

Charge!

Deploying secure & flexible
energy storage

Report by

eurelectric

Eurelectric represents the interests of the electricity industry in Europe. Our work covers all major issues affecting our sector. Our members represent the electricity industry in over 30 European countries.

We cover the entire industry from electricity generation and markets to distribution networks and customer issues. We also have affiliates active on several other continents and business associates from a wide variety of sectors with a direct interest in the electricity industry.

We stand for

The vision of the European power sector is to enable and sustain:

- A vibrant competitive European economy, reliably powered by clean, carbon-neutral energy
- A smart, energy efficient and truly sustainable society for all citizens of Europe

We are committed to lead a cost-effective energy transition by:

investing in clean power generation and transition-enabling solutions, to reduce emissions and actively pursue efforts to become carbon-neutral well before mid-century, taking into account different starting points and commercial availability of key transition technologies;

transforming the energy system to make it more responsive, resilient and efficient. This includes increased use of renewable energy, digitalisation, demand side response and reinforcement of grids so they can function as platforms and enablers for customers, cities and communities;

accelerating the energy transition in other economic sectors by offering competitive electricity as a transformation tool for transport, heating and industry;

embedding sustainability in all parts of our value chain and take measures to support the transformation of existing assets towards a zero carbon society;

innovating to discover the cutting-edge business models and develop the breakthrough technologies that are indispensable to allow our industry to lead this transition.

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Charge! – Deploying secure & flexible energy storage

A Eurelectric report

October 2020

KEY MESSAGES

- By 2050, the EU electricity mix will be dominated by variable RES (wind, solar). In order to ensure security of supply, carbon-neutral firm and flexible capacity will need to be developed at large scale to replace fossil fuels. This will require the use and deployment of different complementary flexibility options, such as storage but also generation and demand-side management, and of different technologies, on a level playing field in the market. Crucially, storage can contribute to flexibility by consuming excess electricity from the system (for example generated during windy or sunny periods) and storing it for subsequent use or reconverting the stored energy into electricity when such electricity is needed.
- The need for flexible power is estimated in the order of 500 GW in 2030. This will increase substantially by 2050 due to a large increase in variable RES generation. To date, almost all of the grid connected electricity storage (>97%) is still carried out by pumped storage hydro with a total capacity over 53 GW in Europe. In its Decarbonisation Pathways study, Eurelectric estimated that batteries alone would represent up to 200 GW in 2045, in a scenario where EU economy is decarbonised at 95%.
- Getting the market framework right should be the most important focus: a strengthened and well-functioning ETS and a well-functioning market should be the main drivers for investments in storage. The Clean Energy Package (CEP) is a major step forward and it must be effectively implemented, especially by allowing customers as users of electric vehicles or as owners of batteries or water boilers, to become active participants on the flexibility markets. However, while the CEP will improve the functioning of short-term markets, there are still challenges for providing long-term investment signals, including for storage, to achieve the energy transition cost-effectively.
- Grid capacities including interconnectors allow for a better pooling of resources. Further market integration is necessary to create new potentials for any kind of flexibility products and a technology neutral level-playing-field for all storage and flexibility facilities.
- Depending at which voltage level storage is connected, it may be useful to solve different needs. For solving local grid constraints storage should be properly located in the distribution network without preventing it from providing services to transmission system operators. Services provided by decentralised storage -among other resources- are a key part of the new active DSO's 'toolkit' so market participants can assist DSOs to operate and better plan their networks and provide services to manage and balance the grid.

- In some Member States, electricity storage (e.g. EV - V2G technologies, pumped hydro storage) and power-to-gas systems are exposed to double taxes and levies and/or to grid tariffs. Storage facilities should not be taxed twice. With regard to levies, while all service providers should be able to fully cover their costs and a fair burden sharing should take place, there should be no market distortion between storage and other flexibility options. As for grid tariffs, they always have to be cost-reflective and non-discriminatory.
- The negative impacts of slow and complex permitting processes across Europe on the building of RES capacity is well known. Clear rules and procedures may be necessary regarding permitting in relation to storage assets. The timely deployment of assets is crucial to achieve the EU decarbonisation objectives.
- Some storage technologies have made remarkable progress (e.g. batteries) and their costs are declining rapidly. However, many technical barriers still exist and R&D funding, especially “close to market” implementation programmes, is still necessary. Mature technologies such as hydropower could also be considered for R&D funding to improve their efficiency.

EXECUTIVE SUMMARY

- Energy storage is set to play a crucial role to support the delivery of carbon-neutral energy supply, including the decarbonisation of transport, buildings and industry through electrification, and more broadly net-zero greenhouse gas (GHG) emissions in the European economy by 2050.
- Electricity storage is the temporary absorption of energy in the form of hydraulic, mechanical energy, gas or heat/cold, at any form or energy source, and the subsequent delivery of electrical energy on request for use by a final consumer, offer on the marketplace or for ancillary service.
- There are many different ways of storing energy: as water in hydro reservoirs or pumped storage plants, as chemical energy in batteries, as gas through power-to-gas, as heat etc. These assets can participate to all markets and also provide a large range of services to the network operators. However, this report focuses on the contribution to the electricity sector.
- As the power system takes on higher shares of variable RES generation, storage – alongside flexible demand assets and dispatchable generation – will be an essential source of the necessary flexibility and will contribute to the operation of the system with a high degree of reliability and in a cost-efficient manner. Storage can also be a solution for both conventional and renewable assets, for example firming or optimising the generation output, as well as possibly providing behind-the-meter support for prosumers to optimise their load/generation balance. It can also serve to reduce local peaks in the grid.
- The electricity system's security of supply and its reliability require flexibility at different time scales – from a sub-second time-scale to seasonal or multi-seasonal scale. In a high RES penetration environment this can only be achieved by largely using all flexibility services including a diverse mix of complementary energy storage technologies, covering different time frames. However, challenges remain huge, both technically and in terms of market design.
- Storage may also provide suitable and cost-efficient options for optimal and smart sector coupling and sector integration (e.g. EV, heating & cooling). It can be a solution for the optimal use of electricity in other sectors as well as an option to optimise the electricity system itself (e.g. reverse charging of EV).
- The Clean Energy Package already goes into the right direction in relation to storage. Getting the market framework right should be the most important focus: a strengthened and well-functioning ETS and a well-functioning market should be the main drivers for investments in storage. There is no need for a specific regulatory framework for storage but existing market design needs to integrate the characteristics of storage services. A level playing field for all technologies and options is needed and all types of barriers have to be overcome, as different storage and other flexibility options will become increasingly important and have to compete between each other. The Clean Energy Package (CEP) is a major step forward but it will need thorough implementation and clarifications especially by allowing customers as users of electric vehicles or as owners of batteries or water boilers, to become active participants on the flexibility markets. However, while the CEP will improve the functioning of short-term markets, there are still challenges for providing long-term investment signals including for storage, to achieve the energy transition cost-effectively.

- Customers' economic incentives to hedge security of supply risks is questionable, since they may rely on governments to take care of it. In some circumstances, it may be necessary to consider capacity markets as an alternative to deliver new firm/flexible capacity (storage, demand-side response, Power-to-X). A mix of technologies, including storage, demand-side response and power-to-X, will deliver the new carbon-neutral firm and flexible capacity. Where capacity markets are deemed necessary, storage should compete with other flexibility solutions on equal footing.
- Stacking of revenues should be allowed where possible, by taking into consideration availability and delivery requirements.
- With an increasing share of variable RES connected at transmission and distribution levels, operating the electricity grids will become increasingly challenging and storage could play a helpful role in meeting this challenge. Depending at which voltage level storage is connected, it may be useful to solve different needs. For solving local grid constraints storage should be properly located in the distribution network without preventing it from providing services to transmission system operators. Services provided by decentralised storage –among other resources– are a key part of the new active DSO's 'toolkit' so market participants can assist DSOs to operate and better plan their networks and provide services to manage and balance the grid.
- In some Member States, the electricity storage (e.g. EV - V2G technologies, pumped hydro storage) and power-to-gas systems are exposed to double taxes and levies and/or to grid tariffs. Power storage pays once when consuming some electricity from grid and then once again when injecting this electricity back to the grid. Storage facilities should not be taxed twice. With regard to levies, it has to be acknowledged that, while all service providers should be able to fully cover their costs and a fair burden sharing should take place, market distortions compared to other flexibility options have to be avoided. Grid tariffs always have to be cost-reflective and non-discriminatory¹.
- Hydropower from natural reservoirs and power-to-X technologies can be a way to store energy and to contribute to the flexibility needs and security of supply of energy systems. These technologies can play a key role to deliver short-term/long-term/seasonal/annual needs of the electricity system by storing excess of renewable power generation, for final uses or uses at a later stage in other sectors. In some Member States reservoir hydro² is also considered as storage potential given its ability to defer electricity generation at a later stage. While hydropower is a mature technology, power-to-X-technologies, especially hydrogen, are promising technologies but are expected to be commercially available at large scale only at a later stage.
- An important deployment of batteries is expected at utility scale but also behind the meter. They will increasingly play a major role to ensure short-term daily flexibility in the system. As an example of sector integration and synergy, the expansion of electric vehicles –“batteries on wheels”– will make a significant contribution to the decarbonisation of transport but is also expected to provide a range of services to the power sector.
- Grid capacities including interconnectors allow for a better pooling of resources. Further market integration with larger interconnected electricity markets instead of separated

¹ More concrete Eurelectric recommendations are under preparation.

² Reservoir hydro is not formally covered by the definition of energy storage.

electricity markets is necessary to create new potentials for any kind of flexibility products and a technology neutral level-playing-field for all storage and flexibility facilities in those markets. Market integration should extend beyond the borders of the European Union in order to take advantage of large storage and flexibility facilities e.g. in Switzerland or Norway.

- For some storage technologies, remarkable progress has been made with innovation and research but technical barriers still exist. Therefore, R&D fundings, especially “close to market” implementation programmes, are still necessary. Over time these barriers will gradually be removed as the storage industry will be experiencing increasing customer interest, rapidly declining costs and a growing number of market players investing in storage solutions. Even for mature technologies like hydropower there are still technology developments and efficiency potential that could be expected. Therefore, they should also be considered for R&D funding. For instance, the conversion of conventional hydro plants into reversible plants could be a main innovation focus.
- Due to the long development periods of some energy storage technologies (e.g. pumped hydro), in order to achieve energy storage goals by 2030 and 2050, construction should start in the short term. Stable regulatory framework and right market signals should be put in place to unlock these developments while respecting a fair level playing field.
- For small isolated systems, such as islands or outermost territories, where interconnection is difficult to develop, storage will be of utmost importance to allow a smooth and secure energy transition towards full renewables systems.

RECOMMENDATIONS FOR POLICY MAKERS

Storage and flexibility integration are necessary to avoid deficit and limit surplus of energy as the electricity system is transformed. In the longer run, storage will help to foster the development and penetration of variable RES, to optimise the quality of supply and the grid services at all levels of the energy system. It will benefit from digitalisation and from integration with other flexibility sources e.g. hydro, conventional flexible plants and demand side response.

1. Ensure a level playing field for all flexibility technologies

A technology neutral approach is needed as regards access to energy markets for different storage technologies. Storage capacities are expected to increase significantly including through the development of new storage technologies. All types of storage will have a role to play and their importance will therefore increase, depending on their competitiveness.

The focus should therefore be on getting the market framework right. The barriers to a level playing field for flexibility solutions should be removed. All technology options –the different electric ones, like generation, demand side and storage, as well as non-electric solutions– should be able to compete on a level playing field. Flexibility is a key issue of the energy transition, it is of utmost importance to be able to provide it at best cost. Storage, if fairly treated, is likely to play a major role.

A sound ground for competition among technologies and services over the different time frames (from short to long term) remains to be created for storage.

2. A holistic approach to regulation of all grid connected assets, including storage, must be applied, reflecting their impact and value at all levels of the energy system

The field for investments in storage, deferring or reducing some grid investments, must be clarified to avoid sub optimisation and market disturbances.

In contrast to former TSO domain, today the DSO is developing part of flexibilities management until then exclusively devolved to the TSO. A regulatory distinction should be made between TSO and DSO to take into account each one's specificities. To enable DSOs to use storage for flexibility needs, they have to be part of the storage system standardisation (technical specifications, reactivity, reliability ...).

A strict technical coordination (frequency monitoring, voltage, management of reactive energy, reserves, etc.) is needed to guarantee the overall balance between production and consumption at all times. Defining appropriate and consistent economic signals is complex but essential. Where possible, their local economic value should be brought to light.

With the development of local variable energy production, storage systems and electrical mobility, it is vital to guarantee grid stability at low and medium voltages. All players may contribute to improving this stability, within the framework of the CEP provisions and the DSO network rules.

Inserting a large active customer or another potential significant flexibility source in a constrained area can help resolve certain constraints, but can also aggravate or create others, to the point of causing the investment that DSO wanted to defer. This is the reason why system operators should be clear and transparent on their network constraints and their needs for (local) flexibility towards market players (including prosumers).

3. A swift implementation of the Clean Energy Package

Member States should be working in the framework provided by the CEP. It is a major step forward and it must be effectively implemented, especially by allowing customers as users of electric vehicles or as owners of batteries or water boilers, to become fully actors of the flexibility markets.

Besides, storage is not recognised as a category on its own to be assessed in the NECPs. Member States should consider the potential of storage when assessing their system needs and ensure the necessary framework for its deployment.

4. Provide clear and stable regulatory frameworks: strengthening of long-term investment signals is needed and the markets need to evolve with the transition of the system

A strengthened and well-functioning ETS and a well-functioning market should be the main drivers for all investments including storage. Policymakers should recognise the need for large investments for a successful energy transition, requiring stable long-term price signals from the market.

Customers' economic incentives to hedge security of supply risks is questionable, since they may rely on governments to take care of it. In some circumstances, it may be necessary to consider capacity markets as an alternative to deliver new firm/flexible capacity (storage, demand-side response, Power-to-X). A mix of technologies, including storage, demand-side response and power-to-X, will deliver the new carbon-neutral firm and flexible capacity. Where capacity markets are deemed necessary, storage should compete with other flexibility solutions on equal footing. Eurelectric expects the revision of the Guidelines on State aid for Environmental protection and Energy (EEAG) to drive the design of long-term risk hedging instruments for carbon-neutral investments³.

Stacking of revenues by market parties should be allowed where possible, by taking into consideration availability and delivery requirements.

5. The need for more and stable grid infrastructure must be supported by storage services

Energy storage can also support grid operations as well as defer network reinforcement. Network operators should consider storage as a flexibility solution in their network assessment

³ Eurelectric, [Response to the Consultation on Fitness Check of State Aid Rules & Targeted Consultation for the Evaluation of the Guidelines on State aid for Environmental protection & Energy 2014-2020 \(EEAG\)](#), July 2019.

and clearly indicate the locations where this kind of technologies would be useful for current grid operation and development plan optimisation and for which services.

Energy storage technologies in some cases could help DSOs by deferring or avoiding asset reinforcement, optimising infrastructure investment needs. Also, under certain circumstances, the construction of energy storage systems can be much simpler and faster compared to the construction of new distribution lines but energy storage can't replace the grid and should be efficiently complementary to grid systems. It is advisable, among various investment alternatives, to optimise the integration of energy storage solutions.

At the same time, grid capacities, including interconnectors, allow for a better distribution of storage capacities from Member States with more favourable resources.

In line with article 36 of the Electricity Directive, energy storage facilities have to be provided by the market players or, by way of derogation, where they are fully integrated network components or market test is negative and the regulatory authority has granted its approval, by system operators. As also recognised in article 36, regulators and policymakers should take into account that there could be exceptional cases in which the provision of services via market arrangements to network operators, especially in very low voltages, may not always be possible at least at the beginning of the local markets development, with low liquidity. If this happen, all the conditions stated in article 36 of the Electricity Directive should apply (e.g. market test, justifying the necessity, not for buying or selling in the electricity markets, etc.).

6. Enhance flexibility at customer side

Behind the meter storage is quite heterogeneous, depending on local markets and countries. As a new market, it is still driven by political aspects, taxes/levies and tariffs and/or subsidies. Dynamic electricity prices and cost-reflective grid tariffs are crucial to increase the responsiveness of consumers and the development of behind-the-meter storage, including electric vehicles. Also netting of auto production should be avoided to give the correct incentives for storage.

Smart charging including both V1G and V2G⁴ should be supported. To this end, key enablers are a future-proof electricity market design coupled with coordinated standardisation measures⁵. In order to facilitate market integration, regulations requiring all EVs and charging stations to have smart charging algorithms in their charging management systems and complementary IT infrastructure supporting smart charging algorithms should be drafted and implemented so that true potential of EV's as storage and flexibility source can be realised. Otherwise "dumb" (forced) EV charging create great risks for distribution networks rather than being a source of flexibility enabling RES integration.

⁴ V1G or smart charging: it is possible to dynamically modify the charge rate or the charge time. V2G: bidirectional energy flow between storage and the charging station. EVs could supply power back to the grid or home in a Vehicle-to-Grid (V2G) or Vehicle-to-Home (V2H) scenario. The cars can be used to store excess power from RES and discharge it at times of high demand.

⁵ For detailed views, see Eurelectric, [Policies for sufficient EV charging infrastructure deployment in the EU – a view from the European electricity industry](#), August 2019.

7. Recognise the importance of new and existing hydro generation as the main flexible generation source when most thermal generation will be phased out

Providing by far the largest amount of flexibility and storage services of all technologies, the significance of hydropower plants will even rise with the increase of variable renewable generation. To maintain its specific role of providing sustainable and renewable flexibility in all timeframes and at all regional levels, all barriers that prevent investments and reinvestments, upgrading or continuous operation have to be minimised as far as possible. The potential for additional flexibility via increased power capacity in existing assets, improved interconnections for distributing the flexibility over wider areas as well as the development of new hydro assets will play a crucial role in the future. More specifically, the European Commission, when specifying requirements by delegated acts, should guarantee that pumped storage is eligible under the EU Taxonomy to ensure a level playing field with other storage technologies: currently pumped storage is the only storage technology that has to fulfil specific requirements in the TEG report⁶.

8. An EU infrastructure framework that supports storage deployment

A broader access to EU funding (such as the Connecting Europe Facility (CEF)) and new investments in infrastructure are necessary, as well a revision of the TEN-E regulation. Regarding storage, the capacity criteria for Projects of Common Interest (PCIs) of at least 225 MW should be lowered to 50 MW to support storage project with local character. Storage systems can contribute to the European balancing network and bring a cross-border impact⁷.

9. Streamline permitting process for storage assets

The negative impacts of slow and complex permitting processes across Europe on the building of RES capacity including on investment certainty is well known⁸. While ensuring a level playing field between flexibility options, a clear and specific permitting process for storage projects may be necessary including when storage is co-located with new or existing power plants (e.g. RES or traditional generators). The retrofitting or investment in power or efficiency increase of hydropower plants should be fast-tracked.

10. Storage should benefit from EU funding for research and innovation

Research and innovation focusing on electric technologies and infrastructures play a crucial role as they directly contribute to the energy transition as well as to the recovery from Covid-19, re-stimulating the European economy while ensuring global competitiveness for our industries. Technologies are progressively developing and consequently leading to direct

⁶ Eurelectric, [Moving forward with a science-based EU Taxonomy for hydropower](#), May 2020.

⁷ [Eurelectric Response to the Targeted Consultation on the Revision of the TEN-E Regulation](#), July 2020.

⁸ Eurelectric, [Statement on RES permitting](#), October 2020.

improvements in the use of storage. Existing technologies and assets adapting to future demands is also an important field of future research as well as the optimal combination of different storage technologies. While ensuring a level playing field between flexibility options, these applications deserve attention from policy makers when designing research and innovation funds. Energy innovation and research including on storage should be given more consideration in the Horizon Europe programme⁹.

⁹ [VGB & Eurelectric letter to Commissioner Gabriel – Broaden Horizon Europe missions](#), July 2020.

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1. Introduction

Variable renewables and electrification will transform the energy system

Electricity is a key solution towards Europe's decarbonisation. Electrification of transports, buildings and industry, coupled with the full decarbonisation of the power sector is a direct, effective and efficient way of reaching decarbonisation objectives for society as a whole. The power sector is committed to leading the required energy transition and secure a cost-effective decarbonisation that supports long-term European competitiveness in the global market place. The electricity industry made a pledge to become carbon neutral by 2045 while keeping the high levels of grid stability and security of supply.

In 2019, carbon-neutral energy sources already represented 60% of the electricity generation mix of the EU, with 35% of renewables, half of it being variable. Just to meet Europe's current 2030 greenhouse gas (GHG) emission targets, the share of renewables in the electricity generation mix must increase to 57%. Additionally, the Commission is seeking to increase this 2030 target to at least 55% in order to make possible net-zero GHG emissions by 2050, which could lead to an increase of the EU 2030 RES target to 38-40%. This share is expected to increase not only due to the commitment at EU level but also due to the cost-competitiveness of these technologies that saw massive cost reductions just in the last 10 years. Eurelectric's Decarbonisation Pathways study¹⁰ shows that in a carbon-neutral power sector, renewables will account for roughly 80% of the total installed capacity and generation by 2045 due to big increases mainly in wind and solar.

The large change in generation mix with wind and solar replacing thermal generation has implications both on system stability and a secure power supply at any time. The delivery of stabilising services to grids from thermal generators has to be replaced by other decarbonised sources. Furthermore, the lack of firmness and flexibility in wind and solar has to be compensated from other sources balancing the power system both in long time scales (up to seasons and years) and shorter ones (days, hours, milliseconds). The development of this new firm and flexibility capacity at large scale is a major technical and economic challenge.

For short-term, daily and intraday up to real-time flexibility, either solutions are already available or there are promising emerging technologies. Long-term flexibility (from more than a few low wind days to seasonal) is considerably more challenging at the additionally needed large scale¹¹. At least in some regions, pumped storage does not constitute the only form of hydropower storage as storage reservoirs defer the generation of electricity to a later stage.

At the same time, direct and indirect electrification of transport, buildings and industry may be aligned with greater use of storage technologies that are an integral part of electrification itself. EVs are a good example of how electrification of transport leads to significant increased volumes of storage capacity which could be used to increase flexibility in the electricity system in addition to driving decarbonised mobility.

¹⁰ Eurelectric, [Decarbonisation Pathways](#), November 2018.

¹¹ Eurelectric, e-invest. The power sector investment challenge: 100 billion per year and counting, September 2019.

Ensuring security of supply

Reliable electricity supply is crucial for society at all times¹². To ensure security of supply, there is a need for flexibility tools that can act when production sources or consumption vary in ways that cannot always be controlled. These flexibility needs have to be categorised following the purpose and time scale they act in¹³.

The success of providing flexibility is often dependent on several factors in the power system, like a chain with several links, consisting of energy reservoir for dispatch generation, the available power for dispatching and the available capacity in transmission/distribution system. Different storage technologies can play a role, individually or in aggregate with other flexibility resources such as demand side response, at every level of service/timescale to provide all four types of flexibility needs.

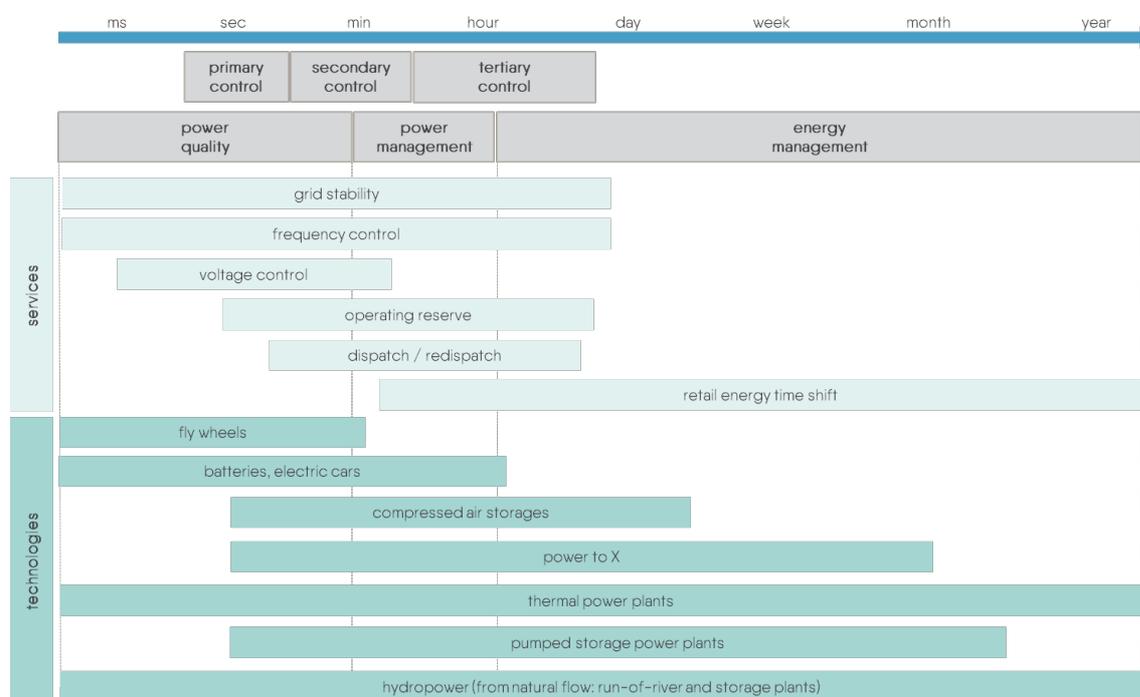


Fig. 1 - Flexibility services according to technologies and timescale. Source: Eurelectric/VGB, 2020.

¹² There are three possible types of electricity deficit that could jeopardise supply reliability:

- Electric Energy deficit: at a given moment (hour, day) the installed capacity cannot produce enough electricity to fulfil demand (operational security).
- Electric Power capacity deficit: the available capacity is not (expected to be) sufficient to deliver the energy needed to cover (the expected) demand (resource adequacy).
- Grid capacity deficit: There is enough energy and capacity available, but the grids cannot transfer the energy from the supply nodes to the demand nodes (grid adequacy).

¹³ Eurelectric, Flexible generation: backing up renewables, October 2011. Eurelectric identified in this earlier report on flexibility four main types of flexibility needs within different time scales:

- Stable power system – continuously balancing variations in consumption and generation (seconds – hour)
- Ramping – take care of sudden deviations or disturbances (n-1 events, storm fronts, within hours)
- Correction and back-up – take care of deviations from plan (varying RES and load, within days)
- Planning – optimise use of power sources (varying load, complement non-dispatchable RES, day – year)

Storage is one of various flexibility options

Storage is one flexibility option and may have different characteristics related to deficit type or other tasks:

Reservoir storage

For a longer time period reservoir storage (input to generation process) helps fulfil security of supply.

Reserve capacity storage

A loaded storage that may be used when the capacity needs to be topped or quickly released. This also includes services to stabilise grid function in frequency and voltage.

Buffer storage

A geographical placed storage to enhance grid capacity to handle congestions situations or other bottleneck effects.

Behind meter storage

Where a storage enhances the function of a grid connected device/user/producer. Please note that this may be useful both at production and consumption connections.

Storage systems can contribute to flexibility by consuming excess electricity from the system (for example generated during windy or sunny periods) and storing it for subsequent use or reconvertng the stored energy into electricity when such electricity is needed. Storage will make a significant contribution to flexibility but it should be considered among other solutions such as flexible generation assets, demand side management (active consumers with their demand response, prosumers with their PVs, and batteries/EVs in the residential, commercial or industrial sectors) or ever better connected transmission and distribution networks.

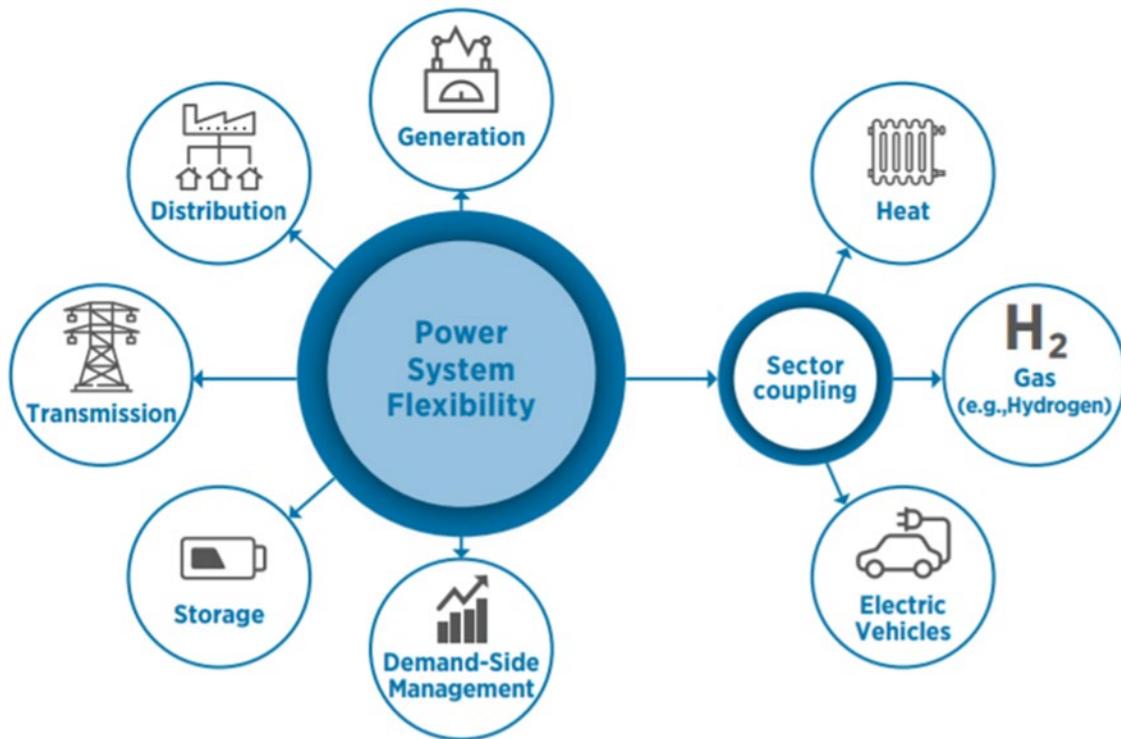


Fig. 2 – Power system flexibility enablers in the energy sector. Source: [IRENA \(2018\), Power System Flexibility for the Energy Transition, Part 1: Overview for policy makers.](#)

To manage this variability in a cost efficient way, the regulatory framework should ensure a level playing field between all options and technologies providing flexibility as to access to flexibility markets. It should also ensure that storage is able to participate on equal footing in the electricity markets and provide ancillary services so that the total possible remuneration, reflecting system value of storage, creates proper investment incentives. It should also provide incentives and requirements, if needed, to make sure that the inherent flexibility potential becomes available as source in the market. There are other benefits when storage solutions are combined with other energy sources to optimise their functioning (e.g. batteries in power plants, PV optimisation). To enable DSOs to use storage for their flexibility needs, they have to be part of the storage system standardisation (technical specifications, reactivity, reliability ...).

Definition of storage and scope of the report

In contrast to consumption, “energy storage” is the temporary absorption of energy, storing of this energy and the controlled reconversion into the system. Thus, storing of energy – from an energy economy perspective – is the absorption of energy, storing of energy at any form or energy source such as mechanical energy, chemical energy, gas or heat/cold, and the subsequent delivery of energy on request for use by a final consumer, offer on the marketplace or for ancillary service.

According to article 2(59) of the Electricity Directive¹⁴, the specific notion of storage from the perspective of the electricity sector means “deferring the final use of electricity to a moment later than when it was generated, or the conversion of electrical energy into a form

¹⁴ [Directive \(EU\) 2019/944 of the European Parliament and of the Council of 5 June 2019 on common rules for the internal market for electricity and amending Directive 2012/27/EU, OJ L 158, 14.6.2019, p. 125.](#)

of energy which can be stored, the storing of such energy, and the subsequent reconversion of such energy into electrical energy or use as another energy carrier". Based on this definition, electricity storage can be a cross sectoral process. All other cross sectoral forms of energy storage are viewed as flexible generation or flexible load from the perspective of the electricity sector, if the primary energy produced is not absorbed and subsequently reconverted into the original electricity sector.

Aside from this new general definition of "energy storage" in the electricity system in the Electricity Directive, further European as well as national regulations, views and interpretations of energy storage, storage capacity and storage facility already exist e.g. including the contribution from natural flow hydropower/run of river reservoirs naturally from different regional system characteristics with different challenges and opportunities. In general, from an energy system perspective, another energy usage, other than reconversion in the electricity system, deferred in time like thermal storage or usage and storage of hydrogen has to be considered as energy storage.

This report discusses storage options for the benefit of the whole energy sector (sector integration and sector coupling) in general, however a stronger focus will be on "electricity storage" – that means storage from the perspective of the electricity system with subsequent feedback into the original electricity system.

The aim of this paper is to explain Eurelectric's views on the contribution of storage to the energy system challenges, the current barriers to its deployment as well as recommendations for an enabling market and regulatory framework.

2. Place and contribution in the energy system

This chapter deals with the applications of storage in the energy system and the technologies that are suitable for these applications in different timeframes. Both perspectives are necessary to describe potentials as well as challenges and recommendations. However, this chapter will not go into technical details of the different technologies which will be given in the annex.

Electricity storage is not new but historically its development had been mainly limited to pumped hydroelectric storage and, to date, almost all of the grid connected electricity storage (>97%¹⁵) is still carried out by pumped storage hydro with a total capacity over 53 GW in Europe.

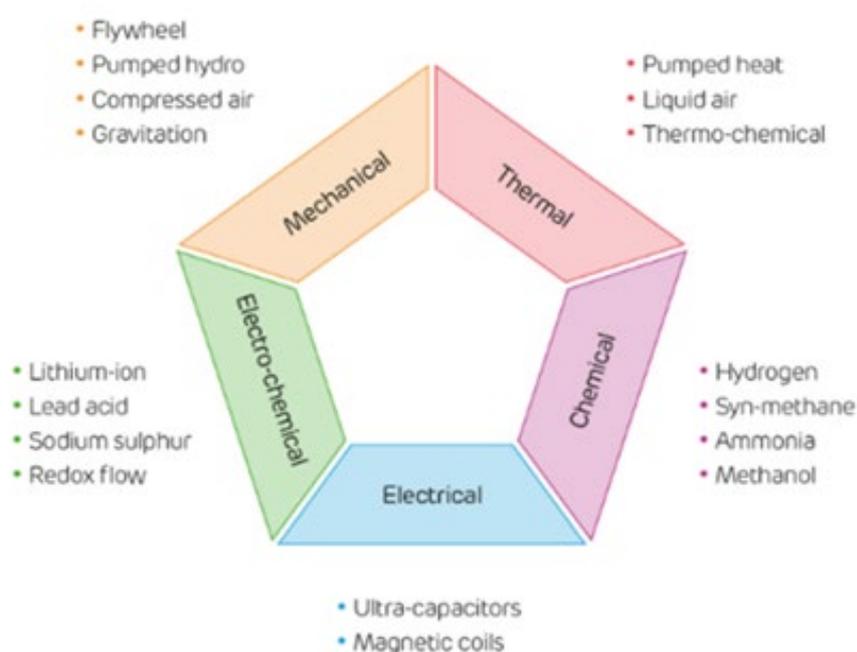


Fig. 3 - The five key principles of energy storage and the main technologies that employ them.
Source: Drax, [Electric Insights Quarterly, Q3-2019](#)

The need to integrate ever increasing shares of variable RES into the electricity system has led to an increasing interest for storage technologies, both at grid level and behind the meter. In its Long-Term Strategy, the Commission estimates that scenarios with more electrification in end-users require a high deployment of storage (6 times today's levels) to deal with variability in the electricity system¹⁶. Ultimately, the objective is to have a cost-efficient, performant energy system to support, facilitate and drive the energy transition. While all scenarios point to an increased need of storage, it must be appropriately

¹⁵ DG Energy, [Quarterly Report on European electricity markets, vol. 12 \(4th quarter 2019\)](#), p 30. According to the report, the total installed capacity in the EU27 stood at 42 GW at the end of 2019. Eurelectric and VGB estimate a capacity above 53 GW for EU27 and UK, Switzerland, Norway in 2018. Eurelectric & VGB, [Hydropower in Europe: Facts and Figures](#), Edition 2020.

¹⁶ European Commission, [A Clean Planet for all A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy](#), COM (2018) 773.

integrated into the system, driven by market needs. Concrete figures are difficult to estimate as this will depend largely on how the rest of the energy system evolves (share from nuclear, renewables, penetration of EVs, deployment of power-to-X, interconnections, demand-response, etc.).

In order to properly assess the long-term system costs, sustainability aspects including the CO₂ footprint of these technologies will have to be included. In this regard, the EU Taxonomy will be a crucial tool to navigate the transition to a low-carbon economy. The European Commission, when specifying requirements by delegated acts, should guarantee a level playing field for all storage technologies: all electricity storage technologies should be automatically eligible under the EU Taxonomy. This should also be the case for pumped storage, which is currently the only storage technology of the TEG report that has to fulfil specific requirements¹⁷.

Volume of the flexibility challenge

There are different ways to explore the existing and future flexibility needs in the energy system. One way is to investigate the residual load. The residual load (load-varying RES) is defined as the load that has to be served by dispatchable technologies (thermal, hydro, storage, demand response, interconnectors, etc.). Time series of residual load will give a base to express a number or order of magnitude of a flexibility need within a chosen time frame. The flexibility need may then be expressed as a need for Power or a need for Energy depending on the deficit that need remedy. Depending on the chosen method, numbers may differ, but the order of magnitude will be less varying. An example of investigation of flexibility needs throughout Europe is given in the report “Mainstreaming RES-Flexibility portfolios”¹⁸ which has also been a reference for the recent report from DG Energy on energy storage¹⁹.

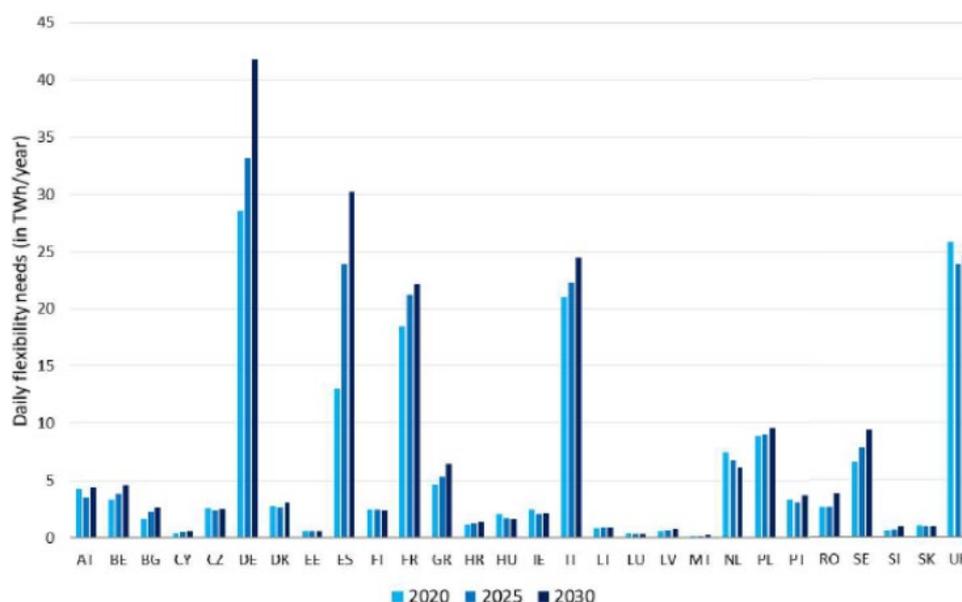


Fig. 4-Daily flexibility needs from METIS study “Mainstreaming RES, flexibility portfolio”. Please note that needs are expressed as TWh/year by multiplying daily needs by 365. Source: METIS Study.

¹⁷ Eurelectric, [Moving forward with a science-based EU Taxonomy for hydropower](#), May 2020.

¹⁸ European Commission, [Mainstreaming RES – flexibility portfolios. Metis study – Electricity](#), July 2017.

¹⁹ European Commission, [Study on energy storage – Contribution to the security of the electricity supply in Europe](#), March 2020.

	Electrical energy planning for long-term variations	Short-term planning including updated prognosis of varying generation and demand	Replanning due to prognosis errors or disturbances in planned generation or demand	High load situations	Balancing due to disturbances	Keeping stability in grids frequency and voltage	Sudden major failures in generation or transmission
Time scale	Month-year	1-14 days	Hour-day	Hour-14 days	Min-hour	Sec-min (automatic)	0-5 sec (automatic)
Technology /Storage	Fuel storage Hydro reservoirs	Hydro reservoirs Fuel storage Industrial sector coupling (heat, gas) Pump storage Time frame	Hydro reservoirs Pump storage Fuel storage Incl Gas turbines Industrial sector coupling (heat, gas) Batteries	Reserve capacity	Gas turbines Hydro reservoirs Pump storage Batteries	Hydro reservoirs Pump storage Batteries	Inertia (production /consumption) Artificial Inertia Batteries Condensers Fly Wheels
Market/ System service	Wholesale Market	Wholesale Market	Energy Balancing Market	Capacity market Import/Export	Secondary and tertiary regulation products (Ancillary Services Market)	Primary regulation (Ancillary Services Market)	System Services Market
GW needs (relative order of magnitude)	30 P	20 P	8 P	4 P	2 P	P	4 P
GWh needs (relative order of magnitude)	100 000 E	2 000 E	20 E		2 E	0.1 E	0.001 E

Fig. 5 – Overview of flexibility needs in a European Power system including aspects of time scales. In bold electrical storage technologies. Source: Eurelectric member.

In Fig. 5 it can be noted that the existing electric storage technologies mainly contribute to shorter time scales. One reason for this is that the amount of storage expressed in energy is very much larger in the longer time scales. See also Box 1.

The need for dispatchable/flexible power is in many studies concluded to be in the order of 50-100% of installed variable RES power when the variable RES generation is the majority of the generation capacity.

To sum up, the need for long term flexible energy is in the order of 500 TWh for EU28 and the need for flexible power is in the order of 500 GW in 2030. The flexibility need for future

scenarios up to 2050 will increase substantially due to a large increase in variable RES generation.

In a more recent study conducted for DG Energy²⁰, three different scenarios are assessed based on the pathways of the Commission's Long-term strategy. The analysis aimed at determining the optimal flexibility portfolio for the power sector and the place of storage in particular among other flexibility options. Overall, according to the report, by 2030 "a large share of the required levels of flexibility can still be provided by conventional power plants (including low-carbon sources such as hydro and nuclear) and by using the power networks to trade electricity between the different European countries"²¹. However, in its 2019 Power Barometer²², Eurelectric highlighted that the acceleration of climate and environment policies could lead to a significant number of Member States facing security of supply risks by 2025 due to the removal of existing traditional power plants. For instance, in Western Europe, a total of 40GW of coal and 20GW of nuclear are set to close by 2025. Flexible and carbon-neutral capacity will be crucial.

In order to achieve decarbonisation of society by 2050, including industry, mobility and heating, the Commission's report further estimates that around 550 GW of electrolyzers would be required in all the scenarios. Combined with other flexibility means, electrolyzers would be able to provide a large amount of the power system flexibility. There would also be a large deployment of smart charging of electric vehicles or space heating combined with short-term thermal storage. Because of the competition between the different flexibility options, pumped hydro storage and batteries are lower in these scenarios in 2050 than in 2030 (around 50 GW). However, Eurelectric, in its own Decarbonisation Pathways study, estimated that power-to-X and hydrogen represent up to 206 GW and batteries up to 196 GW in a scenario where EU economy is decarbonised at 95%²³. In a high-renewable scenario, flexibility will primarily be provided by the electricity system itself but other options, such as energy storage or power-to-gas (e.g. hydrogen) will also play a role. In any case, the uncertainty around future power-to-gas innovation and the expected potential for future commercial availability/maturity must be acknowledged.

An important aspect in this context is the timescale for which storage needs to provide services. For short-term, daily flexibility, either solutions are already available or there are promising emerging technologies. Hydropower storage and batteries are already able to provide fast flexibility (ramps, balancing, etc.) and guarantee firmness, as will eventually power-to-gas combined with (green or decarbonised) gas storages or tanks – if the current cost reduction projections and business models become real, and probably

²⁰ [Study on energy storage – Contribution to the security of the electricity supply in Europe](#), March 2020. In the study the analysis looks at daily and weekly flexibility needs. From Baseline in 2030 to 1.5TECH in 2050 the flexibility needs increase 160%, going from 263 TWh, in 2030 to 707 TWh, in 2050. A small difference can be seen between the two 2050 scenarios, the flexibility needs vary from 707 TWh in 1.5TECH to 693 TWh in P2X. Like the daily flexibility needs, weekly flexibility needs are also substantially higher in both 2050 scenarios when compared to Baseline. From Baseline in 2030 to both 1.5TECH and P2X in 2050, the weekly flexibility needs are substantially higher, going from 224 TWh, in 2030 to 618 TWh for 1.5TECH and 619 TWh for P2X (Section 2.2.2.2)

²¹ Page 10.

²² Eurelectric, [Power Barometer](#), September 2019.

²³ In Eurelectric's Decarbonisation Pathways, for the early years of the model there is still quite a bit of flexibility in the system from thermal power, and at the same time battery storage is still relatively expensive. Closer to the 2035-2045 period, there is significant load both from directly electrified end uses (EVs, industrial, and buildings) as well as from the exogenous demand of H2 and power-to-gas. As these loads are quite flexible, the need for battery storage is less than might otherwise be expected. Batteries are still economic to provide intra-day load shifting in some cases, especially to support system reliability during periods of relatively low wind/sun where flexible load ramp-down has been exhausted. Note that in the 95% scenario where storage costs are lower thanks to faster learning curves, we see an increase both in capacity (GW) and energy (GWh, duration) of the battery storage deployed.

including the large-scale use of the batteries of electric vehicles. By 2030, pumped hydro and lithium-ion batteries (both behind and in front of the meter) are expected to provide the bulk of storage capacity. Like wind and solar, the cost-competitiveness of lithium-ion batteries saw massive cost reductions just in the last 10 years (-85%). For the provision of daily flexibility, according to the Commission's 2020 storage report, up to 108 GW of electricity storage would be necessary for the EU28, with a large development of stationary batteries. Long-term flexibility (from more than a few low wind days to seasonal) is considerably more challenging, as shown in Box 1. R&D programmes are an important element of maturity acceleration for these technologies.

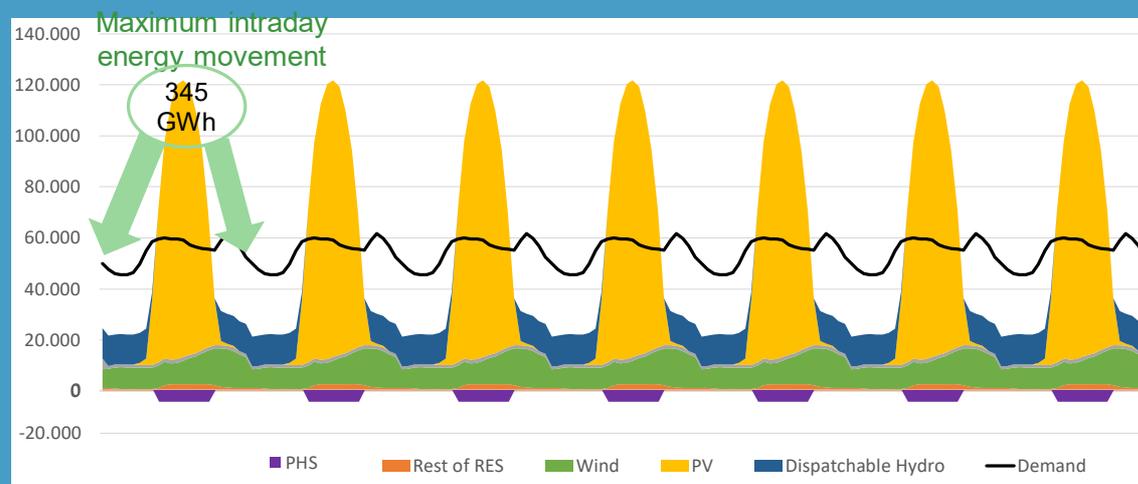
Box 1. The challenge of storage

Storage will play a very relevant role in any electricity system dominated by variable renewables, delivering firmness, flexibility and minimizing renewables spillage. However, the exact nature of this role is not always well-understood, and storage is sometimes presented as the silver bullet of the decarbonised power system. We try to illustrate the volume of the storage challenge using a simplified simulation of a fully decarbonised power system in a European country in 2050:

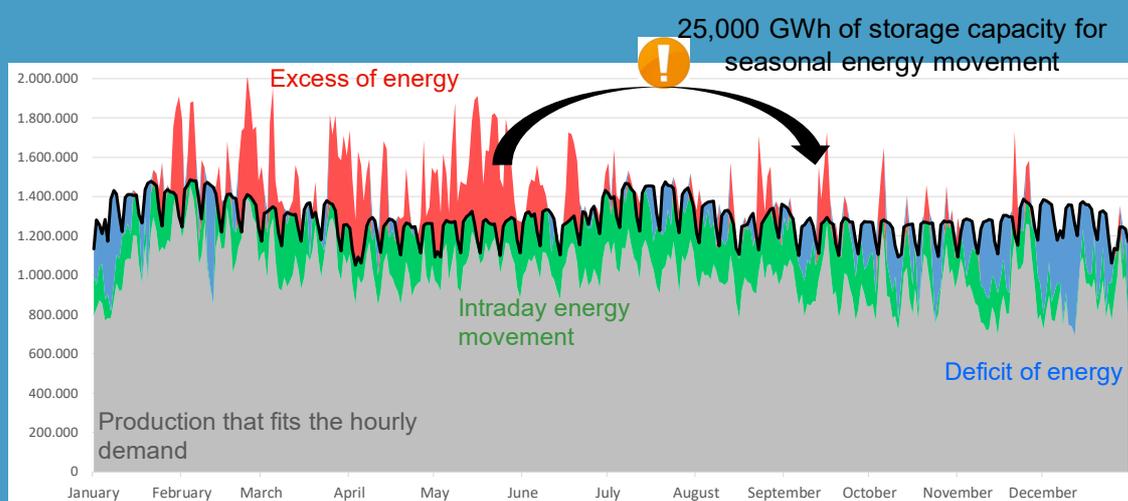
- Total demand is 470 TWh, with 70 GW peak demand. Seasonal patterns are similar to those of today.
- There is a significant presence of hydropower and pumped hydropower storage (35% of the peak demand).
- There are 190 GW of variable renewables (roughly one third wind capacity and two thirds photovoltaic generation, this being a combination that minimises spillage).
- There is no thermal or nuclear generation.
- New storage capacity (beyond the existing hydropower) provides the remaining necessary firm and flexible capacity.

The purpose of this example is not to present a precise forecast of a generation mix, but just to illustrate the relative sizes of the daily and seasonal challenges.

The following figure shows the hourly demand and production in a week with maximum intraday movement of energy, in March 2050. There is a significant photovoltaic production in the sunny hours of the day, well above demand, while production in the early morning and the evening is below demand. The maximum daily excess of photovoltaic production found by the model is 345 GWh. This means that such an amount of additional storage capacity would be needed in the example system to balance the daily photovoltaic production. This is a significant volume: the global yearly production capacity of batteries in 2016 was 28 GWh and it is expected to be 174 GWh in 2020. However, considering the growth rate of battery production capacity in recent years and the fact that these are the needs for 2050, 30 years from now, after the closure of all the existing thermal capacity, it can be considered to be feasible. Obviously, there could be other complementary ways of providing this daily balance, such as demand-side response, new pumped hydropower storage, new thermal capacity with green gases or CCS, etc. The objective of this exercise is not to determine the right combination, but just to assess the volume of the challenge.



However, this would not be enough to maintain security of supply in such a system. If we simulate the whole year, instead of one week, the picture is quite different. Because of the seasonal patterns of demand (high demand in winter and summer, because of heating and cooling; low demand in spring and autumn), and renewable production (higher hydro and wind production in spring, higher photovoltaic production in spring and summer), there is a structural deficit of energy in winter and a structural excess in spring. In this example, the model foresees the need for 25,000 GWh of new storage capacity, 72 times more than the capacity needed for intraday storage. Obviously, other factors could affect these needs. For instance, new nuclear or off-shore wind capacity could provide, in some regions, additional capacity with a high degree of firmness. In any case, the conclusion is that the seasonal challenge is significantly larger than the daily challenge.



This volume certainly looks far from feasible with battery technology only. While batteries will be crucial for short-term/daily balancing, a broad set of storage options will have to be developed to face the seasonal challenge at European scale. Among a variety of storage technologies, some should be able to cope with these seasonal needs, by storing large amounts of energy for months. However, for the time being, pumped hydropower storage is the only available technology capable of such feature, and its potential is limited. This seasonal balance cannot be solved by demand-response, since it would involve shifting demand for months, not for hours or even days. Power-to-hydrogen or power-to-gas seem promising, but we do not know whether and, if so, when, they will become affordable.

When it comes to the role of renewables gases in the electricity system, it should be noted that in the medium to long-term (depending on the countries) renewable gases could indeed provide flexibility, which could be used when variable RES are not producing sufficiently to cover the electricity demand. However, it should also be underlined that from that perspective renewable gases will be in competition with other decarbonised flexibility sources (demand-side response, storage...). A technology-neutral regulatory framework is therefore required.

Source: Eurelectric Member

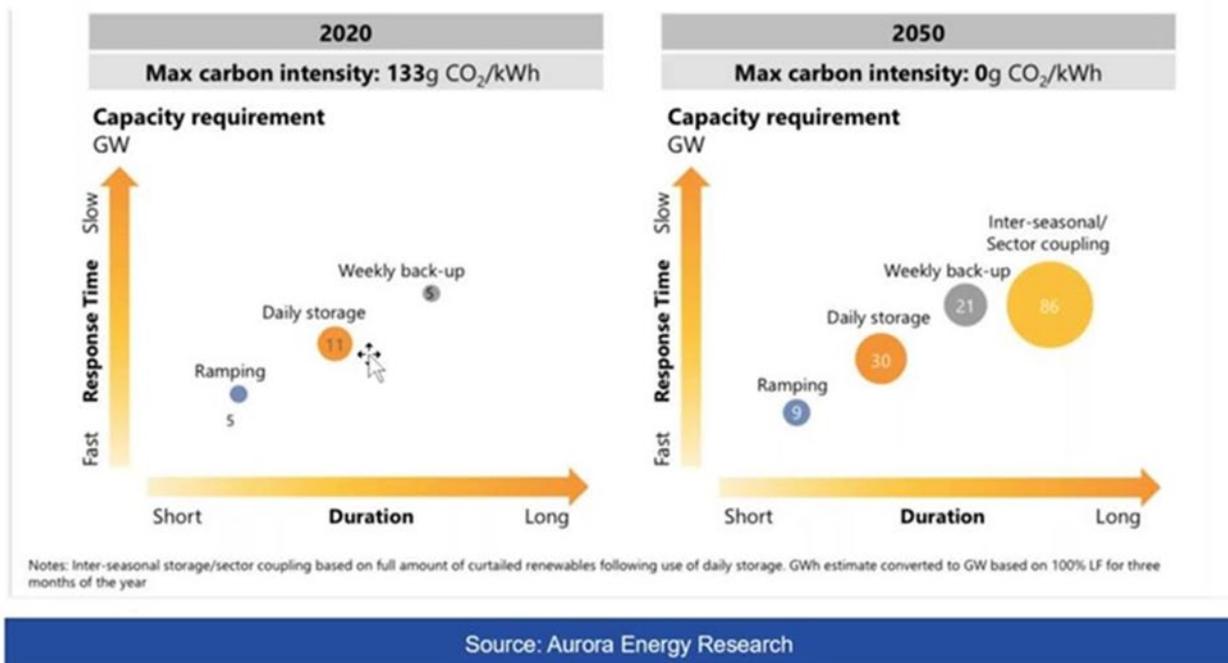


Fig. 6 – capacity requirements for flexibility needs according to time scale, UK example. Source: Aurora Energy Research.

Hydropower storage (with natural inflow and/or pumping) and heat storage are the only proven seasonal storage solutions. The technical or economic cases for other storage solutions are not established yet (e.g. hydrogen and power-to-gas or power-to-liquids)²⁴. However, due to the challenges of the EU objective of being climate-neutral by 2050, especially for the decarbonisation of industrial processes and harder to abate parts of the transport sector (shipping and aviation) as well as industrial policy considerations worldwide, a huge global push for the further development of these technologies is to be expected. This will probably make the deployment of these technologies to a larger extent possible to contribute to the achievement of the 2050 objectives.

In some regions, there are large flexibility capacities and more transmission through Europe could help fulfil flexibility needs and reduce the need for local storage solutions. In particular, full market integration of countries outside of the EU with large storage capacities (e.g. Switzerland or Norway) would allow for a better usage of these flexibility capacities.

²⁴ Annex I focuses on key technologies. For a thorough analysis of energy storage technologies, their applications and potential in Europe, see [EASE-EERA Energy Storage Technology Development Roadmap 2017](#).

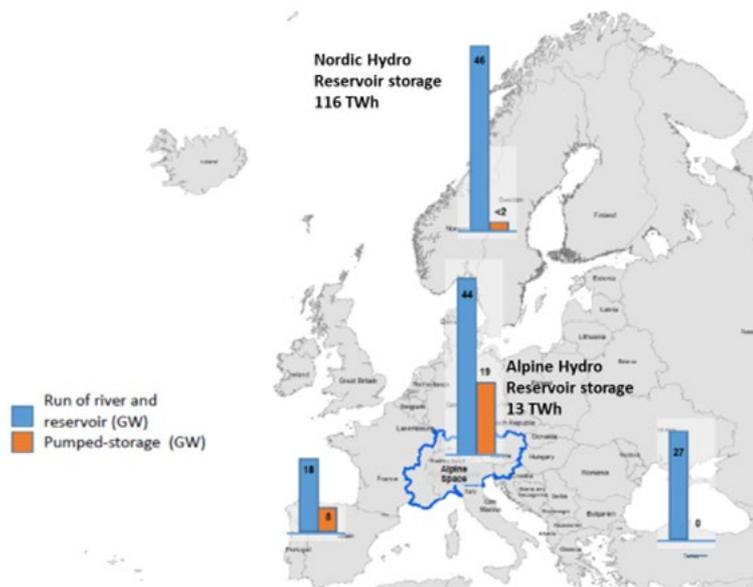


Fig. 7- Hydropower capacity in Europe. Source: Working Group on Alpine Hydropower (AGAW) (2017) Status and future of Alpine Hydro power/Eurelectric (additional reservoir storage data).

Smart sector integration would provide even more options for optimal solutions for the technical and economic challenges of decarbonising the economy over different sectors²⁵. It may be defined as “an approach in which smart electricity, thermal and gas grids are combined and coordinated to identify synergies between individual sectors as well as for the overall energy system”²⁶. In a high renewable future, balancing and flexibility options from both within and outside the power sector will compete. The required flexibility will primarily be provided by the electricity system itself but other options, such as energy storage or power-to-gas (e.g. hydrogen), will also play a role. However, the uncertainty around the future power-to-gas innovation and the expected potential for future commercial availability/maturity must be acknowledged. The effective coordination of the planning and operation of infrastructure of the different energy carriers will also be key. Smart sector integration should also identify and develop synergies with other sectors such as transport, digital, heating, cooling and industry²⁷.

Thermal storage technologies have also developed considerably, especially in some southern European countries during the first years of this century. The storage of energy occurs by means of heat transfer to a hot fluid or a solid medium which in some cases can directly carry out the thermodynamic conversion cycle or used at a later stage for reconversion to electricity or directly for heating purposes.

²⁵ See [Eurelectric response paper to European Commission questions, An EU strategy for smart sector integration, June 2020](#).

²⁶ Henrik Lund, Renewable Energy Systems: A Smart Energy Systems Approach to the Choice and Modelling of 100% Renewable Solutions, 2nd edition 2014, p 136.

²⁷ [A Eurelectric response paper to European Commission questions, An EU strategy for smart sector integration, June 2020](#).

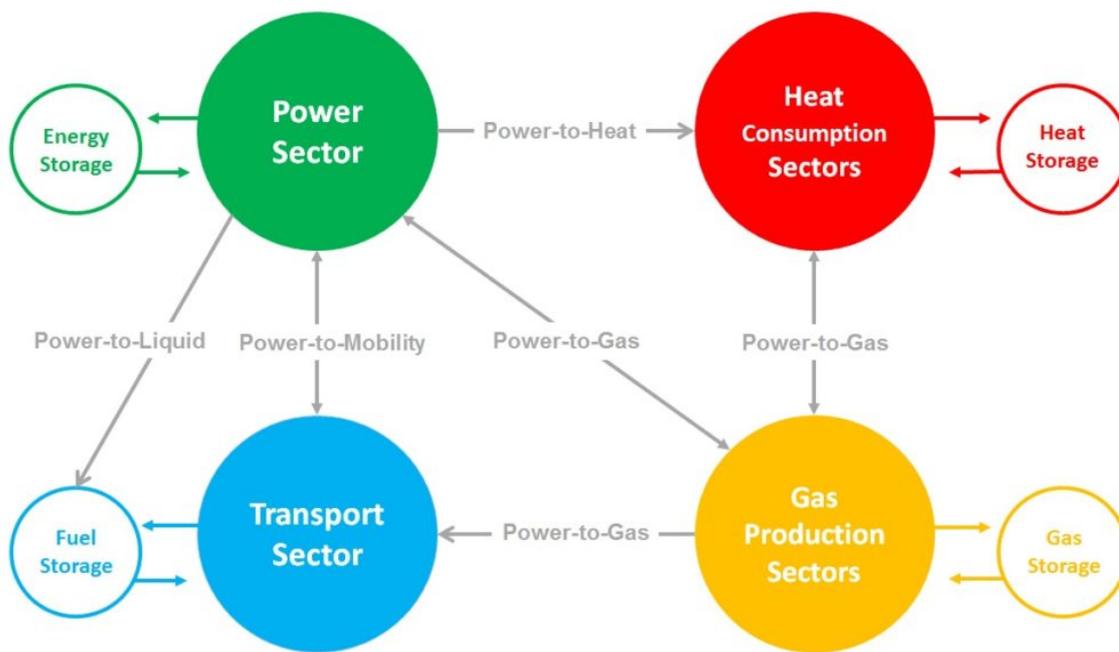


Fig. 8 - Schematic diagram of sector coupling and the interconnected Power-to-X technologies. Source: [Ingenuity-Siemens](#)

Storage applications in the power system and use cases

For the security of the energy system in an economic and efficient way, storage is the major hedging instrument for balancing and stabilisation in a technical and an economic or financial aspect. From the technical perspective, storage delivers the shift of energy from one time period to another, which balances and stabilises the energy system. Economically or financially, the value of the energy will be transformed from a time period with lower market value to another time period with a higher market value. In this case, storage stabilises the energy system by smoothing the prices on the wholesale market or by reducing the costs for final customers on the retail market. While in the beginning, this situation creates exactly the business case for storage, there might be a risk that this business case is cannibalised by itself: the more storage in the system, the flatter the price curve, the more challenging the economics will be. However, it is too early to draw conclusions but this has to be monitored closely.

The price signals from the energy markets are different. On the wholesale market, mostly the prices on the power exchanges are the bases for the price curves, which are fundamental to the dispatch of storage. Other instruments (e.g. power purchase agreements) exist and mostly give price signals in an indirect way (e.g. cost based etc.). On the retail market, the price signals are mostly indirect (e.g. from retail prices, grid tariffs, taxes and levies, agreements of energy communities etc.) because, for small final customers in particular, an explicit “pricing” of the market value is not possible. For instance, in combination with self-consumption, there is a rising demand for being autonomous. On the regulated part of the energy system (TSO’s and DSO’s) there are market based price values from the wholesale market, as well as from tenders, but also cost based regulated remunerations (e.g. tariffs, regulated prices, costs from National Regulatory Authorities).

The spread, the difference between the value of the energy in the different time periods, is the value of storage to remunerate the investment and the operation. Storage can deliver this hedging service on all applications of the energy business: to the wholesale market (e.g. Balance Responsible Party –BRP–, traders, producers etc.), to final customers (e.g. behind the meter, or at the public grid via aggregation or energy communities etc.) and also to the regulated part (TSO, DSO).

Depending on the specific technology and its position in the electric value chain, energy storage has the ability to provide different products to the market and different services to the system. When seen individually, the revenues obtained by each of those revenue streams are likely not to compensate the initial investment, but the aggregation of revenues from different services, the so called revenue stacking (see below), is essential for the profitability of energy storage investments. In Annex II, we explore further and illustrate with concrete examples the different set of services storage can provide to the system (markets, grid and generation) with a special emphasis on use cases (electric vehicles, energy communities, islands and coal regions in transition & coal-fired power plants).

3. Challenges for the further deployment of storage

Technical

The main challenge for the energy storage industry is to find the best technologies able to satisfy the future electricity system needs through a safe, reliable, sustainable –at large scale deployment– and efficient technology portfolio for short and long durations.

While even mature or rather mature technologies like pumped hydro or Li-ion batteries still face technical challenges or can still be improved, other technologies, even if promising, still need considerable technical development to reach a scalable potential like flow batteries, compressed or liquid air storage, fly wheels or power-to-X.

Li-ion technology is one of the most versatile technologies in the energy storage industry with a significant market share. Despite its significant role in the power system, intrinsic technical issues still represent a limit.

These limitations are mainly attributable to the battery lifetime consumption and battery degradation. The lifetime consumption can be directly or indirectly affected by factors like the number of cycles, its calendar life and the depth of discharge (the deeper a battery's discharge, the shorter the expected lifetime), therefore depending very much on the concrete application or individual usage. The battery degradation shows itself in several ways, leading to reduced energy capacity and efficiency. Factors which can drive degradation include, among others, temperature, ramp rate, average state of charge (SoC) and depth of discharge (DoD). Compounding this issue, Battery Energy Storage Systems (BESS) providers offer products with degradation curves that can vary significantly from each other.

Power-to-gas and hydrogen in particular benefit from unprecedented momentum as the European Union prepares to establish its policy in this area²⁸. However, for the power sector and the energy market there are still many problems to be solved about the ways in which hydrogen could be transported over long distances, as well as stored at large scale,

²⁸ European Commission, [EU Strategy for Energy System Integration](#) and [EU Hydrogen Strategy](#), July 2020.

the formats in which it could be delivered to end-users and the definition of standards most importantly on safety²⁹.

Concerning hydro power, even if it is one of the most mature and largely deployed storage option, there are still technical challenges and room for technological improvements. Hence R&D should also have a strong focus on efficiency improvements for hydro storage (see below).

Business case

It is commonly expected that the needs for various storage solutions, both at utility scale and behind the meter, will rise as the share of variable RES in the power system increases. Depending on the concerned Member State, the need for storage might thus rise in various time horizons. However, this doesn't necessarily translate into long-term investment signals to achieve the energy transition cost-effectively. After significant progresses in harmonisation, wholesale markets now successfully coordinate short-term operations and offer mid-term financial hedging possibilities but are frequently unable to support long-term investments. Market frameworks giving long-term signals, if any, are decided and rolled out at national, not European level³⁰.

Impact of CEP

In May 2019, after almost three years of a legislative marathon, the European Union completed the overhaul of its existing energy policy with the adoption of eight pieces of legislation known as the "Clean Energy for all Europeans" package (CEP). The CEP encompasses Energy Performance of Buildings Directive (EU) 2018/844; Renewable Energy Directive (EU) 2018/2001; Energy Efficiency Directive (EU) 2018/2002; Governance of the Energy Union and Climate Action Regulation (EU) 2018/1999; Electricity Regulation (EU) 2019/943; Electricity Directive (EU) 2019/944; Regulation on Risk-Preparedness in the Electricity Sector (EU) 2019/941; and Regulation on the European Union Agency for the Cooperation of Energy Regulators (EU) 2019/942. This was a milestone for the European Union to define an ambitious pathway to decarbonisation, in particular of the electricity sector.

The updated legislative framework is trying to reflect the growing interest in storage. There was for instance no definition of energy storage in the Third Energy Package while the CEP is striving to recognise its value and remove barriers to its deployment. The CEP brings a number of clarifications and improvements in relation to storage, but it will need thorough implementation and clarifications.

It includes for the first time a definition of energy storage which is broad and technology neutral (e.g. batteries, pumped hydro storage, power-to-X, etc) but is focused on the electricity system and does not cover the energy systems in general (see above Section 1).

According to articles 36 and 54 of the Electricity Directive³¹, in order to preserve a competitive framework for the development of storage across Europe, transmission and distribution system operators cannot own, develop, manage or operate energy storage facilities. Member States may allow DSOs to own, develop, manage or operate energy

²⁹ IEA, The future of hydrogen. Seizing today's opportunities, June 2019.

³⁰ [Eurelectric. e-invest. The power sector investment challenge: 100 billion per year and counting. 2019.](#)

³¹ [Directive \(EU\) 2019/944 of the European Parliament and of the Council of 5 June 2019 on common rules for the internal market for electricity and amending Directive 2012/27/EU. OJ L 158, 14.6.2019, p. 125.](#)

storage facilities, where they are fully integrated network components³² (such as capacitors or flywheel which provide services for network security and reliability as well as contribute to the synchronisation of different parts of the system) and the regulatory authority has granted its approval.

In order to achieve increased network stability and security, DSOs can investigate the potential of flexibility services being offered by market providers – according to article 32 of the Directive – or the potential usage of storage facilities being provided by the market. In case of a missing availability of the above mentioned alternatives, and if a Member States allows it, – according to articles 36 or 54 of the Directive – network operators can apply for an exemption at their local authority in order to own, develop, manage or operate energy storage facilities. These facilities then – in contrast to fully integrated network components – would be able to address the DSO responsibilities mentioned above.

The CEP ambitions to improve the functioning of wholesale electricity markets: removal of caps on wholesale prices, clear framework for day-ahead, intraday and balancing markets and a reasonable framework for the European adequacy assessment. Nevertheless, as Eurelectric already highlighted in its report e-invest³³, the CEP fails to deliver a definitive solution to the problem of providing long-term investment signals to achieve the energy transition cost-effectively while ensuring security of supply. Indeed, while the CEP acknowledges the role of flexibility and the need to attract investment in options, like storage, to compensate for variable RES production, it does not offer any comprehensive alternative to efficiently replace the current thermal fleet –which currently largely ensures security of supply– with new carbon-neutral flexible/reliable capacity, including storage. Therefore, in most markets, with the exception of a few regions in Europe, the energy-only market is not able to give the appropriate price signals for these investments because of intervening and overriding regulations. However, a strengthened and well-functioning ETS and a well-functioning market without price caps should be the main drivers for business investments in storage. For pumping storage that may take more than 10 years to be fully operational, market design should consider those long lead times to avoid harming this solution.

The CEP also clearly sanctions the increasing role customers are expected to play in the electricity system as prosumers with a combination of consumption, generation and storage based on solar PV, e-boilers, residential batteries and EVs . Active customers as well as Citizen Energy Communities can install, own and operate electricity storage systems and offer their flexibility services to the grid, also through aggregators. The Electricity Regulation also states that “network charges should not discriminate against energy storage (...)”³⁴.The CEP does not address precisely the question of grid fees, tariffs and taxes for storage.

The swift implementation of the CEP across the EU will form a good basis for the energy transition but there are still uncertainties on how Member States will implement the new regulatory framework. As far as storage is concerned, there are still barriers to its deployment in many Member States. Ambitious and coherent National Energy and Climate Plans (NECPs) are needed to ensure the EU reaches its 2030 targets and to provide

³² According to the Recital (63) of the [Electricity Directive 2012/27/EU](#), energy storage facilities which are fully integrated network components, “are not used for balancing or for congestion management, they should not, subject to approval by the regulatory authority, be required to comply with the same strict limitations for system operators to own, develop, manage or operate those facilities”.

³³ Eurelectric, e-invest. The power sector investment challenge: 100 billion per year and counting, September 2019.

³⁴ Recital 39.

investors with more certainty across sectors. The new Governance Regulation will be central to the achievement of the CEP objectives, as it ensures that Member States are obliged to account on their investment framework in order to meet targets.

Persisting Market/Regulatory challenges

The storage market in some countries is characterised by uncertain revenue streams, in particular in the absence of the appropriate regulatory framework. The presence of adequate long-term price signals could reduce revenue streams uncertainty and encourage investment decisions.

Revenue stacking allows to derive value by serving multiple applications over the course of a day, month or year. In the majority of the countries, where a huge deployment of storage is on-going, the revenue stacking is commonplace even if unsynchronised market mechanisms are sometimes detrimental to an efficient value stacking. In other countries, market windows are not flexible enough (or the national regulation does not allow) to stack revenues and to maximise the business case where possible.

The economic feasibility of storage is increased when it is used for several purposes in the market. Stacking of applications would be possible with most storage resources. In reality, this is not always the case. In addition, due to the fact, that storage is treated as both a demand and a generation unit at the same time, electricity storage has a disadvantage in relation to other market arbitrage resource like generation.

The optimal structuring of storage applications is a complex process, which requires a deep knowledge of the project as well as the market in which it is supposed to be deployed.

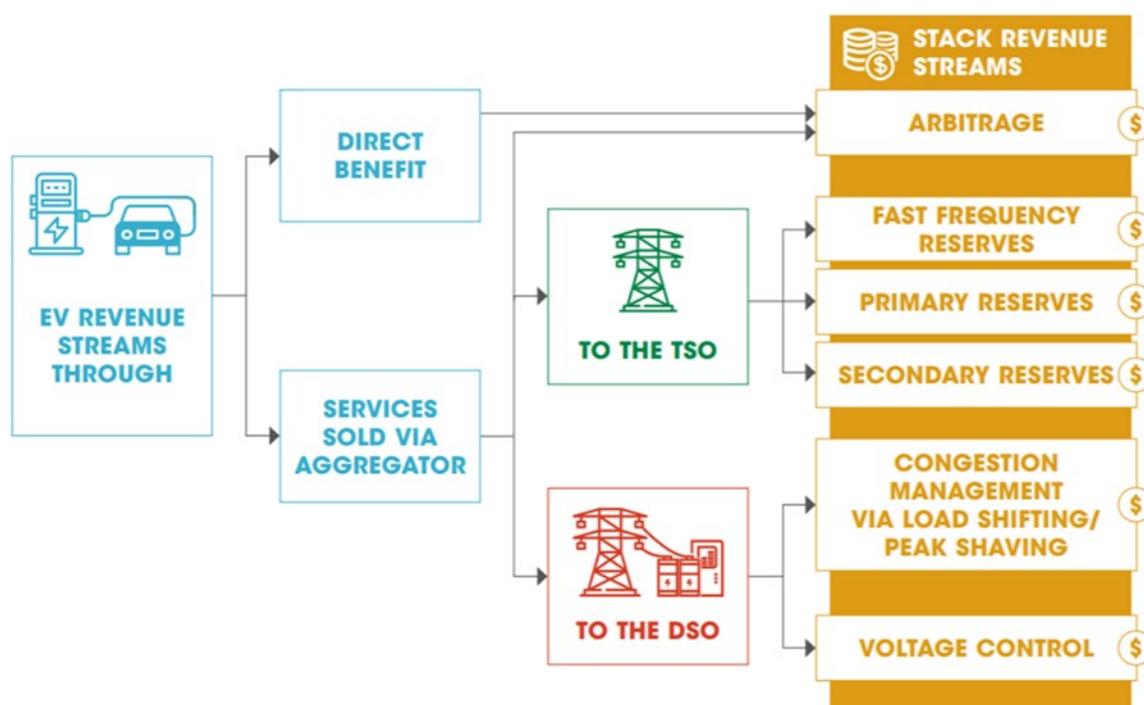


Fig. 9 – possible EV revenue streams that can be stacked. Source: IRENA, [Innovation landscape brief: electric-vehicle smart-charging](#), 2019.

The income of the storage facilities is also varying according to the different potentials of technical storage solutions in relation to the different time ranges.

From the perspective of different technical storage solutions for the electricity system the economic situation differs very much. On the one hand, the investment costs (e.g. acquisition, legal permission process etc.) are not comparable e.g. between batteries and hydro/pumped storage. On the other hand, from the systemic view, these two technologies are also not comparable, because hydro power is able to deliver on many more time frames and unlimited cycles with no kind of degradation than batteries are able to do. On top of the investment costs of each technology, the technical characteristics of a technology (e. g. efficiency, response-time, self-discharge, storage duration, ageing and degradation, etc.) will also have a strong impact on this optimal structure of revenues, by both affecting the services that a technology can provide and the efficiency at which this service is provided.

The economic and regulatory context of the project location (e.g. energy mix, price levels and structure, market regulation, etc) will also strongly impact the structure significantly from one country to another.

In addition, to pursue the principle of technology neutrality (according to the Electricity Regulation³⁵), the time of activation of a storage technology must be considered in relation to when investments are necessary: the need for urgent operation may advantage technologies with shorter realisation times, even if characterised by higher costs. For example, in relation to different storage technologies, pumping systems have a very long time to market (caused by authorisation and implementation), while electrochemical storage could be realised in a shorter time. The different time scales create different types of business cases e.g. a large energy volume needed at few locations is different from a small quick energy volume used several times.

Alike other storage technologies, hydrogen production and power-to-X should be market-based, as they will be in competition with other decarbonised flexibility sources (decarbonised generation, demand-side response, storage...). Europe should focus on how to create the right market conditions and a technology-neutral regulatory framework for flexibility provision to the power system.

On a very short-term and for short-term time frames (e.g. balancing, intraday, day-ahead), storage should be market based (see Electricity Directive) with aggregation (e.g. for batteries on final customer level) or without aggregation (e.g. pumped-storage hydropower plants) to bring the flexibility to the wholesale level.

On the mid-term time frame (e.g. day-ahead, week ahead, month ahead) the markets are very well developed and established. There will not be so much need for improvement.

On the long-term time frame (e.g. year ahead and several years ahead) there is a lack of visibility for investments especially given the lead time for construction and the long amortisation period of storage investments (similarly to other generation facilities hydraulic pumping facilities have a lifetime of several decades). In practice, the current market design does not allow to hedge the investment risks beyond a 5-years horizon. In some cases power purchase agreements (e.g. support schemes with a public counterpart or very long term reserve contracts with TSOs) may deliver some investment security up to 20

³⁵ [Regulation \(EU\) 2019/943 of the European Parliament and of the Council of 5 June 2019 on the internal market for electricity, OJ L 158, 14.6.2019, p. 54.](#)

years. This is one of the main questions for the transition of the electricity system to a CO₂-free future.

Additionally, Member States are exceptionally allowed to open options for non-market based solutions for grid operators for non-frequency ancillary services; with storage as a grid integrated application/device.

Time of use will be short term or very short term, but procurement might be done on a mid/long term time frame³⁶.

From a general standpoint, the regulatory framework should therefore allow to disclose the true value added by the flexibility provided by various solutions, nothing more, and nothing less. The EU should act as an enabler while remaining agnostic when it comes to determining what the best flexibility source for the electricity system is. In other words, it is important to have a legal basis that establishes a level playing field allowing all flexibility solutions (hydrogen, but also decarbonised generation, demand-side response, storage...) to compete on even grounds to match the electricity system needs. On the one hand, the necessary market up-take of hydrogen will need further incentives than just funding of the build-up of capacity and the use of hydrogen for power generation should not be discriminated. On the other hand, the impact of a strong public support for the build-up of a hydrogen economy risks to have considerable impact on the power system and the business case for storage solutions which are already available today much more cost-efficiently. These negative impacts, including for the cost-efficiency of the whole energy transition, have to be avoided.

Box 2. Aggregator launches co-optimisation offers

Kiwi Power is launching a 'co-optimisation' offering that goes beyond traditional fast frequency response (FFR) approach. The energy aggregator will switch assets between multiple market verticals including ancillary and wholesale markets. This new offering would allow asset owners to capitalise on electricity price volatility and other system stress events and could unlock an estimated 41% of additional revenue for battery storage and DSR owners.

Source: [Current news](#).

Box 3. Investment challenges for the development of a 1,500 MW pumped hydro storage

SSE is looking to develop a proposed 1,500 MW capacity and 30 GWh storage volume pumped storage scheme in Coire Glas in the Scottish Highlands (UK).

There are no regulatory, planning or grid-related barriers. Challenges are all commercial and linked to the value the electricity system gives to having storage available and how it wants or intends to pay that value:

- High level of under certainty on arbitrage revenues and self-cannibalistic effect even though it continues to bring positive external benefits to the system by integrating large volume of RES.

³⁶ The CEP definition of non-frequency ancillary services cover the following DSO use cases: "steady state voltage control, fast reactive current injections, inertia for local grid stability, short-circuit current, black start capability and island operation capability" (Article 2(49) of the Electricity Directive).

- Each ancillary service revenue has uncertainty in terms of quantity needed, value to be attached by the TSO. Procurement terms for each service tend to short term or day to day contracts.
- GB Capacity Market lead time of 4 years is insufficient for 5–7 construction period.
- Pumped storage has infrastructure investment profile with high initial construction costs with long term low operational costs and long-term benefits. It makes it more difficult for a utility to finance on balance sheet or attract bank financing.
- Storage is unable to access de-risking instruments available to competitor sources of flexibility e.g. interconnector can access cap and floor support from regulator.

Source: SSE

Box 4. Difficult market conditions for electricity storage in Germany

Specific investment costs for large scale batteries projects are declining (-52% since 2014), being now in the range between 0.6 and 0.8 mio EUR/MW. These costs mainly depend on various components, such as battery cells, software, cooling and heating systems, building, whereas for large scale solutions the main cost factor are the battery cells. Today, more than 75% of large scale battery projects in Germany use the Li-ion technology. Other battery storage technologies, like redox-flow and lead-carbon technologies, have higher specific investment cost.

Generally, large scale batteries are designed for multiple usage, such as to deliver primary control power as well as to pursue arbitrage strategies on the spot market. In this context, it has to be pointed out that declining prices for primary control power can negatively influence the profitability of large scale battery projects and simultaneously lower the incentive to foster new storage projects. Since 2015, the remuneration for primary control power has dropped from 3,000 to 5,000 EUR/MW to below 1,000 EUR/MW in early 2020. The main reason for this downward trend is the increase of the competing pre-qualified large scale battery capacity, which has increased from 30 MW to 380 MW in the same period.

Even though, large scale battery projects can be operated for 15 to 20 years with a nearly constant performance, the current market conditions endanger the amortisation of the investment, which will probably not be reached within the operating time.

Source: [Energate](#)

Box 5. Challenges for energy storage in Poland

Generally:

- Currently a low level of energy storage facilities development in Poland does not enable to assess all aspects of this area.
- Definition of energy storage is included in the Act of Energy Law and consists of an installation storing energy, connected to grid, which can feed electricity to this grid. A different definition is also stated in the Renewable Energy Sources Act.
- Right now, the regulatory framework for energy storage is not sufficiently developed. Removing regulatory barriers increasing investment risk and business

costs (e.g. OPEX), therefore hampering the development of large-scale commercial storage projects, is a challenge.

- A significant challenge is to provide optimal environment for the development of hybrid projects, i.e. RES installations combined with energy storage facilities.
- Environmental taxes and tariff model are currently not adapted to the specifics of energy storage projects.
- A business barrier to boosting commercial energy storage is, inter alia, the current model of the regulatory services market which prevents energy storage from competing with conventional power plants.
- Energy storage in the principles of redispatching of generation units is also necessary to be taken into account.

More in details – grid area:

- There are no specific connection conditions that can be issued by transmission or distribution system operators for energy storage facilities. RfG and DC Network Codes should regulate access conditions to the grid for energy storage.
- Solutions in the area of storage access to balancing and non-frequency ancillary services market are being shaped.
- Flexibility services based on distributed energy sources are to be developed. This creates opportunities for commercial energy storage projects as a source of flexibility for the grid.
- It is necessary to precise the structure of flexibility services in such a way as to ensure the participation of energy storage in such services, at the level of distribution grids.
- The Electricity Directive in the CEP impacts the admissibility of direct use of energy storage by transmission and distribution system operators (exceptionally only is it possible to have and directly operate the storage for TSO and DSO – storage as elements closely integrated with the grid). When implementing article 36 of the Electricity Directive it needs to be clarified how to use stored electricity in emergency grid situations.
- Existing projects mainly established for R&D objectives received funding and are mostly implemented by grid operators.

Permitting

The uncertainties regarding the different steps of the permitting process that have to be followed in a storage project also represent a challenge that must be overcome to develop projects. For instance, although in some countries RES + Storage might compete on a level playing field with other resources in providing services (e.g. resource adequacy, unbalancing reduction), a lack of defined permitting processes are delaying potential deployments or in some cases are not allowing the deployment at all. In particular:

- the absence of clear timelines and procedures to follow. It appears necessary to define a clear and specific permitting process for storage projects, also when co-located with new or existing power plants (e.g. RES or traditional generators). The lack of clear directions from decision makers to local permitting authorities poses significant permitting risks for project developers.

- the environmental legislation should be adapted to cover storage. Otherwise, other environmental rules are applied in order to analyse the impact of the project, with a loss in efficiency and effectiveness.

As regards retrofitting and investments for power or efficiency increase at existing assets – as it is the case for hydropower plants – the same requirements of aligning different policy goals have to be respected as in permitting of greenfield projects. Retrofitting of hydropower assets can increase both the power output and the flexibility capabilities of existing plants (e.g. when Swedish Hydro invested in more power capacity in existing plants without increasing energy production to increase the flexibility to pave the road for base load from nuclear in the 1960s and 1970s), whereas there is still potential throughout Europe for developing new hydropower as well.

Box 6. Change in planning rules for some large storage projects in the UK

The UK has announced a change in planning rules in England and Wales for storage projects above 50MW. It will result in direct approval by local authorities rather than a years-long process involving national authorities. This will apply to battery storage systems and emerging technologies such as compressed air and liquid air storage. Pumped-hydro storage is not included as the environmental footprint of the technology is considered impactful enough to go through a national process while battery storage is compact and has a relatively low landscape impact compared to other technologies. The UK expects that this will remove barriers to energy storage projects and could lead to the deployment of more than 100 large projects. The UK has about 1 GW of storage in operation and 4 GW in the project pipeline.

Source: [Recharge News](#)

Taxes and levies

Regarding taxation, the Energy Taxation Directive (ETD) was adopted almost 20 years ago and it doesn't account for the deep changes that have taken place in the energy system, including the emergence and capacity increase of various storage technologies. According to the ETD, electricity is taxed when it is released for consumption but it leaves open the possibility for electricity to be taxed twice, when it is stored and when consumed by the end consumer. Also for taxes a fair burden sharing is necessary. In its contributions to the expected review of the ETD, Eurelectric has continuously highlighted that energy taxation must support Europe's decarbonisation³⁷.

Tariffs

In some Member States, the electricity storage and power-to-gas systems are exposed to double taxation and grid fees which impact the creation of a business case. Double charging result when charges emerge by off-taking energy by an electricity storage system, reinjection of this energy into the electricity system and charges emerge a second time by off-taking the same energy by the final consumer.

³⁷ [Eurelectric. Energy Taxation Directive review – Inception impact Assessment. A Eurelectric comments paper. 2020.](#)

If grid tariffs are not cost reflective, they may subsidise self-consumption and some flexibility services to the expense of the other customers and are not compatible with the non-distortionary and cost-recovery principles in the long term costs. Network tariffs should take into account these different grid uses. These should take into proper consideration new realities such as energy communities, self-generation and storage. At the same time they have to respect a fair burden sharing of effectively arising costs. Eurelectric is working on a detailed position on these issues.

Connection rules and Grid Codes

Poorly defined connection rules and grid codes are other roadblocks to the effective deployment of storage including variable RES combined with storage. While first adopter TSOs in some countries have already defined full frameworks for hybrid “RES + Storage” plants, in others the following critical issues have been encountered (starting from the most severe):

- lack of rules for storage connection: absence of clear timelines and procedures to follow for merchant projects, double grid tariffs (see above);
- storage capacity is not considered as contributing to the capacity of the hybrid plant. For instance, if the storage (e.g. 20 MW as installed capacity) is combined with a RES power plant (50 MW as installed capacity), the capacity to the point of interconnection is just 50 MW.

Further solutions for a better implementation of the CEP should be examined.

R&D in energy storage in Europe

While batteries will continue to play a significant role in the energy storage landscape in the near term, other energy storage technologies are required that can enable the competitiveness of European companies during the transition to a more decarbonised society. By contrast pumping storage shows a value chain that can be focused in the EU.

The case of lithium-ion batteries should give the electricity industry pause for thought. This technology was developed by the consumer electronics industry to meet its own demand. After 40 years, the large Asian consumer electronics manufacturers dominate both the supply and demand for this technology, making other sectors, such as car manufacturers and the electricity industry, mere price takers. The electricity industry should have the ambition to develop storage technologies better adapted to its specific needs while taking sustainability needs on board.

Therefore, the European electricity industry should have the vision to foster long-term, disruptive research, starting at early stages of technology readiness levels (TRLs) that can rapidly feed new knowledge and concepts across all TRLs leading to commercial products.

Large multi-disciplinary and cross-sectorial research efforts are needed to develop the necessary breakthrough technologies. Europe has the potential to take the lead thanks to both thriving research and innovation (R&I) communities covering the full range of involved disciplines and well-established innovation clusters with industry. However, to realise the vision of inventing the energy storage technologies of the future in Europe, forces should be joined in a coordinated, collaborative approach that unites industry, researchers, policymakers and the public in pursuing those goals.

As an example, the European Battery Alliance (EBA) was launched in October 2017 to support the battery industry in Europe throughout the value chain. Since the EBA launch, a European Strategic Action Plan on Batteries was published in March 2018, setting the direction for the development of a competitive battery industry in Europe. Analogous initiatives are required to extend this vision to all energy storage technologies and not only electrochemical energy storage.

Box 7. Short-term research & innovation priorities for batteries

The Batteries Europe Technology & Innovation Platform published its vision on short-term research and innovation priorities for the European battery sector. This input will feed into the preparation of the European Partnership for an Industrial Battery Value Chain under Horizon Europe.

The following priority topics were identified: sustainable processing of battery raw materials; advanced methods of sorting and recycling of battery materials; proceeding with next generation batteries for e-mobility and stationary storage from advanced materials; manufacturing techniques and batteries integration in key user applications.

Batteries Europe is now also working on its long-term vision for batteries research and innovation priorities.

Source: [European Commission](#).

Box 8. Hydropower, due to its capacity to store energy, has been revitalized as a research topic

Although hydropower technology has been around for a century there are still research needs to make the technology fit the new system and its challenges.

[EERA and its Joint Programme Hydropower](#) aims to facilitate a new role for hydropower as enabler for the renewable energy system by aligning and targeting research efforts in Europe. Thematically, the Joint Programme Hydropower spans the entire energy chain from water catchment to system integration, and it includes cross-cutting elements such as markets and market design as well as environmental impacts, effects of climate change and policy and societal issues.

[HydroFlex](#) is a project that aims towards scientific and technological breakthroughs to enable hydropower to operate with very high flexibility. The project has received funding from the EU's Horizon 2020 research and Innovation programme. Flexibility of operation here means large ramping rates, frequent start-stops and possibilities to provide a large range of system services. All this within (strict) excellent environmental and social conditions while being economically competitive compared to alternative solutions.

In Norway, the Norwegian Research Council has established [HydroCen](#) – a Norwegian Research Centre for Hydropower Technology with the goal to develop knowledge and technology so hydropower can meet new challenges and enable the transition to a fully

renewable energy system. The research areas include hydropower structures, turbine and generators, market and services and environmental design.

Box 9. Plans for an EU-wide hydrogen alliance

On 10 March 2020, the European Commission put forward a [renewed industrial strategy](#) and, on 8 July 2020, communications on an EU Strategy for Energy System Integration as well as a dedicated EU Hydrogen Strategy³⁸, where the launch of a new European Clean Hydrogen Alliance was a central initiative. The European Clean Hydrogen Alliance shall bring investors together with governmental, institutional and industrial partners. The Alliance will build on existing work to identify technology needs, investment opportunities and regulatory barriers and enablers.

Storage in NECPs

Unfortunately, storage is not recognised as a category on its own to be assessed in the National Energy and Climate Plans. However, as an essential element of flexibility and also as a contributor to security of supply, Member States should consider the potential of storage when assessing their system needs and ensure the necessary framework for its deployment.

In its analyses of June 2019³⁹ of the interim national plans, the Commission underlines the significant importance of storage, together with demand-side management. Member States should elaborate much more on energy storage as part of sources of flexibility and quantify the needs. Specifically, in the context of RES expansion, the relation between grid and interconnection extension and storage is not sufficiently highlighted. In general, specific objectives, policies or measures in combination with demand response are missing in most national plans.

In September 2020, the Commission published its analysis of the final plans⁴⁰. It stresses that, among other measures, Member States are invited to ensure that citizens are entitled to become a renewable self-consumer (including in combination with storage systems), as this is generally not included or sufficiently detailed in their NECPs. The increase in decentralised generation, large offshore renewable production and integration of hybrid projects combining renewables with storage, in particular renewable hydrogen, will require further grid rules and infrastructure adaptation. In this regard, the Commission highlights the potential for cross-border regional initiatives which is largely untapped. The report also identifies shortcomings in the energy market in terms of price signals as far as flexibility through smart grids, storage and limited demand-side response are concerned.

More detailed information would also be needed when it comes to research and development needs and measures.

Box 10. Storage in Spanish NECP

³⁸ European Commission, [EU Strategy for Energy System Integration and EU Hydrogen Strategy](#), July 2020.

³⁹ European Commission, [United in delivering the Energy Union and Climate Action - Setting the foundations for a successful clean energy transition](#), COM (2019) 285 final.

⁴⁰ European Commission, [An EU-wide assessment of National Energy and Climate Plans](#), COM (2020) 564.

The NCEP foresees ambitious targets for storage. In 2030 it is expected an increase of capacity of storage from: 3,500 MW of additional hydro-pump storage, 2,500 MW of batteries, 5,000 MW of storage in new CSP plants. The more than 100 GW of grid permits which as of today have already been granted (almost two fold of RES capacity envisaged in the NECP), show a great interest in investing in RES mature technologies as wind and solar PV (which cover the vast majority of these permits). However, and due to the market conditions, the scenario is quite different for the new storage investments which are required (only 300 MW of CSP grid access permits granted).

Annex I – Overview of storage technologies

Pumped Hydro Storage (PHS)

Pumped hydroelectric storage power plants may either have natural inflow in the upper reservoir or not. In case of excess power supply, e.g. by strong wind and/or solar generation, they pump water to a storage basin, the upper reservoir. This act of pumping is often linked to the market opportunity of purchasing energy at very low prices to be re-dispatched later. Systems services of pumped hydro are mainly used to balance the grid or generation-driven fluctuations in supply (peak, off-peak). Typically, PHS plants without natural inflow store energy for several hours or days. The duration of their energy storage potential increases when being designed with natural inflow. A large reservoir with natural inflow and small or no pumping capacity is a hydro storage reservoir (RHS-see below) and may contribute with the same services as PHS. While RHS and PHS can provide flexibility services for short timescales, it is the only technology that can offer long-term flexibility (from more than a few low wind days to seasonal) according to the size of their reservoirs.

PHS is a mature and very efficient technology (around 80%), with unlimited cycles and the potential for new plants – especially when designed without natural inflow – is big. However, hydro resources are not available everywhere. Like all hydropower assets, environmental and social criteria have to be fulfilled in developing and permitting new PHS facilities. Economically, if the services provided by PHS (primary regulation, back-up, voltage stabilisation etc.) were valued by the regulatory framework, it would make sense from a business point of view to build PHS not only in rivers but also in less common infrastructures such as repurposed coal mines (see below). There are also important opportunities for retrofitting and optimising existing facilities and systems. For instance, in Spain there is potential for increasing the current pumped hydropower capacity by 5,000 MW with relatively small investment, but the current market price does not pay for this and the projects are not moving forward.

Reservoir Hydro Storage (RHS)

Hydropower assets impound water in a reservoir to maximize the water input for flexible dispatch. In many cases, one reservoir is used by a cascade of hydropower plants downstream. Even if not defined as storage technology in a strict interpretation, RHS offers flexibility and can even serve as long-term storage asset up to annual storage.

Box 11. A green battery through seasonal multiyear storage

Ulla-Førre is Norway's largest conglomeration of power plants and uses water from a catchment area spanning 2,000 square kilometres in Aust-Agder and Rogaland counties. Suldalsheiane, Bykleheiane and Lyseheiane make up most of the catchment area. It also covers Ulledalsåna, Førreåna and parts of Bratteliåna, which all flow into Suldalsvannet lake. Blåsjø lake, the largest artificial lake in Norway, is the main reservoir for the power plants and comprises 20 small and large dams in all and over 100 km of tunnels.

The four power plants and one pumping station that make up Ulla-Førre have an annual production corresponding to around 3.5 per cent of Norway's energy consumption. The power complex is designed to utilise and even out variation in precipitation in that some of the power plants can be operated as pumping power plants that pump water back up to the reservoirs.

Compressed Air Energy Storage (CAES)

Compressed Air Energy Storage systems use off-peak electricity to compress air which is stored in underground caverns or storage tanks. This air is later released to a combustor in a gas turbine to generate electricity during peak periods⁴¹. There are only two facilities currently in operation which differently from other technologies reviewed here, the units involve fossil energy (though leading to a more efficient use of it).

Flywheels

Flywheels are mechanical devices that spin at high speeds, storing electricity as rotational energy. This energy is later released by slowing down the flywheel's rotor, releasing quick bursts of energy (i.e. releases of high power and short duration)⁴². They are oftentimes used by electricity users but are also suitable for frequency regulation at grid level.

Batteries

Batteries should be able to serve simultaneously all four power circles: local (behind-the-meter), community, DSO and TSO. The use of batteries in particular li-ion batteries for electronics (smartphones, laptops, etc.) and increasingly for supporting the energy transition has raised many environmental concerns. Following the adoption of a Strategic Action Plan for Batteries in 2018, the European Union is considering a regulatory framework to establish minimum sustainability criteria for batteries, including the requirements to efficiently recycle the feedstock.

Lithium-ion (Li-ion)

Despite the high variety of different energy storage technologies, BESS using Lithium-Ion (Li-Ion) batteries have established themselves as the most versatile technology. The market convergence around this technology is driven by the growth of Electric Vehicles as well as Li-Ion's modularity, which makes them ideal also for the higher sizes required for stationary storage. Further, their stage of technology development shows the highest potential of cost reduction with a higher reliability as compared to other technologies still in demo phase (Fig 11).

⁴¹ IEA, Technology Roadmap - Energy storage, 2014.

⁴² IEA, Technology Roadmap - Energy storage, 2014.

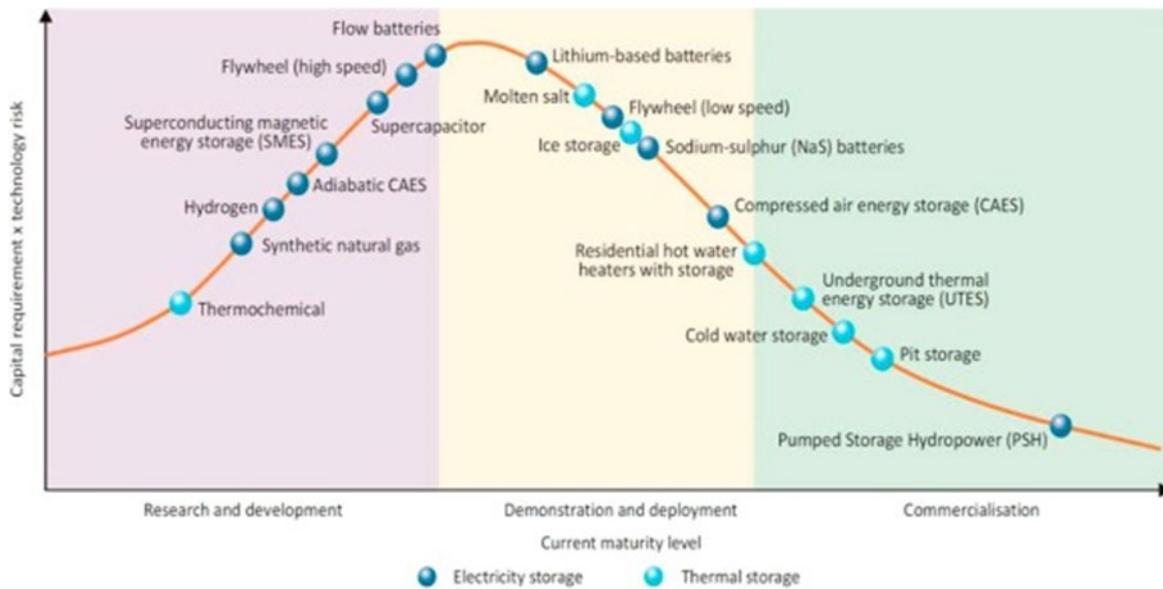


Fig. 10 – Stage of Li-Ion technology development. Source: IEA Energy Storage Technology Roadmap 2014

According to Bloomberg NEF (Fig. 11), utility scale batteries are expected to make the majority of installations. These deployments can be either with a stand-alone configuration or co-located with power plants like PV and wind farms to take the advantage of economies of scope (such as development, construction, infrastructure), and dispatch their production when the system needs it the most.

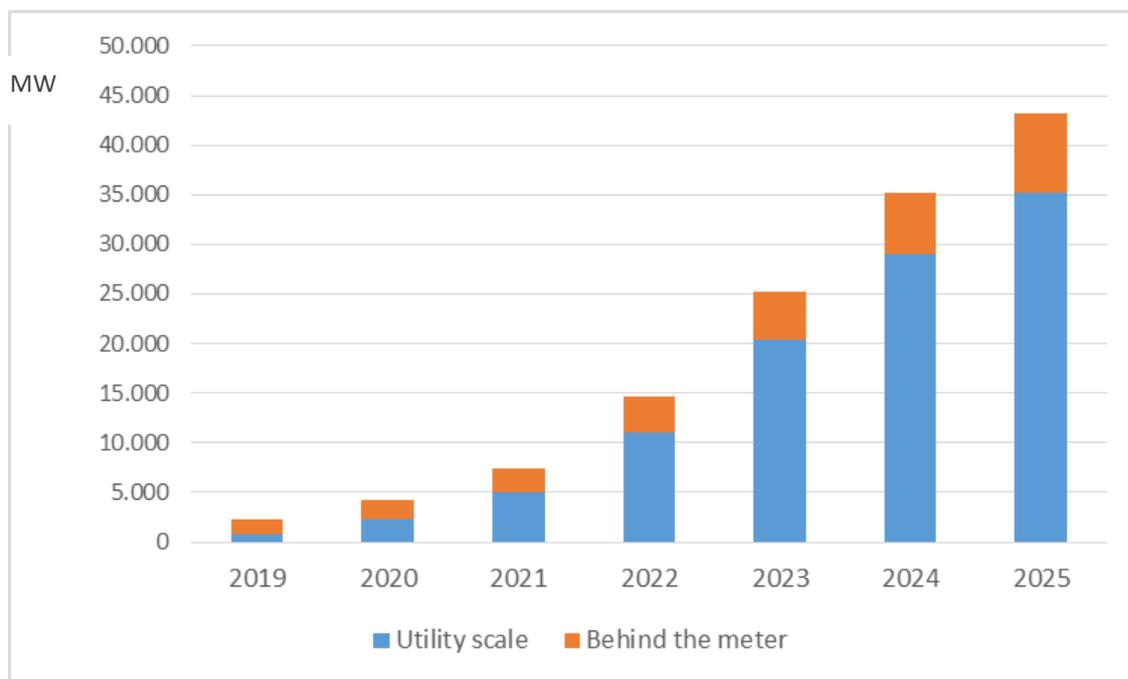


Fig. 11- Cumulative battery storage installations in Europe: system level versus behind the meter. Source: Bloomberg NEF.

Li-ion batteries are increasingly deployed behind the meter especially with electric vehicles. While it is difficult to assess how much capacity is connected at grid level, over 120,000 German households and small businesses have installed PVs and storage. A

recent analysis foresees that Europe's annual home battery installations could rise to more than 550MW in 2024 (source?). Eurelectric estimates that in order to be on the right path to decarbonise the transport sector, 40 million electric cars need to hit the road by 2030. Larger li-ion batteries are also increasingly used at grid level. The potential for further cost reduction is considered high.

The introduction of new chemistries (e.g. reduction of reliance on rare earths like cobalt), new cells and pack designs will positively contribute to the improvement of performance, leading to a lower cost of MWh delivered. The market consensus agrees that the integration of RES plants with energy storage systems has the potential to be a cost-competitive alternative to natural-gas-fired power plants across a number of key energy markets.

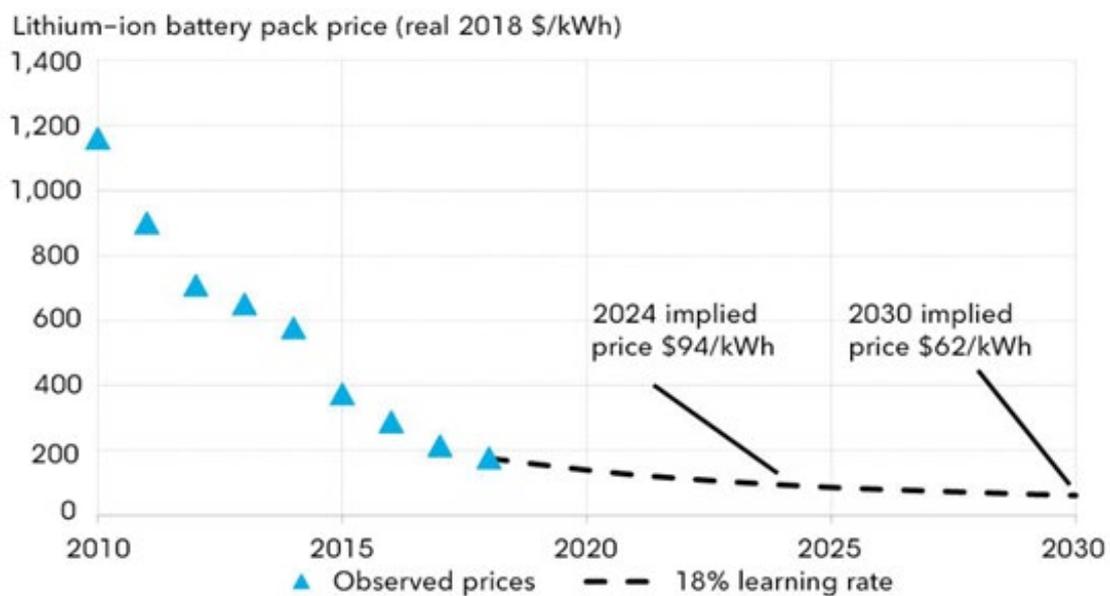
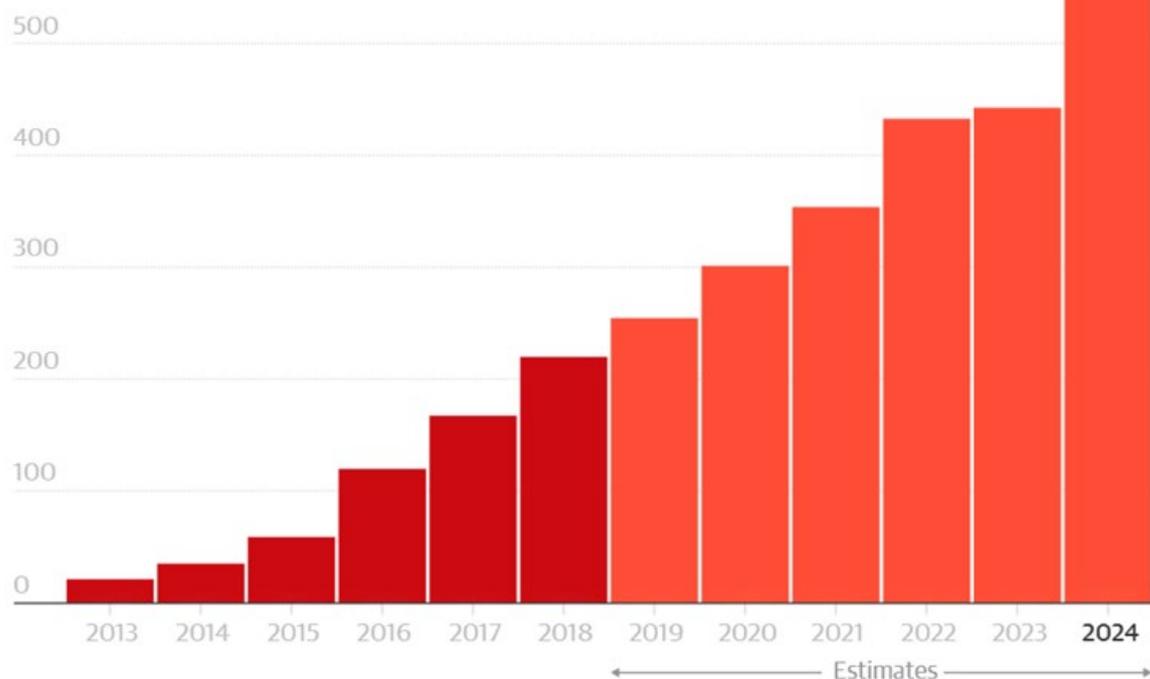


Fig. 12 - [Lithium-ion battery price outlook](#). Source: Bloomberg NEF 2019.

Annual megawatts deployed



Guardian graphic. Source: WoodMac. For comparison a typical gas power plant generates 500MW

Fig. 13 - Annual deployment of home batteries at EU level (MW). Source: [Guardian/WoodMac, 2019](#)

Others

There are many other types of batteries and this is an important area of R&D. Lead-acid and nickel-cadmium batteries have been in use for many years in stationary applications but they are likely to be replaced by newer technologies or, in the case of nickel-cadmium, face increasing restrictions like in the EU because of the toxicity of cadmium.

Sodium sulphur (NaS) batteries are a well-established technology suitable for large scale applications but present safety issues. Its main materials (sodium and sulphur) are however widely available.

Vanadium-Redox-Flow batteries are a type of rechargeable flow battery using vanadium to store chemical potential energy. Because of most notably their large size, they are used for the distribution grid.

Box 12. Storage improves solar load capability

A study conducted for Californian utilities suggests that the addition of four hours of energy storage would allow solar to reach a 99.8% effective load carrying capability, from a mere 4% without storage. According to the study, solar is more reliable to charge a battery so that it's ready when needed. Wind isn't as consistent.

Source: [Bloomberg Green](#)

Power-to-X

This family of technologies is attracting particular attention as it could potentially be used in long-term/seasonal storage applications as well as to decarbonise hard to abate sectors, such as maritime, air transport and industry (high heat requirements). P2X technologies such as hydrogen produced with RES electricity enable the so-called sector coupling that can unlock additional new sources of flexibility for the power sector. The conversion of renewable electricity into renewable synthetic gas (green Hydrogen, synthetic methane, synthetic fuel) could complement other storage technologies and other sources of flexibility allowing a better management of power system and a further integration of renewable energy, providing the expected cost decrease occurs⁴³. It presents indeed a low efficiency and is still costly. Hydrogen produced from renewable electricity sources is expected to be an important driver of electricity demand for the development of the electrical system⁴⁴. There is a growing number of projects at EU level but technological and economic uncertainties remain.

Box 13. Green Hydrogen for Gas Turbines in Austria (“HotFlex”)

VERBUND is building a pilot plant at the thermal power plant site in Mellach, Austria, which can be operated both as an electrolyser and as a fuel cell. The gas fired power plant has an electrical output of 838 MW went into operation in 2012. In its use for supraregional grid support, it contributes significantly to the electricity supply security throughout Austria. The two highly efficient gas turbines are currently operated with natural gas exclusively. As part of the recently launched "Hotflex" research project, energy supplier VERBUND will now test the partial substitution of natural gas with hydrogen from excess wind and solar taken from the grid. This "green" hydrogen will be mixed with natural gas to drive the two gas turbines. The hydrogen is to be produced directly at the power plant site by high-temperature electrolysis with a production capacity of 40 Nm³/h. In fuel cell mode, pilot plant can supply electricity and heat

Source: [Sunfire](#)

Thermal storage technologies

Thermal storage technologies have developed considerably in some southern European countries during the first years of this century. Spain has 50 plants with 2300 MW in operation. Solar thermal electricity is generated by means of a thermal machine that is very similar to conventional coal or gas-fired power plants, but which is fed by a renewable energy source such as direct solar radiation.

Solar thermal power plants have the same interface with the grid as conventional thermal power plants, with a steam turbine and alternator assembly that provides a stability to the grid that other renewable technologies cannot provide. Solar thermal power technology allows storage and hybridization and provides inertial stability to the grid thanks to its

⁴³ The above-mentioned EC study on electricity storage of March 2020 finds that at the 2030 horizon, electrolysers do not appear to be competitive solutions to provide flexibility to the power system.

⁴⁴ Eurelectric, [Decarbonisation pathways](#), November 2018: to achieve 90% decarbonisation in 2050, the average year-on-year growth of electricity supply for indirect electrification was estimated between 0.38% and 0.52% (scenarios 2 and 3). To give an order of magnitude, and for the same scenarios, the average year-on-year growth of electricity supply for the transport sector was estimated at 0.42%–0.56.

rotating turbines and alternator. This makes it an easy to manage energy source, adaptable to variations in both radiation and energy demand.

The storage of energy occurs by means of heat transfer to a hot fluid which in some cases can directly carry out the thermodynamic conversion cycle, for example in the case of steam or air. In other cases, the fluid heated by the solar field will exchange its energy with the fluids that will be used in the turbines or with another fluid, as is the case with systems that use thermal oils as the primary fluid and that will subsequently deliver their energy to the steam that will move the turbine or to the molten salts that will be used as the storage system.

Smart sector integration⁴⁵

Smart energy system integration means linking the various energy carriers or forms of energy (electricity, gas, liquids, heat, cold) with each other as well as with the end-use sectors (buildings, mobility, industry), allowing to identify synergies between individual sector and optimise the energy system as a whole, instead of each sector independently.

Such systems encompass new technologies and infrastructures, which create new forms of flexibility, primarily in the conversion stage of the energy system. The flexibility is achieved by shifting from a simple linear approach in today's energy systems (i.e. fuel conversion to end-use) to a more interconnected approach. This means combining the electricity, thermal, and transport sectors so that the flexibility across these different areas can compensate for the lack of flexibility from renewable resources such as wind and solar.

Heat pumps in the system provide a key conversion technology between electricity and the heating sector, which combined with heat storage and the thermal mass of buildings provides additional flexibility for the integration of fluctuating RES-based electricity sources. Similarly, electric vehicles provide the possibility of not only a dispatchable demand but also actual electricity storage that may be fed back to the grid.

Smart infrastructures in electricity and thermal grids at both local and European level enable flexibility and cost-effective use and form of renewable energy across different sectors, applications, time and space. Digitalisation is used to enhance the integration of variable and local renewables by enabling a better match between supply and demand according to the specific climate conditions.

Among the integrated types of storage, electricity storage has the most direct effect on the ability of the energy system to integrate variable renewable electricity sources.

⁴⁵ Henrik Lund e.a., [Energy Storage and Smart Energy Systems, International Journal of Sustainable Energy Planning and Management](#), 2016.

Annex II – Storage applications and use cases

Market tool and services

Technically, the main application of electricity storage is the use as market tool, to optimise income or costs by enabling some additional flexibility and by providing services to the system operators (like voltage control or congestion management).

Wholesale Market

The wholesale electricity market balances supply and demand over different timeframes from forward markets (Y-5 years) to real-time balancing markets in a cost efficient and risk managing way.

Most standard supply contracts in the market are based on energy (volume), but the option for standardized and individual contracts exist. In addition to these standard contracts, more or less tailored contracts are concluded like Power Purchase Agreements or structured supply contracts. These can also include pricing of services.

Next to these energy markets, there are some organised capacity markets. All TSOs contract operational reserves to be physically able to balance the system in real time. In some countries capacity markets for mid and longer term resource adequacy exist.

Storage can play a role in all these markets depending of the technical capabilities of the resource. In Annex II we give examples for:

- Storage in the intra-day and day-ahead market
- Storage in the forward market

Bottom line for the economics of storage use in this context is that the storage resource absorbs energy at a time of low value in order to release it at a higher value. This results in an option value that can be valorised on energy markets. However, it must be kept in mind that if storage influences short term prices this will have an effect on the long-term risk hedging.

Box 14. Upgrade of Norwegian hydropower project

Nordic Investment Bank (NIB) is set to provide a €59.39m loan to finance Agder Energi's Åseral Nord hydropower project in Norway. The ten-year loan will be used to finance a new dam, a hydro tunnel and an additional turbine. The investment is estimated to increase production capacity by 60GWh a year and will reduce water volumes bypassing the power stations by about 88 million cubic metres annually. The new dam will be 10m higher and sit directly downstream from the old one that was built in the 1950s. Once completed, the dam is expected to increase the reservoir capacity from 22 million cubic metres to 47 million cubic metres. A new 7.2km tunnel will be built as the existing 13km tunnel that connects the dam and the reservoir is at the risk of collapsing. With the enlarged reservoir and additional power capacity (extra turbine) the flexibility is highly increased in addition to an increase in yearly energy production.

Source: [World Energy](#)

Box 15. Tâmega Giga Battery

Iberdrola group is investing more than 1.5 billion euros in constructing the Tâmega hydroelectric complex in northern Portugal, which will involve building three dams and three power plants (Gouvães, Daivões and Alto Tâmega) with a combined capacity of 1,158 MW. The complex will be capable of producing 1,766 GWh per year, enough to meet the energy needs of the neighbouring towns and the cities of Braga and Guimarães (440,000 homes). Furthermore, this large renewable infrastructure will have sufficient storage capacity to serve two million Portuguese households for an entire day.

The project, which will involve an investment of more than 1.5 billion euros, including 650 million euros funding from the European Investment Bank (EIB). Currently, 23% of the group's funding is now what is known as green financing.

Tâmega is one of the largest hydroelectric projects developed in Europe in the last 25 years

Source: Iberdrola

Retail market / Beyond the Meter

The retail market is strongly linked with the wholesale market. Supply prices stem from wholesale prices and include premiums for different market risks. End users, and in some Member States, generation, typically pay the price of the infrastructure, mostly or completely through network tariffs. Furthermore, network users are exposed to taxes and levies. Taking all these into account, storage in the retail market is used for:

- Prosumers/behind the meter
- Increasing predictability of the demand pattern, which results in lower risk premium in the retail price (obviously this is related to the wholesale price)
- Ability to arbitrage market prices
- Reduction of use of grid capacity leading to lower connection costs and capacity tariff
- Avoid penalties applicable for exceeding contracted connection capacity by limiting energy withdrawal of final consumer from grid at peak hours
- Avoidance of taxes, depending on the tax regime
- Increase of security of supply (in case storage is used as back up, e.g. Uninterruptible Power Supply (UPS)).
- Off-grid consumers

This means that storage in the retail domain has a higher value in most cases because it can deliver services to both retail and wholesale markets. This is valid for all types of storage. However, arrangements like netting of self-generation (grid fees are paid only on the basis of the net electricity used from the grid and not for every time of use of the grid) reduce that value. In this context, storage can also have an “emotional” value of a higher autarky.

The market for storage is the “time domain”, the overall balancing of demand and supply. In this context storage competes with any other market flexibility resources. The value is given primarily by the wholesale market prices in the specific markets such as day-ahead, intraday or balancing the storage resource is valorised.

Box 16. Biggest battery storage development in Europe

Penso Power is developing the 150MW Minety battery storage project in the UK. The grid-scale mega battery energy storage project comprises three adjacent battery storage facilities of 50MW capacity each. Construction works were simultaneously started on two 50MW facilities in December 2019 with commissioning expected by the end of 2020. The initial 100MW project is funded by the Chinese state-owned electricity generation enterprise China Huaneng Group and the Chinese sovereign wealth fund CNIC Corporation while the China Huaneng Group is responsible for the construction and operation of the facility. Penso Power announced a 50MW expansion to the Minety battery storage project after securing a multi-year power off-take deal for the initial 100MW capacity in February 2020.

When fully charged, the 150MW battery facility will be capable of holding 150MWh of electricity which will be enough to power approximately 15,000 homes for a day. The project also involves the construction of a 132kV substation to absorb as well as evacuate power into the grid.

Source: [NS Energy](#)

Grid use of storage

Use of storage assets in system operation would:

- increase the capacity of the current grid to serve generation of new renewables, optimising infrastructure use
- support energy security and quality of supply for final users (to improve SAIDI and SAIFI)
- optimisation may be useful for current grid work and allow network development plan optimisation, deferring or decreasing infrastructure investment needs

From the network point of view, functionally, energy storage can be divided into two groups:

1. Storage facilities being grid elements ensuring the safe and reliable operation of the transmission or distribution system.

Energy storages functionalities examples in this area:

- a) Protection of transmission capacities in the highest voltage grid and distribution capacities of high, medium and low voltage networks.
 - switching to charging of energy storage if there was a high electricity generation with low demand for it,
 - switching into discharge of energy storage, if there was a small electricity generation with a high demand for it,
 - b) Compensating power flows to reduce electricity distribution losses.
 - c) Backup power supply to consumers in repairs, maintenance or emergency conditions.
 - d) Other functionalities used only to ensure the safe and reliable operation of the transmission or distribution system.
2. Storage not fully network-integrated are useful for example to increase the effectivity of RES sources operations or EV chargers, but also allow the providing of certain flexibility services to the network. Independent commercial Energy storages, which are source of system services and price arbitration, belong to this category.

Potential advantages of energy storage, related to DSOs responsibilities:

- Grid capacity support, optimising or postponing in time, where justified investments for network modernisation and reinforcement
- Shifting peak load, reducing network congestions as well as voltage fluctuations.
- Reduction of the impact of renewable energy sources on the power grid
- Voltage regulation
- Support network maintenance activities in emergency conditions. Also intended operation in island mode
- Reactive power control
- Reducing network losses
- Energy quality for final users, in this Emergency power supply (to improve SAIDI and SAIFI)
- Local technical power balancing in the DSO grid

Most of these advantages can be achieved by energy storage which are fully integrated network components. Such fully grid integrated energy storages can provide important services for network security and reliability, and contribute to improving cooperation conditions of different system parts.

In this context storage value is in the “location domain”. The value of the service is set by the local circumstances related to the transport and distribution functions of the network, but it is also related to the market value.

Storages can bring benefits to local networks if they are 1) located at the proper location with respect to congestions and 2) operated with a proper injection/consumption with respect to the load of the local network. Stacking storage business values on several markets (local DSO, local TSO, and energy markets) i.e. maximising the value of storage relies on the respect of the above 1) and 2) requirements. Additionally storage should be operated with a proper injection/consumption with respect to the load demand of the upper tension levels networks where it is connected.

In addition, it's to be noticed that the grid also delivers key services to the electrical system by connecting directly variable electricity production to storage facilities. A storage facility could be apprehended as an element of the grid infrastructure, like are today primary substations or high voltage lines.

Flexibility sources give system operators the possibility to shift in supply and demand peaks, to prevent congestion and avoid other grid operational problems. Proper use of flexibility sources also create possibilities to optimise specific network. System operators should evaluate if it is more cost-efficient than traditional grid reinforcement, in a long term perspective. All these actions should be promoted without endangering reliable and secure energy supply and without distorting/intervening in the market.

Congestion occurs inter alia when generation feed-in grows beyond the thermal limits of the network components. This may lead to emergency actions to interrupt generation supply. A similar situation can occur in case of excessive demand on the system. This can be the case when the network is subjected to very high loading conditions, for instance by charging of electric vehicles, heat pumps and electrical HVAC system.

To realise efficient operation and planning of their network, DSOs need a toolbox⁴⁶ comprising different types of solutions for undertaking congestion management and procuring flexibility at distribution level. With this toolbox, grid operators have different options and could for instance compensate network users' behaviour with flexibility to reduce or to modify their consumption on certain times.

Remuneration for the procurement of flexibility services outside the wholesale and frequency-related ancillary services market should be determined by the value of the lost transmission opportunities and the possible extra costs for investment in flexibility means and ideally be defined by a common high-level methodology agreed nationally. However, a more general approach can also be justified as being a simpler solution. As an example, transparent and open auctions appear to be a possible mechanism to set the appropriate remuneration in a fair competition framework, provided there is enough liquidity and potential market failures are avoided⁴⁷. In case there is too little competition a regulated compensation is foreseen. These kinds of services can be offered by demand and generation grid users that can include storage facilities⁴⁸; all these users are unbundled actors and deliver flexibility for a certain price.

Box 17. NICE SMART VALLEY: tomorrow's smart electricity system – smart grid.

The aim of the project is to make the electricity grid more flexible in a given area by using innovative technologies and through the participation of electricity consumers. The DSO, Enedis aims at testing new schemes for the grid management, to draw feedback from the field with its operational teams, in order to assess the benefits for the grid from flexibilities, storage and islanding, at practical level (tests on the field) as well as theoretical level (grid simulations). Energy suppliers EDF and ENGIE can experiment with demand response systems and test the customer response, but also test new business models for electricity flexibilities and assess the relevance of new services to the distribution grid. For industrial partners such as GE and Socomec, the aim is to test their technologies on a real grid and to benefit from the exchange of experiences gained in the field. Regarding storage, the project demonstrates that the level of performance of batteries depends on the services they provide and that the size of the storage in relation to the services it must provide is a key factor in achieving a technical and economic optimum.

Box 18. Smart Grid Battery projects in Austria

Low Voltage Smart Grid “Bucklige Welt”

NÖ Netz runs a Smart Grid with small windmills, a 10 kWp PV plant and a Vanadium-Redox-Flow Battery with 10 kW power and 100 kWh energy capacity. The load consists of several applications, which can be switched on and off by the controller. Their power is between 0.4 kW and 9 kW. A microgrid controller forecasts the renewable production according to the weather forecast and controls the battery in a so called peak shaving mode. This allows the smart grid applications to satisfy the load with most of the renewable energy, either directly, when produced or later (e.g. in the evening) from the battery. Once the medium voltage supply fails, the battery can start and run the island

⁴⁶ [Flexibility in the energy transition – A toolbox for Electricity DSOs, CEDEC, E.DSO, Eurelectric and GEODE.](#)

⁴⁷ Further investigations are required to tackle the challenges that come along with the concept of such an auction model.

⁴⁸ Eurelectric, [Recommendations on the use of flexibility in distribution networks](#), April 2020.

mode on its own, which increases the security of supply for the load/customers. The load applications can be switched from the microgrid controller and are classified in sensible must run applications and other which can be switched off. In island mode only the must run applications are supplied, the others are switched off. A third operating mode, grid support mode, can be managed by this smart grid setting. Within this mode the renewable generation covers the load and the rest together with the energy from the battery is injected into the medium voltage grid with a power set point to prevent congestions there and keep the balance. Once the secure technical operation of this set up with the three modes has been proven, the microgrid controller will be put in operation with “real customers” together with service bundles to prove the whole business case.

Smart Grid Battery Storage Project Prottes

Netz NÖ will erect a large battery system based on Li-Ion technology sized 2.5 MVA and 2.2 MWh at the location of a 110kV/30kV substation. The substation is in a section of Netz NÖ's grid with a high injection of wind energy. The aim of the project is to present how battery systems can contribute to system stability in addition to the contribution for covering the ancillary services in the electrical grid with high share of renewable power producers.

Source: EVN/NÖ Netz

Box 19. Battery storage to support local distribution grid in Switzerland

In December 2019, the Jona-Rapperswil town Electric Utility commissioned a 2 MW BESS. It has a rated power of 2 MW and an energy capacity of 2.2 MWh to support the local distribution grid and to provide ancillary services. A second application is peak shaving to balance, stabilize and flatten demand/generation patterns in the distribution grid. The application supports the local utility of Jona-Rapperswil as a DSO to face its challenges created by increasing distributed, fluctuating and uncertain generation from renewable energy sources.

Source: [Axpo](#)

Box 20. Battery storage to support transmission grid

Battery storage in Sweden

The transmission grid owned by TSO SvK has bottle necks close to the Uppsala region, a fast growing city in Sweden. There is a need for capacity solutions where the transmission and sub-transmission grids cannot be built in time to meet the customers' expectations. A 5MW battery attached to the 10Kv grid is expected to be in operation in summer 2020. The installation of this 5MW Li-ion will be evaluated how it may contribute to solve congestions problems, reduce investment in grids and possibly contribute to grid stabilizing services. Other activities on the demand side, e.g. management of aggregation of customers, are tested in parallel in the same area. The activities are also input in a wider context e.g. CoordiNet an EU financed project.

Battery storage in the UK

A 22MW Li-ion cluster battery at Pen y Cymoedd in South Wales in the UK is located at a wind farm creating infrastructure synergies when connected to the grid. It became operational in 2018 and was one of eight projects (with different technologies) selected by National Grid UK on commercial basis to provide Enhanced Frequency Response service to the grid network. This fast frequency response may achieve 100% output in 1 second. This service will reduce pressure on ordinary frequency response (acting in 5-10 s) when system rotating inertia delivered by large thermal generators will decrease.

Source: Vattenfall

Applications for generation

Furthermore, the co-location of energy storage with power plants can guarantee additional services for certain challenges:

- **Efficiency increase:** for instance, batteries allow a thermal plant to improve its technical performance and, accordingly, to obtain higher levels of efficiency.
- **Ramp improvement:** the integration of energy storage increases the flexibility of thermal power plants. Thermal plant operation can be optimized by bridging between stops and restarts or by providing the needed time to achieve optimal ramp-up/-down, so that fast load changes can be met.
- **Optimization of lifetime of technical equipment:** when combining for instance run-of-river hydropower with a battery, the battery is used for the very first seconds of ramping preserving the machinery
- **Profile firming:** profile firming is the particular case of energy shifting in which the energy storage transforms the typical plant production profile into a baseload profile or into any different profile required by the project off taker. This is mostly applicable to power plants with variable generation pattern such as solar PV and wind power plants.
- This use case also works with **Demand Side profile shaping** (firming) in case the storage is used between the next transformer station and the Demand connection point.

Box 21. Combined hydropower and batteries

Blue Battery on the Blue Danube: to be able to compensate better for fluctuations in the transmission grid, Verbund is planning large-scale battery storage at its Wallsee-Mitterkirchen power plant on the Danube. The Blue Battery project, a combination of a hydropower plant and a lithium ion battery, is intended to utilise synergies and improve network services.

Fortum has chosen the Forshuvud 47MW hydro plant as a pilot project for the hydro-battery concept. Batteries are used to compensate rapid fluctuations in the frequency response and the hydro plant can focus on slower regulations and support the battery to compensate the level of charge. The reduction of many small regulations on the hydro unit will reduce the wear and maintenance cost. Together with the 5MW Li-ion battery, the hydro-battery can provide a response faster than a standard turbine and at the same time improve endurance compared with a standalone battery. Presented in Hydropower & dams, Issue 1 2020.

Electric Vehicles

Electric Vehicles can be considered as widely available mobile energy storage units (and therefore can be a flexibility source).

Electric vehicles can provide flexibility to the system with both unidirectional and bidirectional technologies:

- First - V1G (vehicle 1 grid or unidirectional smart charging): this technology allows for activating a charging process or modify the power of an ongoing one. It can therefore be helpful for multiple grid services (e.g. charging can be scheduled according to: periods of cheaper electricity because of price signals; exploiting self-consumption, start charging when a generation source is operating, therefore there is an excess in

the system; reduce costs of demand charges for consumers by avoiding peaks; energy markets signal of demand response, utility programs; ...)

- Second - V2G (vehicle 2 grid or bidirectional charging): this technology allows, in addition to V1G capabilities, also to discharge the EV battery and therefore giving power back to the grid. This results in a wider grid service capability if compared to V1G.

The best technology to utilise for aggregation purposes has to be chosen according to different considerations:

- Energy and ancillary services markets available in the specific context or future local flexibility markets by DSO;
- difference in initial investments and operating costs for the two technologies, customers' behaviours and needs; etc.

In addition to these factors, the availability of EV models enabled for V2G technology is also a key factor. Nowadays only EVs with "CHAdeMO" DC charging systems are enabled to this bidirectional energy flow control, but in the next OEMs using Combined Charging System (CCS) plan to adopt an equivalent V2G enabling standard⁴⁹ (e.g. IEC 15118 ed2 on CCS or On Board bidirectional chargers). An interesting example was also recently observed, where Tesla is integrating V2G technology in their charging design where the inverter is inside the on-board charger⁵⁰. This allows using the home charger and reduces the cost to set up V2G for the user.

The importance of considering EVs as storage on wheels relies on their impact on the grid. The capability of turning the potential issue for the grid of multiple EVs charging at the same time, increasingly the peak load, into an opportunity to exploit additional GW of distributed storage when not used for mobility purposes. Multiple studies are showing that 80 to 95% of a car's time is spent parked and therefore it is possible to exploit electric vehicles flexibility while meeting customers' needs for mobility services. In any case, it shows the importance of a proper integration of transport sector in the sector integration in order to avoid negative side-effects / create positive externalities for reaching the decarbonisation targets.

Fig. 14 shows, for a given country, the hourly EV charging demand if EVs were to recharge when plugged at home (blue solid line) and the actual charging behaviour when EVs can adapt to price signals (either with smart charging behaviour or including V2G capabilities).

⁴⁹ <https://www.charinev.org/news/news-detail-2018/news/the-five-levels-of-grid-integration-charin-ev-grid-integration-roadmap-published/>

⁵⁰ <https://electrek.co/2020/05/19/tesla-bidirectional-charging-ready-game-changing-features/>

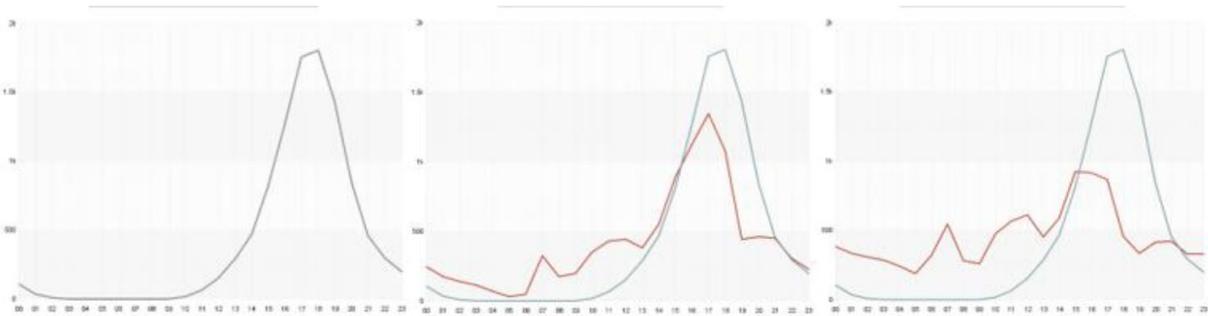


Fig. 14 - Average recharge of electric vehicles at home per hour of day. Source: EC ENER Storage report

- Blue in the three graphs: immediate charging at arrivals
- Red in the center : smart charging
- Red in right : smart charging + V2G

In a case without flexibility, charging follows exactly the EVs charging demand while in the cases where charging is flexible, charging happens mainly in early-morning before vehicles leave home and the total demand is lower, or in the early afternoon, when EVs return home and can still profit from PV generation. By optimizing EVs charging, it is possible to reduce demand night peaks and shift consumption to hours when the sun still shines.

An additional source of flexibility is on commercial energy storages built to support the operation of EV charging stations (usually high power charging station up to 1 MW). While their primary role is peak shaving, balancing electricity consumption and reducing power charges/tariffs costs paid by stations' operators for very short but high peaks, those storages could also be a source of flexibility for the system. For example, this distributed storage could serve for integrating distributed RES.

The ability to smartly connect EVs to the grid can be helpful (also in combination with distributed storage) during emergencies to supply power back to the buildings (V2H).

Box 22. first development and demonstration programme for vehicle-to-grid (V2G) technology in Italy.

Energy technology research firm RSE has partnered with Enel X and Nissan to launch the first development and demonstration programme for vehicle-to-grid (V2G) technology in Italy. Enel X is providing its bi-directional electric vehicle charging system for installation at microgrids owned by RSE. An advanced control platform will be used to optimise charging and discharging of energy from Nissan Leaf vehicles. The V2G pilot project is the first in Europe to trial multiple functions including ancillary services such as the optimisation of user electricity flows. The aim is to enable EV owners to store and deliver energy to help stabilise the main grid as well as accelerate the adoption of EVs in the region. The pilot will help consumers to generate extra revenue by discharging energy to the main grid.

Source: [Smartenergy](#).

Box 23. SYNERG-E. Managed batteries

The project's overall objective is to create synergies between the energy (electricity transmission and storage) and transport (EV charging) infrastructure and to remove barriers for the future roll out of charging stations in Europe. Ten stationary battery storage systems (approx. 0.5 MW each) are deployed in Austria and Germany in a real-life-trial to test installation and management of these batteries for a future roll out at high power EV charging stations. The batteries will serve the HPC stations with a reliable and cost-effective grid connection on the one hand, as well as provide grid services for TSOs. With increasing deployment of HPC networks across Europe, the challenges for the electricity grid will increase. This leads to an increasing problem regarding grid connection at locations most suitable for EV charging, like highway stations, shopping centres or petrol stations. Additionally the electricity generation becomes more and more volatile which increases the requirements for balancing the electricity grid. The SYNERG-E project addresses both challenges by securing a reliable power connection for HPC network operators on the one hand and providing grid services for transmission system operators (TSO) on the other hand. SYNERG-E is a first step to test how local storage systems could provide solutions for these challenges.

Source: [SYNERG-E project](#)

Box 24. Bi-directional charging for electric cars to store solar energy

Audi and the Hager Group will test a new bi-directional charging system: the electric vehicle will store the excess electricity from rooftop PV not used by home appliances. If the customer has variable rates, the EV can supply the entire house when electricity prices are high. At night or during non-productive times of the rate, the car then uses inexpensive electricity to charge up to the desired target SOC (state of charge). Besides, in case of a blackout, the system can supply electricity through the high-performance HV battery.

Source: [Electrek](#)

Energy Communities

The revised Renewables Directive and the Electricity Directive in the Clean Energy Package provide an enabling framework respectively for “renewable energy communities” and “citizen energy communities”. It gives Energy Communities the right to engage in electricity generation, distribution and supply, consumption, aggregation, storage or energy efficiency services.

The development of Citizens Energy Communities using renewable generation at local scale could be a key driver for decarbonisation and consumer's empowerment. They may indeed represent an important added-value for the system and have significant potential for both demand-side flexibility and storage in times of abundant renewable generation through the development of renewable self-generators, electric vehicles and stationary

batteries⁵¹.

Box 25. Collective self-consumption projects

Harmon'Yeu, launched with the town hall of Île d'Yeu, is a collective self-consumption project involving solar energy. The first of its kind in France, it enables 23 households to share the electricity generated by five of them using photovoltaic panels installed on their roofs. Electricity that is not consumed instantly is stored in a communal battery and then in hot water tanks for later use. The energy is distributed dynamically using smart software developed by ENGIE. A similar project is developed in Oud-Heverlle, Belgium, involving 15 neighbours.

Source: [ENGIE](#)

Islands

Electricity systems in islands face technical, market and regulatory particularities that distinguish them from systems in the mainland. This is especially the case for non-interconnected systems, whereas interconnections alleviate only certain aspects, and up to a certain degree, of their insularity. The EU has been endorsing this diversity through various processes, including the [Initiative for Clean Energy for EU Islands](#), special provisions in the Clean Energy Package and, most recently, in the Green Deal.

Energy storage, as a concept, answers critical challenges posed by the insularity nature of islands electricity systems, while acting as an integrator for the various island electricity systems components.

⁵¹ See JRC, [Energy communities: an overview of energy and social innovation](#), 2020 & Eurelectric, [Citizens Energy Communities: Recommendations for a successful contribution to decarbonisation](#), May 2019.

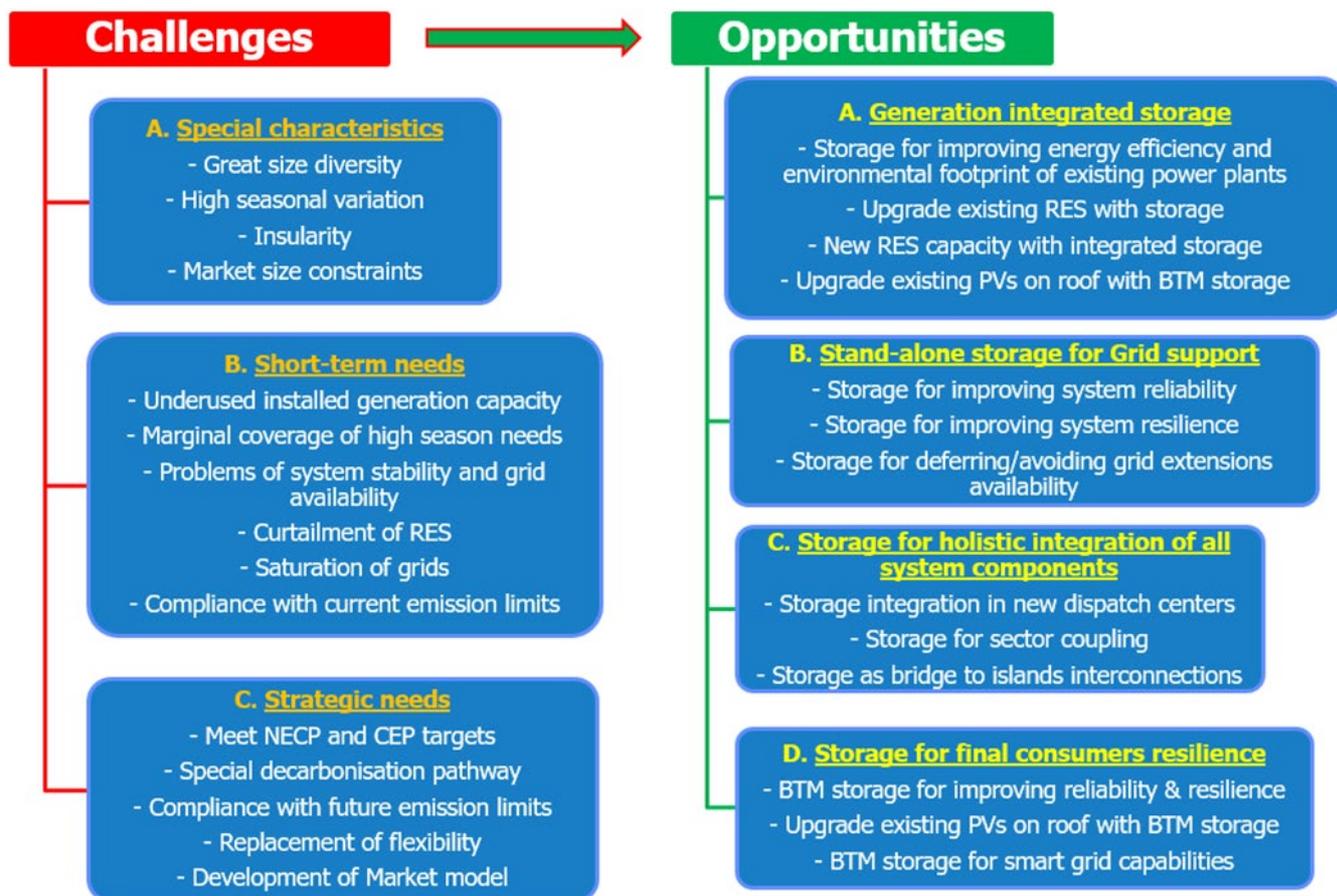


Fig. 15- challenges and opportunities for electricity systems on islands. Source: PPC.

Box 26. Hybrid wind-hydro system on Greek island

In 2019, Greece's Public Power Corporation (PPC) launched a system combining wind and hydropower and energy storage on the -non-connected- island of Ikaria. The main objective of the project is to increase the penetration of RES into the island power system and to reduce the electricity produced by an oil-fired power station.

PPC Renewables has invested EUR 50 million in the project, which will secure 50% of the island's energy needs and decrease CO₂ emissions by 13,800 tonnes a year. The wind-hydro system includes a 2.7 MW wind farm, two hydropower plants with an installed capacity of 4.1 MW, a 3 MW pumping station, two water tanks, and one water reservoir. Estimated power generation of the system is around 9.8 GW/h per year.

The wind farm is capable of delivering electricity directly to the grid, and also to the pumps when there is low demand for the electricity. Pumps are using the energy from the wind farm to pump the water from lower to higher reservoirs. The pumped-storage hydropower plant acts as energy storage and uses water from higher level reservoirs to generate electricity. The hybrid system will be controlled by the Grid Master Control System, which will regulate the availability of energy, frequency, voltage regulation, fuel economy, emission reduction, and noise reduction. The estimated power generation of the system is around 9.8 GW/h per year.

Coal Regions in Transition/Coal-fired power plants

The energy transition in coal regions in Europe leaves areas –which for some Member States can be of substantial socio-economic importance– with extensive installations (coal thermal power plants) and mines (open or underground). Energy storage applications can:

- give a second life to these sites and therefore contribute to maintaining the activities of the electricity industry in these transition regions, thus significantly benefiting the social and economic cohesion in the EU,
- significantly benefit, technically and economically, from the existing highly skilled human capital and the infrastructure capital from the electricity resources in these regions.

Energy storage installations can play a protagonist role in these energy hubs which can evolve in the coal transition regions, by exploiting:

1. Decommissioned (or soon to be) fossil fuelled power plants

- o Decommissioned coal/lignite thermal power plants can be refurbished into very high capacity thermal storage installations by the use and transformation of the existing steam cycle of the power plants, in particular in Southern European countries. For instance, solar thermal power plants share with conventional coal-fired power plants a significant set of equipment (steam cycle, turbine and alternator) that allow the idea of a second life for coal-fired power plants as storage stations. This use of sites, equipment and connections to the already existing grid substantially improves the viability analysis of the facilities and represents an intelligent resource optimization strategy, both from an economic and environmental point of view.
- o Existing electrical facilities and civil work installations can be utilized for accommodating storage applications of various technologies (electrochemical storage, thermal storage, etc) which can be deployed within or adjacent to the old power plants.

2. Depleted (or discontinued) coal mines

- o Exhausted coal/lignite open mines offer the potential of vast areas which could be examined for use as water reservoirs for low-head pumped-storage installations, while also accommodating surface demanding renewable generation (e.g. PVs). Similarly, depleted underground mines could also be examined as reservoirs for pumped-storage installations.
- o Very large storage capacities can be achieved with minimum additional environmental implications from new installations (avoiding creation of new water reservoirs), contributing fast and with a small footprint to the achievement of the national targets for new large storage capacities.

Box 27. Green electricity from old coal mines

There were plans to turn the now closed coal mine of Prosper-Haniel (it closed in 2018) into an underground pumped hydro storage, using the existing coal mining infrastructure. It was set to become a 200MW pumped-storage hydroelectric reservoir, behaving as a battery and with the energy to power more than 400,000 homes. When

needed to compensate variable wind and solar power, as much as 1 million cubic meters of water could be allowed to plunge as deep as 1,200 metres, turning turbines at the foot of the collieries mine shafts. The mining complex comprises 26 kilometres of horizontal shafts. The feasibility study was completed in 2018 and the project drew international interest but the investment decision has yet to be made.

Annex III – Short introduction to the different markets in which storage can be valorised

Energy markets are used for delivery or off-take of electricity and the main market in the European electricity system. They go from forward markets (Y-5 years) to real-time intraday or balancing markets, depending on the market design.

Energy markets

- **Forward market**

The forward markets are mainly used to protect both consumers and producers against price risks. The markets remain mainly national until cross-zonal long-term transmission rights are auctioned, which in most cases are auctioned one month in advance, are baseload products and can cover a yearly, quarterly or monthly period. As a result, liquidity on forward markets vary considerably between countries. Even in the most liquid markets, the ability of market participants to hedge effectively against price risks does not exceed a three to four year horizon.

- **Day-ahead market**

The day-ahead market is currently the reference short-term market timeframe with the largest pool of liquidity. It is used by market participants to close their positions and schedule generation capacity. Through the use-it-or-sell-it mechanism, all available cross-border transmission capacity is available for the day-ahead market to exchange energy flows between countries. As the day-ahead market clears according to the pay-as-cleared principle, each market participant receives or pays the single clearing price. The market also provides a reliable indicator of potential scarcity moments, as most supply and load are being traded on this market.

- **Intraday market**

The intraday market is currently used mainly by market participants to rebalance any deviations from the schedules of the day-ahead market based on new elements. Such elements can be unexpected outages, changes in demand or reforecasts of (variable) renewable energy sources. As these elements can also result in scarcity, the intraday market can at moments signal a scarcity that was not present in the day-ahead market. The Intraday market is a continuous trading market, where prices are based on the outcome of bilateral trades.

- **Balancing market**

The balancing market is not a full market where market participants can exchange energy freely. It is instead an ‘obligatory’ market where market participants with residual imbalances in their portfolio are forced to buy or sell energy at the imbalance price. The imbalance price is a reflection of the cost for the Transmission System Operator to resolve such imbalances. The imbalance price is thus mainly driven by short-term imbalances between supply and demand

- **Congestion Market**

If such market is implemented, cooperation between TSO and DSO is here important. Market products for the services procured should be created ensuring effective participation of all market participants including RES, demand response, and Flexibility

Service Providers (e.g. aggregators, suppliers, prosumers). The products should include the locational information. DSOs should be committed to cooperate with stakeholders to define the specifications required to guide market parties who will provide local flexibility products. It must be clear that the DSO should always be in control of the congestion management services in its system.

Capacity markets: their aim is to ensure the availability of capacity to ensure system integrity. In the European markets, currently two main categories of capacity markets exist: (long-term) adequacy capacity markets and (short-term) ancillary services capacity markets, such as balancing capacity; and congestion management markets. Capacity markets are rather complementary to the energy market, and do not necessarily cover all capacity in the market.

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Eurelectric pursues in all its activities the application of the following sustainable development values:

■ Economic Development

Growth, added-value, efficiency

■ Environmental Leadership

■ Commitment, innovation, pro-activeness

■ Social Responsibility

■ Transparency, ethics, accountability



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