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COMMISSION STAFF WORKING DOCUMENT

Energy Storage - Underpinning a decarbonised and secure EU energy system

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Executive summary

The rapid ongoing deployment of variable renewable energy generation will only reach its full potential with the deployment of additional energy storage[1].

The future energy system will need more flexibility, stability and reliability to achieve the objectives of the European Green Deal and the REPowerEU initiatives.

Energy storage can play a crucial role in the current and future energy system. It can help decarbonise the economy and increase the efficiency and security of energy supply by **providing flexibility, stability and reliability**. Energy storage can also: (i) **lower electricity prices during peak times**; (ii) reduce price fluctuations; and (iii) **empower consumers** to adapt their energy consumption to prices and their needs. The diversity of energy-storage technologies makes them suitable for many applications. And it is important to fully exploit the added value they can bring to the energy system and its users, together with other flexibility tools and energy-efficiency measures, while taking into account their environmental impact.

Energy storage provides flexibility. And flexibility needs increase greatly – in some cases exponentially – when the share of variable renewable generation in the electricity system is above 74% of total installed capacity[2]. Substantial investment therefore needs to be directed to energy storage, including thermal energy storage and long-duration energy-storage technologies, to ensure a cost-effective, deep, and secure decarbonisation of the energy system. Debt financing has an important role to play in this investment. Furthermore, energy storage technologies can be an important element in interlinking electricity to other forms of energy, e.g. through hydrogen and power-to-x technologies.

Different EU regulations, initiatives and financial tools support the development and deployment of energy storage in the EU. Nevertheless, the necessary uptake of energy storage in the EU could be further increased, including via: **the timely and full implementation of EU electricity-market legislation at national level.**. In particular, the **double role (consumer- generator) of energy storage (i.e. energy storage both 'consumes' energy, when it absorbs electricity from the grid, and 'produces' energy, when it reconverts stored energy into electricity) requires special treatment** when setting the regulatory framework and procedures. In addition, **tailored support may be necessary,** in particular for technologies that have better carbon, environmental and material footprints and technologies that have a greater potential to contribute to decarbonisation objectives and the security of energy supply.

On financing, increasing the revenues from – and reducing the risks associated with – energy-storage projects could mobilise private financing. Every potential service that can be provided by energy-storage technologies and that can be monetised enables a wider combination of different revenue streams **('revenue stacking').** In particular, the services that revenue stacking should focus on are the use of flexibility in distribution networks and the provision of non-frequency ancillary services[3]. Furthermore, **the long-term visibility and predictability of revenues**, as well as regulatory stability, help to reduce the risk profile and improve the investment case for energy-storage projects. However, the different storage technologies may require different business models

[1] This Staff Working Document refers to energy storage as defined in Article 2(59) of Directive (EU) 2019/944 on common rules for the internal market for electricity (OJ L 158, 14.6.2019, p. 125- 199) as well as thermal storage using heat as an input. It does not cover gas storage or oil storage/stocks.

[2] Energy Transition Expertise Centre (EnTEC), Study on Energy Storage, 2022, https://data.europa.eu/doi/10.2833/333409

[3] Other sources of revenue stacking may come from short term (day-ahead and intraday) markets.

depending on their characteristics and applications. Different public and private supporting tools and enabling signals could further facilitate the development and deployment of energy storage. There is particularly good scope for additional tailor-made financing models for 'behind-the-meter' storage (i.e. energy storage in the energy consumer's home).

Energy storage could be further exploited by network operators when planning their networks, granting access to these networks, and operating the energy system. Incentives for system operators to opt for innovative solutions and less costly network investments could increase the role of storage as 'network upgrade deferral' assets. In addition, **well-designed network charges and tariff schemes** with locational and temporal signals (that can alter pricing based on the time of day or week or based on where the energy is being produced/used) could further increase the use of energy storage and help to reduce consumption during peak hours. Currently, there are no **specific network charges and tariffs for energy storage, but such tariffs and charges could be explored further** on both the consumer side and the generator side. **Permit-granting procedures** for utility-scale energy-storage projects are considered lengthy and complex and do not always take into consideration the specificities of energy storage.

Raw materials used by several energy-storage technologies have been identified as critical. These raw materials require specific monitoring to ensure resilient supply chains of energy-storage technologies in the EU.

Market and regulatory conditions in each Member State also affect and determine the deployment of energy storage. The main drivers observed in Member States have been specific **ancillary services** (e.g. the fast-frequency response market) **and supporting schemes** (e.g. capacity mechanisms or tax breaks). In addition, several Member States have added a **definition of energy storage** into their legislative framework, reducing the risk that energy storage might be treated as both a consumer issue and a producer issue. Some Member States have also adopted **strategies or national targets in their National energy and climate plans (NECPs)** for energy storage for 2030 and 2050 to incentivise the deployment of energy storage at national level.

The maturity and competitiveness of energy storage in terms of costs and capacity is improving worldwide, but significant efforts are still required to advance mature technologies and develop emerging ones. Alongside the research and innovation programmes at EU and national level, **regulatory sandboxes** could further help to develop demonstration projects for less-mature storage technologies.

The **development of flexibility services and new market products (such as fast-frequency response services or non-frequency ancillary services) could bring additional opportunities** for energy-storage technologies. **Capacity mechanisms incentivising renewable and low-carbon technologies could further support** the development of energy storage, and long-duration energy storage in particular, interlinking electricity to other forms of energy, e.g. through hydrogen and power-to-x technologies. Two initiatives will be critical in this area: (i) the **revision of the EU's electricity-market design;** and (ii) the forthcoming **EU network code on demand-side flexibility**. These two initiatives can play a role in: (i) facilitating the deployment of flexible resources to complement intermittent renewable production; and (ii) addressing specific barriers for distributed flexibility sources, including energy storage.

The development of **standards** can also facilitate the rapid deployment of **behind-the-meter storage**. And the huge potential of **electric vehicles** could be further exploited to increase cost savings for their users and to ensure the flexibility and security of the electricity system.

Transparency, data availability and sophisticated analytical tools are crucial for making decisions about the location of new energy-storage facilities. These tools will also be crucial for structuring the investments in these facilities and for evaluating these investments.

In conclusion, **the EU regulatory, market, and financing frameworks already provide the conditions needed to exploit the value of the different energy-storage technologies**. Nevertheless, there is **remaining potential to be unlocked** to provide benefits to consumers and to ensure a cost-effective and environmentally positive transition to the future energy system in the EU.

1. Introduction

The EU energy system is undergoing a profound transformation, characterised by: (i) an increasing share of renewable energy sources; (ii) more players; and (iii) more decentralised, digitalised and interconnected systems. This offers new opportunities to the energy sector but also new challenges, including in the current context of high energy prices.

The EU objective is to become climate neutral by 2050, with an intermediate target of a 55% net reduction of greenhouse-gas emissions compared to 1990 levels by 2030. The **European Green Deal**[4] laid down the strategy to achieve this objective, reinforced in the Fit for 55 package[5], which was turned into a legal obligation by the **European Climate Law**[6]. The production and use of energy account for more than 75% of the EU's greenhouse-gas emissions, and decarbonising the EU's energy system is therefore critical to reach these climate objectives.

Given the current geopolitical circumstances caused by Russia's unjustified invasion of Ukraine and weaponisation of its energy supply, a renewed priority has been given to reducing dependency on fossil fuels and shielding European consumers from high and volatile energy prices. The **REPowerEU Communication**[7] and the **REPowerEU plan**[8] put in place measures to make Europe independent from Russian fossil fuels well before 2030 through energy savings, diversification of energy supplies, and the accelerated deployment of renewable energy.

The EU's future energy system will need more flexibility, in part to complement the massive and rapid deployment of variable renewable generation and the phase-out of fossil-fuelled generators, while ensuring security of energy supply and an affordable energy transition. System flexibility could be defined as the ability of the energy system to adapt to the changing needs of the grid and the ability to manage the variability and uncertainty of demand and supply across all relevant timescales[9]. The future energy system, including the heating and cooling sector, will need to adapt generation and consumption to optimise and balance the energy system and to delay the consumption of excess variable renewable energy production – during sunny and windy days – to the times when energy is more needed ('energy shifting'). This will increase the overall efficiency and resilience of the energy system.

System behaviour, the way energy is produced and consumed will also change significantly in the coming years, with more variable renewable technologies, the increase of electronic interfaced devices, and the reduction of conventional synchronous generators. All these changes **will require more ancillary services to ensure the stability and reliability of the system, and ultimately, the**

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[4] COM/2019/640 final, https://ec.europa.eu/info/publications/communication-european-green-deal_en. On the top of climate neutrality, European Green Deal aims at halt biodiversity loss, reduce and eliminate pollution, and decouple economic growth from resource use through circular economy approaches.
[5] COM(2021) 550 final
[6] Regulation (EU) 2021/1119 establishing the framework for achieving climate neutrality, http://data.europa.eu/eli/reg/2021/1119/oj.
[7] COM/2022/108 final, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2022%3A108%3AFIN.
[8] COM/2022/230 final, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2022:230:FIN.
[9] IEA, Status of Power System Transformation 2019 – Power system flexibility, Technology report, May 2019, https://iea.blob.core.windows.net/assets/00dd2818-65f1-426c-8756-9cc0409d89a8/Status_of_Power_System_Transformation_2019.pdf.

security of energy supply[10]. Moreover, such services will have to be increasingly provided by low-carbon technologies.

Energy storage is key to providing the necessary flexibility, stability and reliability of the whole energy system. Energy-storage technologies are diverse and have different features that make them suitable to provide many services to the energy system and contribute to the decarbonisation goals. In particular, **energy storage can support the integration of renewable energy, the electrification of the economy, and the decarbonisation of other economic sectors**. Energy storage is therefore a key pillar of energy-system integration. **Energy storage also makes it easier for consumers to manage their use of energy and participate in energy markets**. Furthermore, energy-storage technologies could be fairly rapidly deployed (assuming that the right regulatory framework and incentives exist) as a short-term measure to support energy security and help achieve the REPowerEU objectives. For example, batteries could be deployed in less than one year for stand-alone projects or in a matter of days for behind-the-meter storage. This would contribute to both energy efficiency and demand response.

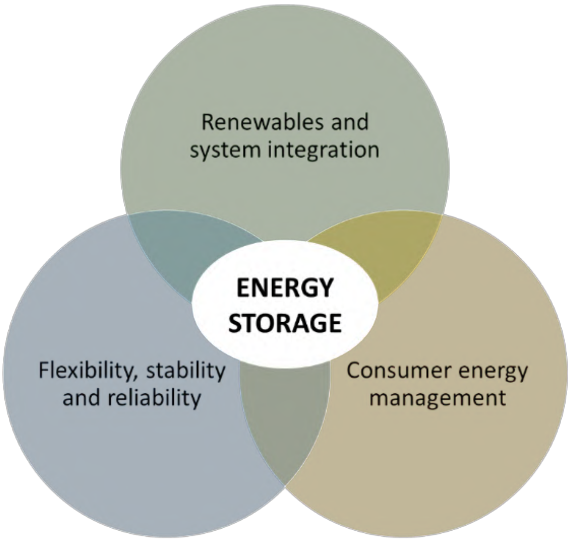

Figure 1.The contribution of energy storage to decarbonisation and security of supply

The rapid ongoing deployment of renewable energy generation will only reach its full potential with the deployment of additional energy storage, which needs to be able to accompany the rapid deployment of variable renewable energy generation. This can be a challenge because the need for energy storage is directly related to the share of specific renewable production sources in the power system. For some types of renewable energy, such as solar photovoltaics, storage needs grow exponentially with the increase in renewable energy deployment. Energy-storage technologies should be further developed to make it possible to store large quantities of energy at a competitive price. In addition, the phase-out of fossil fuels in the energy system increases the need for a radical shift in the way we supply and store energy, in particular electricity and heat. Therefore, substantial investments will need to be directed to energy storage to ensure a cost-effective, deep and secure decarbonisation of the energy system.

This Staff Working Document analyses the role of energy storage in the energy transition. It identifies potential barriers, opportunities and best practices applicable in the EU for the

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[10] ENTSO-E, Stability Management in Power Electronics Dominated Systems: A Prerequisite to the Success of the Energy Transition, Position Paper, June 2022, https://eepublicdownloads.azureedge.net/clean-documents/Publications/Position%20papers%20and%20reports/220616_entso-e_pp_stability_management.pdf.

development and deployment of energy storage. It considers the EU's current regulatory, market, and financing framework and existing proposals following the European Green Deal and REPowerEU. The Staff Working Document follows up on the Commission's Staff Working Document on the role of energy storage in the context of the Clean Energy for all Europeans package[11] and the European Parliament resolution on a comprehensive European approach to energy storage[12].

2. Energy storage in the energy transition

2.1. Role of – and applications for – energy storage

The great diversity of energy-storage technologies[13] makes them suitable for many applications, including: generation-support services; grid-support services; ancillary services; and energy-management services for consumers[14].

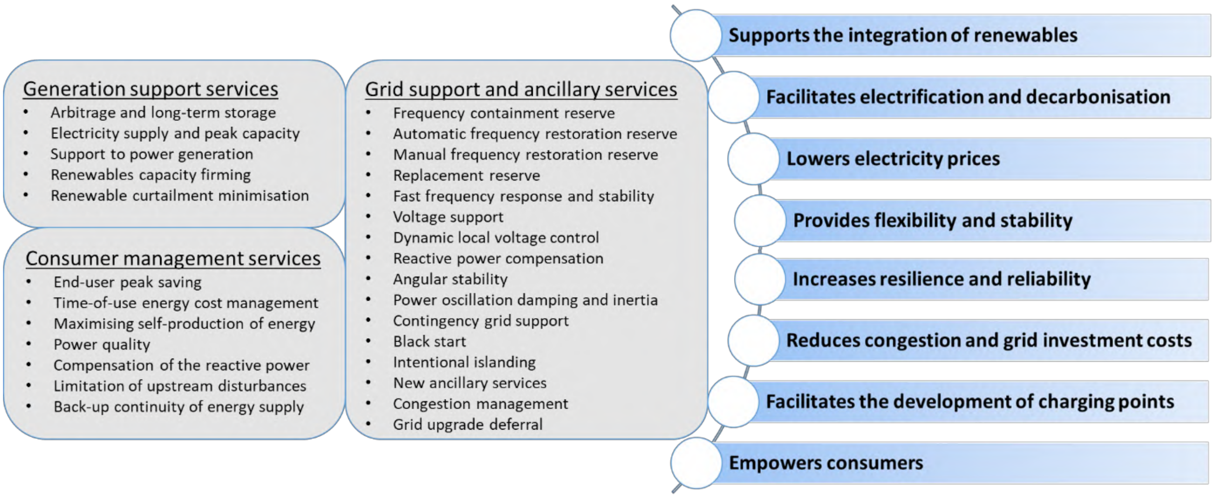

Figure 2. Energy-storage applications and added value

To fully understand energy-storage technologies and applications, it is necessary to understand the **process of storing energy**, which can be divided into three phases: (i) absorbing electricity from the electricity grid or from a directly connected power generator; (ii) storing that electricity in the form of electricity or any other energy carrier; and (iii) reconverting the stored energy into electricity (power-to-x-to-power) or using the stored energy as another energy carrier itself (power-to-x).

It is important to fully exploit the significant added value[15] that energy-storage technologies can bring to the energy system and its users. The numbered paragraphs below briefly detail the eight main services provided by energy storage.

1) **Energy storage supports the integration of renewables (including thermal energy) into the system by:** (i) managing variable renewable-generation output; (ii) maximising

[11] SWD(2017) 61 final, https://energy.ec.europa.eu/system/files/2017-02/swd2017_61_document_travail_service_part1_v6_0.pdf.
[12] European Parliament resolution of 10 July 2020 on a comprehensive European approach to energy storage, 2019/2189(INI), https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020IP0198.
[13] EASE, Energy storage technologies fact sheets, https://ease-storage.eu/energy-storage/technologies/.
[14] EASE, Energy storage applications fact sheets, https://ease-storage.eu/energy-storage/applications/.
[15] IRENA, Electricity Storage Valuation Framework - Assessing system value and ensuring project viability, March 2020, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Mar/IRENA_storage_valuation_2020.pdf.

renewable generation depending on grid and market circumstances; and (iii) increasing the capacity of congested grids so that new renewable-generation facilities can be deployed.

2) **Energy storage facilitates the electrification of the economy and the decarbonisation of other economic sectors** by buffering renewable energy in electrical energy or other energy carriers, like thermal energy or hydrogen. This also facilitates the electrification of isolated areas.
3) **Energy storage reduces price fluctuations and electricity prices** during peak times and by providing peak capacity and by 'shifting' energy from periods of low prices (or energy surplus) to periods of high prices (or energy deficits), thus smoothing out fluctuations and peak demand in renewable generation.
4) **Energy storage provides flexibility and stability to the electricity system** as a low-emissions alternative technology to fossil-fuelled power plants providing peak capacity, balancing, and non-frequency ancillary services.
5) **Energy storage increases the resilience and reliability of the energy system** by providing restoration capabilities if there is a loss of primary power supply in the electricity system and by serving as an alternative, low-carbon back-up solution if there are interruptions to the supply of energy.
6) **Energy storage reduces congestion and grid-investment costs,** particularly in areas with favourable renewable-generation potential. It does this by providing network-congestion-relief services in congested grid areas to absorb locally produced renewable electricity. This avoids, defers, or reduces the need for new construction or for upgrades of transmission and distribution networks.
7) **Energy storage facilitates the integration of charging points for electric vehicles into the electricity system** by reducing investments in upgrades to the local grid infrastructure and reducing costs related to peak-energy consumption during fast charging.
8) **Energy storage empowers consumers** by maximising 'self-consumption' of local renewable energy (i.e. consumers using the energy that they themselves have produced) and increasing energy efficiency. This reduces consumers' energy bills (both the fixed and variable components of these bills) and increases their participation in electricity markets as active consumers, including through energy communities.

Figure 3 and Figure 4 illustrate the **different characteristics and capabilities** offered by energy-storage technologies as well as the **different maturity levels of these technologies**[16].

[16] Energy Transition Expertise Centre (EnTEC), Study on Energy Storage, 2022, https://data.europa.eu/doi/10.2833/333409.

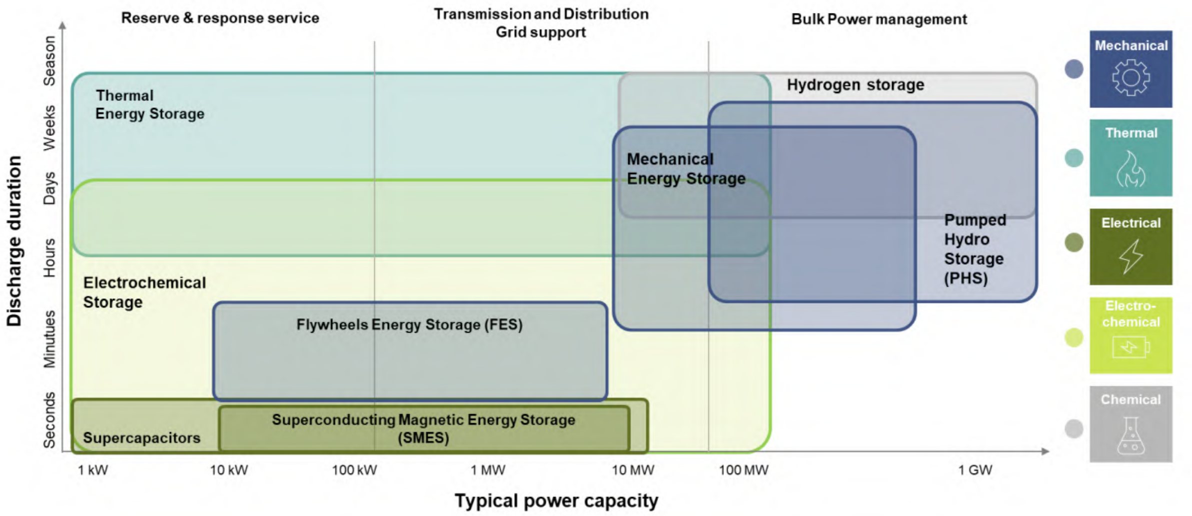

Figure 3. Power ranges and discharge duration of different energy-storage technologies. Source: EASE, Energy Storage Targets 2030 and 2050: Ensuring Europe's Energy Security in a Renewable Energy System, 2022.

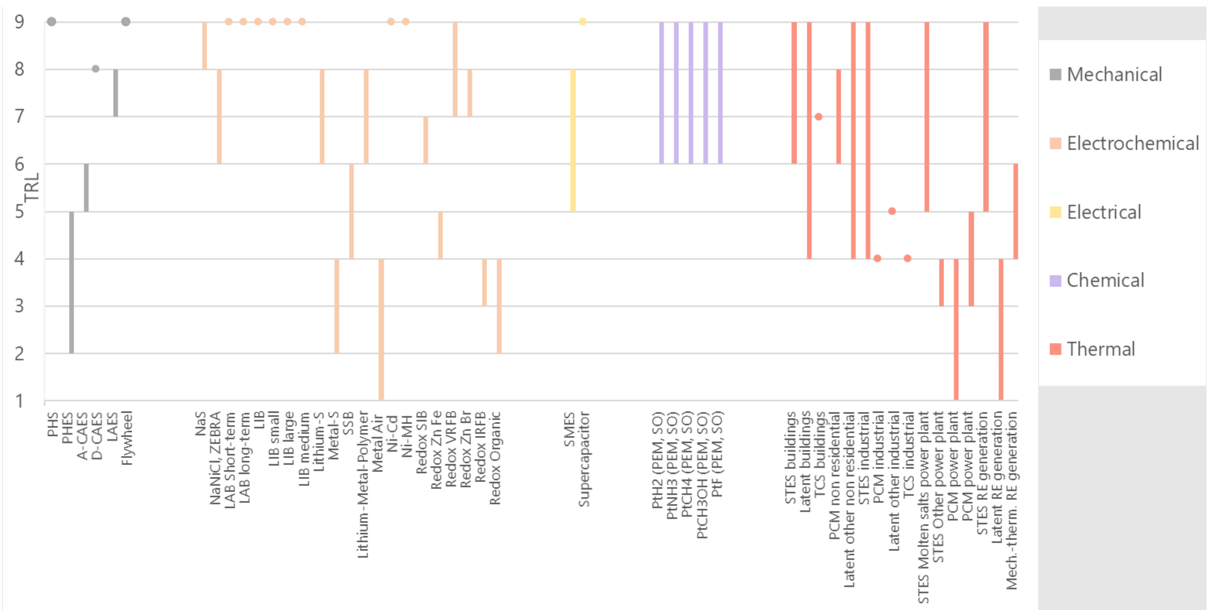

Figure 4. Technology readiness levels (TRLs) of energy-storage technologies. Source: Fraunhofer, EnTEC Study on Energy Storage, 2022.

Behind-the-meter energy storage will be especially useful in helping households and industries to: (i) maximise self-consumption of self-produced renewable energy (including thermal energy); and (ii) adapt their energy consumption to price signals. This will ultimately reduce energy bills – both the energy component and the component related to network charges, tariffs and levies. By reducing energy consumption from the grid and 'shifting' energy consumption to periods of lower prices, behind-the-meter energy storage reduces the energy component of the bills. Additionally, it allows consumers to reduce their peak energy withdrawal from the grid, allowing them to potentially reduce their contracted capacity, thus reducing their network charges and tariffs. The cost-efficient use of decentralised storage and its integration into the energy system should be enabled on an equal footing and in a non-discriminatory manner in the energy system.

Behind-the-meter storage also helps households and industries to participate in the electricity markets as active consumers and providers of flexibility services, including through energy communities. As highlighted in the EU solar energy strategy[17], behind-the-meter energy storage could increase the benefits of decentralised solar installations and demand-side flexibility[18]. Furthermore, **it can provide power quality and reliability of energy supply to specific users** (e.g. for specific high-level power-quality requirements or as a low-emission back-up technology if there are outages in the grid).

Thermal energy storage is an essential enabler for the decarbonisation of the energy system, in particular to replace fossil fuels with renewable-energy solutions in heating systems. Storing energy to complement renewable heating and cooling generators as part of individual and district heating systems makes it possible to cover a higher proportion of heating demand with variable and low-temperature renewable sources (such as shallow geothermal, solar thermal, and ambient energy) especially in buildings. Thermal energy storage can make it possible for renewable heating systems to achieve the same performance level as fossil-fuel heating systems and thus eventually replace fossil fuels in heating and cooling.

In addition, thermal storage, in particular large thermal storage in district heating systems, can provide flexibility and balancing services to the electricity grid. In so doing, it can become a cost-saving, system-integration solution by absorbing variable production of renewable electricity (e.g. from wind and solar) when it is abundant and in surplus and storing it for later use for heating or cooling (e.g. via energy 'shifting'). Thermal storage deployed together – and integrated – with renewables-based heating and cooling generators in individual and district heating and cooling systems is essential to maximise the capacity of renewable-energy sources to cover heating demand. It is particularly needed in buildings (for space heating and sanitary hot water) where it can make the most impact and increase energy-efficiency. It is important for vendors and installers of heating systems to provide combined solutions, especially for residential and SME customers. This is because such combined solutions make it easier for customers to access cost-saving and energy-saving renewable heating and cooling technologies.

[17] COM/2022/221 final, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2022:221:FIN.
[18] SolarPower Europe, Unleashing the Potential of Solar & Storage, 2021, https://api.solarpowereurope.org/uploads/Mini_report_FINAL_59a73bf607.pdf.

Spotlight on the role of thermal-energy storage

Thermal-energy storage has a very important role to play in the energy transition. This is because heating and cooling are responsible for more than half of the total final energy consumption in the EU[19], and the share of electricity used for heating and cooling is expected to increase in the coming years[20].

There is a wide variety of thermal-energy-storage technologies (using sensible, latent or thermos-chemical heat storage). They vary in temperature levels, applications and technological maturity. **The different thermal-storage technologies could play many roles in 'shifting' the final use of electrical and thermal energy[21],** including through the thermal inertia of assets themselves (e.g. building spaces, water tanks or fridges). District heating and cooling systems, industries, buildings, and households could benefit from thermal storage, which would give consumers more flexibility and greater cost savings[22]. In addition, thermal storage plays an essential role in thermoelectric solar-power plants.

Thermal storage (whether it involves: (i) renewable electric input and heat output; or (ii) renewable heat input and heat output) is an integral part of renewable and highly efficient heating and cooling systems that replace high-temperature fuels in general and fossil fuels in particular. Thermal storage in all sizes and with all storage timescales (including seasonal and long-term thermal storage) is necessary to complement renewable heating and cooling generation technologies.

2.2. The increasing need for flexibility, stability and reliability

System flexibility is particularly needed in the EU's electricity system[23], where the share of renewable energy is estimated to reach around 69% by 2030 and 80% by 2050[24]. **Significant system-flexibility technologies – both short duration and long duration – will need to be deployed quickly** to provide the necessary flexibility solutions in line with the future needs of the system and the gradual phase-out of fossil-fuel generation[25].

As shown in Figure 5, **the need for flexibility in the electricity system will increase significantly in all Member States, reaching 24% (288 TWh) of total electrical EU demand in 2030 and 30% (2 189 TWh) by 2050 across all timescales.** The daily, weekly and monthly flexibility[26] requirements reach averages of 2.52 TWh/day, 14.6 TWh/week and 41.68 TWh/month by 2050 (Figure 6)[27].

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[19] DG ENER, Mapping and analyses of the current and future (2020 - 2030) heating/cooling fuel deployment (fossil/renewables), September 2016, https://energy.ec.europa.eu/mapping-and-analyses-current-and-future-2020-2030-heatingcooling-fuel-deployment-fossilrenewables-1_en.

[20] COM(2020) 299 final, https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=COM:2020:299:FIN.

[21] HEATSTORE, Evaluation of new business models for flexible energy systems with UTES in Europe, 2021, https://www.heatstore.eu/documents/HEATSTORE_WP6_D6.3_Final_2021.06.03.pdf.

[22] Energy Transition Expertise Centre (EnTEC), Study on Energy Storage, 2022, https://data.europa.eu/doi/10.2833/333409.

[23] IEA, Power systems in transition Challenges and opportunities ahead for electricity security, October 2020, https://iea.blob.core.windows.net/assets/cd69028a-da78-4b47-b1bf-7520cdb20d70/Power_systems_in_transition.pdf
EURELECTRIC, Charge! - Deploying secure & flexible energy storage, October 2020, https://www.eurelectric.org/energy-storage-2020/.

[24] SWD(2022) 230 final.

[25] ENTSO-E, A Power System for a Carbon Neutral Europe, 2022, https://eepublicdownloads.entsoe.eu/clean-documents/tyndp-documents/entso-e_Vision_2050_report_221006.pdf.

[26] Beyond daily, weekly and monthly flexibilities other timeframes exist, varying from very long-term (intra-year) to very short-term (incl. intraday and balancing)

[27] European Commission, JRC, Koolen, D., De Felice, M. and Busch, S., Flexibility requirements and the role of storage in future European power systems, 2023, https://publications.jrc.ec.europa.eu/repository/handle/JRC130519.

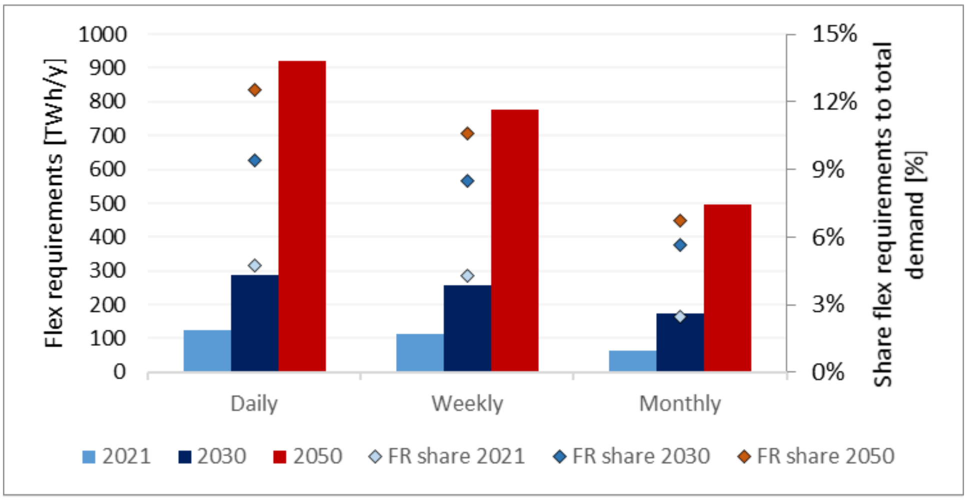

Figure 5. Daily, weekly and monthly flexibility requirements in the EU in 2021, 2030 and 2050. Source: JRC Flexibility requirements and the role of storage in future European power systems, 2022.

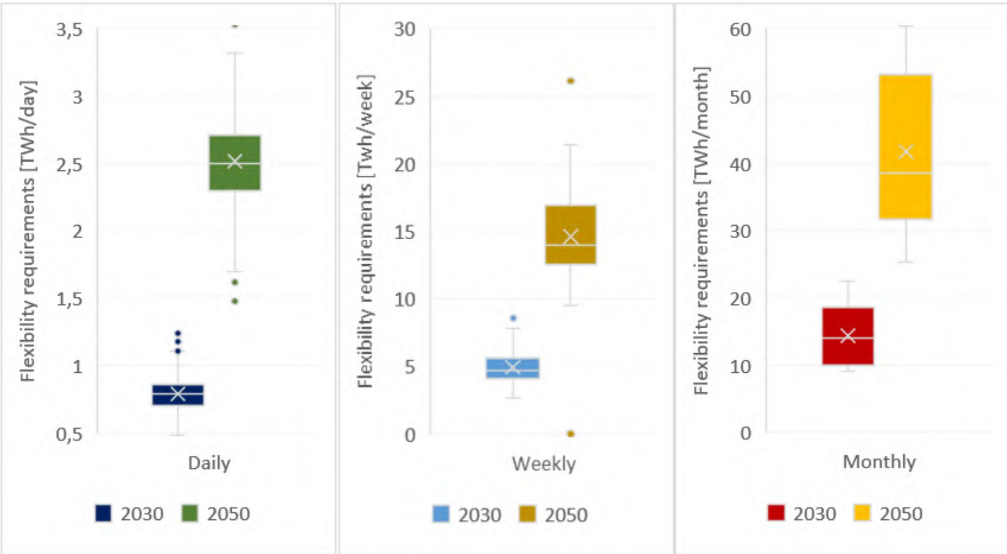

Figure 6. Distribution of EU daily, weekly, and monthly requirements for flexibility per respective timescale, in 2030 and 2050. Source: JRC, Flexibility requirements and the role of storage in future European power systems, 2022.

Several technologies can provide flexibility to the energy system, including for example, energy-storage, demand response, supply-side flexibility and interconnections. Energy storage is particularly well suited to providing a complete range of flexibility services at different scales and timeframes. Furthermore, energy storage can be combined with other flexibility technologies to increase their potential in providing flexibility to the system (e.g. energy storage combined with demand response capabilities). Energy-storage technologies compete with each other, and their deployment needs to be market-driven.

The results of the model simulation[28] (Figure 8) show that short-term-storage technologies like batteries could offer a considerable amount of daily flexibility in 2030, but that they would be less able to provide weekly and monthly flexibility. The simulation also shows that pumped hydro storage could play an important role across all three timescales. Interconnections play a central role in providing flexibility on all timescales as a flexible demand-buffering form of energy technology.

[28] European Commission, JRC, Koolen, D., De Felice, M. and Busch, S., Flexibility requirements and the role of storage in future European power systems, 2023, https://publications.jrc.ec.europa.eu/repository/handle/JRC130519.

Electrolysers could also make a considerable contribution to the flexibility requirements at EU level in 2030. And combined-cycle gas turbines (CCGT) could still contribute significantly to addressing daily and weekly flexibility needs in 2030[29]. The simulation shows that the diversification of flexibility technologies increases their individual contribution to covering the flexibility requirements, as technologies combined outperform the sum of the individual contributions[30].

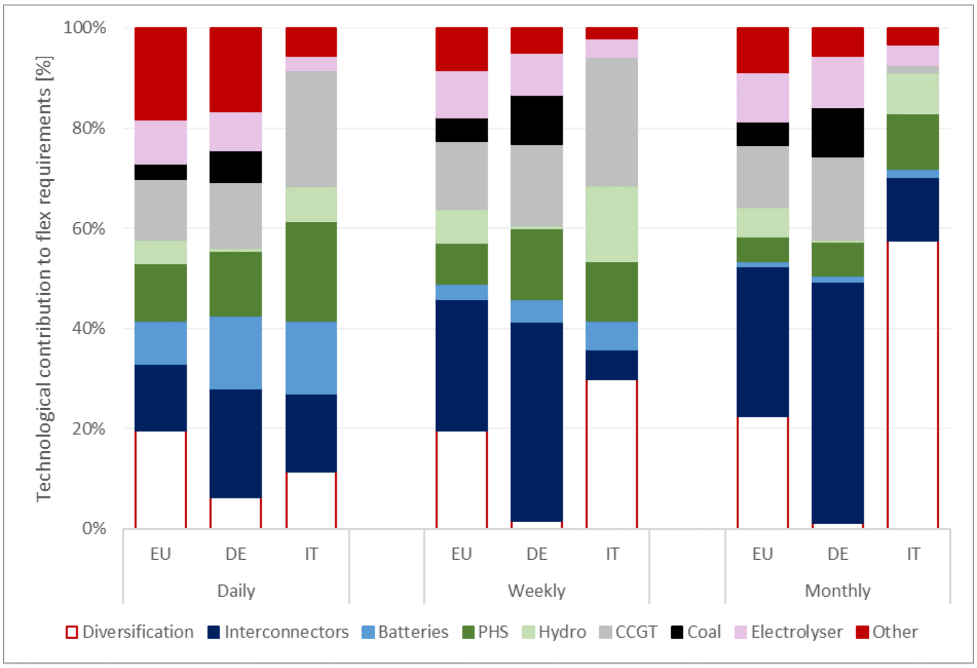

Figure 7. Technological contribution to flexibility requirements in the EU, Germany and Italy, 2030. Source: JRC Flexibility requirements and the role of storage in future European power systems, 2022.

The needs for system flexibility in the electricity system are driven by many factors, including the level of interconnection in the system and the share of variable renewable generation[31]. **The model simulation[32] shows a direct relation between flexibility requirements and renewable-generation deployment** with: (i) an exponential relation between daily flexibility needs and the share of production from solar photovoltaics (PV); and (ii) a strong linear relation between weekly and monthly flexibility needs and the share of energy generated from wind. On average across EU Member States, **the overall flexibility requirements increase significantly when the share of renewable generation in the electricity system is above 74% of total installed capacity** (Figure 8).

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[29] European Commission, JRC, Koolen, D., De Felice, M. and Busch, S., Flexibility requirements and the role of storage in future European power systems, 2023, https://publications.jrc.ec.europa.eu/repository/handle/JRC130519.

[30] The main driver for the selection of newly deployed technologies in the modelling is the price. Nevertheless, the absence of ancillary services and the lack of distribution and transmission grids in the modelling may underestimate the contribution of energy storage.

[31] European Commission, DG ENER, The role and need of flexibility in 2030 focus on energy storage: study S07, 2019, https://data.europa.eu/doi/10.2833/639890.

[32] European Commission, JRC, Koolen, D., De Felice, M. and Busch, S., Flexibility requirements and the role of storage in future European power systems, 2023, https://publications.jrc.ec.europa.eu/repository/handle/JRC130519.

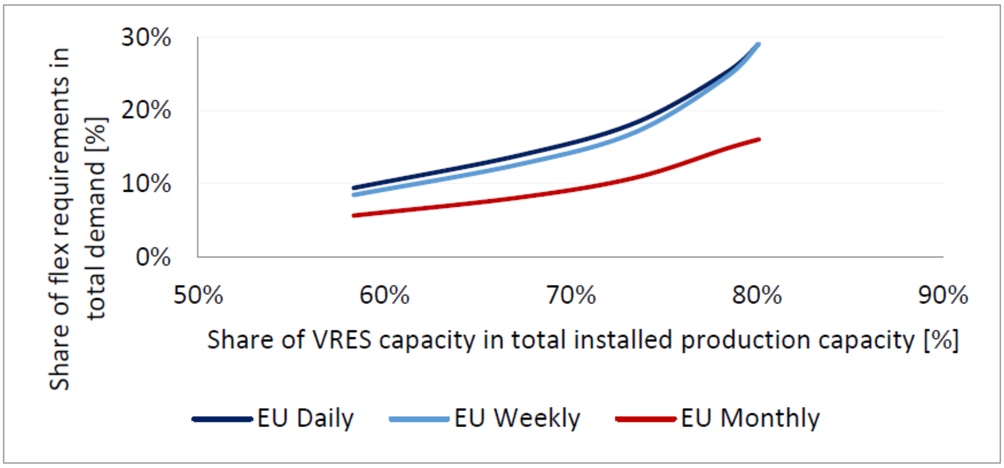

Figure 8. Share of daily, weekly and monthly flexibility requirements in total demand in relation to increasing share of variable renewable energy sources (VRES) capacity in total installed production capacity in the EU. Source: JRC Flexibility requirements and the role of storage in future European power systems, 2022.

On the shorter timeframes, **the future power system will also have to be more sophisticated, in particular to provide additional balancing and non-frequency ancillary services**[33] such as: (i) fast frequency response; (ii) fast reactive current injections; (iii) inertia for local grid stability; (iv) short-circuit-current capability, or black start capability; and (v) island-operation capability. Some storage technologies have proven to be a good technical solution for those services[34]. **The electricity system will also require more technologies providing stability and reliability – like energy storage**[35] **– to cope with existing and new system operational challenges**. These challenges include the Duck Curve[36] (the periods during sunrise and sunset when solar technologies rapidly increase and decrease generation) and the Dark Doldrums[37] (when little to no energy is generated by wind or solar power generators due to specific climate conditions).

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33 EU-SysFlex, Product Definition for Innovative System Services, 2018, https://eu-sysflex.com/wp-content/uploads/2019/08/D3.1_Final_Submitted.pdf.
34 ENTSO-E, Inertia and Rate of Change of Frequency (RoCoF), December 2020, https://eepublicdownloads.azureedge.net/clean-documents/SOC%20documents/Inertia%20and%20RoCoF_v17_clean.pdf.
35 ENTSO-E, Technology Factsheets, 2021, https://eepublicdownloads.entsoe.eu/clean-documents/RDC%20documents/2021_Technology%20Factsheet.pdf.
36 California Independent System Operator, What the duck curve tells us about managing a green grid, Fast facts, 2016, https://www.caiso.com/Documents/FlexibleResourcesHelpRenewables_FastFacts.pdf.
37 Yuhji Matsuo, Seiya Endo, Yu Nagatomi, Yoshiaki Shibata, Ryoichi Komiyama, Yasumasa Fujii, Investigating the economics of the power sector under high penetration of variable renewable energies, 2020, https://doi.org/10.1016/j.apenergy.2019.113956.

The increasing relevance of longer-duration energy-storage capabilities

With the deployment of more renewable energy sources and short-term flexibility technologies, the need for energy 'shifting' solutions becomes greater. As a result, the system requires more energy that can be stored for longer durations[38], and this represents a new opportunity for emerging technologies[39].

Long-duration energy-storage (LDES) technologies[40] could 'shift' energy over timescales ranging from a few hours (more than 4-10 hours) to weeks or even months. In particular:

- There is a continuous increase in the duration capabilities of **batteries**, led by flow batteries with discharge durations of up to 10 hours.
- **Pumped hydro storage (PHS) and other mechanical storage** (like compressed air energy storage (CAES), liquid air energy storage, or gravity-based technologies) could have an important role in providing weekly and seasonal flexibility[41]. Although there are still potential locations for new PHS facilities in the EU[42], the refurbishment of existing facilities could increase PHS capacities more quickly and with a lower environmental and social impact. Novel technologies using underground reservoirs could be further explored[43].
- **Renewable hydrogen and other chemical storage technologies** (including power-to-x, in form of methane, and novel technologies like reactive metal-based storage) could also play an important role: (i) during periods of high peak consumption or tight adequacy situations; or (ii) as an energy buffer making energy available across different regions, end-use sectors, and energy markets.
- **Thermal energy storage**, as a key technology for energy-system integration, could play an important role in providing flexibility and in particular long-term and seasonal storage.

LDES becomes more necessary as the share of renewable generation increases and as fossil-fuelled generators are phased out[44]. In systems with high penetration of renewable energy, LDES could avoid between 35% and 88% of the curtailment of renewable generation[45]. LDES will provide additional value in long-duration services and services that are difficult to predict, such as seasonal storage or security of supply and reliability services.

2.3. Global figures and international landscape

[38] JRC report (Flexibility requirements and the role of storage in future European power systems, https://data.europa.eu/doi:10.2760/384443) concludes that while the flexibility needs increase the most in absolute terms for short-term applications, they increase the most in relative terms for long duration purposes.
[39] NREL, Blair, Nate, Chad Augustine, Wesley Cole, et al., Storage Futures Study: Key Learnings for the Coming Decades, 2022, https://www.nrel.gov/docs/fy22osti/81779.pdf.
[40] LDES Council, McKinsey & Company, Net-zero power – Long-duration energy storage for a renewable grid, November 2021, https://www.ldescouncil.com/assets/pdf/LDES-brochure-F3-HighRes.pdf.
[41] International Forum on Pumped Storage Hydropower, Pumped Storage Hydropower Capabilities and Costs, September 2021, https://www.hydropower.org/publications/pumped-storage-hydropower-capabilities-and-costs.
[42] eStorage_D4.2 Overview of potential locations for new variable speed PSP in Europe, November 2015, eStorage_D4.2 Overview of potential locations for new variable speed PSP in Europe (estorage-project.eu).
[43] International Forum on Pumped Storage Hydropower, Innovative Pumped Storage Hydropower Configurations and Uses, 2021, https://assets-global.website-files.com/5f749e4b9399c80b5e421384/61432192836f8d346bc2928e_IFPSH%20-%20Innovative%20PSH%20Configurations%20%26%20Uses_%2015%20Sept.pdf.
[44] MIT, The Future of Energy Storage, 2022, https://energy.mit.edu/wp-content/uploads/2022/05/The-Future-of-Energy-Storage.pdf.
[45] NREL, Paul Denholm and Trieu Mai, Timescales of Energy Storage Needed for Reducing Renewable Energy Curtailment, September 2017, https://www.nrel.gov/docs/fy17osti/68960.pdf,
LCP, Renewable curtailment and the role of long duration storage, May 2022, https://www.drax.com/wp-content/uploads/2022/06/Drax-LCP-Renewable-curtailment-report-1.pdf.

Korea, China, the United States (US) and Germany accounted for more than 60% of storage deployment in 2019, and these countries also led the world in the number of new additions to energy storage in 2020. In 2021, 10 GW (22 GWh) of energy storage were deployed built newly worldwide, led by lithium-ion battery technologies[46].

The **US** is the world's biggest market, with installed storage capacity of 4 GW (11 GWh) in 2021[47]. The cost decline in energy-storage technologies has increased their role in the decarbonisation and reliability of the power grid[48]. The strong performance of the US storage market is led by large projects in specific states, in particular California, which has a specific energy-storage target of 11.5 GW by 2026. The strong development of solar PV, mainly driven by the solar-investment tax credit, also plays an important role. In addition, the US has also seen front-of-the-meter projects are also being developed by private companies due to high peak prices in the electricity markets. Specific initiatives such as the Inflation Reduction Act or the American Battery Materials Initiative aim at further strengthening the development and deployment of energy storage in the US.

In Asia, **China** saw a significant jump from 0.6 to 1.6 GW in yearly installations between 2020 and 2021[49]. The national energy-storage target of 30 GW by 2025 and specific supporting policies (such as giving stored energy priority connection to the grid) are the main drivers for the deployment of energy storage. **Japan** is a market leader for behind-the-meter storage, while in **Korea** annual energy-storage installations fell by 80% in 2019 since the record year of 2018, when the country accounted for a third of the total new capacity installed worldwide thanks to federal subsidy schemes.

India is looking to integrate energy storage into its energy planning, primarily to facilitate the greater penetration of renewable generation, promote green mobility, and support peak-demand management and grid development. In addition to the PHS projects under development[50], various public entities have been issuing tenders for storage projects, including one of the largest globally with 1 000 MWh of battery storage. And India's production-linked incentive scheme for advanced chemistry cells aims to boost battery manufacturing in the country[51].

The United Kingdom is expected to have installed 3.6 GW of capacity by 2022[52], with an enormous project pipeline dominated by front-of-the-meter installations. The main drivers for this come from specific ancillary services, such as dynamic containment or fast reserve services, and capacity auctions. In **Germany**, behind-the-meter storage is developing strongly, driven by a context of strong development of rooftop PV and electric vehicles (EVs), increasing incentives for energy management by consumers.

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[46] Energy Transition Expertise Centre (EnTEC), Study on Energy Storage, 2022, https://data.europa.eu/doi/10.2833/333409
IEA, Tracking Energy Storage 2020, 2020, https://www.iea.org/reports/tracking-energy-storage-2020.
[47] Energy Transition Expertise Centre (EnTEC), Study on Energy Storage, 2022, https://data.europa.eu/doi/10.2833/333409
[48] NREL, Storage Futures Study, https://www.nrel.gov/analysis/storage-futures.html.
[49] Energy Transition Expertise Centre (EnTEC), Study on Energy Storage, 2022, https://data.europa.eu/doi/10.2833/333409.
[50] Status of pumped storage development in India, January 2022, https://cea.nic.in/wp-content/uploads/hepr/2022/01/pump_storage_1-1.pdf.
[51] NITI Aayog and Green Growth Equity Fund Technical Cooperation Facility, Advanced Chemistry Cell Battery Reuse and Recycling Market in India, May 2022, https://www.niti.gov.in/sites/default/files/2022-07/ACC-battery-reuse-and-recycling-market-in-India_Niti-Aayog_UK.pdf.
[52] EASE and Delta-EE, Webinar presentation of the European Market Monitor on Energy Storage 6.0, June 2022, https://ease-storage.eu/publication/emmes-6-0-june-2022/.

Many **European energy-storage markets** are growing strongly, with 2.8 GW (3.3 GWh) of utility-scale energy storage newly deployed in 2022[53] , estimated to reach more than 9 GWh. Market deployment is led by front-of-the-meter installations, representing around 70% of the 2022 energy-storage market, followed by around 30% of residential storage and with limited growth of less than 2% planned for commercial and industrial storage[54].

Public support for the deployment of storage worldwide is mainly driven by the need to increase system flexibility. For example, the low interconnection levels in some states in the US increases the need for flexibility. And China's system in the mid-2010s faced significant flexibility constraints, which led to the curtailment of renewable-energy production. In the EU, flexibility requirements are expected to be higher in the Ireland-Northern Ireland and Nordic synchronous areas[55].

Looking forward, the International Energy Agency (IEA) expects global installed storage capacity to expand by 56% in the next 5 years to reach over 270 GW by 2026. It also expects utility-scale batteries to account for most of the storage growth, followed by PHS and concentrated solar power (CSP)[56]. In fact, for utility-**scale batteries alone the IEA's net-zero scenario shows that the worldwide installed capacity needs to expand 44-fold between 2021 and 2030, reaching 680 GW. This will require an average installation of more than 80 GW per year** (Figure 9)[57].

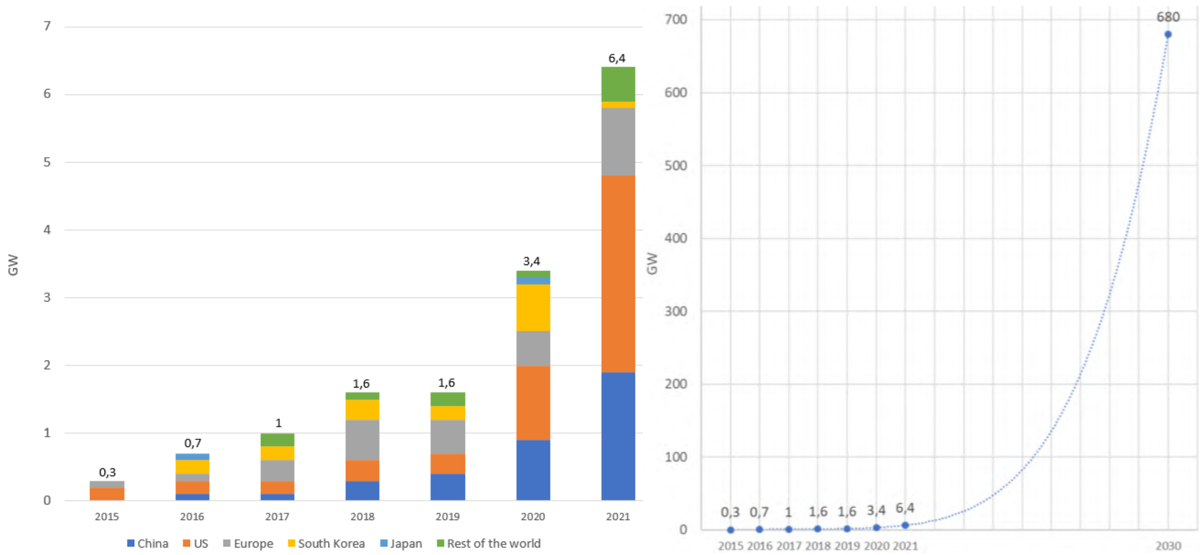

Figure 9. Global utility-scale battery-storage additions 2016-2021 and 2016-2030. Source: IEA, How rapidly will the global electricity storage market grow by 2026?, 2021

Different studies[58] have analysed the likely future paths for the deployment of energy storage in the EU. These studies point to more than 200 GW and 600 GW of energy storage capacity by 2030 and 2050, respectively. As shown in Figure 10, annual battery installations in Europe are expected to increase significantly in the coming years. However, the future deployment of energy storage depends on many factors, in particular: (i) changes in costs; (ii) changes in the performance of

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[53] Wood Mackenzie, Anna Darmani, Europe's grid-scale energy storage capacity will expand 20-fold by 2031, April 2022, https://www.woodmac.com/news/opinion/europes-grid-scale-energy-storage-capacity-will-expand-20-fold-by-2031/.
[54] EASE and Delta-EE, Webinar presentation of the European Market Monitor on Energy Storage 6.0, June 2022, https://ease-storage.eu/publication/emmes-6-0-june-2022/.
[55] Energy Transition Expertise Centre (EnTEC), Study on Energy Storage, 2022, https://data.europa.eu/doi/10.2833/333409.
[56] IEA, How rapidly will the global electricity storage market grow by 2026?, 2021, https://www.iea.org/articles/how-rapidly-will-the-global-electricity-storage-market-grow-by-2026.
[57] IEA, Grid-Scale Storage, 2022, https://www.iea.org/reports/grid-scale-storage.
[58] EASE, Energy Storage Targets 2030 and 2050 - Ensuring Europe's Energy Security in a Renewable Energy System, 2022, https://ease-storage.eu/wp-content/uploads/2022/06/Energy-Storage-Targets-2030-and-2050-Full-Report.pdf.

different energy-storage technologies; and (iii) changes in other flexibility and stabilising technologies competing with energy storage.

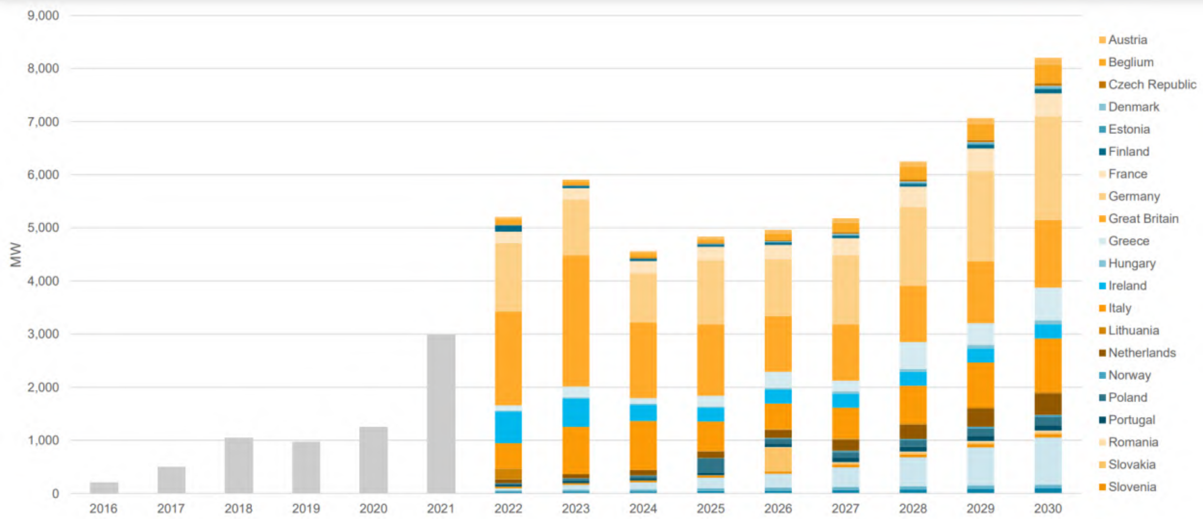

Figure 10. Forecast annual battery installations. Source: EASE and Delta-EE, Webinar presentation of the European Market Monitor on Energy Storage 6.0, June 2022

3. EU regulatory framework and initiatives

3.1. The EU policy framework on energy storage

A cross-cutting approach is required when developing the EU and national regulatory framework and policies for energy. This is because of the diversity of technologies and applications. Specifically, **energy storage has a double role (consumer-generator[59]). This double role means that special attention should be paid** when drawing up the applicable regulatory framework and procedures to: (i) avoid existing barriers; and (ii) maximise the added value that energy storage can bring to the energy system. For example: (i) incentives could be given for demand-side flexibility; (ii) removing double taxation; (iii) specific permit-granting procedures could be developed; and (iv) specific network charges and tariffs could be developed for energy storage[60].

A number of EU regulations and initiatives already facilitate the development and deployment of energy storage as a key technology to support the decarbonisation objectives of the **European Green Deal**. For example, the **REPowerEU plan** specifically highlights the importance of energy storage in ensuring flexibility and security of supply in the energy system by: (i) facilitating the integration of renewable generation; (ii) supporting the grid; and (iii) 'shifting' energy so that it is available when it is most needed. The REPowerEU plan also recognises the role of energy storage in reducing the use of gas power plants in the energy system.

The **EU strategy for energy system integration**[61], in synergy with the **hydrogen strategy for a climate-neutral Europe**[62], lays down the foundations for the decarbonised European energy system

[59] Acting as a 'consumer' of energy by absorbing excess energy production when demand is low and it is not needed, and then acting as a 'producer' of energy by supplying that stored energy back when demand is high and it is needed.
[60] European Commission, DG ENER, Andrey, C., Barberi, P., Nuffel, L., et al., Study on energy storage: contribution to the security of the electricity supply in Europe, 2020, https://data.europa.eu/doi/10.2833/077257.
Energy Transition Expertise Centre (EnTEC), Study on Energy Storage, 2022, https://data.europa.eu/doi/10.2833/333409.
[61] COM(2020) 299 final, https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=COM:2020:299:FIN.
[62] COM(2020) 301 final, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0301.

of the future and shows the relevance of energy storage for both system integration and sector coupling[63].

More specifically, the **EU's Fit-for-55 package**[64] contains relevant provisions on energy storage. For example, as part of the package, a proposal to revise the **Energy Taxation Directive**[65] and this proposal includes a specific provision to end the double taxation of energy storage, in line with the consideration of energy storage as a substantial contributor to climate-change adaptation and mitigation in the **EU taxonomy**[66].

Another part of the Fit-for-55 package is a proposal to revise the **Renewable Energy Directive (RED)**[67]. This proposed revision had originally included a proposal to increase the EU's renewable target to 40% by 2030. Following the REPowerEU proposal, the proposal for a revised Renewable Energy Directive has now raised this target to 45% by 2030[68]. The revised Renewable Energy Directive also contains specific provisions facilitating the deployment of electric vehicles, and encouraging demand-response and energy storage as a source of flexibility, including for thermal energy storage.

A further element of the Fit-for-55 package is the proposed revision of the **Energy Efficiency Directive**[69]**,** also encouraging demand-response and energy storage to increase efficiency. On the top of these, the revision of the **Energy Performance of Buildings Directive**[70] encourages: (i) the effective control, storage, and use of energy; and (ii) the installation of smart recharging infrastructure in buildings, which is particularly important since this is where electric vehicles park regularly and for long periods of time.

The **proposals to decarbonise the transport sector**[71] seek to increase the deployment of electric vehicles and other clean modes of transport, where energy-storage technologies (such as batteries, hydrogen or synthetic fuels) have huge potential.

In addition to the EU's Fit-for-55 package, the proposals for a **directive and regulation on the internal markets for renewable and natural gases and for hydrogen**[72] will encourage the use of energy carriers that can be stored and provide flexibility, such as hydrogen and hydrogen storage, and renewable methane.

The **EU action plan on the digitalisation of energy**[73] will accelerate the deployment of new technologies, including energy-storage technologies, in particular by: (i) enhancing interoperability,

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63 ETIP SNET, Smart Sector Integration, towards an EU System of Systems, July 2021, https://smart-networks-energy-transition.ec.europa.eu/sites/default/files/publications/ETIP-SNET-PP-Sector-Coupling-towards-an-EU-System-of-Systems-.pdf.
64 COM/2021/550 final, https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=COM:2021:550:FIN.
65 COM(2021) 563 final, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52021PC0563.
66 Regulation (EU) 2020/852 on the establishment of a framework to facilitate sustainable investment, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:32020R0852,
Commission Delegated Regulation (EU) 2021/2139 of 4 June 2021 supplementing Regulation (EU) 2020/852, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:32021R2139.
67 COM/2021/557 final, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52021PC0557.
68 COM/2022/222 final, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2022:222:FIN.
69 COM(2021) 558 final, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52021PC0558.
70 COM/2021/802 final, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021PC0802&qid=1641802763889.
71 Revised CO2 standards for cars and vans, revision of Directive on Deployment of Alternative Fuels Infrastructure, FuelEU Maritime and ReFuelEU Aviation initiatives.
72 COM/2021/803 final, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2021:803:FIN,
COM/2021/804 final, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2021:804:FIN.
73 COM/2022/552 final, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2022:552:FIN.

coordination and data exchanges; and (ii) promoting investment in digital electricity infrastructure via legislative initiatives, investments and coordination with Member States. The **Green Deal Industrial Plan**, aiming to provide a more supportive environment for the scaling up of the EU's manufacturing capacity for the net-zero technologies and products required to meet Europe's ambitious climate targets, also focusses on batteries has a clear energy storage dimension.

Under the Governance Regulation, Member States shall include in their National **energy and climate plans (NECPs)** national objectives, and relevant policies and measures, related to energy storage in particular in view of increasing the flexibility of the energy system and ensuring a non-discriminatory participation to the energy markets[74]. The guidance on the update of the NECPs[75] invites Member States to fully explore synergies across the relevant dimensions of the Energy union and, in particular how progress in storage could contribute to enhance energy security and speed up the roll-out of renewable energy while increasing energy efficiency in the overall energy system and improve the integration of the internal energy market.

3.2. EU electricity market design

The EU electricity market design[76] includes a definition of energy storage that accommodates the different energy-storage technologies. It also **promotes the participation of energy storage in the market; and the provision of flexibility services** on a level playing field with other energy resources. **Energy storage should be developed as a market-based activity**and system operators should only own, develop, manage and operate energy-storage facilities in exceptional cases.

In terms of connection requirements, **the suitability for energy storage of the three grid-connection network codes[77] is being assessed**, as currently these three network codes do not elaborate on specific requirements for energy-storage units[78].

Energy storage can support the power system in terms of adequacy[79] (. The regulatory framework already takes into account storage for the **European Resource-Adequacy Assessment (ERAA)**[80] and

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[74] Article 4(d) (3) of Regulation (EU) 2018/1999 on the Governance of the Energy Union and Climate Action and Annex I point 2.3 (iv) and 2.4.3 (i) and (ii).

[75] COM (2022/C 495/02) Commission Notice on the Guidance to Member States for the update of the 2021-2030 national energy and climate plans

[76] Comprising, among others, Regulation (EU) 2019/941 on risk-preparedness in the electricity sector; Regulation (EU) 2019/943 on the internal market for electricity; and Directive (EU) 2019/944 on common rules for the internal market for electricity.

[77] Commission Regulation (EU) 2016/631 of 14 April 2016 establishing a network code on requirements for grid connection of generators, http://data.europa.eu/eli/reg/2016/631/oj;
Commission Regulation (EU) 2016/1388 of 17 August 2016 establishing a Network Code on Demand Connection, http://data.europa.eu/eli/reg/2016/1388/oj;
Commission Regulation (EU) 2016/1447 of 26 August 2016 establishing a network code on requirements for grid connection of high voltage direct current systems and direct current-connected power park modules, http://data.europa.eu/eli/reg/2016/1447/oj.

[78] ACER policy paper on the revision of the network code on requirements for grid connection of generators and the network code on demand connection, September 2022, https://www.acer.europa.eu/sites/default/files/documents/Media/News/Documents/260908%20ACER%20GCNCs%20Policy%20Paper_final.pdf.

[79] Adequacy refers to the ability of electricity supply and transmission capacity to sufficiently cover electricity demand.

[80] Methodology for the European resource adequacy assessment, https://eepublicdownloads.entsoe.eu/clean-documents/sdc-documents/seasonal/Methodology%20for%20Short-term%20and%20Seasonal%20Adequacy%20Assessment%20-%20ACER%20Decision%2008-2020%20on%20the%20RPR8%20.pdf.

[80] ENTSO-E, The Assessment of Future Flexibility Needs in Practice, October 2021, https://eepublicdownloads.azureedge.net/clean-

the **Short-term and Seasonal Adequacy Assessments**[81]. Nevertheless, factors like the contribution of energy storage to security of supply or the daily, weekly, and seasonal flexibility metrics are expected to play an ever-increasing role in optimising cost-efficient adequacy assessments[82]. **Capacity mechanisms** address adequacy concerns by ensuring the availability of enough firm capacity, and these mechanisms are open to the participation of all capacity resources, including energy storage, while complying with the CO_2 emissions limits[83].

3.3. Public financing and support in the EU

Public funding also contributes to the financing of energy-storage technologies, addressing certain investment barriers (regulatory, economic and technical) to make it more attractive to invest in projects. There is no one-size-fits-all solution for financing given the variety of technologies and the different technologies': (i) readiness levels; (ii) duration capabilities (e.g. from minutes to months); (iii) project applications (e.g. from services to the grid to savings to final consumers); and (iv) sizes (e.g. ranging from large, stand-alone or front-of-the-meter utility-scale down to smaller behind-the-meter distributed energy storage). **Tailored support may be necessary, in particular for technologies that have better carbon, environmental and material footprints and for projects that have a greater potential to contribute to the decarbonisation and environmental objectives and the security of energy supply**. These contributions could be: (i) increasing the flexibility, stability and reliability of the system; (ii) reducing EU dependencies; and (iii) contributing to the 'energy efficiency first' principle.

There are specific support and financing tools available to incentivise the deployment of energy storage in the EU, financed from both EU's long-term budget as well as from the NextGenerationEU (NGEU) package.

Energy storage was identified among the reform and investment priorities to be considered by Member States when drafting their **recovery and resilience plans (RRPs)**[84] and is therefore eligible to receive funds from the **Recovery and Resilience Facility (RRF)**[85]. Some Member States have included specific reforms and investments related to energy storage in their RRPs. This is the case for the measures approved under EU state-aid rules to support the construction and operation of storage facilities in Greece[86], and for the measures helping to partially finance the procurement and installation of utility-scale batteries to provide balancing services in Croatia[87]. The proposed

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documents/Publications/Position%20papers%20and%20reports/2021/ENTSO-E%20Report%20on%20the%20assessment%20of%20future%20flexibility%20needs%20in%20practice%20211019.pdf.

[80] As provided for in Article 22 of Regulation (EU) 2019/943 on the internal market for electricity https://ec.europa.eu/energy/sites/default/files/methodology_for_the_european_resource_adequacy_assessment.pdf.

[81] Methodology for Short-term and Seasonal Adequacy Assessments, https://eepublicdownloads.entsoe.eu/clean-documents/sdc-documents/seasonal/Methodology%20for%20Short-term%20and%20Seasonal%20Adequacy%20Assessment%20-%20ACER%20Decision%2008-2020%20on%20the%20RPR8%20.pdf.

[82] ENTSO-E, The Assessment of Future Flexibility Needs in Practice, October 2021, https://eepublicdownloads.azureedge.net/clean-documents/Publications/Position%20papers%20and%20reports/2021/ENTSO-E%20Report%20on%20the%20assessment%20of%20future%20flexibility%20needs%20in%20practice%20211019.pdf.

[83] As provided for in Article 22 of Regulation (EU) 2019/943 on the internal market for electricity.

[84] https://ec.europa.eu/info/business-economy-euro/recovery-coronavirus/recovery-and-resilience-facility_en.

[85] Regulation (EU) 2021/241 establishing the Recovery and Resilience Facility, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32021R0241.

[86] Case SA.64736, https://ec.europa.eu/competition/elojade/isef/case_details.cfm?proc_code=3_SA_64736.

[87] Case SA.64374, https ://ec.europa.eu/competition/elojade/isef/case_details.cfm?proc_code=3_SA_64374.

amendments to the Regulation[88] to integrate dedicated REPowerEU chapters into the existing RRPs are an opportunity for new energy-storage projects, as highlighted in the accompanying guidance on RRPs in the context of REPowerEU[89].

In addition, the **Trans-European Networks for Energy (TEN-E) Regulation**[90] makes it possible to identify energy-storage projects with cross-border impacts in the **EU-wide ten-year network development plan (TYNDP)** and their selection as a **project of common interest (PCI)** in the Union list. By being selected as a PCI, the project can benefit from accelerated permitting procedures and financial support from the **Connecting Europe Facility funding stream for energy**[91]. There are already 8 energy-storage projects in the fifth PCI list: 7 PHS and 1 CAES[92]. To better assess the positive role of energy storage facilities in the energy system, a new methodology specific to energy storage is being developed to assess the costs and benefits of candidate projects under the TEN-E Regulation[93]. Furthermore, the TYNDP 2022 scenario report[94] highlights the increasing relevance of flexibility options and the need to develop technologies other than transmission technologies[95]. The draft TYNDP 2022 includes 23 storage projects that would result in energy storages reaching 41 GW[96]. The guideline for cost-benefit analysis of grid-development projects[97] includes a specific section for the assessment of energy-storage technologies.

Cohesion policy will continue to support Member States, regions and local authorities to invest in energy storage through the available funding of the **European Regional Development Fund (ERDF),** the **Cohesion Fund (CF)** and the **Just Transition Fund (JTF**). For instance, in September 2022, the Commission has approved an investment of more than EUR 70 million from the ERDF, under the 2014-2020 programming period, to develop lithium-ion battery recycling technology in Silesia, in southern Poland.[98] In the new programmes of the 2021-27 cohesion policy, many Member States have allocated support to energy storage projects. Such investments are part of the almost EUR 6 billion planned to be invested in smart energy systems and related storage. Cross-border cooperation, including on energy storage, is a particular feature of the ERDF co-financed Interreg[99] programmes: for example in the STEPS project[100], business support and knowledge partners from the Netherlands, Ireland, Belgium, Germany and the United Kingdom have joined forces to

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[88] COM(2022) 231 final, https://ec.europa.eu/info/files/proposal-regulation-european-parliament-and-council-amending-regulation-eu-2021-241-regards-repowereu-chapters-recovery-and-resilience-plans-and-amending-regulation-2021-1060-2021-2115-2003-87-ec-2015-1814_en.

[89] C/2022/3300, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52022XC0531(01).

[90] Regulation (EU) 2022/869 on guidelines for trans-European energy infrastructure, https://eur-lex.europa.eu/eli/reg/2022/869/oj.

[91] ACER, Consolidated report on the progress of electricity and gas Projects of Common Interest, June 2022, https://acer.europa.eu/sites/default/files/documents/Publications/2022_ACER%20Report%20on%20progress%20of%20PCIs.pdf.

[92] https://ec.europa.eu/energy/infrastructure/transparency_platform/map-viewer/main.html.

[93] https://energy.ec.europa.eu/consultations/targeted-consultation-methodologies-assessing-costs-and-benefits-candidate-projects-under-revised_en.

[94] https://2022.entsos-tyndp-scenarios.eu/.

[95] https://www.acer.europa.eu/events-and-engagement/news/acer-will-adopt-new-framework-guidelines-scenarios-network-development.

[96] https://tyndp.entsoe.eu/news/2022/07/entso-e-releases-pan-european-network-development-plan-for-2030-and-2040-tyndp-2022-for-consultation-until-16-september/.

[97] 2nd ENTSO-E Guideline For Cost Benefit Analysis of Grid Development Project, September 2018, https://eepublicdownloads.entsoe.eu/clean-documents/tyndp-documents/Cost%20Benefit%20Analysis/2018-10-11-tyndp-cba-20.pdf.

[98] https://ec.europa.eu/commission/presscorner/detail/es/mex_22_5911

[99] https://interreg.eu/

[100] https://www.nweurope.eu/projects/project-search/steps-storage-of-energy-power-systems-in-nwe/#tab-1. STEPS is a project within the Interreg North-West Europe (NWE) programme.

strengthen the competitiveness of innovative energy storage (e-storage) providers in North-West Europe.

Energy storage is also eligible for support under the **EU Renewable Energy Financing Mechanism (REFM)** when deployed in combination with new renewable-energy capacity.

Other instruments and funds contribute in some specific territories to the financing of storage, such the **Innovation Fund (IF)** and the **Modernisation Fund (MF)**.

In addition, specific support and financing tools at national level help the deployment of energy-storage projects. The revised guidelines on **state aid for climate, environmental protection, and energy (CEEAG)**[101] have introduced a set of new provisions facilitating support for energy storage. These provisions cover: (i) the reduction of greenhouse-gas emissions; (ii) improving on-site renewable energy installations in buildings; (iii) ensuring the 'smart' readiness of the recharging infrastructure; and (iv) increasing security of electricity supply, as a fully integrated network component or as thermal storage for district heating and cooling. In addition, the **state aid General Block Exemption Regulation (GBER)**[102] is under revision to further facilitate public support for the EU's green and digital transition, including relevant provisions for energy-storage projects in the revised proposal[103].

3.4. Research and innovation for a strong energy-storage value chain

The maturity and competitiveness of energy storage in terms of costs and capacity is improving worldwide. This is particularly the case for batteries, although many energy-storage technologies have substantially increased their maturity level and improved their costs in recent years, becoming fully operational and more competitive in the energy sector. **Nevertheless, tremendous effort is still required** to improve mature technologies and develop emerging ones to ensure a sufficient portfolio of technologies to meet the energy-storage needs of the future energy system.

The research and innovation programmes at EU level pay special attention to energy-storage technologies and their integration in the energy system, in particular through Horizon Europe[104]**.** These programmes include substantial funding support for hydrogen and battery partnerships over the 2021-2027 period. In addition to the support to for lithium-ion batteries and hydrogen, a number of Horizon Europe projects also support alternative battery chemistries (such as sodium-ion or organic flow batteries), thermal storage, other storage technologies as well as the integration of these technologies into the energy system. Furthermore, innovative and sustainable pumped hydropower technologies are covered. Renewable Fuel and power-to-x technologies are supported as an important element in transforming renewable electricity into other forms of energy.

In addition, energy storage is also eligible for support under the **InvestEU programme**, which supports market-based demand-driven projects.

BATT4EU[105] is a co-programmed partnership between the European Commission and the Batteries European Partnership Association (BEPA) that brings together the battery stakeholders from the

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[101] C/2022/481, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.C_.2022.080.01.0001.01.ENG.

[102] Commission Regulation (EU) No 651/2014 declaring certain categories of aid compatible with the internal market in application of Articles 107 and 108 of the Treaty, https://eur-lex.europa.eu/eli/reg/2014/651/2017-07-10.

[103] https://ec.europa.eu/commission/presscorner/detail/en/ip_21_5027.

[104] https://ec.europa.eu/info/research-and-innovation/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe/cluster-5-climate-energy-and-mobility_en.

[105] https://bepassociation.eu/.

European research community. BEPA investments will reach EUR 925 million over the 2021-2027 period, complemented by another EUR 925 million from Horizon Europe. This partnership, together with other partnerships[106], such as **Clean Hydrogen, Towards zero-emission road transport (2ZERO),** or **the Clean Energy Transition**, provide a framework for cooperation and help to co-finance projects from the Horizon Europe programme on key technologies like batteries or hydrogen.

Other research and innovation programmes complement and exploit the synergies with Horizon Europe funding for energy storage. This is the case with: (i) the **European Regional Development Fund**[107] to support economic development across all Member States; (ii) the NER 300 programme[108] for innovative low-carbon technologies in line with the **strategic energy technology plan (SET-Plan); (iii) COSME**[109] to support competitiveness and innovation for **SMEs**; or (iv) the **LIFE Clean Energy Transition sub-programme**[110] to facilitate the energy transition.

Specific working groups and initiatives facilitate coordination, the exchange of information, and in particular, the exchange of best practices. This is the case with: (i) the **BRIDGE initiative** at the European Commission; (ii) the working group on storage technologies and system flexibilities at the **European Technology and Innovation Platforms Smart Networks for Energy Transition (ETIP SNET)**; (iii) the working group on energy storage at the Smart Energy Systems ERA-net community; (iv) the **FLORES network** on redox-flow batteries; (v) the storage joint programming initiative at the **European Energy Research Alliance (EERA)**; and (vi) the **Energy Storage Technology Collaboration Programme** at the IEA[111]. Specifically for batteries, Batteries Europe – the technology and innovation platform of the **European Battery Alliance (EBA)**[112] helps to coordinate the different research and innovation initiatives, including activities to promote training, through the EBA Academy and the Alliance for Batteries Technology, Training and Skills (ALBATTS).

EU funding is complemented by national funding for research and innovation, with general calls for clean technologies and specific calls for energy-storage projects (e.g. Bulgaria, Germany, Spain, France, Croatia, Luxembourg, Austria or Slovenia)[113].

To provide public support and unlock additional private investments in research and innovation in the battery value chain, two multi-billion **Important Projects of Common European Interest (IPCEIs)** were approved in 2019 and 2021[114] involving up to 12 Member States, and several companies and research organisations. Similarly, two IPCEIs in the hydrogen-technology value chain were approved in 2022[115] involving up to 15 Member States.

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[106] https://ec.europa.eu/info/research-and-innovation/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe/european-partnerships-horizon-europe/climate-energy-and-mobility_en.

[107] https://ec.europa.eu/regional_policy/funding/erdf_en

[108] https://ec.europa.eu/clima/eu-action/funding-climate-action/ner-300-programme_es.

[109] https://ec.europa.eu/growth/smes/cosme_en.

[110] https://cinea.ec.europa.eu/programmes/life/clean-energy-transition_en#:~:text=The%20LIFE%20Clean%20Energy%20Transition%20sub%2Dprogramme%20has%20a%20budget,actions%20(Other%20Action%20Grants)%20across.

[111] https://iea-es.org/.

[112] https://www.eba250.com/.

[113] Energy Transition Expertise Centre (EnTEC), Study on Energy Storage, 2022, https://data.europa.eu/doi/10.2833/333409.

[114] https://ec.europa.eu/commission/presscorner/detail/en/IP_21_226 https://ec.europa.eu/commission/presscorner/detail/en/ip_19_6705.

[115] https://ec.europa.eu/commission/presscorner/detail/en/ip_22_4544 https://ec.europa.eu/commission/presscorner/detail/en/ip_22_5676.

An energy-storage industry that is fit-for-purpose

The EU needs a strong, sustainable, and resilient industrial value chain for energy-storage technologies. Specifically for batteries, the **EU proposal for a batteries regulation**[116] includes important provisions to harmonise requirements, minimise environmental impact, and encourage the recycling, reuse and repurposing of batteries. These provisions cover issues such as sustainability and safety, performance and durability, labelling and information, and end-of-life and second-life management. The proposal puts circularity at the heart of the EU battery value chain.

As highlighted in the **EU strategy on standardisation** to support a resilient, green and digital EU single market[117], European standards could deliver great benefits by creating a level-playing field in the single market for businesses and increasing consumer confidence. Batteries and other energy-storage technologies could reap the benefits of fit-for-purpose performance, safety and grid standards and harmonised protocols on charging, interoperability and information access.

The energy-storage industry should contribute to achieving the EU's zero-pollution ambition for a toxic-free environment and support climate, energy and circular-economy policies. In this regard, there are several ongoing policy initiatives that will lay down important rules for energy-storage technologies and for batteries in particular. These rules will cover areas such as: (i) permitting procedures and emission limits for manufacturing and supply chains; (ii) inspecting, classifying and labelling toxic or hazardous materials; and (iii) recycling requirements. The ongoing initiatives include:

- the proposed revision of the **Industrial Emissions Directive**[118], the ongoing revision of the Regulation on the **Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH)**;
- the revision of the **Classification, Labelling and Packaging Regulation (CLP**);
- the revision of the **End-of-Life Vehicles Directive**.

4. Increasing the uptake of energy storage

4.1. An appropriate financing environment for the uptake of energy storage

Energy-storage projects and their evaluation present several challenges, such as lengthy and complex permit-granting procedures or the lack of long-term revenue visibility. These challenges can hinder access to finance for these projects. The availability of finance and access to capital is still a highly relevant concern, particularly for fully 'merchant' projects (i.e. projects without state subsidies) and first-of-their-kind technologies. Equity financing is the main source of financing for utility-scale energy-storage projects nowadays[119]. This is because most energy-storage projects are not attractive for risk-averse investors due to the uncertainty of their economic and administrative

[116] COM/2020/798 final, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020PC0798.
[117] COM(2022) 31 final, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52022DC0031.
[118] COM/2022/156 final/3, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52022PC0156R(02).
[119] Sandia National Laboratories, Energy Storage Financing: Project and Portfolio Valuation, 2021, https://www.sandia.gov/ess-ssl/wp-content/uploads/2021/01/ESF4_Report_SAND2020-0830.pdf.

assumptions. However, **debt financing has an important role to play in financing energy-storage projects efficiently**[120].

In fact, the riskiness of projects is one the main barriers to investment in energy storage perceived by stakeholders[121]. **Energy-storage projects can be made more attractive to investors by increasing the returns they offer and reducing or reallocating the risks associated with the projects through: (i) wider revenue stacking; (ii) long-term visibility and predictability of revenues; (iii) specific supporting tools; and (iv) enabling signals.**

Different technologies may require different business models depending on their characteristics and applications. For example, behind-the-meter storage could be financed based on the savings for the final consumer through leases, savings-sharing agreements, or power-purchase agreements. Large-scale, long-term energy-storage projects may require visible long-term revenue streams. Furthermore, some technologies are not yet mature and are classed as having a low technology-readiness level. These not-yet-mature technologies may encounter difficulties in securing financing throughout the whole lifecycle of technology development. And this in turn poses a challenge for policymakers to keep innovative companies and solutions in the EU after they have reached an early stage of development. If not managed well, such immature but potentially promising technologies may face limited prospects for commercialisation in the EU market[122].

The **Investors Dialogue on Energy initiative**[123] has a specific working group on energy storage. This initiative will: (i) help to assess existing financing schemes in the EU; (ii) discuss barriers to investments; and (iii) discuss possible new types of instruments to mobilise financing for the deployment of energy storage in the EU.

4.1.1. The need for wider revenue stacking

Energy-storage technologies can provide many different services to the energy system. It is essential that all those services are monetised and can provide a stream of revenues. This will make it possible for energy-storage technologies to 'stack' different revenue streams, which will ultimately maximise the added value of energy storage to the energy system. The EU electricity market design makes it possible for energy-storage solutions to participate in all electricity markets, thus providing the basis for revenue stacking[124]. **Nevertheless, not all services are properly valued and monetised yet, and this limits the stacking of revenue streams and prolongs the payback times of an investment.**

'Wide' revenue stacking (i.e. securing a flow of revenues from many different services) increases the return on investment and the attractiveness to investors of projects. The revenue streams could be fixed or variable, and could come from energy markets, private contracts, or public support (including revenue streams coming from expected energy and cost savings). Energy-storage assets could maximise their revenues by providing different services and participating in different markets such as arbitrage, firm capacity for peak demand, ancillary services and congestion management, transmission and distribution replacement, network deferral or black-start capability. Remunerating

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120 EUSEW 2021 - Energy Storage: Financing and economic signals, https://www.youtube.com/watch?v=eS8Q2vIOreE.

121 Energy Transition Expertise Centre (EnTEC), Study on Energy Storage, 2022,https://data.europa.eu/doi/10.2833/333409 EASE and Delta-EE, Webinar presentation of the European Market Monitor on Energy Storage 6.0, June 2022, https://ease-storage.eu/publication/emmes-6-0-june-2022/.

122 Problem of "Valley of death" and other barriers – see Investors Dialogue on Energy, ibidem.

123 https://energy.ec.europa.eu/topics/funding-and-financing/investors-dialogue-energy_en.

124 Revenue stacking can also arise from arbitrage (by exploiting forward premiums between the various markets)

some undervalued services that energy storage can provide to the system (e.g. decarbonisation of peak capacity or black-start capability) will also help the emergence of viable business models.

Nowadays, revenues for energy storage in the EU mostly come from participation in arbitrage trading and balancing. However, **revenues from some services are still not fully captured in all Member States, partly because the use of flexibility in distribution networks[125] is still not fully developed and the provision of non-frequency ancillary services is often not remunerated[126].** These non-frequency ancillary services include both short-timescale services (e.g. fast-frequency response; voltage control; black-start capabilities; or inertia) and long-term services (e.g. network-upgrade deferral; or energy reliability). In fact, the lack of local flexibility markets is one the main barriers to investment in energy storage perceived by stakeholders[127].

Overall, the future business models for energy storage are likely to be more diverse with multiple 'value stacking' opportunities for all technologies. Nevertheless, like renewable energy technologies, increasing the penetration of energy-storage technologies and other flexibility technologies could reduce the revenues for energy-storage operators who are reducing peak prices and price spreads in the energy market (a 'cannibalisation effect')[128]. The application of optimisation techniques, including software solutions, becomes crucial in this context to optimise the operation and maximise the cash flow of a facility providing different services. Energy storage could benefit from price variability and uncertainty. Uncertainty adds a layer of complexity over variability, which needs adequate software technologies for an optimal bidding behaviour.

4.1.2. The need for long-term visibility and predictability of revenues

Long-term visibility and predictability of revenues (either private or public) reduce the risk profile of the projects and facilitate decision-making about risk management. This in turn makes projects more attractive to investors and improves access to debt and equity financing. Indeed, insufficient incentives for long-term storage is one of the main barriers to the installation of energy-storage projects perceived by stakeholders[129].

Even when market conditions provide satisfactory revenue streams and a positive business case for energy-storage projects, long-term visibility and predictability of revenues are generally required by financers. These are needed by financers to: (i) reduce their exposure to market risks related to revenue uncertainty; and (ii) to meet their risk-assessment conditions. **Energy-storage stakeholders suggest that this could be achieved via specific supporting tools and enabling signals**, such as: (i) decarbonised capacity contracts; (ii) floor and ceiling pricing; (iii) 24/7 clean power purchase agreements; (iv) contracts for difference; (v) hourly energy attribute certificates; or (vi) energy

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[125] As provided for in Article 32 of Directive (EU) 2019/944 on common rules for the internal market for electricity.
[126] Energy Transition Expertise Centre (EnTEC), Study on Energy Storage, 2022, https://data.europa.eu/doi/10.2833/333409.
[127] Energy Transition Expertise Centre (EnTEC), Study on Energy Storage, 2022, https://data.europa.eu/doi/10.2833/333409,
EASE and Delta-EE, Webinar presentation of the European Market Monitor on Energy Storage 6.0, June 2022, https://ease-storage.eu/publication/emmes-6-0-june-2022/.
[128] Javier López Prol, Karl W. Steininger, David Zilberman, The cannibalization effect of wind and solar in the California wholesale electricity market, 2020, https://doi.org/10.1016/j.eneco.2019.104552.
[129] Energy Transition Expertise Centre (EnTEC), Study on Energy Storage, 2022,https://data.europa.eu/doi/10.2833/333409
EASE and Delta-EE, Webinar presentation of the European Market Monitor on Energy Storage 6.0, June 2022, https://ease-storage.eu/publication/emmes-6-0-june-2022/.

savings performance contracts[130]. Combining renewables and storage projects could create portfolio benefits that increase the attractiveness of investing in energy storage projects.

Day-ahead price volatility and intraday price volatility have grown in Europe since 2020. This is a positive development for energy-storage technologies. In the future, according to our model simulation[131], **higher profitability ranges for energy storage are likely in market zones with higher shares of variable renewable-energy sources.** However, price volatility is seasonal and difficult to predict, and energy-storage facilities will need to optimise their ability to capture the best arbitrage spread while generating other revenue streams. Specifically for longer-duration storage technologies, opportunities for arbitrage could be limited by cycling charging and discharge constraints. In particular, **seasonal storage represents one of the main technological and financial challenges, as only energy-storage systems that have a low capital cost and long lifetime will be cost effective** because the number of cycles per year for seasonal storage are very low (close to one cycle only).

Similarly, regulatory stability could facilitate access to financing by reducing the risk of the project.

4.2. Grids and permits that are fit for energy storage

4.2.1. Specific considerations in network planning, charges, and tariffs

Energy-storage facilities generally operate in the 'opposite' way to other users connected to the grid. This means that they distribute energy when there are low levels of generation and that they 'consume' energy when there are high levels of generation. This 'opposite' quality of energy storage could be further accommodated by operators when planning networks, granting access to these networks, and operating the energy system (e.g. by making flexible connection contracts)[132]. However, energy storage plays a minor role in most national plans for network development, as it is rarely assessed as an alternative option that could help operators to defer investment in networks. Incentives for system operators to opt for innovative solutions and less costly network investments could increase the deployment of energy storage as network- deferral assets and improve the efficient use of transmission and distribution assets[133].

The deployment of **smart electricity grids is a necessary for an efficient integration of energy storage** in the energy system. Smart grids enable more efficient use of existing networks and help fully tap on the benefits energy storage can provide, in particular in terms of flexibility and ancillary services. Thus, electricity grid planning should dully assess the need for deployment of smart electricity grids and for reinforcement of existing distribution grids to enable incorporation and further development of both large and behind the meter energy storage projects.

Network charges and tariffs are particularly relevant for promoting energy storage. **Well-designed network charges and tariff schemes could increase the use of flexibility tools like energy storage** to reduce consumption from the grid during peak hours. In particular, locational or temporal signals in

130 LDES Council, The journey to net-zero - An action plan to unlock a secure, net-zero power system, June 2022, https://www.ldescouncil.com/assets/pdf/journey-to-net-zero-june2022.pdf.

131 European Commission, JRC, Koolen, D., De Felice, M. and Busch, S., Flexibility requirements and the role of storage in future European power systems, 2023, https://publications.jrc.ec.europa.eu/repository/handle/JRC130519.

132 Energy Transition Expertise Centre (EnTEC), Study on Energy Storage, 2022, https://data.europa.eu/doi/10.2833/333409.

133 ACER, Position on incentivising smart investments to improve the efficient use of electricity transmission assets, November 2021, https://www.acer.europa.eu/events-and-engagement/news/infrastructure-efficiency-role-regulation-incentivising-smart.

network tariffs (such as time-differentiated network tariffs or nodal pricing) could incentivise investments in energy storage[134]. Time-of-use tariffs (ToU), which apply different prices at different times to encourage consumers to use electricity at times when there is no congestion in the grid, are already a good incentive for energy storage in many Member States[135].

However, **specific network charges and tariffs may be needed for energy-storage in view of its double role as a 'consumer' and 'generator' of energy.** In fact, the double taxes and grid charges faced by providers of energy storage is one the main barriers to the wider rollout of energy storage perceived by stakeholders[136]. 'Injection' charges (charges for adding stored or newly generated power to the energy system) apply to energy storage in most of the Member States where injection charges exist. And in several Member States, injection and withdrawing charges (charges for 'withdrawing' energy to a storage system) apply to energy storage and other grid users (e.g. 'prosumers') who are both injecting to and withdrawing from the grid[137]. Some Member States have special tariff structures or tariff exemptions for energy-storage facilities[138]. Under these special structures or exemptions, active consumers that own an energy-storage facility cannot be subject to any double charges for stored electricity remaining within their premises or when providing flexibility services[139].

4.2.2. Specific considerations in permit-granting procedures

Utility-scale energy-storage projects must comply with permit-granting procedures that are usually perceived as lengthy and complex. Although permit-granting procedures help to ensure that the projects are safe and secure, the complexity, variety and duration of those procedures is a major barrier to the swift and necessary deployment of new projects. This is because these procedures entail high transaction costs and uncertainties about timelines. Moreover, these **procedures do not always take into consideration the specificities of energy storage,** as they are usually designed for consumers or generators but not for technologies with a double role of both 'consumer' and 'generator'.

To address some of these issues, the **REPowerEU plan introduced targeted regulatory amendments**[140] to speed up the permitting processes for energy storage combined with renewable-energy projects through co-located projects and go-to areas; and to ensure that energy-storage assets related to the deployment of renewable generation are presumed to be of overriding public

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[134] European Commission, DG ENER, Andrey, C., Barberi, P., Nuffel, L., et al., Study on energy storage: contribution to the security of the electricity supply in Europe, 2020, https://data.europa.eu/doi/10.2833/077257.

[135] IRENA, Time-of-use tariffs innovation landscape brief, 2019, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Feb/IRENA_Innovation_ToU_tariffs_2019.pdf?la=en&hash=36658ADA8AA98677888DB2C184D1EE6A048C7470.

[136] Energy Transition Expertise Centre (EnTEC), Study on Energy Storage, 2022,https://data.europa.eu/doi/10.2833/333409
EASE and Delta-EE, Webinar presentation of the European Market Monitor on Energy Storage 6.0, June 2022, https://ease-storage.eu/publication/emmes-6-0-june-2022/.

[137] ACER, Practice Report on Transmission Tariff Methodologies in Europe, December 2019, https://documents.acer.europa.eu/Official_documents/Acts_of_the_Agency/Publication/ACER%20Practice%20report%20on%20transmission%20tariff%20methodologies%20in%20Europe.pdf;
ACER, Report on Distribution Tariff Methodologies in Europe, February 2021, https://documents.acer.europa.eu/Media/News/Pages/ACER-reports-on-electricity-distribution-tariff-methodologies-in-Europe-and-recommends-how-to-improve-them.aspx.

[138] Energy Transition Expertise Centre (EnTEC), Study on Energy Storage,2022,https://data.europa.eu/doi/10.2833/333409.

[139] Article 18(1) of the Electricity Regulation and Article 15(5) of the Electricity Directive.

[140] COM/2022/222 final, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2022:222:FIN.

interest. Additional urgent measures were proposed[141] and subsequently adopted by the Council to streamline the permit-granting process for renewable-energy sources that have the highest potential for quick deployment and the least impact on the environment, including co-located energy-storage projects. In addition, the **Recommendation on permitting procedures and power-purchase agreements**[142] and the **guidance on permitting procedures and power-purchase agreements**[143] put forward measures to reduce lengthy and complex permitting procedures, including for the assets needed to store the energy produced.

4.3. Resilient energy-storage supply chains

Prices for raw materials and commodities have risen in the last year due to an increase in demand and logistical constraints, resulting in greater uncertainty and greater costs for energy-storage projects. Constraints in global supply chains may particularly impact mid-term projects that have not yet started construction, even within secure contracts. In this context, developers and system integrators need to effectively manage the energy-storage supply chains, including their exposure to price fluctuations of raw materials. Specifically for batteries, prices for nickel, manganese and cobalt (NMC) have risen, leading manufacturers of electric vehicles to move to lithium-ion phosphate (LFP) batteries instead. Although lithium-ion continues to be the preferred technology for utility-scale applications, the global shortage in lithium plus the increased demand for electric vehicles may lead to constraints in the availability of material for stationary energy-storage[144]. Sodium, zinc and silicon-based batteries may also emerge as commercially viable alternatives to lithium-based batteries[145].

The clean-energy transition entails a paradigm shift in energy security for raw materials and supply chains[146]. The resilience of critical supply chains is crucial for ensuring the EU's security of energy supply and for achieving the EU's clean-energy transition, including for energy-storage technologies[147]. As shown in Figure 11, **some of the most important raw materials for batteries and fuel cells are included in the EU's list of critical raw materials**[148], as they must be closely monitored because of their high importance to the EU economy and the high risk associated with their supply[149]. These materials include cobalt, lithium, niobium, silicon, titanium and graphite, as well as platinum group metals and rare earth elements. Nickel is also closely monitored, given its role in demand for batteries.

141 COM(2022) 591 final, https://energy.ec.europa.eu/document/download/6ee7f7a1-6d74-407f-b49a-bc8eba28da1b_en?filename=COM_2022_591_1_EN_ACT_part1_v6.pdf .
142 C/2022/3219 final, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=PI_COM:C(2022)3219.
143 SWD/2022/0149 final, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52022SC0149.
144 IEA, Tracking Energy Storage 2020, 2020.
145 EASE and Delta-EE, Webinar presentation of the European Market Monitor on Energy Storage 6.0, June 2022, https://ease-storage.eu/publication/emmes-6-0-june-2022/.
146 IEA, The Role of Critical Minerals in Clean Energy Transitions, 2021, https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions.
147 European Commission, DG ENER, Guevara Opinska, L., Gérard, F., Hoogland, O., et al., Study on the resilience of critical supply chains for energy security and clean energy transition during and after the COVID-19 crisis, 2021, https://data.europa.eu/doi/10.2833/946002.
148 COM/2020/474 final, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0474.
149 Raw Materials Information System: https://rmis.jrc.ec.europa.eu/?page=crm-list-2020-e294f6.

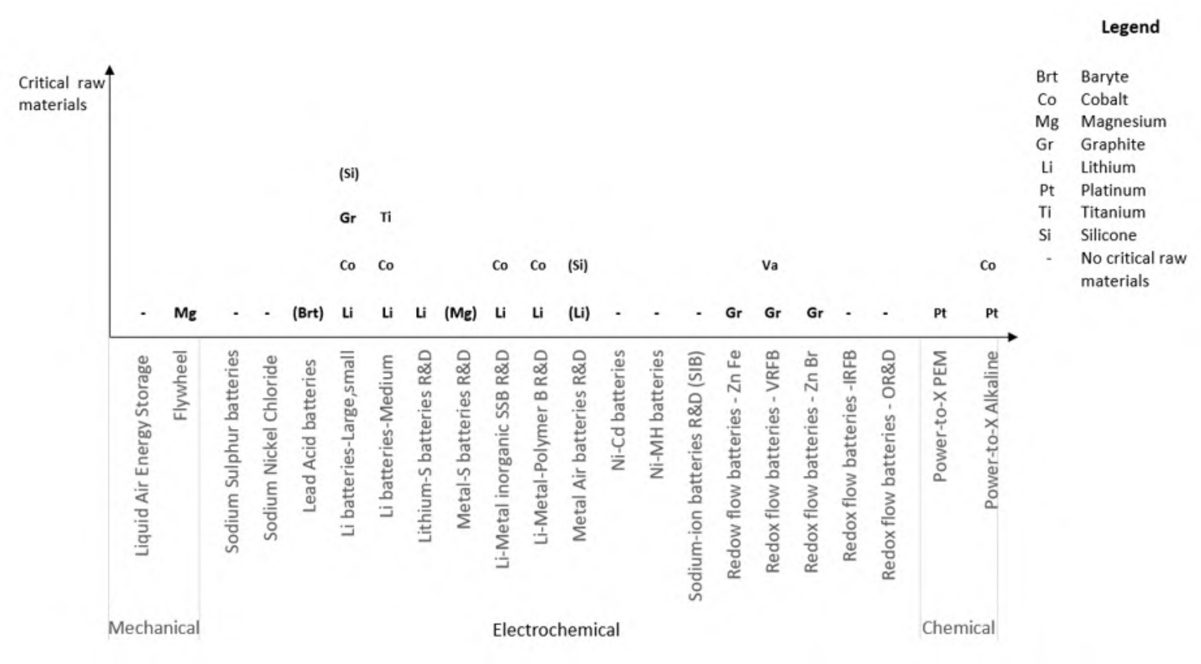

Figure 11. Critical raw materials by technology. Source: Fraunhofer, EnTEC Study on Energy Storage, 2022.

Energy-storage technologies like batteries and renewable hydrogen are considered strategic areas where the EU faces dependencies on non-EU countries, as highlighted in the in-depth reviews on Europe's strategic dependencies[150]. In the new geopolitical context, increasing the EU's strategic autonomy for critical raw materials is vital for the green and digital transition as well as for the resilience of the EU economy and defence capabilities. Building on the **EU's Raw Materials Initiative**[151], the Commission has drawn up an **action plan on critical raw materials resilience**[152] to tackle vulnerabilities in raw-material supply chains and a foresight study assessing critical raw materials for strategic technologies and sectors in the EU[153], including lithium-ion batteries and fuel cells. A second foresight study has been published assessing the challenges for the twin green and digital transitions in the new geopolitical context[154]. This second study covers materials for energy storage and conversion, such as batteries, fuel cells, hydrogen and other alternative energy-storage and conversion systems. The upcoming **European Critical Raw Materials Act**[155] will strengthen monitoring and strengthen the EU value chain and EU external policies on critical raw materials.

The **European Raw Material Alliance (ERMA)**[156] dedicates its efforts to ensuring a resilient supply chain for raw materials in the EU. It has a specific cluster to support the domestic production of raw and advanced materials for energy storage, complementing the **collaborative framework on critical**

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150 European Commission, DG GROW, Strategic dependencies and capacities, Mat 2021, https://ec.europa.eu/info/sites/default/files/swd-strategic-dependencies-capacities_en.pdf;
European Commission, DG GROW, EU strategic dependencies and capacities: second stage of in-depth reviews, February 2022, https://ec.europa.eu/docsroom/documents/48878/attachments/2/translations/en/renditions/native.
151 COM/2008/0699 final, https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:52008DC0699.
152 COM/2020/474 final, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0474.
153 European Commission, DG GROW, Critical Raw Materials for Strategic Technologies and Sectors in the EU – A Foresight Study, September 2020, https://ec.europa.eu/docsroom/documents/42881.
154 COM/2022/289 final, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52022DC0289.
155 https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/13597-European-Critical-Raw-Materials-Act_en.
156 https://erma.eu/.

materials for the energy transition of the International Renewable Energy Agency (IRENA)[157] and the increasing work in this area by the **IEA**[158]**.**

Additionally, the **EU's external energy strategy**[159] will facilitate long-term partnerships with suppliers to ensure access to critical raw materials, including cooperation on hydrogen and other green technologies such as: (i) smart, cyber-secure and flexible power grids; (ii) long-duration energy storage; or (iii) sustainable raw materials.

As **for investments in the infrastructure of the distribution and storage of renewable hydrogen**, the **European Clean Hydrogen Alliance (ECHA)** has established a roundtable on infrastructure to identify investment requirements and bottlenecks to the roll out of such infrastructure projects within the EU. This also covers non-grid projects that could provide storage capacity at short notice when imbalances in the grid would require.

4.4. Best practices and opportunities for energy storage

4.4.1. Favourable market conditions and regulatory signals at national level

The market and regulatory conditions in each Member State directly affect and determine the deployment of energy storage[160]**.**

Specific ancillary services in Belgium, the Netherlands and the Nordic Member States provide additional revenues for energy storage and are an important driver for its development. New opportunities are arising for energy storage from the introduction of fast-frequency response services in some Member States. This is the case for Ireland where 1.4 GW is expected to be installed in 2022 and for the Fast Reserve project in Italy. The phase-out of conventional thermal power plants will increase the revenue opportunities for energy-storage technologies.

Large-scale projectsare incentivised by specific tenders for energy storage or in combination with renewable generation in some Member States (e.g. France, Germany, Greece or Hungary)[161]. These tenders provide long-term signals facilitating the development of storage as described in Section 4.1.2. In addition, in some Member States, specific projects aim to develop applications for energy storage to support the grid. These applications include network-upgrade deferral, congestion management, and contingency support. This is the case for innovative projects in Italy[162] and France[163] for the installation of large-scale energy storage to alleviate congestion and increase the integration of renewable energy in the system. It is also the case for the two energy-storage pilot facilities in Germany[164] testing grid boosters to optimise the operation of existing grids by making it possible to rapidly intervene when faults in the grid occur.

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[157] https://irena.org/events/2022/Sep/Working-Group-III-IRENA-Collaborative-Framework-on-Critical-Materials.
[158] https://www.iea.org/news/2022-iea-ministerial-communique.
[159] JOIN/2022/23 final, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=JOIN:2022:23:FIN.
[160] Energy Transition Expertise Centre (EnTEC), Study on Energy Storage, 2022,https://data.europa.eu/doi/10.2833/333409;
EASE and Delta-EE, Webinar presentation of the European Market Monitor on Energy Storage 6.0, June 2022, https://ease-storage.eu/publication/emmes-6-0-june-2022/.
[161] Energy Transition Expertise Centre (EnTEC), Study on Energy Storage, 2022, https://data.europa.eu/doi/10.2833/333409.
[162] https://www.terna.it/en/electric-system/system-innovation/pilot-storage-projects.
[163] https://www.rte-france.com/projets/stockage-electricite-ringo.
[164] https://www.bmwi-energiewende.de/EWD/Redaktion/EN/Newsletter/2020/02/Meldung/direkt-account.html.

Several Member States have incorporated a definition of energy storage into their legislative frameworks (e.g. Belgium, Poland, Spain, Germany or Ireland), which simplifies and facilitates the specific consideration of energy storage in national procedures, thus reducing the burden of energy storage being treated simultaneously as both consumer and producer[165].

Additionally, some Member States have adopted strategies or national targets for energy storage for 2030 and 2050 (e.g. Spain, Italy, Greece, France and Croatia)[166].

Regulatory sandboxes, which make possible the small-scale testing of innovative solutions under specific regulatory frameworks, could further support the development of demonstration projects of less-mature storage technologies[167]. Some national regulators have already put in place such measures to facilitate innovation, both in demonstration and in deployment stages[168].

4.4.2. Increasing opportunities in the electricity markets

The design of the electricity market is crucial in increasing revenue-stacking opportunities and providing long-term visibility and predictability of revenues. **The timely, correct and full implementation of EU electricity-market legislation at national level is key to ensure the deployment of energy storage and its full participation in all electricity markets.**

The implementation of some key elements of EU legislation could facilitate the uptake of energy storage in the electricity markets, for example: (i) removing price caps; (ii) reducing minimum bid sizes; (iii) developing new flexibility services; or (iv) avoiding non-remunerated, non-frequency ancillary services[169]. Some product specifications and features could be particularly helpful in increasing the participation of energy storage in balancing markets. Such specifications and features include: (i) shorter delivery periods and minimum capacities required in the pre-qualification process; (ii) shorter minimum activation periods for frequency containment reserves; (iii) smaller minimum bid sizes; (iv) promoting the participation of low-carbon technologies; or (v) longer contractual periods[170].

The degree to which energy storage is remunerated through capacity mechanisms has historically been very limited. However, capacity mechanisms may in the future become a crucial tool for the development of energy storage, in particular for long-duration energy storage. Capacity mechanisms are potentially open to different technologies – subject to de-rating factors. However, there are some specific requirements that can make it difficult for energy storage to participate in capacity mechanisms. These requirements include: very high de-rating factors; minimum eligible

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[165] Energy Transition Expertise Centre (EnTEC), Study on Energy Storage, 2022,https://data.europa.eu/doi/10.2833/333409.
[166] Energy Transition Expertise Centre (EnTEC), Study on Energy Storage, 2022, https://data.europa.eu/doi/10.2833/333409.
[167] Council of European Energy Regulators (CEER), Paper on Regulatory Sandboxes in Incentive Regulation, May 2022, https://www.ceer.eu/documents/104400/-/-/72eab87d-9220-e227-1d26-557a63409c6b.
[168] International Smart Grids Action Network (ISGAN), Innovative Regulatory Approaches with Focus on Experimental Sandboxes 2.0, October 2021, https://www.iea-isgan.org/wp-content/uploads/2021/10/Regulatory-Sandbox-2.0_For-Publication.pdf;
Filippo Bovera, Luca Lo Schiavo, From energy communities to sector coupling: a taxonomy for regulatory experimentation in the age of the European Green Deal,2022, https://doi.org/10.1016/j.enpol.2022.113299.
[169] European Commission, DG ENER, Andrey, C., Barberi, P., Nuffel, L., et al., Study on energy storage: contribution to the security of the electricity supply in Europe, 2020, https://data.europa.eu/doi/10.2833/077257;
Energy Transition Expertise Centre (EnTEC), Study on Energy Storage, 2022, https://data.europa.eu/doi/10.2833/333409.
[170] ACER Market Monitoring Report 2020 – Electricity Wholesale Market Volume, https://acer.europa.eu/Official_documents/Acts_of_the_Agency/Publication/ACER%20Market%20Monitoring%20Report%202020%20%E2%80%93%20Electricity%20Wholesale%20Market%20Volume.pdf.

capacities, restrictions on aggregation; and minimum bid sizes[171]. Furthermore, some new elements could further facilitate the participation of energy storage in capacity mechanisms, such as lower carbon-cap requirements or the prioritisation of lower-carbon technologies.

The future network code on demand-side flexibility[172] will address specific regulatory barriers to unlock the potential of distributed assets as flexibility sources, including energy storage. The rules will cover specific technical and market-related measures and will also include new responsibilities for network operators and other relevant stakeholders to ensure the necessary coordination in the market.

In addition, and as highlighted in the Assessment of the EU Wholesale Electricity Market Design[173] by the European Union Agency for the Cooperation of Energy Regulators (ACER), the future electricity market design will need to ensure that flexible resources complement intermittent renewable production where and when needed. According to this assessment, price signals are necessary to drive relevant investment efficiently, and price limits should therefore be removed for the use of such flexibility resources, including for longer-term flexibility[174]. The assessment also recognises that: (i) fossil-fuel power plants (such as gas and coal plants) and hydro power plants with large reservoirs currently provide seasonal flexibility; and that (ii) when fossil fuels are phased out, alternatives to provide this flexibility will be needed[175]. These issues will be assessed in the long-term review of the electricity market design, as announced in the Communication on short-term energy-market interventions and long-term improvements to the electricity market design[176].

4.4.3. Harvesting the potential of behind-the-meter energy storage

Behind-the-meter storage is mainly driven by high retail prices and specific public support schemes. This is the case for Germany (through its solar storage programme)[177], which led the EU for energy-storage deployments in 2022, with 3.9 GW of installations that year. Germany also has the largest residential market due to its: (i) comparatively high retail prices (particularly when all price components such as renewable-energy surcharges are considered); (ii) strong support for the development of rooftop residential PV for self-consumption; and (iii) strong support for electric vehicles[178]. Italy has also seen significant developments, and expects to reach 0.9 GW of storage newly installed in 2022, driven by support schemes for building renovations and the fast-frequency response reserves. The installation of PV-storage systems is generally more favourable for the consumer in Member States that have higher retail electricity prices. Net metering schemes[179],

171 ACER Market Monitoring Report 2020 – Electricity Wholesale Market Volume, https://acer.europa.eu/Official_documents/Acts_of_the_Agency/Publication/ACER%20Market%20Monitoring%20Report%202020%20%E2%80%93%20Electricity%20Wholesale%20Market%20Volume.pdf.

172 Based on Article 59(1)(e) of Regulation (EU) 2019/943 on the internal market for electricity the Electricity Market, https://www.acer.europa.eu/events-and-engagement/news/acer-initiates-drafting-new-framework-guidelines-demand-response.

173 ACER's Final Assessment of the EU Wholesale Electricity Market Design, April 2022, https://www.acer.europa.eu/sites/default/files/documents/Publications/ACER%26%23039%3Bs%20Final%20Assessment%20of%20the%20EU%20Wholesale%20Electricity%20Market%20Design.pdf.

174 Executive summary of ACER's Final Assessment of the EU Wholesale Electricity Market Design.

175 Section 4.1 of ACER's Final Assessment of the EU Wholesale Electricity Market Design.

176 COM/2022/236 final, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2022:236:FIN.

177 https://www.energieagentur.rlp.de/service-info/foerderinformationen/solar-speicher-programm.

178 Energy Transition Expertise Centre (EnTEC), Study on Energy Storage, 2022,https://data.europa.eu/doi/10.2833/333409.

179 Net metering schemes are to be phased out for active consumers as provided for in Article 15(4) of Directive (EU) 2019/944 on common rules for the internal market for electricity.

where energy that is injected into the grid is rewarded with high prices, reduce incentives for energy-storage systems[180].

In addition to an appropriate metering and sub-metering system, the development of standards could further facilitate the rapid deployment of behind-the-meter storage. However, there are still a number of challenges related to: (i) ensuring interoperability on how technologies (i.e. batteries) communicate between themselves; and (ii) access to data, in particular data on the 'smart' charging of electric vehicles. In addition, **direct current (DC) projects** creating smart homes with a DC power installation could be an innovative option to further facilitate the combination of PV renewable generation and energy storage.

Behind-the-meter energy storage is expected to increase in the coming years due to the greater number of active consumers and energy communities, driven by the expected increase in electric vehicles, self-generators, heat pumps, smart devices, etc.

Electric vehicles as distributed energy storage

Electric vehicles can serve as a mobile behind-the-meter energy-storage facility, providing flexibility to the power system when economically and technically feasible, and resulting in lower energy bills for their users.

Due to the expected increase in electric vehicles in the coming years (more than 30 million zero-emission cars expected by 2030[181]), **electric vehicles have enormous potential in ensuring flexibility and security of supply for the future electricity system**[182]. Electric vehicles could adapt to the needs of the power system or even provide vehicle-to-grid (V2G) services using unidirectional smart charging or bidirectional smart charging[183].

The revised Renewable Energy Directive (as well as the Energy Performance of Buildings Directive) will further promote the uptake of electric vehicles thanks to the requirements for Member States to ensure **non-discriminatory access to electricity markets for small mobile systems** such as domestic and electric vehicle (EV) batteries so that they can provide flexibility services – including storage – to the electricity grid.

4.4.4. Exploiting the benefits of transparent and comprehensive information

There is an increasing need for data transparency and availability, greater data granularity, including on network congestion, renewable energy curtailment, market prices, renewable energy, GHG emissions content and installed energy-storage facilities. This need becomes more important for decisions about investing in, choosing a location for, and evaluating new energy-storage facilities. Specifically for energy-storage facilities, data are available for stand-alone projects in the EU, but the information available on behind-the-meter storage facilities and thermal storage is very limited, with

[180] As provided for in Article 18 of the Electricity Regulation (Regulation (EU) 2019/943) on charges for access to networks, use of networks and reinforcement, Article 11 of the Electricity Directive (Directive (EU) 2019/944) on dynamic electricity price contract, and Article 15(2)(e) of the Electricity Directive on active customers.
[181] COM/2020/789 final, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0789.
[182] European Commission, DG ENER, Effect of electromobility on the power system and the integration of RES, 2019, https://data.europa.eu/doi/10.2833/12919.
[183] BRIDGE, Vehicle-to-Grid to support grid stability and RES integration, Case study #2, 2020, https://bridge-smart-grid-storage-systems-digital-projects.ec.europa.eu/sites/default/files/case-studies/02%20Vehicle%20to%20Grid.pdf.

only a few Member States providing detailed information (e.g. Germany)[184]. The recently created European Storage Inventory[185] will make it easier to monitor the development and deployment of energy storage in the EU.

Moreover, the complexity and variety of services and business associated with energy storage will require sophisticated analytical tools and models to illustrate and calculate the added value of energy storage in the future energy system[186]. For example, analytical tools and models should further explore the combination of market data and modelling, including sector-coupling interdependencies and environmental, security and operational constraints. Greater time and geographical granularity in the models could capture additional needs for flexibility, while additional markets could capture additional potential services and revenues for energy-storage technologies. In addition, the use of stochastic scheduling could help to capture the variability and uncertainty of renewable production.

[184] Energy Transition Expertise Centre (EnTEC), Study on Energy Storage, 2022,https://data.europa.eu/doi/10.2833/333409.
[185] C(2022)7550, Horizon Europe Work Programme 2023-2024, Climate, Energy and Mobility, https://ec.europa.eu/info/funding-tenders/opportunities/docs/2021-2027/horizon/wp-call/2023-2024/wp-8-climate-energy-and-mobility_horizon-2023-2024_en.pdf.
[186] European Commission, JRC, Zucker, A., Hinchliffe, A., Spisto, A., Assessing storage value in electricity markets: a literature review, 2013, https://data.europa.eu/doi/10.2790/89242.