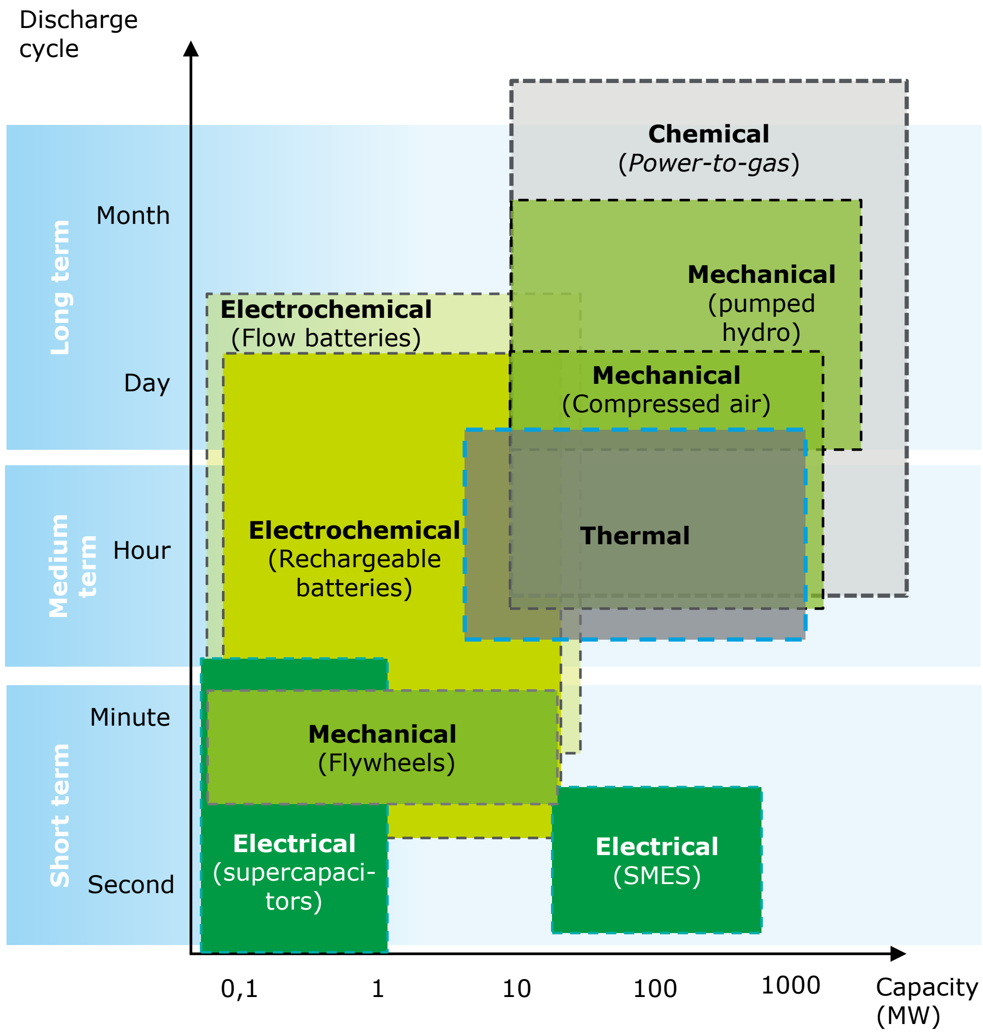
Storage comes as a potential solution to RE integration

Group	Type		Speed Ramp-up	Lifespan	Efficien.
Mechanical	Pumped hydro		◔	●	◑
	Compressed air		◑	●	◑
	Flywheel		◕	●	◕
Electrochemical	Rechargeable batteries	Lithium -ion	●	◕	●
		Sodium	●	◑	●
		Lead Acid	●	◔	●
	Flow Batteries (Vanadium)		●	●	◕
Electrical	Capacitor / Supercapacitor		●	◕	●
	Superconducting		◕	◑	●
Chemical	Hydrogen		◑	◑	◑
Thermal	Heat storage / Latent		○	◑	◔

Storage categorisation



Source: UBS, EASE, IRENA; DoE; Lazard, Monitor Deloitte

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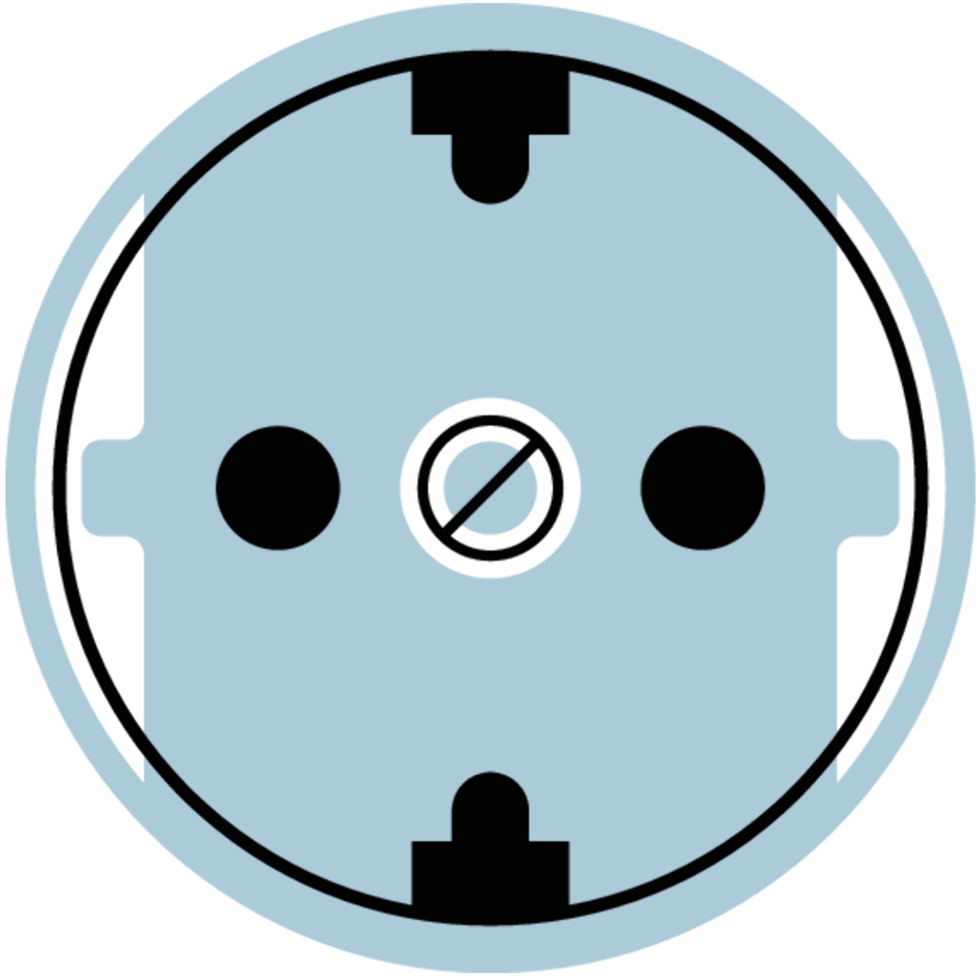
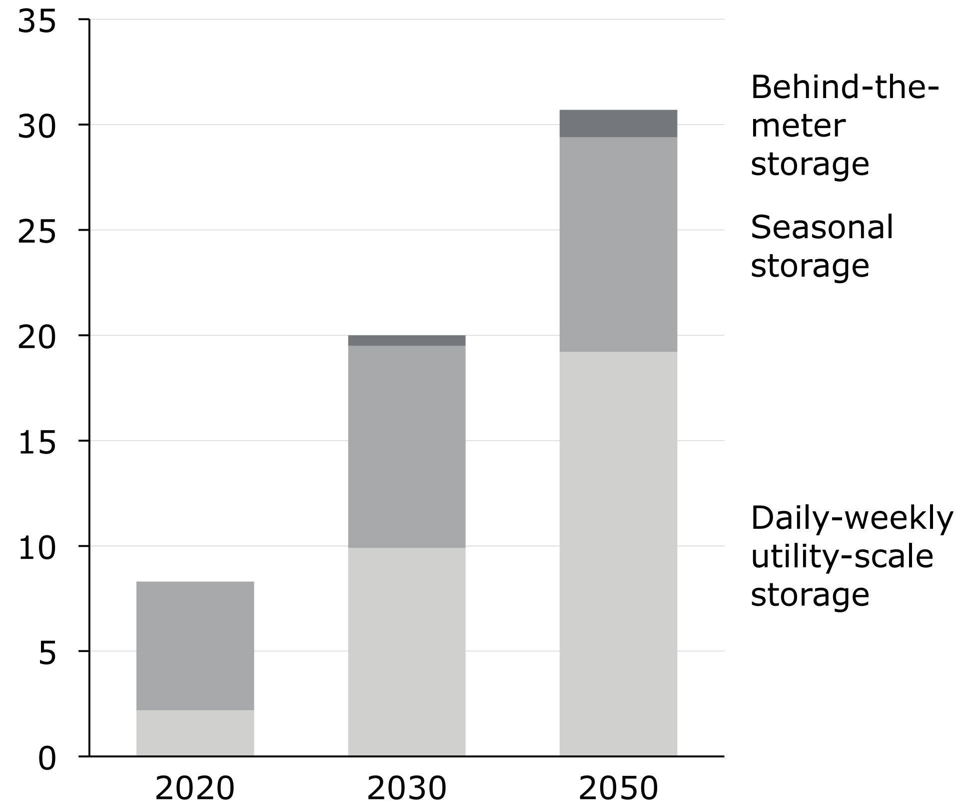


The Spanish Energy Storage Strategy consists of 66 measures aiming to reach capacity targets of 20 GW by 2030 and 30 GW by 2050

Energy storage targets[1]
(GW)



Main lines of action of the Spanish Energy Storage Strategy: 66 measures

Regulatory and policy framework	• **Modify System Operating Procedures** to incorporate storage technologies participation • **Foster sectoral integration**: green H2, Power-to-X, etc. • **Eliminate network tariffs double charging**
New business models definition	• Promote the role of **independent aggregator** • Strengthen **domestic industry** • **Boost renewable energy communities**
Innovation & Develop-ment	• **Develop prospective studies** regarding storage's needs, cost/benefit and life cycle assessments • **Boost collaboration** among academia, industry, citizenship and government (Quadruple helix initiatives)

To make economically feasible electricity storage projects it is necessary to redefine markets to give a price signal for these technologies' benefits

(1) Considers pumped-storage, batteries and other large-scale storage systems, behind-the-meter batteries and thermal energy storage
Source: Monitor Deloitte; MITERD

Energy storage can be integrated across the electricity value chain and provides benefits to end-user, utilities and grid infrastructures

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Potential effects across the value chain main players

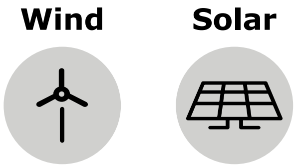
Player		Potential effects
End-User		• **Cost reduction through grid operation and energy management with flexibility (**flattering demand curve**)** • **Disturbances reductions improving power quality**
Producers		• **Integration with RES,** increase utilization • **Arbitrage** (daily and seasonal), taking advantage of price fluctuations • **Support to conventional generation minimizing curtailment,** facilitating ramp-ups, hedging imbalances and complying with grid requirements • **Manage peak fluctuations rapidly** (ramp-up)
Grid Network	**Central / bulk power**	• **Production/demand matching** (primary reserve – FCR)**, quick response, flexibility** • **Capacity firming** (losses and stability) • **Frequency support** (secondary reserve – aFRR with local approach and tertiary reserve - mFRR to correct congestions)[1] **and voltage control** • **Grid upgrade deferral** / better optimization of existent grid
	Distributed	• **Save O&M costs** • **Power oscillation dumping** • **Manage peak fluctuations and minimize curtailments** • **Integration with self-consumption**

Source: Monitor Deloitte

(1): aFRR – Automatic frequency restoration reserve; mFRR – Manual frequency restoration reserve

As LCOS decreases, energy storage will optimise grid and energy management, and add stability and reliability to the power system

1 Energy Management



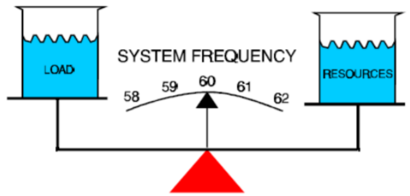
Issue

Solar and wind plants **intermittence** and stochastic might cause a mismatch in production / demand resulting in **power curtailments**

Storage benefits

- Allows **more efficient energy management** allowing to store energy when production exceed demand
- Allows **arbitrage** potentially reducing price volatility
- Reduce **loses** in DSO and **optimize grid capacity** (upgrade deferral)

2 Frequency Control



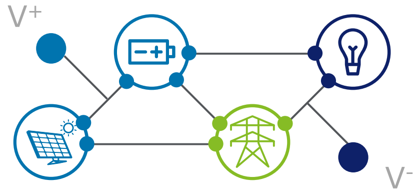
Issue

The **reduction of system inertia** due to **increase of small generator** units will often lead to demand/generation imbalances creating instabilities

Storage benefits

- **Batteries will react quickly** to frequency spikes / drops, re-establishing the nominal value
- **Bigger generators** from thermal plants and pumped hydro **will add inertia to the system** and recover the secondary and tertiary frequency regulation

3 Voltage Control



Issue

Distributed generation and **variations in production/demand** might cause voltage rise on feeders increasing the risk of damaging equipment. Traditional equipment (VAR) reacts slow

Storage benefits

- **Batteries will react injecting/receiving reactive power** from the RES at the point loads in a local basis reducing the problem in the global grid, that can be managed by On-load tap changers
- **Smart grids will allow coordination** of traditional VR with storage units

1 Arbitrages can be short term (daily) or long term (seasonal) depending on the type of technology used and the system's need

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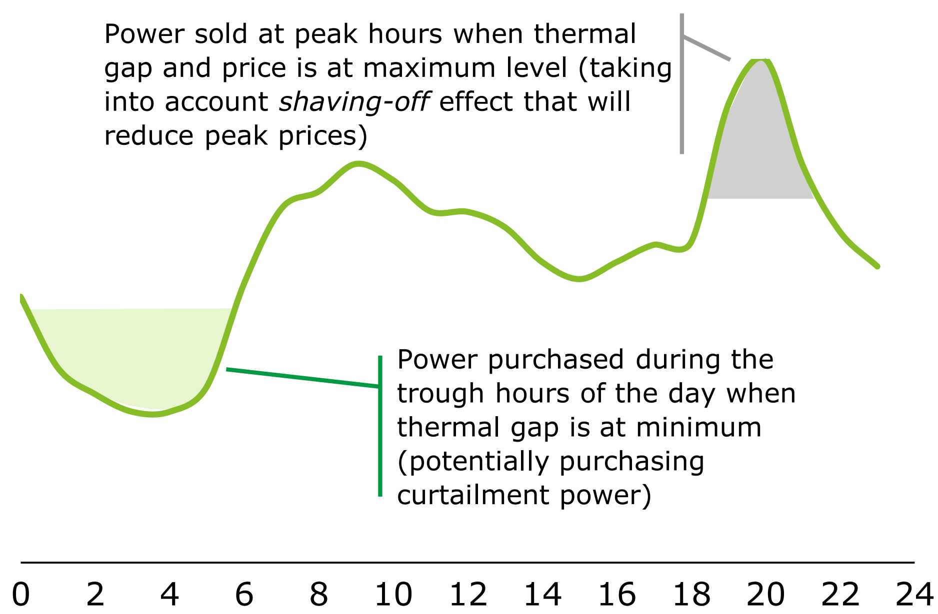
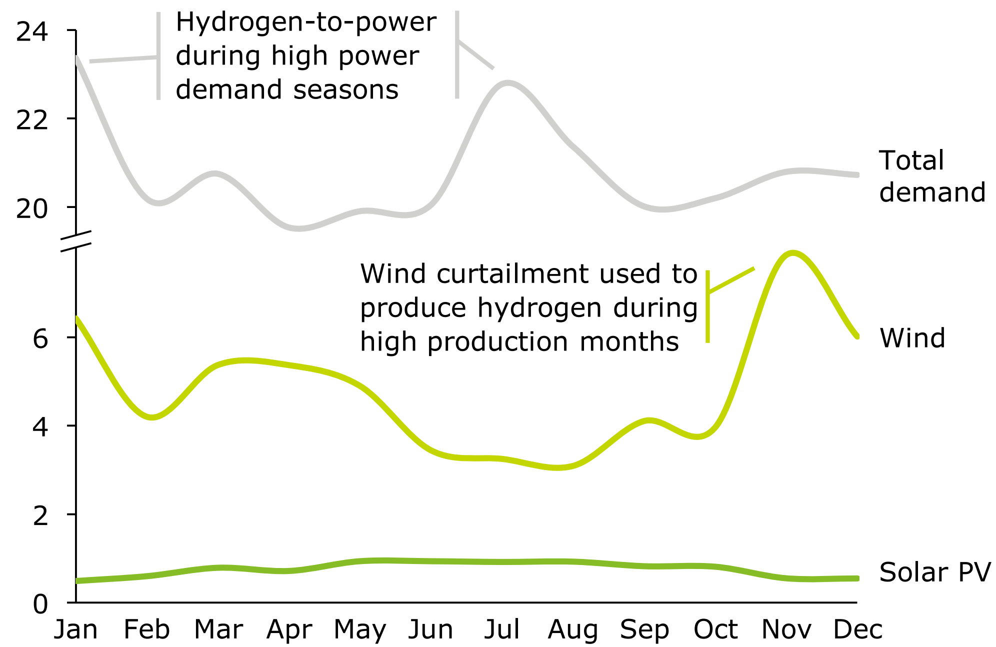
Daily peak-trough arbitrage

Daily market power price
(€/MWh)



Seasonal arbitrage

Monthly demand and production
(TWh)



While most of the lithium batteries are suitable for daily arbitrage due to high flexibility and short discharging cycles, pumped hydro will enable seasonal storage. On the other hand, hydrogen at different scales will be suitable in both

Source: REE; Monitor Deloitte

1 In the next decade, technology reduction costs can drive utility-scale batteries' LCOS down to 60-70€/MWh

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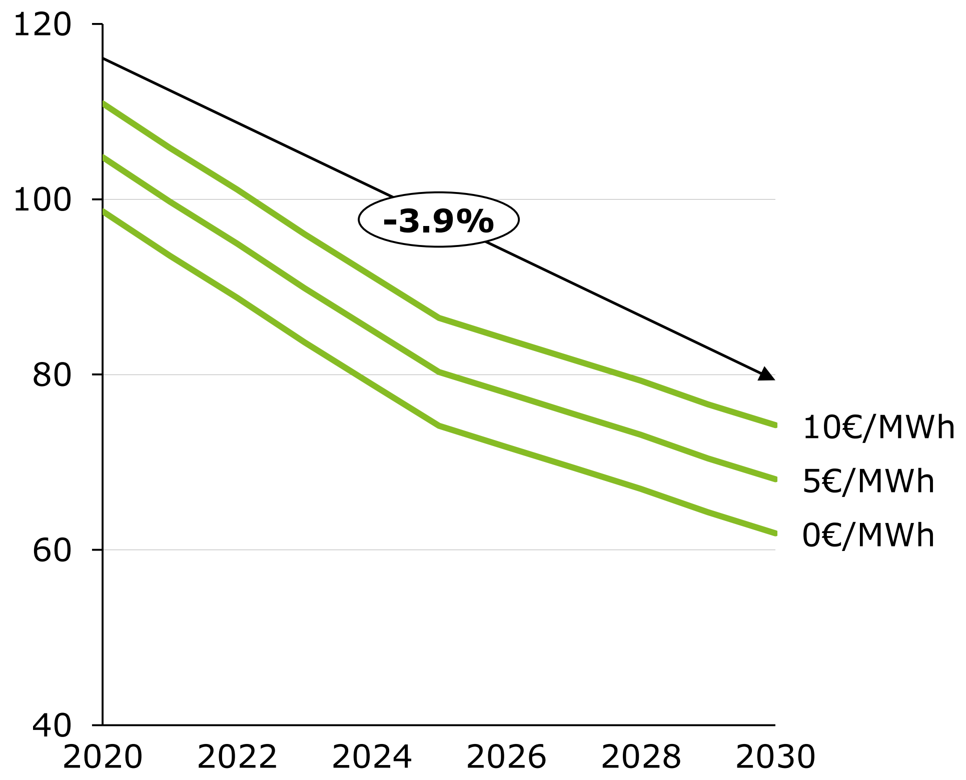
Key technological enablers that are expected to reduce energy batteries costs (2030)

Manufacture process improvement	• **Automation and optimization of the manufacturing process:** increasing demand of the electric vehicle will drive important economies of scale and investments • **Cells used to make up modules for electric vehicles batteries** and those of a stationary storage system are the same.
Batteries energy density improvement	There will be an **increase** of the **active material** of a cell while **the non-active** material will be **reduced** • **Cathode**: it is the most expensive element of a battery where many of its benefits reside. Cheaper chemicals will be used (nickel), reducing expensive materials (cobalt) • **Anode**: introduction of silicon instead of current graphite, reducing anode's size and cost
Disruptive technologies	• Use of **electrolytes that tolerate higher voltages** or **materials with higher thermal resistance** that will increase operating cycles and life of the batteries • **Solid state electrolytes** that will eliminate the separator and provide greater security • New **lithium sulfide batteries**

LCOS projection at different power purchase prices (€/MWh)



This cost reduction will be key to determine when can batteries begin to participate in energy markets

Source: Monitor Deloitte; NREL

1 The feasibility of using batteries for daily price arbitrages depends on technology evolution but also on the price spread evolution

Hypotheses

Consumption:

- Storage demands power (additional demand) when the thermal gap is minimum over a day
- Storage only demands when they are not fully charged

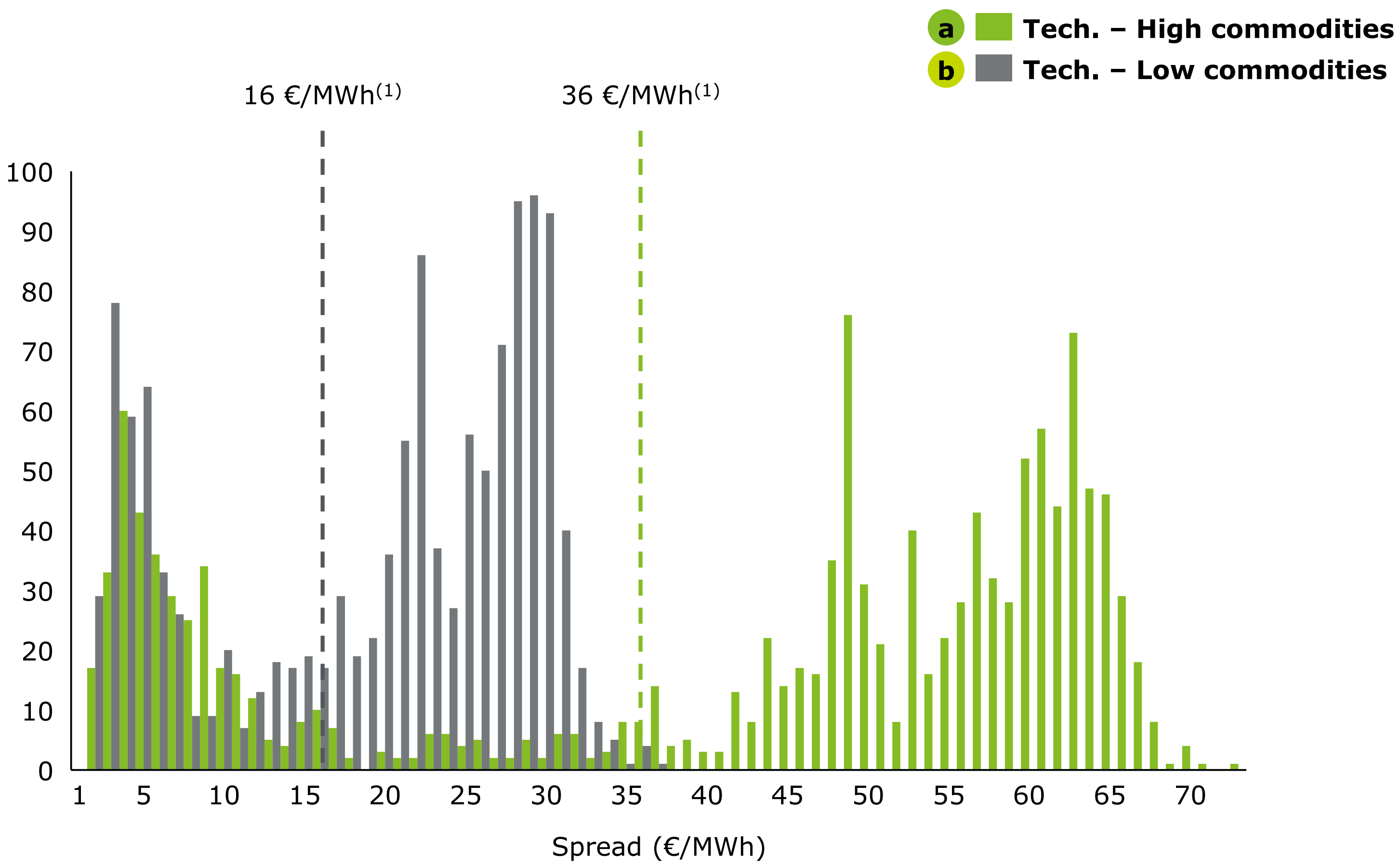
Generation:

- Storage sells power when the thermal gap is maximum over a day at 15% below CCGTs price
- Storage only sells energy when it has previously been charged

Minimum spread:

- **50-60 €/MWh spread required to pay for LCOS**
- If the spread is not at least 2€/MWh, storage does not generate

Price spread histogram (purchasing price-selling price) of storage in scenarios A (Tech. – High commodities) and B (Tech. – Low commodities) in 2030 (#)



(1) The weighted average price spread between energy acquisition and energy selling
Source: Monitor Deloitte

2 But shall batteries rely on energy-only markets or are the business models based on capacity and ancillary services markets?

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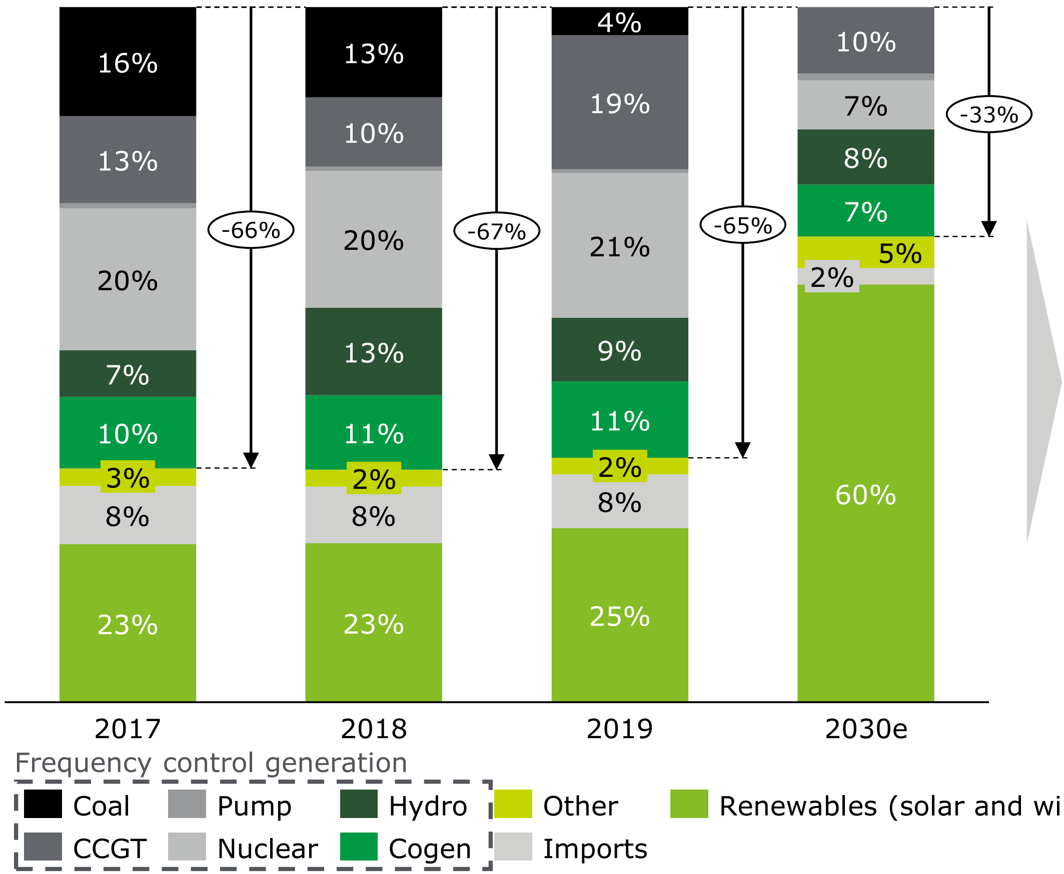
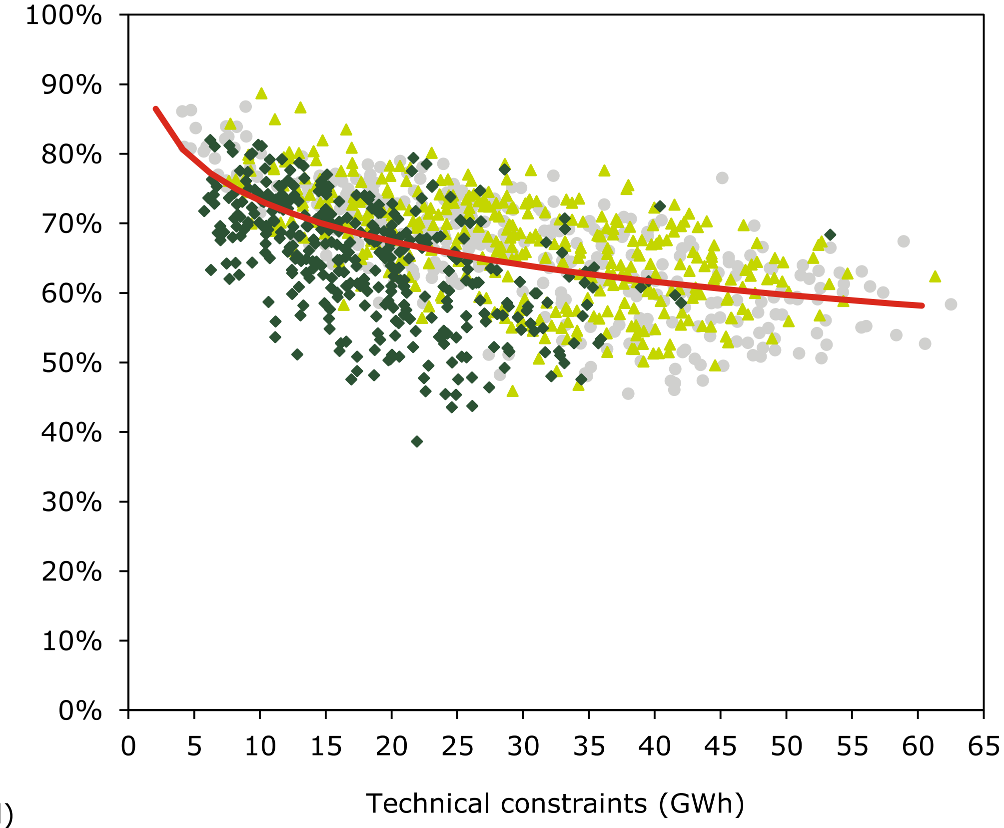
Mix Generation - Frequency control generation
(%)



Frequency-controlled generation vs Volume of technical constraints
(%, GWh)



Stability devices will be required to manage renewables penetration and batteries to keep power system firmness

Source: PNIEC, REE, Deloitte Monitor

2 RTE (French TSO) has recently published a report on the requirements that a power sistema will have as renewbales production increases

The role of synchronous capacity

- **The existing electrical system works with alternating current (AC) and voltage, generated by synchronous machines** (in coal, gas, nuclear, biomass and hydro power plants) which contain magnets (or electromagnets) **that the rotation speed of the magnet is directly related to the frequency of oscillation of the voltage**
- **Frequency shall be stable, for many different reasons:**
  - **Customers' appliances require the frequency to be in a narrow band around nominal**
  - **Big generators are designed to operate at a nominal frequency**, so any deviation from this leads to loss of efficiency and/or fulltrips
  - **Some components of the transmission grid have also been designed for a frequency** when the frequency deviates from nominal, the losses increase

Scenarios for renewables penetration

Today's wind and PV generators are operated as "grid following" units. They only "read" the frequency set by the alternating current signal in the AC power system, they do not impose a voltage and frequency reference to the network as do conventional generators **therefore 3 horizons can be defined for renewable penetration**

60% renewables

- **Mantain at least 40% of rotation machines is required to keep the system inirtia**
- **Storage can start provide some minor suport**

80% renewables

- **New services for fast frequency response** (FFR) (very short reaction delays, at the scale of a second)
- These services could be procured from a variety of assets, **including variable renewables, batteries and EV chargers.**

100% renewables

Synchronous condensers may be a viable option when system strength becomes an issue but will not be enough

Grid-forming solutions can be applied to push the level of instantaneous variable renewable infeed higher. This will require further innovation and demonstration projects to increase technology readiness levels for large-scale implementation

Syncronus capacity will be required until storage alternative solutions and syncronuos coderser technologies are further developed

2 Frequency response mechanisms are a potential source of revenues for batteries given their fast response times

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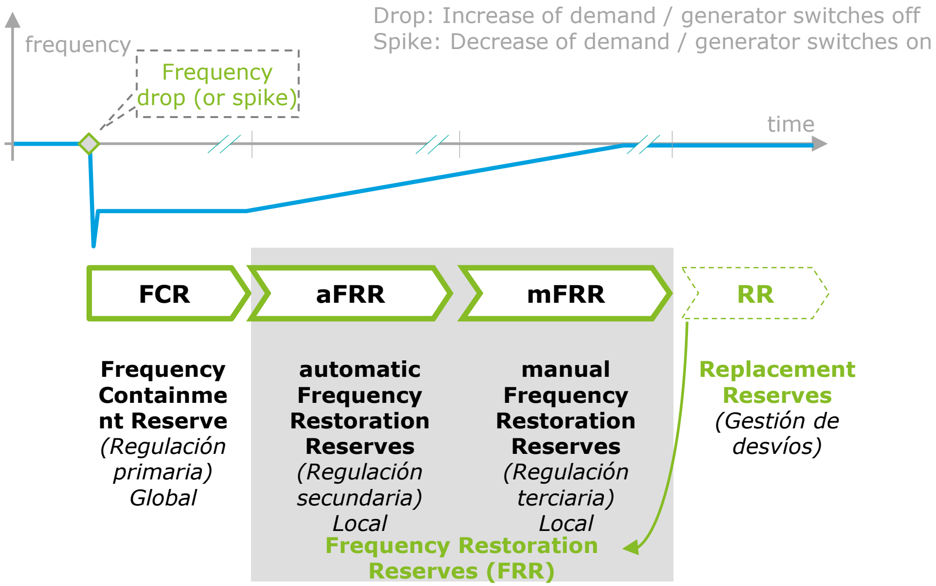
Physical frequency restoration mechanisms



Applications

- Storage will correct frequency deviations from nominal and power imbalances by absorbing or supplying power
- Batteries are **high responsive**, it can be used for **primary and secondary** (>10MW) **frequency response** providing a better operations than thermal generator and conventional droop control based
- Frequency control is more **critical in smaller systems with lower inertia with a more variable demand** than centralized power system
- 50% RE energy mix, would require 5% of storage; **Power / Energy ratio = 2 / 1**
- Might **reduce capacity reserves** of production schemes -> improves asset optimization

Causes of frequency deviations

- RES penetration **increases uncertainty** and variability in the system operations creating challenging **frequency disturbances** from 50Hz
- The **total system inertia** (all of generators) will be reduced, since large synchronous generators will represent a smaller part of the energy mix

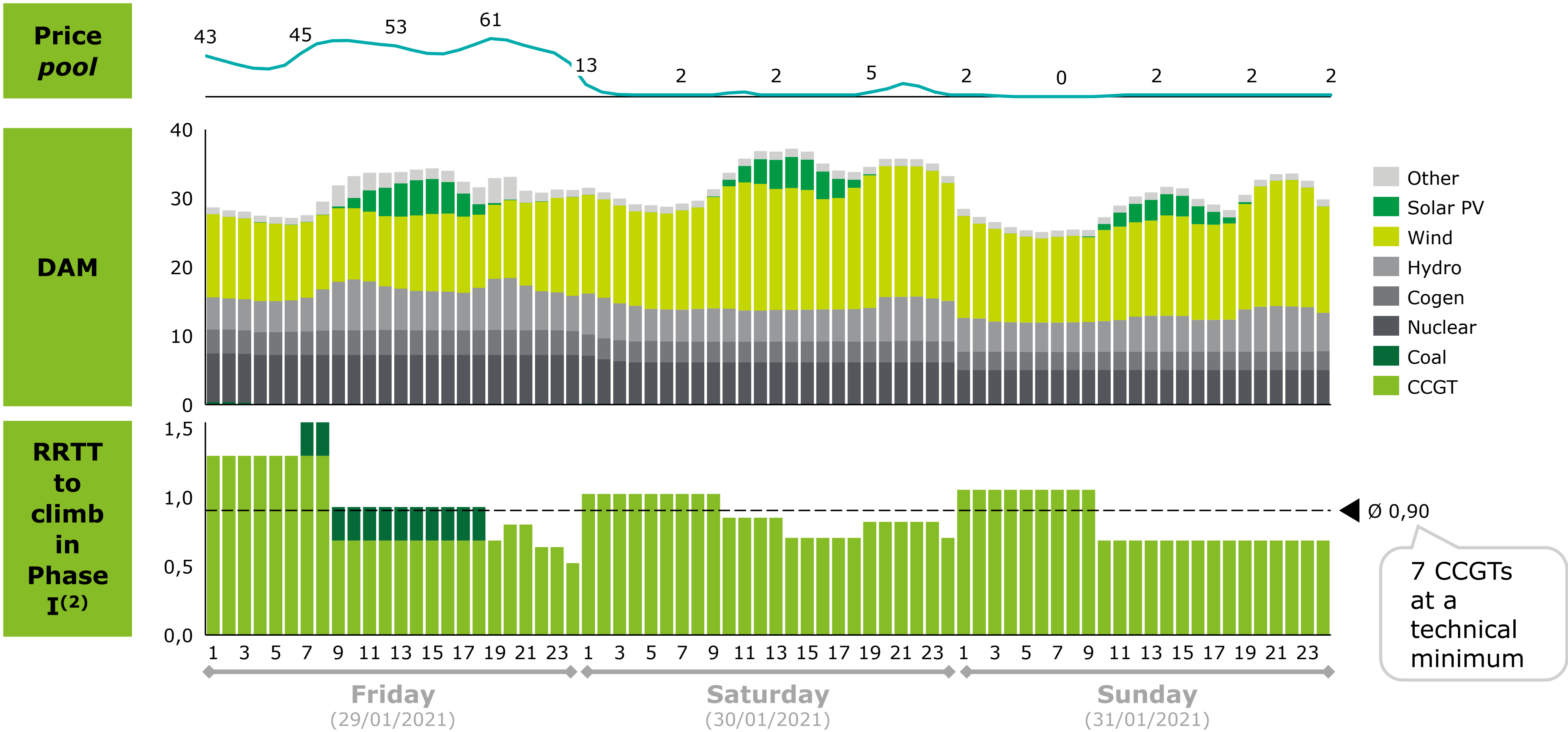
Future challenges

- **Storage alternatives should be adapted to energy uses** (e.g. batteries are constrained by both energy and power and the fact that their degradation is heavily affected by their operating state of charge and cycling requirements)

Source: Greenwood et. All. Frequency response services designed for energy storage. Knap V et. All. Sizing of an energy storage system for grid inertial response and primary frequency reserve; Monitor Deloitte

2 In electricity pool scenarios with high renewable share and low price, it is necessary to increase 0.5-1.5 GW of combined cycles in the RRTT market

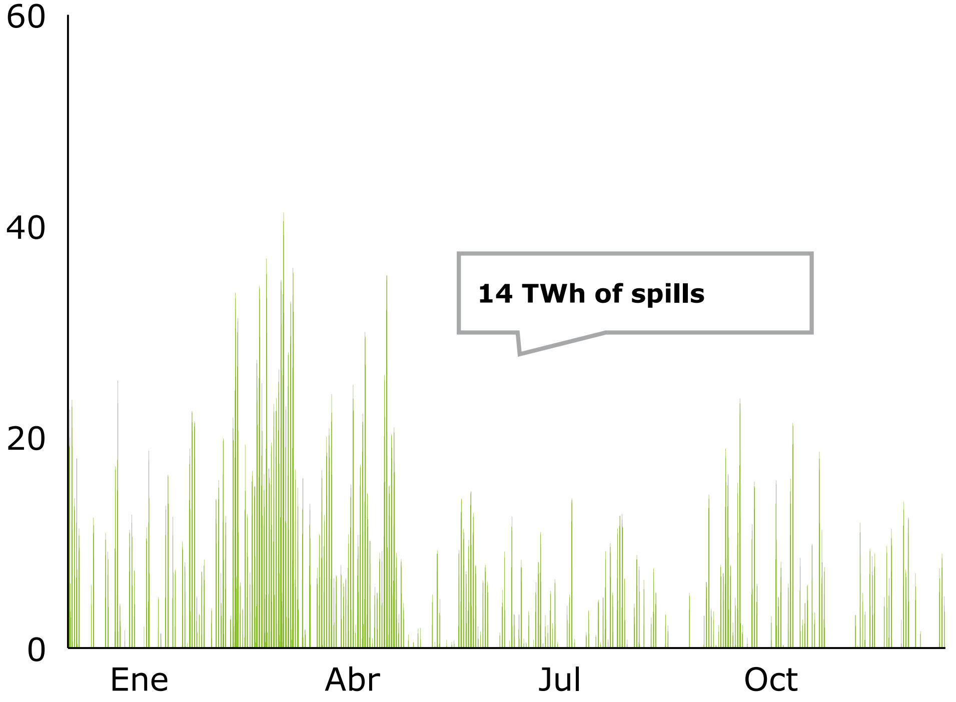
Pool price and results by technology in Daily Market and Technical Restrictions Market, (29-31 January 2021) (€/MWh; GWh)



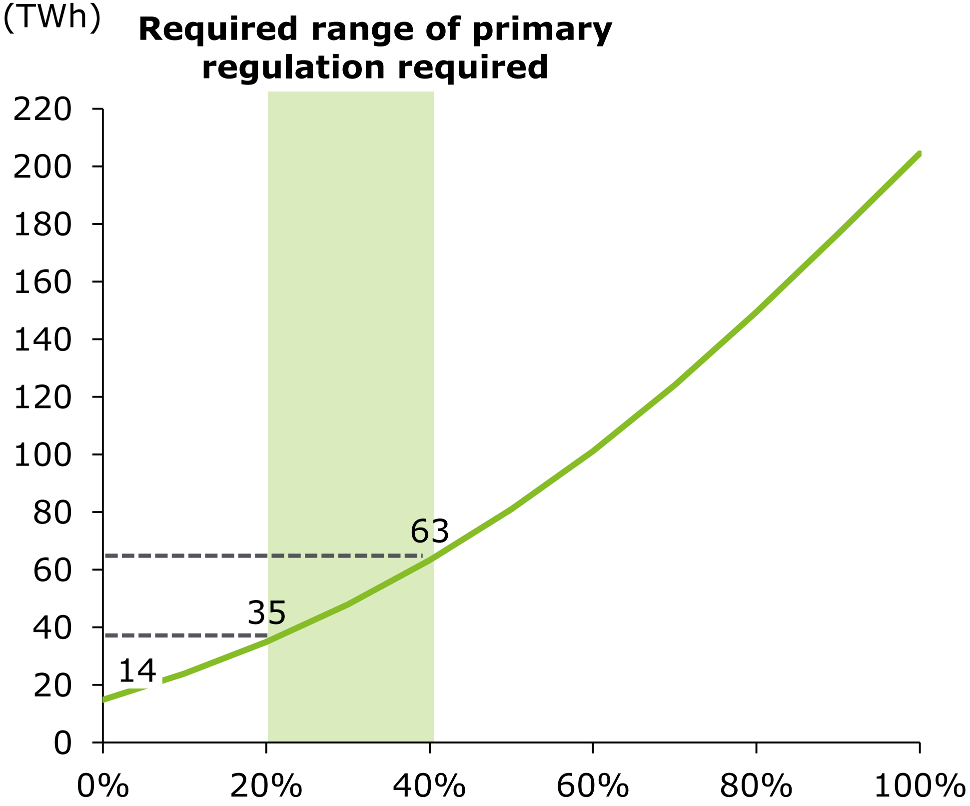
(1): Other technologies include solar thermal, turbine pumping, other renewables and non-renewable waste
(2): Resolves technical restrictions that may arise from network congestion, frequency control needs or avoid creating voltage gaps, modifying the necessary unit programs for network security reasons and for booking needs, paid system "Pay-as-Idb". Phase II re-frames the groups to minimize the cost of the RRTT solution
Source: REE; OMIE; Monitor Deloitte

2 By 2030, Power system balance will request a large amount of storage technologies to cope with spills

Surplus electricity generation in the Daily Hourly Market estimated in 2030
(GWh)



Potential spills after frequency and voltage reserve is adjusted in TC
(TWh)



Frequency control, load Management and voltage management must be reviewed to analyse storage business models

(1) Landfill production is considered considering its zero price and PEM electrolysis technology and a 20% efficiency reduction due to discontinuous power supply
Source: Deloitte Monitor

2 The total addressable market for batteries participating in frequency response mechanisms is up to 200-300mn€

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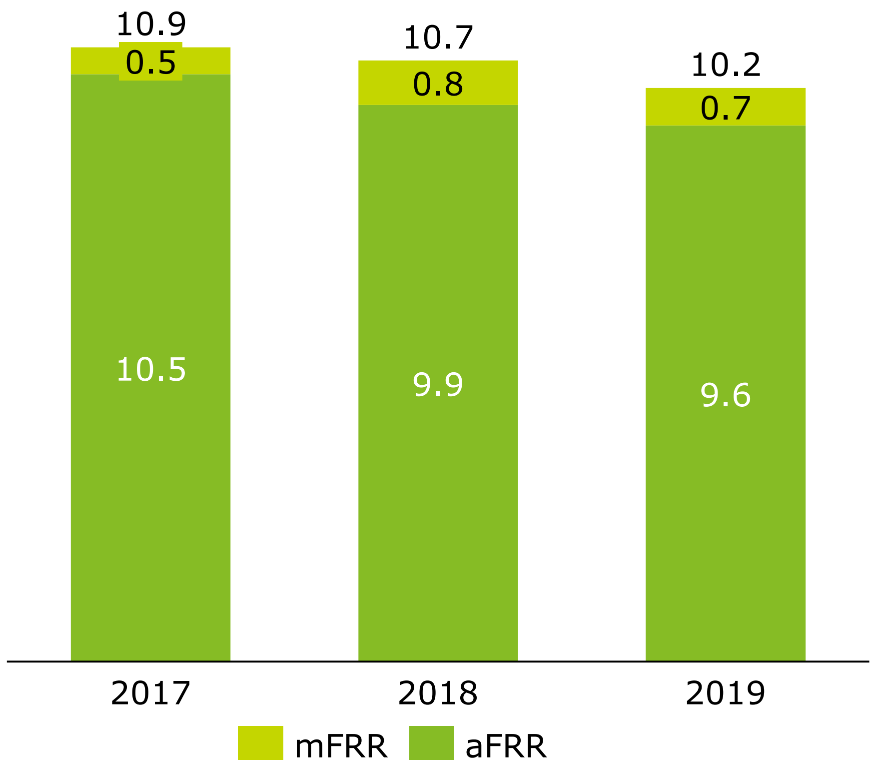
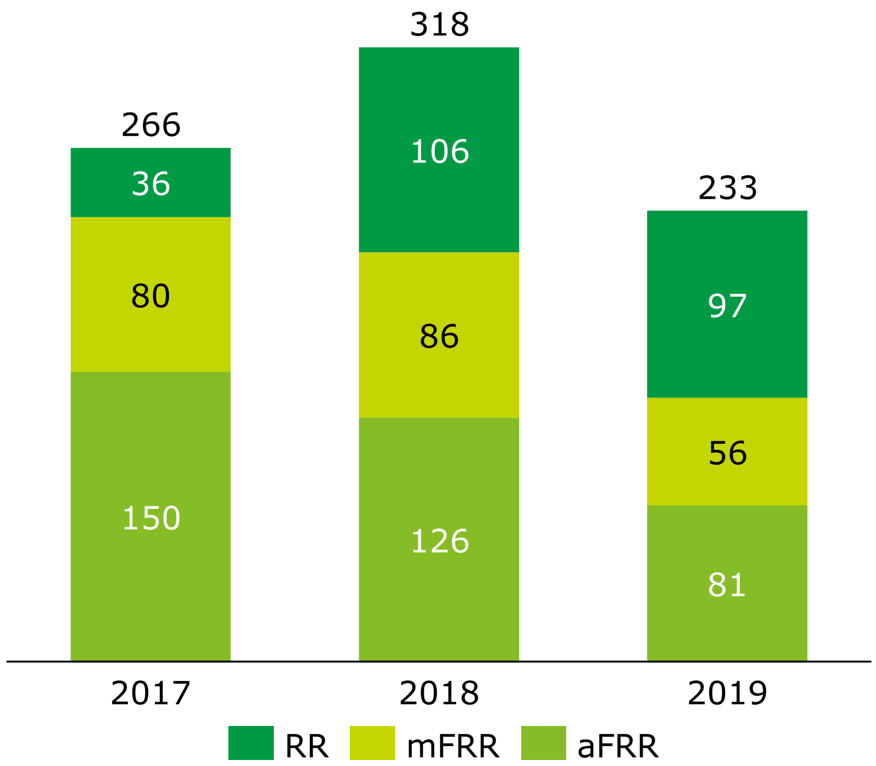
Volume negotiated in frequency regulation market and technical constrains
(TWh)



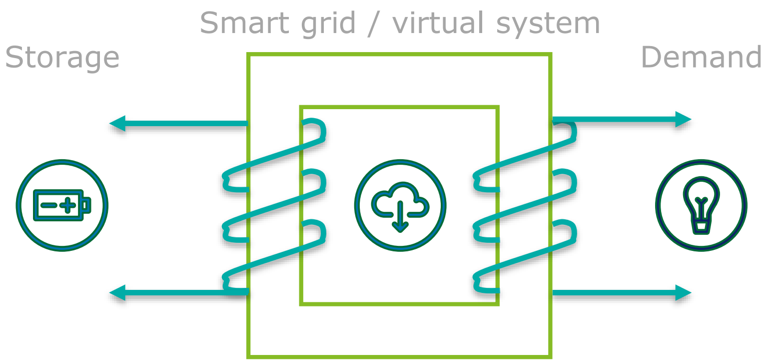
Revenues
(mn€)



In the medium term, CCGTs and nuclear plants will begin phasing out and frequency regulation needs will become an even more relevant market

3 A combination of batteries behind the meter and smart grid systems will improve voltage stability and defer grid upgrades

Voltage restoration mechanisms in combination with smart grids



Exchange of active and reactive power
- Smooth integration of intermittent feeders
- Might reduce capacity reserve and defer grid upgrades

Causes of voltage disruptions

- The penetration of distributed RE generation will reduce grid loses (distributed generation) and are faster to build, however its integration with storage units leads to **bidirectional flows** causing **dynamic voltage changes**
- The **electrification of the energy sector leads to supply peaks.** The grid will need a flexible **demand to optimize grid capacity to avoid congestion**. Variation of the demand will vary the voltage in distribution networks

Applications

Integration of energy storage with microgrids

Will enable to operate a distributed network providing **consumption and generation in a local basis**. **Batteries** connected to consumers **behind the meter** allows:
- Reduces feeder loses
- Reduce bidirectional flows in bigger distribution / transmission grids
- Local voltage management, reduce global unbalances (**reactive power management**)
- Improve power quality

Implementation of virtual storage and smart-grid

Implementation of **virtual energy storage** system will **centralize** the control system and **aggregate** small production with storage units enabling:
- Storage near generation / consumption
- Voltage control is done using a **local approach** with distribution lines and global control through transmission (main nodes needs >30MW)
- **Telematic centralized** control, but independent operations and ownership

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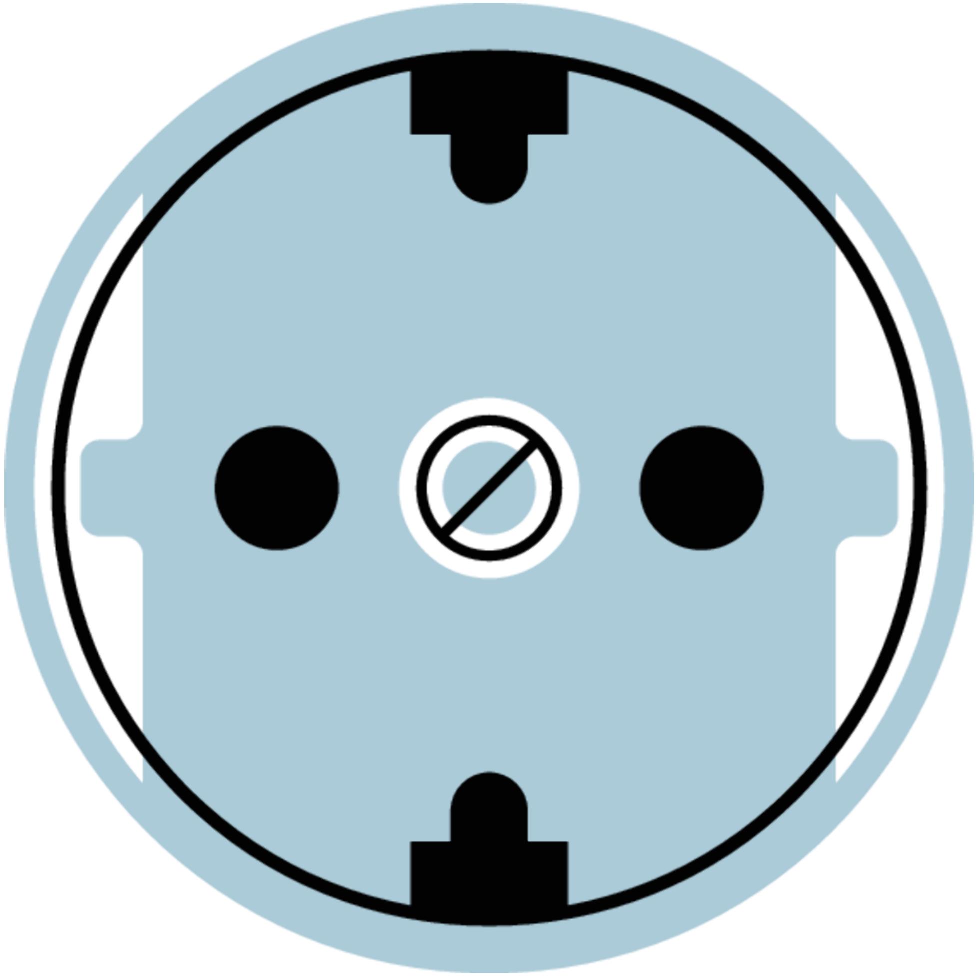

Traditional existing retribution mechanisms might not be enough to cover LCOEs, and new innovative schemes should be defined

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Potential existing markets		Battery	Hydrogen	Pumped hydro	Flying wheel	Compr. air
1 Energy Management	Daily	✓	✓			
	Seasonal		✓	✓		✓
2 Frequency Control	FCR	✓			✓	
	aFRR		✓	✓	✓	✓
	mFRR		✓	✓		
3 Voltage Control	Smart grid	✓	✓	✓	✓	✓
	Nodes		✓	✓		
	VPP[1]	✓	✓	✓	✓	✓

Remuneration schemes

1 Energy Management

Energy arbitrage, power purchase when thermal gap is minimum and discharge when the thermal gap is high. **Power price spread** (€/MWh) will cover **LCOE** for the storage unit

2 Frequency Control

Ancillary services are an important revenue line from thermal units that could be covered by **sustainable storage** systems:

- FCR: It is **not remunerated in Spain**, but compulsory to serve. Other schemes (California - USA) remunerate speed (milliseconds) and power output (MWh). Technical constrains are great source of revenues that also balance frequency
- aFRR and mFRR: **Regulated payment schemes** for capacity in the secondary reserve (MW) and power output in the tertiary (MWh). It requires system > 10MW

3 Voltage Control

Replacement services are retributed through a public auction paying for each **MWh for the real-time demand**. However voltage control is not retributed.

- **Transmission voltage control** (>30MW) close to nodes
- This require to have a **reserve**, that might be reduced with smart devices **achieving more asset utilization**
- **Loses reduction** due distributed generation

Source: Monitor Deloitte
(1): VPP – Virtual Power Plant

Integration of storage with self-consumption and distributed generation with innovative payments schemes add already value to customers and electricity producers

Integration of storage and RE in new business models

Grid	New business models	Description	**Large-Scale** (Industry and utilities)	**Mid-scale** (MUSH)[1]	**Small-scale** (Residential & small business)
Grid connected	Communities	Allow members of a community **to share the RE and storage benefits**: • i.e. reduced CapEx through solidarity, lower energy costs, integration with virtual power plants, potential to ancillary markets			✓
Grid connected	Aggregators	Aggregation & operation of distributed RE with virtual power plant. Small distributed producers will give energy management to a **centralized system**. **Storage** will be easily integrated since it has **immediate response**	✓	✓	
Grid connected	Energy-as-a-service (EaaS)	Customers purchase energy through a **subscription/leasing** with a fixed capacity. New RE system integrated with **storage, smart grid devices and demand management** will make a more efficient installation reducing costs. Customers will pay **no upfront CapEx**	✓	✓	✓
Platform	P2P Trading	**Platform** whereas distributed generators and consumer **can trade electricity storage packs.** It competes with electricity retailers, however **regulation and grid challenges** are present in most of the countries	✓	✓	
Off-grid	Pay-as-you-go (PAYG)	Typical **off-grid customers** purchase electricity with **prepayments / credit buying**. The credit will decrease as energy consumption increase. **Internet access smart meter is needed**. Remoted locations and emerging markets through **microgrids and self-consumption**	✓	✓	

Large and medium scale can be the key players in the new energy business model integrating storage devices, however customer empowerment will be the main trend driver

MUSH: municipal buildings, universities, schools, and hospitals

Finding a retribution scheme for ancillary services, managing the impact of grid integration and needed technological improvements are some of the key potential barriers

Potential analysis to be develop to foster batteries integration into the grid

Policy support and revenues from ancillary services

- **Marginal economic feasibility** (not feasible in many cases), since the spread peak-valley is not too high
- Create **market economic signals** to incentivize the storage capacity development, see examples from USA (Californa), Germany and Italy.
- Global vs regional, static vs dynamic nodal resolution (distributed generation)
- **Alternative schemes for frequency and voltage control retribution** (grid codes / market-based mechanism)

Grid integrations

- Definition of **a complete system providing flexibility**, **integration of large centralized applications with decentralized**
- Integration of **aggregators** and **virtual power plants** (VPP)
- Impact of **massive self consumption installation and storage behind-the-meter**

Technological development

- Storage is still **more expensive** than power generation
- Improve **efficiencies**, **capacities**, **lifespan, maintenance and energy density**
- Developing technologies to **adapt domestic/centralized systems**

Future confident

To navigate the future with confidence, organizations need to make the right choices: clear, timely and inspirational choices that deliver growth in a dynamic, disrupted world. Monitor Deloitte's strategy practitioners combine deep industry insights with cutting edge methods to help leaders resolve their most critical decisions, drive value, and achieve transformational success