

A European Market Design for Energy Storage

Unleashing a Multitude of Flexibility Solutions for System Stability

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On the path towards climate neutrality, flexibility is becoming a critical factor for the stability of Europe's energy system. However, while measures to speed up grid expansion have been seized, the EU is still lacking a strategy that addresses the key role of energy storage. Storage investments are currently limited by two factors: the lack of regulatory harmonization and insufficient market rewards for their societal benefits. This ceplnput highlights the potential and key barriers to energy storage in Europe. To establish a diverse landscape of storage solutions in Europe, the author calls for a targeted support strategy that combines the removal of regulatory barriers with innovative price incentives.

- ▶ To boost investment incentives for storage solutions, EU and Member States should take efforts to speed up approval procedures, implement flexible connection agreements and strengthen the role of storage in grid planning. Moreover, a level playing field on markets needs to be created, requiring the harmonization of market access rules, a general abolishment of double taxation and the promotion of storage PPAs.
- ▶ Achieving socially optimal capacity growth requires measures to internalize the long-term system benefits of energy storage, particularly its contribution to reducing the need for grid expansion. This justifies the use of direct public support schemes. Relying solely on capacity markets is not the most efficient form of support, as payments do not address revenue risks and are largely unconditional on market activity.
- ▶ Combining market-based capacity payments with innovative revenue support schemes — particularly a percentage price mark-up — is a more cost-efficient way of stimulating storage expansion. This approach incentivizes storage activity during periods of imbalance while limiting fiscal risks and avoiding double funding.

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1 Background

The ongoing transformation of the European energy system towards renewable energy sources involves far more than a temporary investment boost. Integrating the naturally volatile energy sources of wind and solar power asks for a whole new management approach. Recent events like the massive power outage in Spain demonstrate this necessity.¹ System optimization is no longer simply a matter of selecting a cost-minimizing portfolio of power plants. Rather, it is a complex, dynamic balancing act involving various flexibility options, such as grids, peak-load power plants, front-of-the-meter storage solutions and demand-side management. This requires society to recognize the economic value of supply security, something that was previously taken for granted. This is the basis for determining the most cost-effective combination of flexibility options, both concerning the choice of technological solutions and their optimal distribution in space.

Instead, the public debate in Europe is narrowed down to a few solutions, a fact that is also reflected in political action. For instance, the new German government intends to prioritize the construction of new gas-fired power stations to facilitate system integration.² The European Commission's latest Action Plan for Affordable Energy also shows a strong focus on incentives for faster grid expansion.³ In contrast, the system benefits of energy storage — a field which is itself already highly diverse — receives less attention.

The economic conditions for battery storage in particular are currently favorable. Battery prices have recently fallen significantly due to overcapacities in Asian production.⁴ The increasing price volatility on European electricity exchanges is also strengthening the business model of storage system operators. Furthermore, new technical solutions, such as high-temperature thermal storage and compressed air storage systems, have entered the market, expanding the range of possible applications even further. However, after years of rather sluggish storage expansion, even a short-term boom will not spark sustainable capacity growth unless conditions are created for a level playing field in the competition with other flexibility options. In particular, this holds for technologies offering long-term storage, an area that gains importance with increasing seasonal variation in electricity supply.

This requires firstly the removal of regulatory barriers during commissioning (slow administrative authorization procedures, long waiting times for grid connection) and operation (double application of taxes and network tariffs for stored energy). Secondly, the fundamental challenges that storage solutions face as a business model, especially in comparison to the highly regulated area of grid operation, should be addressed. Grid operators receive a guaranteed compensation for the costs of grid expansion through the existing schemes of revenue regulation. In contrast, market-driven storage facilities need to refinance the costs of capacity expansion via uncertain market revenues and do not receive a secure remuneration for making flexible storage capacities available to the system.

Against this backdrop, this ceplnput examines the increasing importance of energy storage services in a decarbonized energy system. First, it analyses the existing technology portfolio and its contribution

¹ CNN (2025). [Spain says April blackout was caused by grid failures and poor planning, not a cyberattack.](#)

² Enerdata (2025). [Germany plans to develop 20 GW of gas power plant capacity by 2030.](#)

³ European Union (2025). Action Plan for Affordable Energy Unlocking the true value of our Energy Union to secure affordable, efficient and clean energy for all Europeans. Communication from the Commission. COM/2025/79 final.

⁴ Sirma, G., Wicke, T. (2025). Competitive market for battery materials: Market leaders, technologies and cost analysis. Fraunhofer ISI, Battery Update.

to the social goals of the green transformation. Then, it discusses the economics of energy storage and their impact on investment incentives for utility-scale storage solutions, investigating the impact of new direct support schemes in a simulation analysis. Based on this, policy recommendations are developed for an incentive-based market design, providing input for a future dedicated EU strategy on energy storage.

2 The role of storage technologies in the energy system

Energy storage technologies can perform several important functions in the management of energy flows. Unlike on markets for industrial products or other commodities, a balancing of supply and demand on electricity markets needs to occur at every moment in time. Grid operators need to maintain a constant grid frequency to ensure stable power supply and the proper functioning of electric devices. Deviations from this frequency are caused by mismatches between electricity supply and demand, with bigger mismatches causing bigger deviations. Already small temporary deviations from the target frequency increase the risk of light flickering, overheating of equipment and permanent device damage. A significant decline in grid frequency can end up in power system failure due to cascading effects. An unmanaged frequency drop induces power plants to switch off one after another, worsening the imbalance until a total breakdown of supply (blackout). By forcing industrial plants reliant on continuous electricity supply to shut down, the economic damages caused already by short-term outages can be significant.⁵ Longer-term outages threaten the functioning of basic public services like public transport and water transport, adding up to exponentially rising societal costs.

To avoid this development, grid operators can resort to a range of safety operations to stabilize grid frequency. This includes the use of disposable reserve energy, usually procured through tender procedures on specific balancing markets (see Subsection 4.2). Energy storage systems are important suppliers on these markets. **In particular, due to its short reaction time, battery storage is ideal for providing frequency stabilization services.** After a major black out, storage systems can provide the necessary initial energy for a black start, helping to bring back power plants online. Moreover, they can provide further ancillary services to grids that help to secure the proper functioning of electricity transmission like support to maintain voltage and angular stability.⁶

Their flexibility also directly supports the decarbonization of electricity supply, by facilitating the integration of volatile renewable sources into the system. Compared to peak-load generation capacity, this is an important additional feature of storage services. Their supporting role is not limited to the provision of compensating electricity in times of low supply from renewables, but also includes the storage (and later reinjection) of excess renewable energy in times of high supply. This avoids the curtailment of renewable power plants and thus enhances the usage efficiency of renewable sources. By skimming off supply peaks, storage facilities located in close proximity to large supply sources help to limit the necessary degree of grid expansion and contribute to a better utilization of network capacities. This both concerns the roles of short-term-storage to balance volatility and of long-term storage to balance cyclical supply patterns (see Section 3). This, in turn, reduces the network fees paid by electricity customers, providing further impulses for electrification.

⁵ Wolf, A., & Wenzel, L. (2016). Regional diversity in the costs of electricity outages: Results for German counties. *Utilities Policy*, 43, 195-205.

⁶ EASE (2020). Energy storage applications summary. European Association for Storage of Energy.

Finally, through their arbitrage activities, storage operators exert a smoothing effect on price fluctuations on electricity wholesale markets. Front-of-the-meter storage operators directly engage in intra-day trading on the electricity exchange. Behind-the-meter systems exert an indirect price effect by raising price sensitivity of final electricity demand. Reduced price volatility, in turn, reduces the costs of short-term price hedging for traders.

3 Overview on storage technologies

3.1 Storage media

A wide range of technologies exist for the conversion and subsequent storage of energy. They can be broadly classified based on the type of storage medium: chemical, electrochemical, electromagnetic/-static, mechanical or thermal.

Chemical storage comprises solutions that store energy within the bonds of molecules, by using electricity as an energy source in the artificial creation of chemical bonds. Currently, the electrolytical production and subsequent storage of hydrogen is seen as the most promising option in this field. It allows for a (depending on the electricity source) potentially emission-free form of long-term storage for high amounts of energy. On the downside, conversion losses are still comparatively high.⁷

Electrochemical storage comprises solutions to store energy in battery systems. The storage technique consists of achieving a continuous flow of electrons between the two electrodes (anode, cathode) of the system. The storage performance is highly sensitive to battery chemistry. In addition to the traditional lead-acid batteries, further solutions like zinc-based batteries and the promising vanadium redox flow batteries were developed.⁸ In recent time, Lithium-Ion batteries have become the most popular form of battery technology, due to their combination of high power density, low conversion losses and rapid response times. On the downside, storage capacity is comparatively expensive, limiting its cost efficiency in storing large amounts of energy over long time periods.

Electromagnetic/-static storage has the unique property that it does not convert electrical energy, but stores it directly as an electric field.⁹ This includes capacitors, which consists of two conductors separated by a non-conductive region. The current state of development offers so-called supercapacitors with superior storage capacity compared to conventional capacitors. Superconducting magnetic energy storage stores energy by magnetic field. Main advantages are the extensive lifetime and very rapid response times of these systems. However, disadvantages like low energy density and the energy needs for system maintenance still prevent a widespread application.¹⁰

Mechanical storage converts electrical into mechanical energy (either as potential or kinetic energy). It is the traditional form of power-to-power storage. Pumped Hydroelectric Storage uses electrical energy to pump water from a lower to an upper reservoir, thus storing it as potential energy. Compressed

⁷ Guerra, O. J., Zhang, J., Eichman, J., Denholm, P., Kurtz, J., & Hodge, B. M. (2020). The value of seasonal energy storage technologies for the integration of wind and solar power. *Energy & environmental science*, 13(7), 1909-1922.

⁸ Šimić, Z., Topić, D., Knežević, G., & Pelin, D. (2021). Battery energy storage technologies overview. *International journal of electrical and computer engineering systems*, 12(1), 53-65.

⁹ Rodriguez-Martinez, L. M., & Omar, N. (Eds.). (2017). *Emerging nanotechnologies in rechargeable energy storage systems*. William Andrew.

¹⁰ Khan, H. R., & Ahmad, A. L. (2024). Supercapacitors: Overcoming current limitations and charting the course for next-generation energy storage. *Journal of Industrial and Engineering Chemistry*.

Air Energy Storage uses electrical energy to compress air, which can subsequently be stored underground in large reservoirs like caverns. Flywheel Energy Storage uses electrical energy to accelerate a rotor to high speed, thus storing it as kinetic energy. Gravity Energy Storage uses electrical energy to lift heavy objects to a higher elevation. Mechanical systems offer environmentally friendly and potentially highly efficient ways of storage. However, the use of its most widespread form Pumped Hydroelectric Storage is subject to geographic limitations, while other forms are still in an early development phase.¹¹

Thermal storage converts electrical energy into heat energy. Variants can be distinguished based on their impact on the heated material. Sensible heat storage does not change the physical state when changing the temperature of the storage medium. Typical storage media are water and minerals. Latent heat storage involves a phase change of the storage medium (e.g. melting). Typical storage media are paraffin and salt hydrates. Thermochemical storage involves the dissociation of chemical bonds in the heating process. Storage media used include various forms of metal hydrides.¹² Thermal storage constitutes a scalable and potentially very efficient way of using electricity from renewables to meet the heat demand of industries and homes, thereby offering an important contribution to sector coupling. However, they tend to be less suitable for power-to-power applications, due to high energy losses in reconversion.¹³

3.2 Application forms

A major distinction is made between front-of-the-meter and behind-the-meter storage systems. **Front-of-the-meter storage** is a term for (usually large-scale) storage applications that are connected to the energy system on the utility side of the grid, i.e. in front of the electricity meter. This includes utility-scale stand-alone storage solutions tied to the transmission grid as well as storage devices that are co-located with generation facilities, especially wind and PV power plants, behind a common point of interconnection. Their main purpose is to act as a stabilization device, either for the output of specific generation plants or for grid stability in general.¹⁴ **Behind-the-meter storage** refers to (typically small-to medium-scale) storage systems located on the customer side of the electricity meter. Their main purpose is to reduce the electricity bill of customers by smoothing out electricity demand and reducing the sensitivity to price peaks. For home owners with rooftop PV panels, they also raise the revenue potential from selling excess electricity on wholesale markets. At the same time, their smoothing function represents a valuable service to the energy system, especially with the accelerated dissemination of new electricity-based technologies like rooftop PV, heat pumps and battery-driven cars. Besides technical and regulatory barriers to the roll-out of smart electricity meters in some Member States, their implementation is still hampered by behavioral barriers and the lack of time-flexible pricing in electricity retail contracts.¹⁵

¹¹ Salvini, C., & Giovannelli, A. (2022). Techno-economic comparison of utility-scale compressed air and electro-chemical storage systems. *Energies*, 15(18), 6644.

¹² Kandhasamy, M., Duvaragan, B. K., Kamaraj, S., & Shanmugam, G. (2024). An Overview on Classification of Energy Storage Systems. *Materials for Boosting Energy Storage. Volume 2: Advances in Sustainable Energy Technologies*, 1-25.

¹³ Energy Monitor (2020). [Can thermal storage fire up the net-zero transition?](#)

¹⁴ Kittner, N., Schmidt, O., Staffell, I., & Kammen, D. M. (2020). Grid-scale energy storage. In *Technological learning in the transition to a low-carbon energy system* (pp. 119-143). Academic Press.

¹⁵ Thunshirn, P., Mlinaric, I., & Berg, J. (2025). A qualitative analysis of consumer motivations and barriers towards active smart meter utilization. *Energy Policy*, 203, 114623.

Storage systems can also be distinguished by the typical length of storage periods. The purpose of **short-term storage** is to bridge spontaneous fluctuations in electricity generation or demand. The storage duration can last from milliseconds to a few hours. It offers important system services to grid operators to maintain the safety and stability of power grids, e.g. by stabilizing the grid frequency. It requires storage systems with rapid response times, low conversion losses and high power capacity.¹⁶ **Long-term storage** comprises storage durations ranging from a couple of hours over multi-day/weekly storage up to seasonal shifting. Its main purpose is to bridge systematic gaps in electricity generation or demand arising from regular supply and demand patterns. It also contributes to system resilience as a backup for times of an unexpected extensive shortfall of generation capacity. It requires storage systems with high energy capacity and low long-term energy losses. With increasing shares of PV-based electricity, **seasonal storage** will become more and more important as a device to store excess electricity from the summer for winter times, thereby contributing to the system integration of renewables.¹⁷ Based on their characteristics, Table 1 lists typical application cases for different storage technologies.

Table 1: Typical usage forms of storage technologies

Class	Promising technologies	Application area(s)	Typical storage duration
Chemical	Water electrolysis (H2)	Power-to-chemicals, power-to-power	Very long-term (seasonal) or no reconversion
Electrochemical	Lithium-Ion Batteries, Vanadium Redox Flow (VFR) Batteries	Power-to-power	Very short-term (milliseconds) to medium-term (few hours)
Electromagnetic/-static	Supercapacitors, Superconducting magnetic storage	Power-to-power	Very short-term to short-term
Mechanical	Pumped Hydroelectric (PHS), Compressed Air (CAES)	Power-to-power	Short-term to long-term (days)
Thermal	High-temperature storage	Power-to-heat, power-to-power	Short-term to long-term or no reconversion

Source: own representation

3.3 Market situation

At the global level, the current portfolio of energy storage solutions is still very limited. Pumped Hydroelectric storage is still the dominant technology. Batteries are catching up and increasingly conquer the area of utility-scale front-of-the-meter storage. Other storage solutions only make up a marginal share of installed capacities.¹⁸ For the situation in Europe, the European Market Monitor on Energy Storage (EMMES) reports a similar pattern.¹⁹ Of the estimated 89 GW of total storage capacity, more than half are contributed by (partly quite old) Pumped Hydroelectric facilities. Electrochemical storage ranks second with 35 GW. However, recent dynamics are starting to make a change. This primarily affects the technology mix. According to the EMMES, the year 2024 has been a record year for new storage installations in Europe, with added capacity amounting to 12 GW. The driving force have been investments in battery storage. By the end of the decade, battery storage is projected to have outpaced

¹⁶ López Prol, J., & Schill, W. P. (2021). The economics of variable renewable energy and electricity storage. *Annual Review of Resource Economics*, 13(1), 443-467.

¹⁷ Serpell, O. (2020). *The Opportunities and Limitations of Seasonal Energy Storage*. Kleinman Center for Energy Policy, University of Pennsylvania.

¹⁸ IEA (2025). [Grid-scale storage](#). International Energy Agency.

¹⁹ EASE (2025). [EMMES 9.0 - March 2025](#). European Association for Storage of Energy.

mechanical storage in terms of power capacity, not least due to an expected boost in state aid.²⁰ This is supposed to be largely driven by strong dynamics in the utility-scale segment, meeting the increased demands for large-scale system balancing. In geographic terms, Germany and Italy are currently the by far most important European markets for battery deployment, revealing a strong inequality in investment dynamics in Europe.²¹ No alternative storage solutions are projected to face similar growth trajectories in the nearer future.

4 Economics of storage investments

4.1 Cost structure

In essence, all storage applications require investment in three key components: a power conversion system, a storage unit and a control system. The **power conversion system** includes all the components necessary for converting electricity into the specific storage medium. For power-to-power storage, this includes process technologies for reconvertng stored energy into usable or transportable forms of electricity. For example, integrating battery storage applications into PV systems for households requires a battery inverter to convert the direct current (DC) stored in the battery into alternating current (AC) for direct household usage or for feeding excess electricity into the grid. The size of the conversion system, together with parameters such as age, temperature and charging mode, influences the power capacity of the storage system, i.e. the amount of energy the system can take up per hour (in watt (W)), and thus its operational flexibility.²²

The **storage unit** is the device used to store converted energy over time. In recent battery storage applications, this is often a lithium-ion battery pack. The size of the storage unit determines the energy capacity of the system, i.e. the maximum amount of energy that can be stored at a given time (in watt-hours (Wh)). When scaling up energy capacity, common storage systems usually exhibit significant economies of scale. This means that systems with a higher energy capacity require lower investment per MWh of energy capacity, resulting in lower capital costs.²³ Finally, investments in **control units** for monitoring and managing the energy flows of the storage systems (the balance of system (BOS)) are needed. The purchase prices of the individual components, together with the system lifetime and risk-adjusted discount rates, determine the annual capital costs. Figure 1 shows medium-term projections by the US Department for Energy for the installed capital costs (including installation costs) of different storage systems in the US.²⁴

²⁰ LCP Delta (2025). Between new state aid & more rules. Webinar presentation.

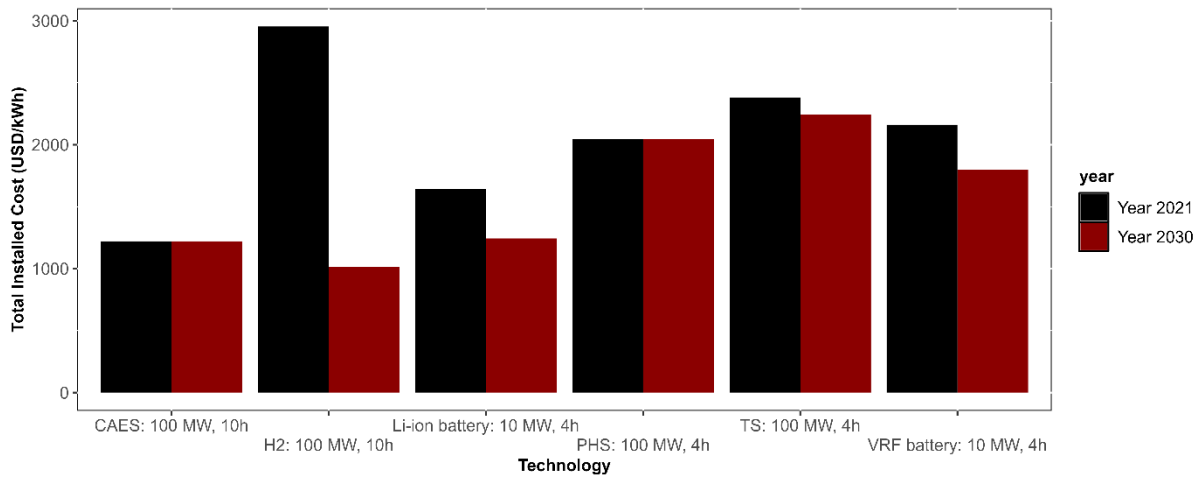
²¹ SolarPower Europe (2025). European market outlook for battery storage 2025-2029.

²² Lian, J., Zhang, Y., Ma, C., Yang, Y., & Chaima, E. (2019). A review on recent sizing methodologies of hybrid renewable energy systems. *Energy Conversion and Management*, 199, 112027.

²³ Mauler, L., Duffner, F., & Leker, J. (2021). Economies of scale in battery cell manufacturing: The impact of material and process innovations. *Applied Energy*, 286, 116499.

²⁴ Viswanathan, V., Mongird, K., Franks, R., Li, X., Sprenkle, V., & Baxter, R. (2022). 2022 grid energy storage technology cost and performance assessment. *Energy*, 2022, 1-151.

Figure 1: Comparison of installed system costs across storage technologies



Source: Viswanathan et al. (2022). h: max. storage duration in hours. TS: Thermal storage (representative average).

The remaining part of the cost balance consists of Operating and Maintenance (O&M) costs. These include fixed, i.e. purely capacity-determined O&M (general maintenance, administration, insurance) and variable operating costs varying with the frequency of storage operations and the actual amount of energy stored. In the case of Pumped Hydroelectric and Compressed Air Storage, for instance, these include the costs of pumping a specific amount of energy. Another component of operating costs crucial for the overall efficiency is energy loss during charging, storage and discharging. This is typically reflected by the indicator **round-trip efficiency**. It measures the ratio of electricity output from the storage device to electricity input to the device during one charging and discharging cycle.²⁵ For various reasons, no storage technology is able to achieve an actual round-trip efficiency of 100%. Depending on the storage type, losses can occur in the processes of conversion/reconversion, due to emission of heat caused by side reactions or, in the case of batteries, due to phenomena like internal cell resistance or accidental cell discharge.²⁶ Table 2 presents estimated round-trip efficiencies for different storage technologies.

Table 2: Estimated round-trip efficiencies of characteristic storage systems

Technology	Year 2021	Year 2030 (projection)
Compressed Air: 100 MW, 10h	52%	52%
Hydrogen: 100 MW, 10h	31%	31%
Lithium-ion Battery: 10 MW, 4h	83%	85%
Pumped Hydroelectric Storage: 100 MW, 4h	80%	80%
Thermal Storage: 100 MW, 4h	51%	53%
Vanadium Redox Flow Battery: 10 MW, 4h	65%	65%

Source: Viswanathan et al. (2022).

²⁵ Grid PIQ (2025). [Energy Storage System Efficiency](#).

²⁶ Liu, K., Hu, X., Yang, Z., Xie, Y., & Feng, S. (2019). Lithium-ion battery charging management considering economic costs of electrical energy loss and battery degradation. *Energy conversion and management*, 195, 167-179.

Hence, the choice of a storage system — including storage technology, size and location — is governed by the interplay of technical limitations (storage capacities, response times), cost structure and intended use. In particular, the different technical requirements for short-term and long-term storage (see Subsection 3.2) imply a different importance of specific cost factors. Short-term storage applications primarily require high responsiveness to sudden market developments and a high power-to-energy ratio to match the typical operating mode of a potentially large number of short charging and discharging cycles. Therefore, storage solutions should exhibit rapid response times and cost-efficient power capacities. In contrast, energy capacity constraints and associated costs are of minor relevance as stored energy is rapidly discharged. Conversely, long-term storage solutions are designed to even out systematic supply fluctuations through fewer but longer charging/discharging cycles. They require sufficient capacity for accumulation, as well as a low power-to-energy ratio for economic operation. Energy capacity constraints and associated costs are therefore crucial economic parameters.

Another distinction concerns the relevance of round-trip efficiency. For short-term balancing operations, round-trip efficiency is an important economic indicator as storage cycles typically involve the reconversion of stored energy to electricity. For the long-term storage of excess electricity, technical solutions in the field of power-to-heat and power-to-chemicals are available (see Section 3), providing alternative direct usage options for stored energy as process heat and chemicals for industrial processes, respectively. For seasonal storage in particular, this assigns a role to electrolytically produced hydrogen. It allows large amounts of excess energy (e.g. excess PV electricity in the summer) to be stored with small long-term losses. Conversion into derivatives such as ammonia and methanol creates various usage options beyond reconversion to electricity.

These trade-offs allow a clear assignment of different technologies to different use cases. Batteries and capacitors are ideal candidates for short-term storage. Pumped Hydroelectric storage and Compressed Air Storage are technologies for long-term power-to-power storage, while hydrogen and thermal storage are best suited for the direct utilization of stored energy as process chemical or heat, respectively. Recent simulations indicate that applying a technology mix to match short-term and long-term storage needs can indeed minimize system costs.²⁷ However, implementing such a technology mix requires sufficient revenue sources for all technology options. Furthermore, the regulatory framework must guarantee a level playing field by overcoming technology-specific barriers.

4.2 Revenue models

Depending on their specific technical constraints, storage systems can exploit different kinds of revenue sources. In the following, we will focus on the business opportunities of power-to-power storage systems. A traditional revenue base for such storage systems is **arbitrage on electricity spot markets**. Charging electricity in times where market prices drop to low levels and discharging during price peaks allows operator to realize margins from price differentials. Due to price uncertainty and the occurrence of energy losses (see previous subsection), such an arbitrage strategy is not risk-free. Given the limited energy capacity, every charging activity reduces flexibility for further charging during the period of storage. Charging decisions thus depend not only on expected margins, but also on the expected time distance between temporary price peaks and troughs. Moreover, while the evolution of spot market

²⁷ Yang, G., Yang, D., Liu, B., & Zhang, H. (2024). The role of short-and long-duration energy storage in reducing the cost of firm photovoltaic generation. *Applied Energy*, 374, 123914.

prices over a day shows some typical patterns, these daily patterns tend to vary over time (workday vs. weekend, summer days vs. winter days) and are sometimes overshadowed by short-term disruptions. Determining an optimal charging/discharging strategy for market arbitrage is thus highly complex and sensitive to investors' risk preferences.

The increasing share of volatile renewables in the electricity system has mixed effects on these arbitrage models. On the one hand, by contributing to price volatility on spot markets, it creates the prospect of higher returns to short-term arbitrage. On the other hand, it makes price patterns even less predictable, thus raising the uncertainty of net revenue flows for storage operators. Against this background, those market segments are most attractive where the consequences of spontaneous imbalances between supply and demand (e.g. due to erroneous weather forecasts or unexpected demand fluctuations) can be best exploited. This concerns markets in which trading occurs over the shortest time intervals and closest to the delivery date.²⁸ For this reason, European storage operators usually prefer the intraday electricity markets for their arbitrage activities.

At the same time, increased supply volatility has raised demand by network operators for system services, which are partly tendered on specific markets. Due to their flexibility, storage systems are ideal candidates for providing many kinds of these ancillary services, thus opening an important additional revenue source. A key institution are the **markets for balancing energy** organized by the Transmission System Operators (TSOs). These are platforms to procure and deploy balancing energy to support TSOs in their responsibility to maintain grid stability. On these platforms, trading occurs in a multi-stage process and separately for different time windows of activation. The German balancing energy market currently distinguishes three different balancing products by activation mode: Frequency Containment Reserve (to be provided within 30 seconds), automatic Frequency Restoration Reserve (5 minutes) and manual Frequency Restoration Reserve (12.5 minutes).²⁹ The EU has formulated binding guidelines for the operation of such markets.³⁰ It foresees a mandatory pre-qualification phase for service providers before being allowed to bid on balancing energy markets. The procurement processes are split into tenders for offering balancing capacity and subsequent tenders for offering actual amounts of balancing energy, both conducted on a day-to-day basis. First, bids in the balancing capacity tenders are ordered by offered capacity price until the tendered capacity has reached. Successful bidders receive their offered capacity price ("pay-as-bid") and are in turn obliged to submit their bids to the subsequent balancing energy tenders. There, market clearance occurs based on the short-term balancing needs of the TSOs. Hence, remuneration to successful capacity bidders has both a fixed (guaranteed capacity price) and a variable (time-dependent rewards for delivered balancing energy) component. Unsuccessful capacity bidders can also participate in the balancing energy bidders. Their remuneration hinges completely on actual balancing needs.³¹

²⁸ Bertrand, G., & Papavasiliou, A. (2019). Adaptive trading in continuous intraday electricity markets for a storage unit. *IEEE Transactions on Power Systems*, 35(3), 2339-2350.

²⁹ 50hertz/Amprion/TenneT/Transnet BW (2024). Regelreserveprozesse 2030 - Das Grünbuch der deutschen Übertragungsnetzbetreiber für die Regelreserve.

³⁰ European Commission (2017). Commission Regulation (EU) 2017/2195 of 23 November 2017 establishing a guideline on electricity balancing.

³¹ German Federal Network Agency (2019). Teilgenehmigung des Vorschlags der regelzonenverantwortlichen deutschen Übertragungsnetzbetreiber (ÜNB) gemäß Art. 18 Abs. 1 lit. a der Verordnung (EU) 2017/2195 (EB-Verordnung) für die Modalitäten für Regelreserveanbieter betreffend die Einführung eines nationalen Regelarbeitsmarktes sowie die Ausnahmen von Veröffentlichungspflichten. BK6-18-004-RAM.

Compensation payments for re-dispatch measures carried out by the TSOs are another revenue opportunity. These are short-term interventions in the generation capacity of power plants and storage facilities in order to protect certain sections of electricity grids from overloading. In accordance with the requirements of the EU Electricity Market Regulation, the selection of re-dispatched units should be carried out using market-based mechanisms wherever possible. Even in the case of non-market-based selection, financial compensation must always be paid to compensate for additional operating costs and/or lost market remuneration. In the case of storage operators, this also applies to lost net revenues from market arbitrage.³²

Some Member States have also incorporated electricity storage into their **national capacity markets for flexible power supply**. These mechanisms aim to remunerate controllable capacities directly for their contribution to balancing volatile electricity generation (in euros per MW of guaranteed available capacity). This is intended to strengthen investment incentives in controllable capacities. Currently, capacity markets in Europe are organized partly centrally, in the form of capacity auctions conducted by public entities, and partly decentralized, via the obligation for energy traders to purchase capacity certificates. Capacity auctions are organized independently of the trading of energy on electricity markets. Typically, capacity remuneration is associated with only limited restrictions on supply behavior in the electricity spot market, e.g. readiness to feed in if electricity prices exceed a certain threshold. To strengthen investment security, the capacity price is typically contractually guaranteed as an annual premium over a long period (10–17 years).³³ Compared to capacity remuneration on balancing energy markets, which takes place on a day-to-day basis, long-term capacity markets thus offer storage systems a higher revenue security.

Finally, the growing popularity of Power Purchase Agreements (PPAs) as a long-term marketing strategy for electricity generation is creating new opportunities for storage operators. To date, the public debate has focused heavily on PPAs for electricity producers, with owners of renewable energy plant as sellers and electricity consumers as buyers. However, there are also models of **storage PPAs**, in which storage operators conclude long-term contracts with off-takers (usually large commercial electricity consumers) for the provision of certain pre-defined storage services. These services consist of implementing certain market-dependent charging/discharging activities. For instance, this can involve the resale of electricity previously purchased by storage operators at times of low spot market prices, i.e. a participation in arbitrage profits. Storage operators can also sell stored electricity during periods of imminent grid overload to help off-takers avoid the risk of their electricity consumption being curtailed by grid operators ('peak shaving').³⁴ Storage PPAs therefore create additional flexibility for storage operators to marketize their services. At the same time, by fixing the service remuneration contractually, they can stabilize their revenue flows over time.

To optimize total revenues and diversify revenue risks, combining the revenue models discussed (**'value stacking'**) can be an attractive option. The simplest model to manage is one that combines market arbitrage with operation-independent capacity remuneration. However, providing several types of storage services simultaneously can set high demands on system management, as different services may require different charging/discharging patterns. This can be practically solved by

³² European Union (2019). Regulation (EU) 2019/943 of the European Parliament and of the Council of 5 June 2019 on the internal market for electricity.

³³ Wilkening, L., Leykam, K., Müller, J. (2024). Battery storage on a capacity market. PV Magazine, July 30th 2024.

³⁴ Oliviera, T. (2024). [Understanding storage PPAs](#). Synertics.

managing specific parts of storage capacity separately for specific services. However, such an organizational split might conflict with market norms (e.g. exclusivity clauses in service contracts) or regulatory requirements.³⁵

4.3 Barriers

The general economic conditions for expanding energy storage solutions in Europe are largely favorable (see Subsection 3.4). Growing price volatility in wholesale electricity trading increases the potential returns for storage operators from traditional arbitrage. At the same time, grid operators are demanding more balancing energy and flexibility services, creating new markets and increasing the potential for value stacking. For battery storage systems in particular, the significant decline in purchase prices is a key driver of growth. A recent global battery market analysis by Fraunhofer ISI reveals that the average price of anode materials has fallen by around 45% since 2020. The average price of cathode materials has fallen by at least 25% over the same period, despite rising prices for critical raw materials such as lithium and nickel. The analysts attribute this evolution mainly to improvements in production methods and the cost-reducing effect of economies of scale. In the near future, the presence of global overcapacities in material production, primarily due to China's strategy of achieving global supply chain dominance, is expected to lead to further price declines.³⁶

Nevertheless, **high upfront expenses for capacity building** still characterize the needs of storage business models, particularly for utility-scale storage solutions. Therefore, expectations concerning the level and variance of long-term net revenues from storage operations have a significant impact on investment incentives and bankability. While framework conditions differ greatly between Member States³⁷, various technical, market-specific and general regulatory barriers to rapidly increasing storage capacity can be identified.

One technical barrier to new storage projects is the average length and uncertainty of the lead time between commissioning and start of operation. This first concerns the **length of public approval procedures**. A 2022 survey among storage operators revealed concerns about the high complexity and cost-intensity of such procedures for both Pumped Hydroelectric and battery storages, with a large bandwidth of observed time lengths ranging from one year to more than seven years.³⁸ Another factor contributing to delays are **long waiting times for the establishment of grid connections**. In addition to complex certification procedures to document the technical storage requirements, the slow overall growth in grid capacity in Europe is a limiting factor, in particular for stand-alone utility-scale storage. The currently dominating form of fixed connection agreements requires a prior updating of grid capacity in areas with insufficient initial capacity.³⁹ Delays in grid expansion thus directly translate into connection delays for large-scale storage solutions.

In economic terms, this problem is exacerbated by the **lack of incentives for grid operators to consider storage in long-term grid planning**. From their perspective, payments to storage operators for

³⁵ EnTEC (2023). Study on energy storage. European Commission, Energy Transition Expertise Center.

³⁶ Sirma, G., Wicke, T. (2025). Competitive market for battery materials: Market leaders, technologies and cost analysis. Fraunhofer ISI, Battery Update.

³⁷ EASE (2024). Energy storage overview of the 2023 draft updated National Energy and Climate Plans. European Association for Storage of Energy.

³⁸ See EnTEC (2023).

³⁹ EM Power Europe (2025). Flexible Grid Connection Contracts – More Renewables, Less Grid Congestion? Trend paper.

balancing services are operating costs. Unlike capital costs of grid expansion, additional operating costs can typically not be recovered immediately within a multi-year regulatory period under the existing revenue regulation schemes. Furthermore, the option to participate on several markets (see Subsection 4.2) makes the timing of storage activity difficult for grid operators to predict, thus increasing the cost of capacity planning. Consequently, TSOs tend to prioritize grid capacity over storage capacity in their long-term network development plans.⁴⁰

The first market-specific barrier to storage deployment concerns the **pre-qualification and participation requirements for storage services** in certain markets. For example, the markets for balancing energy in Europe are characterized by complex, segment-specific pre-qualification processes, e.g. concerning the testing of technical capabilities, IT infrastructure and creditworthiness.⁴¹ These increase the cost of market entry for small-scale flexibility providers, such as small storage facilities. In some Member States, the option to pre-qualify as a group of units (e.g. a wind farm together with a storage facility) to jointly provide balancing energy is not yet available, thus preventing small storage systems from participating in balancing energy markets. Moreover, no EU-wide remuneration schemes for other kinds of storage services have yet been implemented. This includes their contribution to saving long-term costs of grid expansion as well as short-term ancillary services such as support for voltage maintenance and angular stability. This is particularly relevant in Member States where no capacity remuneration schemes are in place.

Barriers also affect the **implementation of innovative storage service markets**, such as storage PPAs (see previous subsection). High search and negotiation costs may be incurred before concluding such a contract. Another obstacle to the development of PPA markets is the existence of default risks when purchasing contractually agreed electricity volumes, which requires off-takers to provide financial assurance. Furthermore, due to its restricted time resolution, the current system of Guarantees of Origin (GOs) for electricity production in Europe hardly contributes to the dissemination of storage PPAs. GOs were introduced at EU level by the 2018 reform of the Renewable Energy Directive (RED II) to certify the origin of a quantity of traded electricity.⁴² This enables electricity consumers to demonstrate that their electricity stems from renewable sources, while creating an additional marketable asset for electricity producers and storage operators within PPAs. Currently, GOs typically feature only annual granularity, thus ignoring the supply volatility of PV and wind power when documenting consumption coverage over the course of the year. Storage operators in particular receive no reward for their ability to supply renewable-based electricity even in times of low generation. Consequently, their contribution to a continuous provision of green electricity is not fully recognized.⁴³

A regulatory risk specific to European electricity spot markets are **new price interventions by regulators in times of energy crises**, in particular in the form of price ceilings. While the preceding crisis in 2022 did not witness direct spot market interventions at an EU-wide level, some Member States did

⁴⁰ Kyon Energy (2023). [The grid connection as a bottleneck of the energy transition?](#) Technical Article.

⁴¹ ACER (2021). Wholesale Electricity Market Monitoring 2021 - Prequalification processes for the provision of balancing services. European Union Agency for the Cooperation of Energy Regulators.

⁴² European Union (2018). Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources.

⁴³ EPICO & Aurora Energy Research (2022). Guarantees of origin for green energy –granular green electricity marketing for a market-based energy transition. Study for the Konrad-Adenauer-Foundation.

intervene (e.g. the price cap on natural gas for electricity production in Spain and Portugal⁴⁴) or at least seriously considered the options available. Both direct and indirect ceilings on spot prices effectively limit the ability of storage operators to generate net revenues from market arbitrage, and thus their rewards for mitigating temporary imbalances. Given that a major risk factor for future energy crises, Europe's dependence on volatile import prices for natural gas, is unresolved, future price ceilings are a real risk for today's storage investments.

Excessive taxation is still a regulatory hurdle to the economic operation of storage systems in some Member States. If a Member State's tax system considers storage systems to be both regular electricity consumers (when charging) and producers (when discharging), the same amount of electricity will be taxed twice during the storage process: first on the side of the storage operators themselves, and then on the side of final electricity consumers. This form of double taxation limits storage operators' opportunities to exploit market price differences. In particular, it penalizes power-to-power storage systems compared to systems involving direct usage of the storage medium. Consequently, compensating for the short-term supply volatility of renewables is less incentivized than permanent energy conversion. For this reason, some Member States, such as Germany and Finland, have introduced energy tax exemptions for power-to-power storage systems.⁴⁵ A similar issue can apply to grid fees. However, since power-to-power storage implies that the grid is burdened twice, the argumentation for an exemption from grid fees is less clearcut.

Moreover, as for emerging clean technologies in general, **uncertainty concerning the long-term path of climate policies** is an investment barrier. First, this applies to the ambition of renewable energy promotion. Both the systemic importance and economic returns to storage solutions are sensitive to inconsistencies in renewable energy targets and the related regulatory environment. A green electricity mix is a prerequisite for marketing storage solutions as sustainable technologies and for the necessary market fluctuations that form the basis of their business models. Second, uncertainty regarding future CO₂ pricing is a related economic barrier. High CO₂ prices support the breakthrough of all forms of storage solutions. For power-to-power storage, high CO₂ prices on fossil peak load generation capacities allow to realize higher price differentials through market arbitrage. For power-to-heat and power-to-chemicals solutions, they raise the costs for fossil end use alternatives. Hence, for various reasons, unsteady climate policies raise the financing costs for storage systems and risk to cause socially inefficient growth paths for storage capacity expansion.

Finally, the situation for Long Duration Energy Storage (LDES) requires specific attention. This term comprises storage solutions designed for storing energy for at least a couple of hours (according to a common definition for more than ten hours⁴⁶). Their specific value for the energy system lies in balancing out medium-term to long-term variations in electricity supply from volatile renewables. Their technological characteristics impose specific restrictions on their business models. This first concerns physical limitations. Pumped Hydroelectric Storage systems, the established form of LDES in Europe, face clear spatial limitations: achieving a sufficient energy capacity requires a setup with either large flows and/or large differences in height between two water reservoirs located close to each other.⁴⁷

⁴⁴ González-de Miguel, C., Wunnik, L. V., & Sumper, A. (2024). Mapping the wholesale day-ahead market effects of the gas subsidy in the iberian exception. *Energies*, 17(13), 3102.

⁴⁵ See EnTEC (2023).

⁴⁶ US Department of Energy (2025). Long-Duration Energy Storage.

⁴⁷ Drax (2020). [Pumping power: pumped storage stations around the world.](#)

Other forms like Compressed Air Storage are still in their scaling phase and lack the maturity for competing with established solutions. Moreover, on the revenue side, the longer average duration of storage in power-to-power LDES systems implies a high sensitivity to medium-term market price uncertainty. In particular, this holds for systems with very long duration like seasonal storage: they accumulate large amount of energy in the charging season with only limited knowledge on price trends in the discharging season. Securing revenue flows often requires forward contracts. The limited liquidity of forward markets in European electricity trading⁴⁸ thus represents a particular hurdle for LDES systems.

4.4 Support options

The existing set of technical, market-specific and general regulatory barriers asks for a multi-level policy approach. With important reforms been recently brought under way at EU level, it is mainly up to the Member States to take appropriate implementation action. However, the EU will continue to play a key role for a number of reasons. It should support Member States in establishing competitive, flexible markets by providing technical assistance and targeted financial aid. The EU should also perform a coordinating function, defining clear framework conditions for future market rules and state aid allocation. Furthermore, it should closely monitor the evolution of national regulations to ensure that any future expansion of storage is compatible with the goal of establishing cross-border energy markets.

With regard to **technical barriers**, the actions of Member States could focus on streamlining the process of granting permits for storage facilities and component manufacturers, thereby reducing lead times and creating greater predictability for investors. Training and digitalization initiatives for administrative bodies could support this. Another way to achieve streamlining and reduce existing time gaps between Member States is through regular information exchange on best administrative practices, thus also contributing to a level playing field in storage deployment. Furthermore, to increase flexibility in grid access and reduce waiting times for grid connection, Member States could establish a legal framework for flexible connection agreements. To address the underrepresentation of storage in network plans, grid operators could be directly involved in the planning process. Alternatively, incentives for TSOs to consider storage solutions could be increased through changes to their revenue regulation, e.g. by reducing the CAPEX bias in cost compensation. While the EU's role could be advisory, it could also involve taking regulatory action, when necessary, such as imposing new or more ambitious time limits on national permit granting (see Section 5).

Market-specific barriers can be reduced by creating market access rules that reflect the technical conditions of storage-based flexibility services, while also strengthening technological and size neutrality (i.e. no discrimination of specific storage technologies or small-scale storage). This applies to the pre-qualification and bidding rules for balancing energy markets, as well as to the design of national capacity remuneration schemes. Regular consultations between Member States could help to optimize national frameworks and reduce inconsistencies in the internal market through harmonization. To support the development of new PPAs and associated revenue models for storage facilities, Member States could establish the legal framework for more granular origin certification and address

⁴⁸ ACER (2023). Further development of the EU electricity forward market. European Union Agency for the Cooperation of Energy Regulators. ACER Policy Paper.

bankability issues through public guarantees. Finally, Member States could assure storage investors that they will refrain from any direct price-depressing interventions on electricity wholesale markets in situations where market prices are rising. The EU's role would be to monitor national market regulation further and highlight any inconsistencies with the EU framework, while defining more precise market design criteria when necessary.

Concerning the **general regulatory barriers**, an important step in ensuring a fair reward for flexibility services and an optimal spatial allocation of storage facilities in Europe would be the abolition of effective double taxation of power-to-power storage across the EU. Furthermore, to promote general electrification and improve the market position of power-to-heat and power-to-chemical applications relative to fossil fuels, Member States should harmonize and, where possible, reduce tax rates on end-use electricity. The EU could support this process by pushing for the timely adoption of the revised Energy Taxation Directive (see Section 5).

Finally, achieving a socially efficient deployment of storage capacities requires regulators also to deal with the issue of (partly) unpaid system services. This involves specific complementary technical services like support to voltage maintenance, angular stability and outage recovery, but also long-term cost savings from network upgrade deferral. In principle, this could be mitigated by designing new service markets or adding new segments to existing tendering schemes. However, technical difficulties in defining the extent of service requirements and their monetary value to grid operators could delay implementation and lead to new internal market distortions due to a lack of harmonization.

Therefore, a more pragmatic response is to bundle and reward the social value of these additional services through targeted public support programs. One traditional way of achieving this is to let storage facilities participate in market-based remuneration schemes for flexible capacities. Alternatively, specific capacity markets could be created exclusively for non-fossil flexibilities, as recently advocated by the EU (see Section 5). These capacity mechanisms offer a stable, regular reward to compensate for the costs of capacity creation. In this respect, they are similar to an annualized version of a traditional public investment grant. However, they do not address the revenue uncertainty associated with storage operators' activity on volatile wholesale and balancing markets. This can result in higher financing costs for storage capacities, thus raising the social costs of storage expansion.

This has fueled ideas for support schemes that would contribute to more stable net revenues from market activities of storage operators.⁴⁹ In the most extreme case, this could take the form of a **Contracts-for-Difference (CfD) model** for storage operators, in which regulators guarantee a certain level of net revenue per storage cycle through compensation payments dependent on price. A milder version could consist of a cap-and-floor system, in which net revenues fluctuate within a pre-defined spectrum, thus guaranteeing a minimum level of net revenue. Besides reducing financing costs, such risk-reducing schemes could incentivize storage facilities to participate more frequently in markets, thereby enhancing the extent of system services provided. However, more frequent participation could undermine the role of market price signals in ensuring system-friendly storage operation patterns. For example, if there are insufficient behavioral requirements in place, CfDs could cause storage facilities to discharge at inappropriately low price levels. In the worst case, this could impose additional balancing costs on the system. Therefore, when contemplating risk-oriented support measures, careful

⁴⁹ KPMG (2024). Energy storage and support schemes: “the new normal”? Energy Storage Global Conference, Brussels.

attention must be given to their specific design. We will address this issue in our policy simulations in Section 6.

5 Current regulatory treatment

5.1 Storage in the EU electricity market design

Regulation (EU) 2019/943⁵⁰ and **Directive (EU) 2019/944**⁵¹ on common rules for the internal market for electricity jointly set the regulatory framework for electricity markets in the EU, including the conditions for market activities of energy storage systems. The framework defines energy storage in a comprehensive form. It involves both storage activities that reconvert stored electricity and those that use stored energy as another energy carrier.

The framework defines clear requirements for public authorities to consider the role of energy storage in developing the national energy mix. As part of the criteria for authorizing new electricity generation projects, they shall consider the availability of alternatives to additional generation capacity, explicitly mentioning demand response and energy solutions as examples. Moreover, it asks Member States to ensure that active storage facilities are granted a specific set of rights. This includes the right to be connected to the grid within reasonable time (provided technical conditions are fulfilled) and the right to deliver several services simultaneously (possibility of value stacking). Grid operators may not refuse the network connection of energy storage facilities because of possible future limitations to available network capacities. Moreover, storage facilities shall be freed from double charges for stored energy that is either not released to the system again or used for providing balancing services to grid operators. In general, network charges shall not discriminate either positively or negatively against energy storage.

The framework also asks Member States to ensure fair access for storage facilities to markets for flexibility services. The procurement of balancing energy by TSOs shall occur through transparent, non-discriminatory and market-based procedures. On these markets, access of all qualified undertakings shall be assured, including energy storage operators. Similar rules apply to the procurement of non-frequency balancing services. Moreover, in cases where peak-shaving products are introduced as a response to an electricity price crisis, the dimensioning of such products shall take into account forecasts of the activity of energy storage facilities, thus ensuring that such products do not interfere with the business model of storage operators. Beyond flexibility services, the framework also asks Member States to guarantee access of storage facilities to national capacity mechanisms.

Provisions also address the consideration of energy storage in grid planning. In their mandatory regular ten-year network development plans, TSOs shall fully take into account the potential of alternatives to grid expansion, including energy storage facilities. At the same time, the framework sets clear unbundling requirements. As a rule, grid operators may not own, develop, manage or operate energy storage facilities. Exceptions apply to cases where facilities are fully integrated network components (i.e. are

⁵⁰ European Union (2019a). Regulation (EU) 2019/943 of the European Parliament and of the Council of 5 June 2019 on the internal market for electricity

⁵¹ European Union (2019b). Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on common rules for the internal market for electricity.

solely used to secure regular grid operation and not engage in congestion management) and tender procedures for an external commissioning of storage operations have failed.

The recent amendments of the two pieces of legislation made by the electricity market reform 2024 also have direct implications for the business model of energy storage systems. **Directive (EU) 2024/171**⁵² has introduced the concept of flexible connection agreements to the framework. It asks relevant authorities in Member States to develop a framework that allows grid operators to offer flexible connection agreements to new installations like storage facilities in areas where there is little or limited network capacity. These agreements shall define a maximum injection and withdrawal of electricity from and to the grid throughout the year, allowing storage facilities to start operation even though local grid capacities are not yet able to fully meet their power capacity (see Subsection 4.4). As a rule, flexible connection agreements shall only be temporary in nature, i.e. they are to be converted to firm connection agreements once the network is fully developed. Moreover, they may not delay the process of network expansion in the region. An exception is made in cases when regulatory authorities consider grid expansion not to be the most efficient solution. Then, flexible connection agreements may take a permanent form.

Moreover, the reform has introduced the obligation for Member States to produce national reports on estimated flexibility needs on a regular basis. Based on the results of the report, Member States are asked to formulate indicative national objectives for non-fossil flexibility, including the contribution of storage capacities. To fulfill these objectives, Member States may apply designated non-fossil flexibility support schemes, independent of potentially existing general capacity mechanisms. The Clean Industrial Deal State Aid Framework (CISAF) defines the requirements for such a support system to be considered compatible with Union state aid law.⁵³ They are limited to support investments in non-fossil flexibilities such as demand response and storage. Their dimensioning shall be restricted by the national non-fossil flexibility goal and subject to further design principles, such as requirements concerning a minimum level of actual participation on electricity markets.

Finally, the increased focus on PPAs, especially the task for Member States to promote their uptake and remove existing market barriers, is in light of emerging storage PPAs a relevant factor for storage business models.

5.2 Other relevant EU regulation

Further elements of the EU climate and energy policy framework have additional direct and indirect impacts on the economics of storage operations and their supply chains. First, the EU-wide and national renewable energy targets specified in the **Renewable Energy Directive** are of basic importance as a steering instrument for national renewable energy support schemes, and thus also the systemic role of storage solutions. The most recent reform (**RED III**⁵⁴) has raised the ambition of medium-term goals. Moreover, it has for the first time formulated binding targets for increasing renewable energy

⁵² European Union (2024). Directive (EU) 2024/1711 of the European Parliament and of the Council of 13 June 2024 amending Directives (EU) 2018/2001 and (EU) 2019/944 as regards improving the Union's electricity market design

⁵³ European Commission (2025). Framework for State Aid measures to support the Clean Industrial Deal. Communication from the Commission. C(2025) 7600 final.

⁵⁴ European Union (2023). Directive (EU) 2023/2413 of the European Parliament and of the Council of 18 October 2023 amending Directive (EU) 2018/2001, Regulation (EU) 2018/1999 and Directive 98/70/EC as regards the promotion of energy from renewable sources, and repealing Council Directive (EU) 2015/652.

use in heating and cooling, thus contributing to the roll-out of thermal energy storage. Moreover, the RED III sets requirements for Member States to speed up approval procedures for renewable energy projects. For projects in dedicated acceleration areas, concrete time limits for approval procedures are imposed. This includes projects involving co-located energy storage, for whose approval the time limit is set at six months (offshore: 12 months). Finally, the reform also paves the way for more granular GO certificates for renewable-based electricity, by stating that the standard size of guarantees (1 MWh) can be split into smaller fractions, which can in turn be linked to more narrowly defined time windows of production (e.g. hours instead of years).

The **Net-Zero Industry Act**⁵⁵ addresses the manufacturing side of clean technologies like storage solutions. It defines for the first-time concrete targets for the deployment of production capacities for a pre-defined list of net-zero technologies in the EU. The list includes battery and other energy storage technologies. By 2030, domestic manufacturing capacity for net-zero technologies shall reach a share of 40% of the annual deployment needs of the EU. Moreover, by 2040, it shall capture 15% of the world market for the corresponding technologies. Net-zero technology manufacturing projects may be recognized by Member States as “strategic” if they contribute to the capacity goals of the legislation and provide European industries with the best available technologies and fulfill at least one other criterion within each of two lists of criteria. Strategic net-zero projects shall be assigned a priority status in national permit granting procedures including the speed of handling any lawsuits related to permit granting. Even stricter time limits apply to the permit granting procedure, consisting of 9 months for small-scale (< 1 GW capacity) and 12 months for large-scale (≥ 1 GW) projects. Moreover, strategic net-zero projects can apply for specific advice on project financing by the newly established Net-Zero Europe Platform. This entails stakeholder consultations on suitable available funding channels like existing financial support instruments at EU and Member State level and additional private sources. However, it does not involve any new dedicated EU support fund.

Regarding the issue of double taxation, a reform of the **Energy Taxation Directive** could achieve a harmonized solution. As part of its reform proposal in 2021⁵⁶, the Commission proposed to add the possibility to consider energy storage facilities as redistributors. This would limit taxation to the discharging processes, as the Directive states that electricity shall be subject to taxation at the time of supply by the distributor or redistributor. Moreover, the proposal foresees an adjustment of minimum tax rates based on the carbon content of energy carriers. This would imply a higher relative minimum taxation of fossil energy carriers and thus further contribute to the viability of storage solutions, in particular in areas that directly compete with fossils (thermal storage, hydrogen). However, due to the blockage by some Member States, the reform is still pending.

Finally, national capacities to directly support storage investments depend on the Commission’s interpretation of state aid rules. With the Temporary Crisis and Transition Framework⁵⁷, the Commission started to formulate transparent rules for Member States for supporting the necessary transformative

⁵⁵ European Union (2024). Regulation (EU) 2024/1735 of the European Parliament and of the Council of 13 June 2024 on establishing a framework of measures for strengthening Europe’s net-zero technology manufacturing ecosystem and amending Regulation (EU) 2018/1724.

⁵⁶ European Commission (2021). Proposal for a Council Directive restructuring the Union framework for the taxation of energy products and electricity. COM/2021/563 final.

⁵⁷ European Commission (2023). Temporary Crisis and Transition Framework for State Aid measures to support the economy following the aggression against Ukraine by Russia. 2023/C 101/03.

investments on the road towards a net-zero economy. Aid may be granted to accelerate the roll-out of renewable energy and to decarbonize industrial production processes, conditional on that certain instrument-specific thresholds are not exceeded. With the recent publication of the **Clean Industrial Deal State Aid Framework**⁵⁸, the rules have been updated and prolonged until 2030, to match the new ambitious Clean Industrial Deal agenda. It explicitly states that support to electricity storage and thermal storage is considered compatible with the internal market, provided that – in addition to meeting the general state aid conditions - storage facilities is granted market access to electricity wholesale markets, markets for flexibility services as well as market-based redispatch measures. Moreover, the framework spells out the criteria for supporting storage facilities through the new tool of non-fossil flexibility support schemes (see Subsection 5.1). Accordingly, such a scheme may not discriminate between different flexibility solutions. It must grant aid based on estimated capacity volumes and competitive bidding processes, and in the form of contracts lasting no longer than ten years.

5.3 The Affordable Energy Action Plan

In an EU Action Plan for Affordable Energy published in February 2025, the Commission has announced new measures to bring energy costs in all EU countries back down to a globally competitive level.⁵⁹ Some of these measures also directly concern energy storage. To further reduce permitting time for new storage facilities, the Commission aims to provide technical support to Member States by promoting exchange on best practices, installing an expert group to identify remaining barriers and provide guidance on the formation of dedicated grid and storage acceleration areas. It also announces new legislative proposals to further shorten permitting times.

Moreover, it stresses the necessity to remove the remaining barriers storages face in accessing wholesale and balancing markets in some Member States. Specifically, behind-the-meter storage shall be promoted by adopting new rules on demand response and providing guidance on promoting remuneration of flexibility in electricity retail contracts. On the financial side, it envisages a new clean flexibility instrument to reward storage facilities based on PPAs and industry commitments.

The Commission will also aim to enforce more efficient designs of network tariffs to reduce energy system costs. In particular, national tariff methodologies shall incentivize flexibility in electricity supply and demand. To reduce the relative tax burden on clean technologies, it asks Member States to finally complete the revision of the Energy Taxation Directive and reminds them of the possibility to reduce electricity taxes to the permitted minimum level.

Finally, the investment gap observed for clean technologies like energy storage is supposed to be tackled by a Clean Energy Investment Strategy. It shall streamline EU funds to support clean tech investments and thereby mobilize private capital. Storage systems marketing their services through PPAs could also benefit from a pilot support program launched by the Commission together with the European Investment Bank. It serves to back the financial guarantees involved in PPAs.

⁵⁸ See European Commission (2025).

⁵⁹ European Union (2025). Action Plan for Affordable Energy Unlocking the true value of our Energy Union to secure affordable, efficient and clean energy for all Europeans. Communication from the Commission. COM/2025/79 final.

6 Impact analysis of direct support schemes

6.1 Model

To analyze the effects of different forms of public support schemes on storage deployment, we undertake a simulation analysis of stylized business models. The goal is to estimate the expected returns to investments for power-to-power storage systems and their dependence on the type of support offered. To stress the growing role of utility-scale storage in combatting temporary grid imbalances, we consider the case of large-scale stand-alone systems connected to the grid. As discussed in Subsection 4.1, a crucial determinant of the optimal operating mode of such a storage system is the relative cost of power versus energy capacity. Storage technologies that strongly differ in this parameter will tend to show different time patterns of operation, affecting the length of charging periods and the sensitivity to short-term vs. medium-term price signals. They can thus perform complementary functions to the energy system. To illustrate the specific impact of a support policy on different storage types, we compare two stylized systems:

- A 100 MW Lithium-ion battery (Li-ion battery) system
- A 100 MW Compressed-Air Energy storage (CAES) system

The low ratio of power-to-energy costs and the high round-trip efficiency of the Li-ion battery system make it an ideal candidate to combat short-term imbalances in the grid. In contrast, due to the relatively low costs of energy capacity, the CAES system can serve to accumulate larger amounts of energy to balance out systematic variation in electricity supply and/or demand over a longer time horizon. Therefore, we use these two systems as stylized examples in the following simulations, without denying the future benefits of other power-to power storage technologies currently emerging (see Section 3).

Investment returns strongly depend on the expected net revenues from market activity. In practice, storage facilities sometimes engage on several markets simultaneously, leading to complex models of value stacking. Moreover, revenues on single markets are subject to significant (short- and long-term) price uncertainty. This turns the determination of the profit-maximizing time pattern of storage activity into a highly complex problem. In the following, we adopt the simplified approach of Giulietti et al. (2018).⁶⁰ They determine the optimal charging/discharging behavior in a heuristic manner. They consider the scenario of storage operators generating net revenues solely by engaging in arbitrage on electricity wholesale markets. Their approach in dealing with price uncertainty is choosing a recurring pattern of operation that maximizes expected net revenues over a specified time period (in their paper: one day). The considered storage facility is assumed to be too small to affect market prices. Any charging and discharging activity is supposed to take place at full power capacity.

Based on time series for spot market electricity prices, they determine the activity pattern that would have maximized average daily net revenues for a pre-defined number of settlement periods (i.e. number of charging and corresponding discharging periods). To this end, the optimal combination of charging and discharging periods over the course of a day is calculated numerically. Then, the optimal number of settlement periods is determined as the one that yields the profit-maximizing time pattern.

⁶⁰ Giulietti, M., Grossi, L., Baute, E. T., & Waterson, M. (2018). Analyzing the potential economic value of energy storage. *The Energy Journal*, 39(1_suppl), 101-122.

To simulate the consequences of applying a fixed time pattern of activity to unknown future market situations, the multiannual price dataset is split in two subsamples. The first subsample serves to determine the optimal pattern, while the second serves to estimate the net revenues obtained from applying this pattern to the price development in subsequent years. Hence, this approach addresses price uncertainty through rigid, but empirically based operating rules, a strategy not uncommon in real-life storage operations in Europe.⁶¹

In the following, we adopt this approach to obtain optimal activity patterns and net revenues based on German wholesale market data. This is done by assuming daily cycles, i.e. daily recurring time patterns maximizing average daily net revenues. In doing so, to consider the potential effects of systematic variations in the supply and demand mix of scenarios, we distinguish between summer and winter as well as between workdays and weekend, thus requiring us to determine optimal activity patterns for four different types of days. In identifying all optimal patterns, the level of energy capacity is determined endogenously as the minimum level needed to absorb the accumulated charged energy in the course of a cycle. For this reason, the costs of required energy capacity are considered when calculating the expected net revenues from a specific activity pattern.

Due to their stylized nature, these simulations do not serve to assess the viability of real-life business models, but to analyze the sensitivity of the economic returns of storage investors to different policy regimes.

6.2 Support scenarios

To investigate the effects of different support instruments on investment decisions and storage operations, we compare four policy scenarios distinguished by the point of intervention and the question of conditionality. Regarding the point of intervention, we first consider a scenario where support is granted as a reward to available storage capacity, in the form of fixed annual payments per MW over the lifetime of the facility. These payments can result from the participation of storage facilities in general capacity market, as is already the case in some capacity markets. Alternatively, they could be earned through innovative non-fossil flexibility schemes as envisaged by the EU (see Section 5). Currently, prices on national capacity markets in Europe show significant variation, due to differences in national capacity needs and market designs. Moreover, changes in market perspectives and external supply shocks can cause significant fluctuations in capacity prices over time. For instance, prices obtained in the French capacity auctions varied between 17.000 €/MW/year and 42.000 €/MW/year over the delivery period 2019-23.⁶² We deal with this uncertainty by presenting results for a wide range of plausible capacity prices, thus demonstrating the sensitivity.

As an alternative form of intervention, we consider measures that aim to reduce revenue risks for storage operators. As discussed in Subsection 4.4, if improperly designed, such measures could endanger a system-friendly operation of storage facilities. In particular, this would hold for net revenue guarantees through CfDs or unconditional Cap-and-Floor schemes for net revenues. Instead, a smart instrument would not encourage market activity of storages in general, but specifically reward charging and/or discharging in those market situations where it is most needed for economic and physical balancing. Against this background, we propose to consider a percentage mark-up on the electricity

⁶¹ See Bertrand and Papavasiliou (2019).

⁶² Flexcity (2022). [The price of the second auction of the French Capacity Mechanism for the year 2023 has been fixed.](#)

price when discharging as an alternative support option. Its role is to amplify the market rewards from arbitrage, thereby implicitly internalizing the unpaid short- and long-term system services (see Subsection 4.4) of system-friendly storage activity into the economic rationale of storage operators. In the following, we examine the eligibility of such an instrument in the form of a second support scenario, distinguishing between different levels of percentage mark-ups.

Alternatively, direct price support could take the form of a guaranteed minimum discharging price. In such a framework, regulators would pay storage operators the difference between market price and minimum price in discharging periods with market prices below the minimum price. This does not amplify existing price signals, but works instead by securing operators a minimum gross revenue base. In the following, we will compare the implications of these two variants.

In sum, we investigate the following three support scenarios:

- 1. Fixed capacity remuneration**
- 2. Percentage mark-up on discharging prices**
- 3. Minimum discharging price**

6.3 Data

Relevant cost data for specific storage technologies are usually reported in the form of unit costs in the literature, i.e. per MW (power capacity, fixed OPEX) or MWh (energy capacity, variable OPEX). These estimates typically vary both over time and with system size, reflecting dynamic and static scale economies. Moreover, also for given sizes and time periods, available literature estimates partly show significant discrepancies, reflecting different measurement methods or a focus on different markets. Concerning the procurement situation in Europe, no recent representative cross-technology cost data is available. However, the storage technology assessments by the US Department for Energy provide such an overview for the US market, distinguishing a wide range of technologies and size classes.⁶³ We adopt the estimates from their most recent assessment for the technologies and size classes relevant for our examples and convert them into euros.

The electricity price data to determine the activity patterns and associated market net revenues is retrieved from the transparency platform of the European Network of Transmission System Operators (ENTSOE-E).⁶⁴ It consists of a multiannual time series of prices on the German electricity day-ahead market for all 15-minutes trading periods, thus including a total of $96 \times 365 = 35040$ price observations per year.⁶⁵ In specifying the subsamples used for training and for later operation, we are confronted with the structural effects of the energy crisis in 2022, especially the impact of the significant increase in import prices for natural gas. More expensive peak load capacities have contributed not only to rising average prices, but also to enhanced short-term price volatility⁶⁶, thus directly affecting the business model of storage facilities. Restricting the sample to earlier periods would ignore the structural

⁶³ See Viswanathan et al. (2022).

⁶⁴ ENTSOE-E (2025). [Transparency platform](#).

⁶⁵ Unfortunately, no equally granular time series of prices on intraday markets, a segment more suited for storage participation, is publicly available.

⁶⁶ Zakeri, B., Staffell, I., Dodds, P. E., Grubb, M., Ekins, P., Jääskeläinen, J., ... & Gisse, G. C. (2023). The role of natural gas in setting electricity prices in Europe. *Energy reports*, 10, 2778-2792.

price effects of the crisis. Rather, it is plausible to assume that rational storage operators will consider these effects and adjust their operating modes to the most recent market observations. We therefore choose prices in the year 2023 as the basis for determining the optimal operating modes and prices in 2024 to estimate the net revenues from their application.

Table 3 presents an overview on the chosen simulation parameters and their sources. Technical parameters are projected values for 2030, thus reflecting the medium-term market situation.

Table 3: Overview on simulation parameters

Parameter	Value	Source	Parameter	Value	Source
Li-ion system			CAES system		
Discount rate	7%	Eszoneo (2025) ⁶⁷	Discount rate	10%	Eszoneo (2025)
Lifetime	20 years	Viswanathan et al. (2022)	Lifetime	60 years	Viswanathan et al. (2022)
Round-trip efficiency	85%	Viswanathan et al. (2022)	Round-trip efficiency	52%	Viswanathan et al. (2022)
Power capacity	100 MW	Scenario assumption	Power capacity	100 MW	Scenario assumption
Price power capacity	131,000 USD/MW	Viswanathan et al. (2022)	Price power capacity	1,153,000 USD/MW	Viswanathan et al. (2022)
Price energy capacity	220,000 USD/MWh	Viswanathan et al. (2022)	Price energy capacity	6,840 USD/MWh	Viswanathan et al. (2022)
Fixed OPEX (O&M)	8,990 USD/MW	Viswanathan et al. (2022)	Fixed OPEX (O&M)	16,120 USD/MW	Viswanathan et al. (2022)

Source: own representation

6.4 Results

6.4.1 Absence of public support

Table 4 presents the simulation results in the form of key economic parameters for a scenario without public support schemes in place. Due to the differences in cost structure and round-trip efficiency, the training data delivers different operating modes for the two systems. Due to the comparatively high costs of storage capacity, the Li-ion battery system is less active (higher number of settlement periods) in the course of a day. The CAES system is able to accumulate more net revenues from market arbitrage, but its high fixed costs of power capacity worsen the economic balance. As a consequence, potential net earnings from market arbitrage are in both cases insufficient to cover the capital costs and fixed operational costs of the storage systems: annual profits are predicted to be negative.

Table 4: Simulation results of the no-support scenario

System	Daily settlement periods (no. quarter hours)	Energy-to-Power ratio (MWh/MW)	Charged electricity per year (MWh)	Annual profit (€)	Annual profit (€/MW)
Li-ion battery system	4	1	36,500	-906,270 €	-9,063 €
CAES system	20	5	182,500	-8,984,039 €	-89,840 €

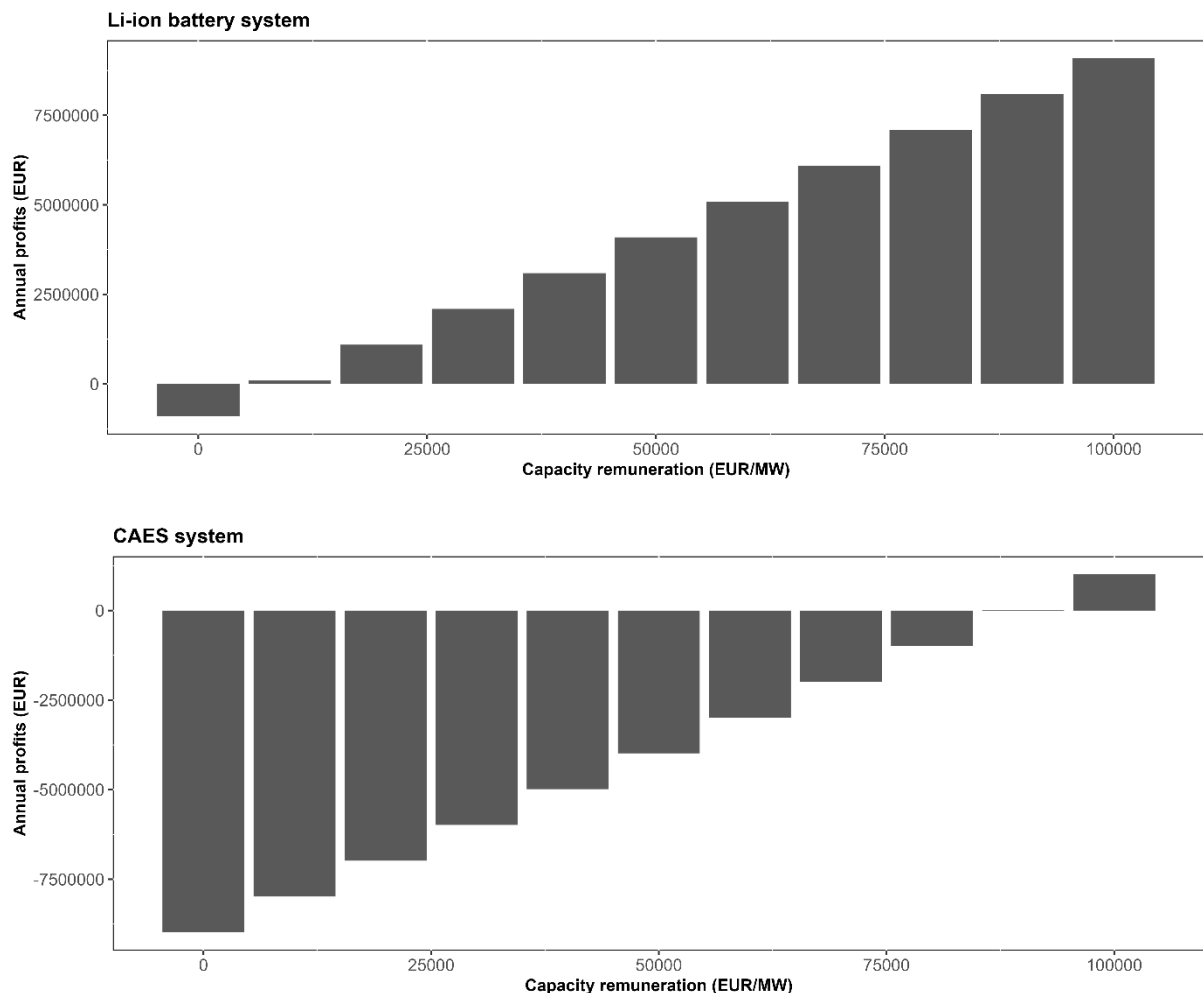
Source: own calculations

⁶⁷ Eszzoneo (2025). [Discount rates for energy storage systems.](#)

6.4.2 Fixed capacity remuneration

Introducing an unconditional capacity remuneration scheme improves the economic returns to invested capital, but does not directly interfere with the operating mode of storages. Hence, optimal patterns of charging/discharging activity are at least in the short term unaffected by such a scheme, i.e. as long as its positive effect on capacity formation does not affect price patterns on electricity markets. Under this condition, its sole effect consists of raising annual profits by compensating parts of the capital costs. Figure 2 shows how annual profits for the two systems evolve over a realistic spectrum of capacity premia. In order to become profitable, the Li-ion battery system would require an annual capacity premium in the magnitude of 10,000 €/MW. This value lies at the lower end of the spectrum of capacity price fluctuations observed in recent years e.g. on the French capacity market.⁶⁸ For the CAES system, instead, capacity prices would need to reach a magnitude of about 90,000 €/MW, which is still well above current market price levels. Hence, the promotion a technologically diverse storage landscape will be costly and difficult to achieve exclusively through capacity markets.

Figure 2: Impact of fixed capacity remuneration on annual system profits



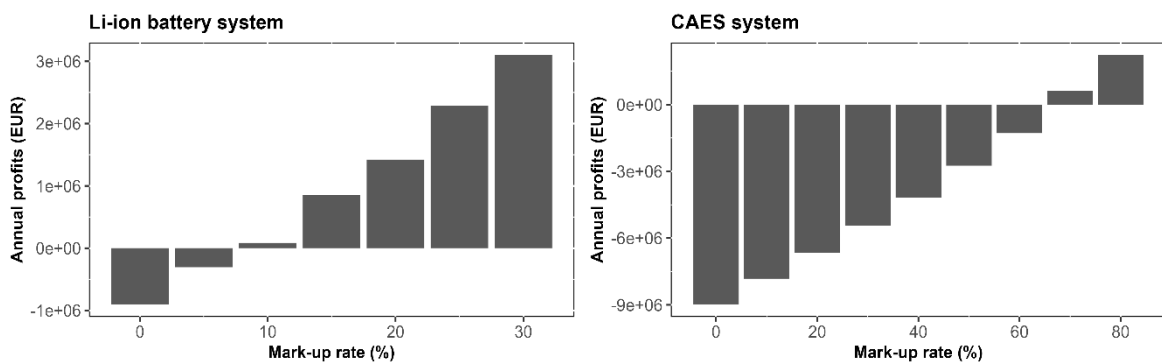
Source: own calculations

⁶⁸ Haya Energy Solutions (2024). [The mechanism of opportunities.](#)

6.4.3 Percentage mark-up on discharging prices

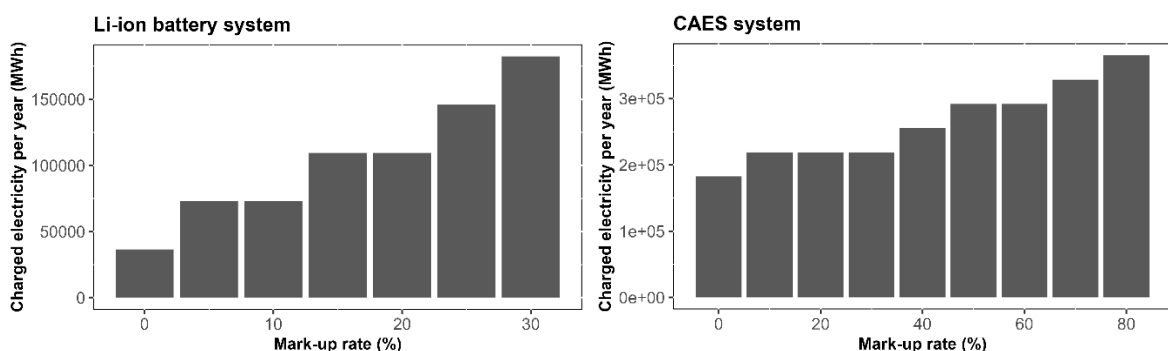
Unlike fixed capacity premia, the impacts of support schemes targeting market revenues are less straight forward to predict. They do not simply inflate net revenues in a proportional manner, but by affecting operating modes of storage systems, are likely to exert non-linear effects. This holds in particular for our envisaged scheme of a percentage mark-up on discharging prices. It should boost overall storage activity by improving the net pay-offs in times of only small expected price fluctuations. At the same time, the risk of causing undesired charging/discharging patterns is limited by the fact that charging in low price periods still pays off. Our numerical optimization approach (see Section 6.1) is able to capture this effect. Figure 3 shows the impact of different mark-up levels on annual profits, Figure 4 on the annual amount of electricity charged. The activity level of the Li-ion battery system exhibits a much stronger response to the mark-up subsidy than the CAES system. This is associated with stronger effects on profits: With a 10% mark-up, the Li-ion battery system is expected to become profitable. For the CAES system, a price mark-up of about 70% would be needed. This is again explicable by the differences in cost structure and round-trip efficiency. Due to the higher conversion losses in the CAES systems, the same mark-up translates into lower additional revenues. Moreover, its high fixed costs of power capacity require a large revenue compensation.

Figure 3: Impact of a price mark-up on annual system profits



Source: own calculations

Figure 4: Impact of a price mark-up on charged amount of electricity

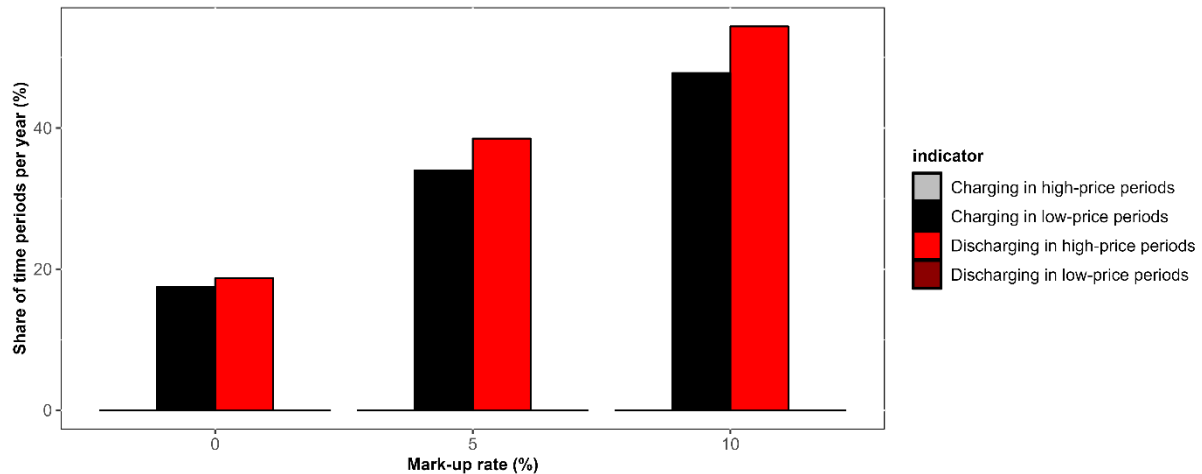


Source: own calculations

The fact that mark-ups change operating modes requires an investigation into the impact of these changes on the energy system. A detailed investigation of the impact on grid balance and congestion would require a physical grid model. By using observed prices as indicators of scarcity, we get at least

an impression how storage activity will tend to alleviate or exacerbate temporary imbalances. We draw on the Li-ion battery system as an example. We focus explicitly on charging and discharging activity in times of very high (> 95% of annual price distribution) and very low (< 5% of annual price distribution) prices during the application year 2024. For different mark-up levels, Figure 5 shows the relative frequencies of storage activities in the two situations.

Figure 5: Charging/discharging activity in extreme-price-periods for different mark-up rates



Source: own calculations

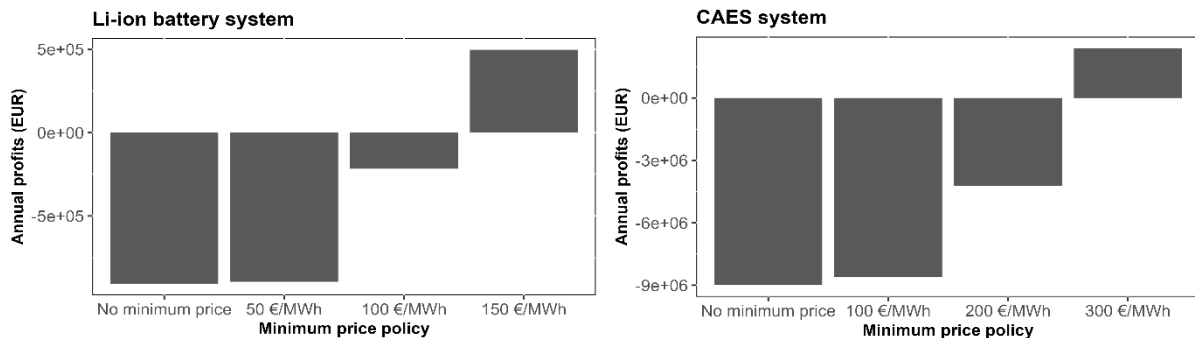
There are no observations where storage contributes to existing stark imbalances (i.e. charging at very high prices or discharging at very low prices), not even at very high mark-up levels. This is because mark-ups do not eliminate downside risks, so storage operators still need to align with typical price patterns. At the same time, the revenue-augmenting effect of the mark-up results in higher frequencies of charging and discharging activities at times when they are most needed. Precisely, by helping storage facilities to afford higher energy capacities, mark-ups raise their capacity to intervene while maintaining incentives to do so when expected price discrepancies are greatest.

6.4.4 Minimum discharging price

Guaranteeing a minimum discharging price is a way to insure storage operators against the risks of unexpectedly low prices in discharging times. Such an insurance does not necessarily distort the economic rationale of storage activity. The net revenues from a storage cycle still depend on market prices in charging periods. Hence, even with high guaranteed discharging prices, there is still a rationale to limit charging to periods of typically high supply of renewables (and thus low market prices) and discharging activity to the remaining periods when renewables are less abundant. However, unlike with a percentage mark-up, the effects on storage activity can be expected to be highly non-linear and thus difficult to predict. If a minimum price is set below the market price levels typically expected for peak load times, it will only protect against high losses from unexpected price disturbances (e.g. very windy periods), but hardly affect regular activity patterns of storage systems. If it is set at very high levels, it could drastically inflate storage activity and thus impose a high burden on public budgets. Figures 6 and 7 illustrate our simulation results for different minimum price levels. Due to the less favorable economic balance of the CAES system, a significantly higher minimum price is needed for investments in the CAES system to break even. For both systems, activity patterns are only affected at minimum prices of at least 100 €/MWh. Minimum prices on and above this level incentivize an expansion of

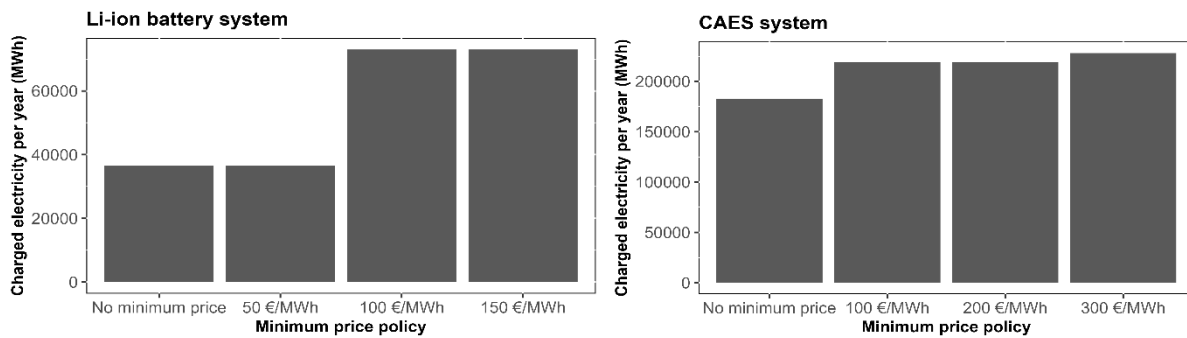
storage capacity, as more frequent market interventions would be associated with additional net revenues also in periods of normal market price behavior.

Figure 6: Impact of a minimum price on annual system profits



Source: own calculations

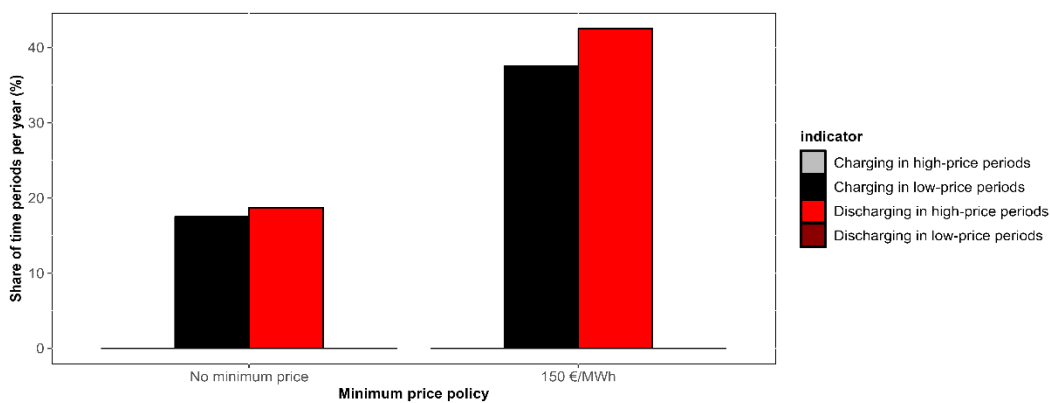
Figure 7: Impact of minimum price on charged amount of electricity



Source: own calculations

Similar to the percentage mark-up scenario, the minimum price is not predicted to endanger the balancing effect of storage systems, as shown in Figure 8. Instead, a minimum price of 150 €/MWh would have promoted more frequent system-friendly storage activity during periods of extreme prices in 2024, both in the form of more frequent charging in low-price periods and discharging in high-price periods.

Figure 8: Charging/discharging activity in extreme-price-periods with and without minimum price

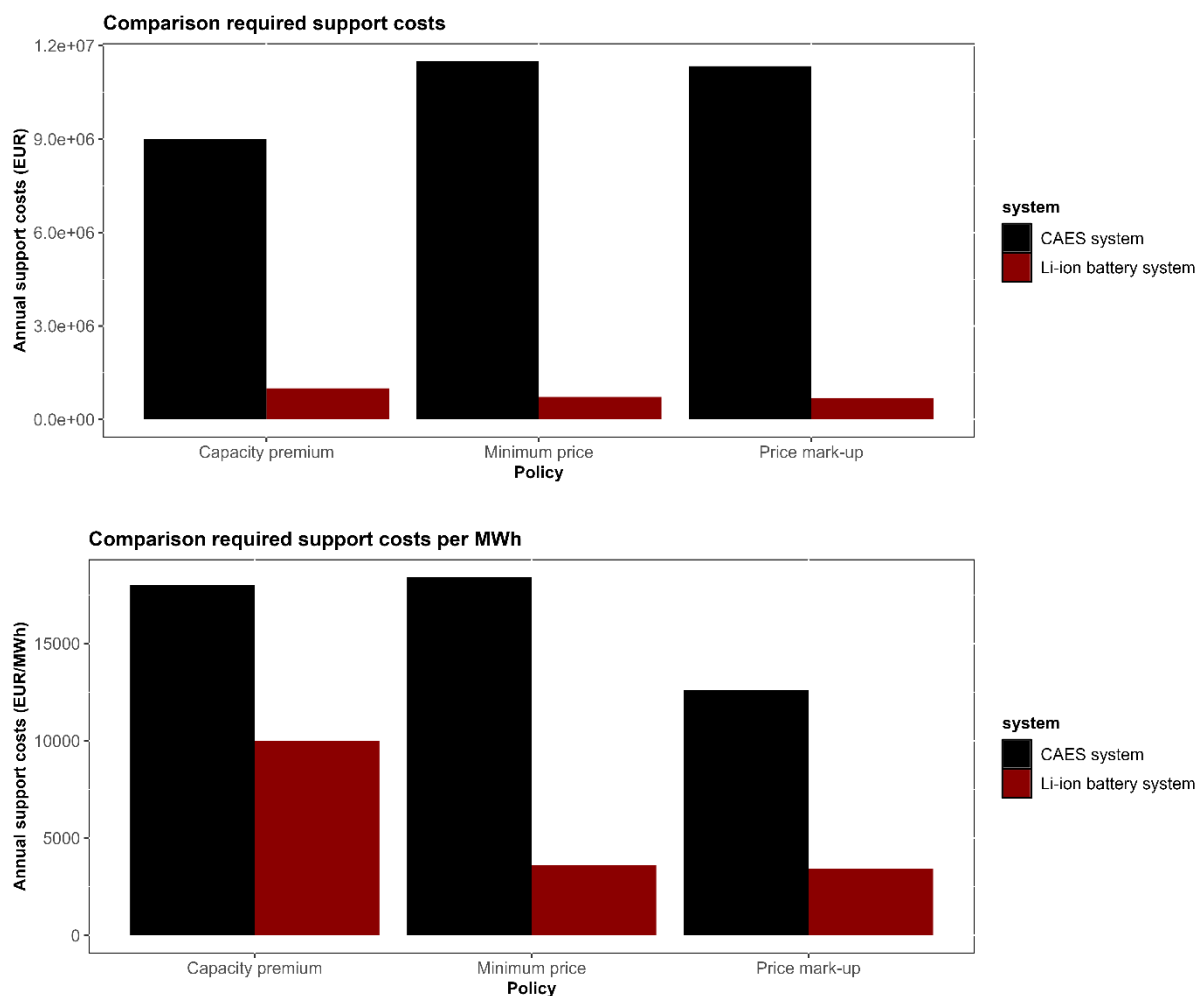


Source: own calculations

6.4.5 Comparative analysis

The preceding analysis has demonstrated that the different support scenarios, although they are all potentially effective, influence storage economics in slightly different ways. One way to compare their efficiency in fiscal terms is to estimate the annual public support expenditures needed in each support scenario to reach the break-even point for storage investments. Figure 9 presents such a comparison of needed minimum support levels for both storage systems investigated. In absolute terms, the capacity mechanism is estimated to be the cheapest option to generate positive net returns for the CAES system, while price-based support schemes are cheaper options for the Li-ion system. However, these comparisons hide the fact that the support scenarios differ in their effect on energy capacities. When putting support costs in relation to the amount of MWh energy capacity incentivized, the price mark-up turns out to be the most cost-efficient options for both storage systems. This is due to the activity-promoting effect of raising market revenues, which cannot be achieved through a pure fixed cost compensation.

Figure 9: Comparison of required support costs between policy instruments



Source: own calculations

At the same time, policy comparisons turn out to be very technology-specific. Firstly, for the CAES system, discrepancies are less pronounced than for the Li-ion system. This can again be attributed to

differences in cost structure. For CAES systems, the main economic obstacle is the high cost of power capacity. Therefore, capacity remuneration per MW significantly alleviates the cost burden. In contrast, activity-based remuneration is clearly the most efficient solution for Li-ion systems as it compensates for the relatively high cost of expanding storage capacity. Secondly, in general, rendering the CAES system profitable is a much more costly endeavor, primarily due to its lower round-trip efficiency.

6.5 Discussion

Our simulations emphasize the importance of choosing the right instrument when developing direct support schemes for power-to-power storage. At the same time, the costs and benefits of different support instruments vary greatly, depending on the storage technology used. **Given these conditions, there are several reasons why a sound policy framework should comprise a variety of support measures.** Although price-based support measures have proven cost-efficient on average in our simulations, they entail significant fiscal risks. In particular, the concept of a percentage mark-up on discharging prices means that support costs depend directly on short-term spot market volatility. New temporary crisis situations (e.g. relating to energy imports) causing higher and/or more frequent price spikes in electricity wholesale trading would directly result in higher support payments - and even in an amplified form. While maximum limits for support could mitigate this risk, they would also increase regulatory complexity and complicate investment planning. By contrast, capacity payments are less sensitive to short-term risks because bidding prices in capacity markets are based on participants' long-term market expectations.

Therefore, balancing regulatory efficiency against fiscal risks asks for an instrument mix. One option is to implement a capacity mechanism for storage systems -either through access to existing cross-technology capacity markets or through dedicated non-fossil flexibility schemes - and to complement it by a moderate price support scheme to encourage capacity scaling. As the expected price support reduces the required capacity payments and thus bids on capacity markets, this would not constitute a form of double funding.

Moreover, such a balanced approach can promote technological diversity. Having different support schemes in place enables regulators to address the specific cost challenges of different storage technologies. In particular, discrepancies in the cost ratio of power to energy between short- and long-term storage technologies can be accounted for. This increases the likelihood of simultaneous and increasingly (through scale economies) self-supporting growth in storage solutions for different time horizons and end-use needs. It thus satisfies the diverse flexibility requirements imposed by the energy transition. Besides meeting multiple system requirements, such technological diversification would also help to reduce Europe's external supply chain risks. For example, the risk of importing lithium and cobalt for battery storage systems could be mitigated by complementing batteries with other storage technologies that require different raw materials.

Finally, when implementing large-scale price support schemes, the potential impact on market outcomes must be considered. Effective and system-friendly schemes that promote storage activity should contribute to lower price volatility in electricity wholesale trading and reduce the market value of balancing energy. This helps to limit fiscal risks, but also depresses expected returns to storage. However, with the current medium-term cost forecasts (see Subsection 4.3) in mind, the negative

impact of such a decline in market margins on storage investments is likely to be offset by the cost-reducing effect of scale economies.

7 Policy recommendations

7.1 Elimination of technical and market barriers

The central goal of a policy strategy should be to reward storage technologies for their contributions to supply flexibility and reduced system management costs, while maintaining a market-driven remuneration model. Given the current EU regulatory framework, close cooperation and a clear division of labor between the EU and its member states is required. Initially, joint efforts are needed to eliminate the technical barriers and market access issues that currently impair the profitability of storage investments.

At the European level, the Commission should take further action to help Member States reduce the lead time for new storage projects. Regular exchange on best practices and the preparation of detailed administrative guidelines by the Commission would be useful steps to speed up national approval procedures, especially given the huge discrepancies in average approval times between Member States (see Subsection 4.3). However, consultation alone is unlikely to create a level playing field in terms of lead times due to different national policy priorities. To put additional pressure on Member States, obliging them to plan and implement dedicated storage acceleration areas would be an effective second step. In addition to the renewable acceleration areas, these could be used as a strategic tool to promote utility-scale stand-alone storage solutions at critical points in national grids, with specific time limits for project approval. Besides reducing investment barriers, this could also help secure efficient spatial allocation of storage capacities within Member States, particularly in large countries with a single bidding zone, such as Germany. Furthermore, to reduce waiting times for network connection, the Commission should urge Member States to swiftly incorporate the option for grid operators to establish flexible connection agreements, as created by the 2024 electricity market reform, into national legislation.

To raise incentives for grid operators to fully consider the beneficial effects of energy storage in grid planning, the Commission should recommend Member States to reduce existing biases in national grid remuneration schemes. In particular, this concerns the relative treatment of OPEX and CAPEX in cost compensation. Spontaneous increases in the OPEX of grid operators caused by a more frequent or comprehensive use of balancing services should underlie the same economic rationale as increases in CAPEX caused by grid expansion. For this reason, provisions like the immediate adjustment of revenues to increased CAPEX from grid investments within regulatory periods⁶⁹ should be extended to cover increased OPEX from the purchase of balancing services. Again, enhanced consultation and cooperation between Member States on regulatory best practices could be a suitable low-level first step in this direction.

To facilitate access to balancing energy markets, the Commission should consult Member States on ways to reduce the burden on storage operators of proving they fulfil pre-qualification criteria, without lowering general reliability standards. In particular, it should push for homogeneous

⁶⁹ Eckhart, P., Wolf, A. (2025). [Ausbau von Digital- und Energienetzinfrastrukturen](#). cepStudie.

implementation of the option to pre-qualify as a group of units (see Subsection 4.3) in balancing energy markets. This would also promote innovative flexibility services by encouraging cooperation between electricity producers, small-scale storage providers, and demand-side response. To establish a further long-term revenue source for storage operators, the EU and its Member States should intensify their efforts to develop liquid PPA markets in Europe that reward the specific benefits of storage PPAs. Apart from temporary fiscal support to overcome financing obstacles, the marketability of supply flexibility within such contracts should be strengthened. Guarantees of Origin (GO) with fine-grained time resolution offer storage operators a unique opportunity to demonstrate the value of their balancing activity in ensuring the supply of green electricity. Member States should be urged to implement granular GOs in their regulatory frameworks.

Creating a fair competition environment for storage technologies in Europe also requires a homogeneous approach to the double taxation issue (see Subsection 4.3). The appropriate instrument for this is the Energy Taxation Directive. Commission and Member States should come to an agreement on the long-pending reform proposal, including a recognition of energy storage facilities as redistributors. Moreover, as an additional incentive mechanism, more Member States should consider the option of a temporary lifting of grid fees on electricity charged by storage facilities.

Finally, to meet the specific needs of Long Duration Energy Storage (LDES), forward markets in electricity wholesale trading in Europe should be strengthened. Existing barriers to more liquid forward markets are manifold and include high market fragmentation due to design differences across bidding zones as well as insufficient monitoring of competition. Measures should focus on improving liquidity and competition by promoting cross-zonal market integration.⁷⁰

7.2 Design of direct support schemes

Even with measures addressing the aforementioned barriers fully in place, the need for direct support for storage investments will remain. Firstly, many promising storage technologies, especially in the area of LDES, are still in an infant development stage and not yet cost-competitive. Temporary targeted support will be necessary for them to realize the expected scale economies, as it is currently observed for battery storage. Secondly, neither electricity wholesale markets nor markets for short-term balancing services reward storage systems for their contribution to reducing the long-term system costs from grid expansion or maintenance of peak load generation capacity. Direct support is one way to internalize this system-wide externality, thus contributing to a socially efficient investment mix.

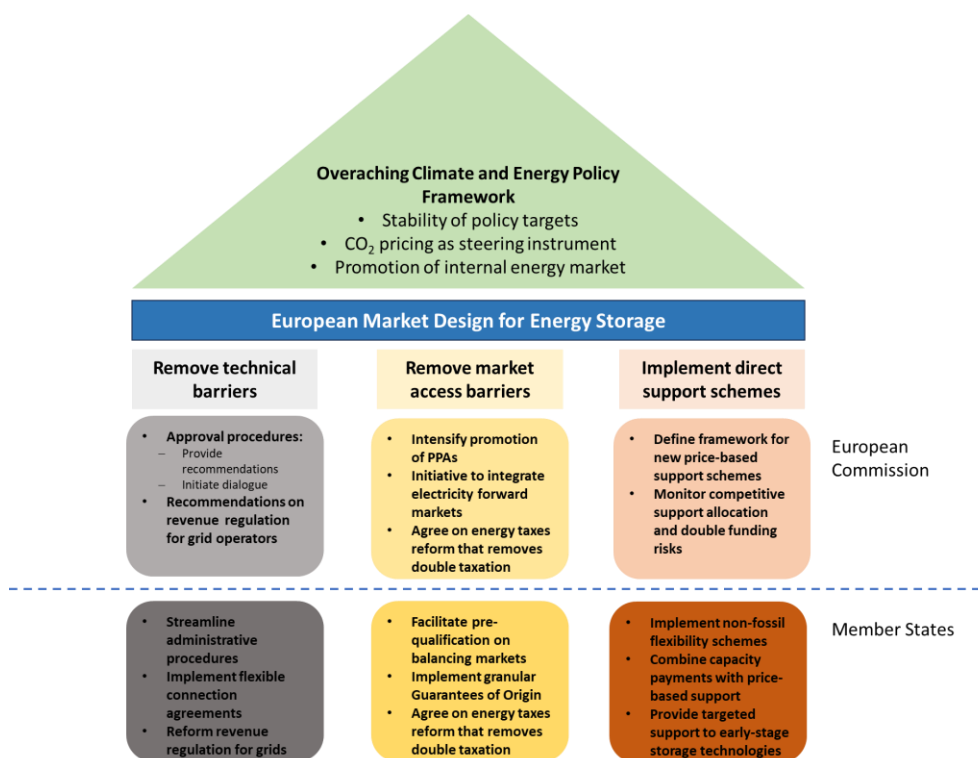
A conservative approach to rewarding system services is to implement capacity remuneration schemes (centralized or decentralized), as is currently practiced in many Member States (see Subsection 4.4). These schemes compensate for some of the regular fixed costs of storage systems. This reduces the minimum revenues necessary for storage market activities to break even. Storage systems must be able to benefit from this effect. Member States should grant fair access to existing cross-technology markets for flexible capacities to all storage solutions. Furthermore, Member States should take advantage of the opportunity to establish dedicated non-fossil flexibility schemes created by the electricity market reform of 2024.

⁷⁰ See ACER (2023).

However, while having a stimulating effect on storage investments, capacity mechanisms alone are unlikely to ensure a socially efficient growth path for storage capacities. This is because they do not address investment risks arising from uncertainty on the revenue side and are largely unconditional on system-friendly storage activity. **Against this background, our policy simulations (see Section 6) suggest that price-based support mechanisms — particularly the concept of a mark-up on electricity wholesale prices when discharging — are the most cost-efficient way to promote growth of storage capacity. Balancing this efficiency advantage against the higher fiscal risks of price-based support speaks in favor of a diversified instrument mix.**

We therefore propose that Member States adopt a mixed policy strategy providing temporary direct support for storage technologies in the form of regular capacity-based payments and moderate price surcharges for a pre-defined, limited time period. The level of payments should be determined through competitive bidding procedures. In terms of the specific design, sufficient consideration should be given to promoting infant storage technologies with the potential to provide new forms of system services, particularly in the area of long-duration storage. Additionally, alongside these measures designed for power-to-power storage, further instruments are required to encourage storage solutions that focus on the direct use of stored energy (e.g. power-to-heat, power-to-chemicals). Traditional support measures such as investment grants or income tax incentives will continue to play an important role for these technologies. Member States should utilize the scope provided by the CISAF rules to support these alternative end-use cases, thereby reducing energy losses from reconverting stored energy to electricity. This concerns both investments in storage capacities and in new energy infrastructure for transporting energy in its converted form (e.g. district heating networks, hydrogen pipelines). Figure 10 summarizes our policy recommendations in the form of a strategic multi-pillar roadmap.

Figure 10: A European market design for energy storage – building blocks and tasks distribution



Source: own illustration

8 Conclusion

Objectively, the near future offers all the prerequisites for a golden era of energy storage in Europe. Increasing shares of electricity supply from volatile renewables, the remaining need to decarbonize peak load flexibilities, impressive scale economies for battery storage and the advent of new complementary storage technologies all add up to a picture in which energy storage in its various forms becomes a cornerstone of the energy transition. Yet, a consistent EU storage strategy is still missing and Member States like Germany get tangled up in debates about artificially prolonging the fossil age. With the new state aid flexibilities created, it becomes all the more important that policymakers take a long-term perspective and consider the value of different technologies for a future carbon-free energy system in policy design.

This cepInput aims to shed light on both the future potentials and current barriers of storage solutions in Europe. It argues for creating an economic level playing field, for storage vis-à-vis grids and peak load generation as well as among different storage technologies. First of all, this requires an EU-wide dismantling of the technical constraints and regulatory barriers storage systems are facing. In addition, the contribution of energy storage to reducing the long-term costs from grid expansion and peak load capacities should be rewarded. Besides traditional capacity markets and the new option of non-fossil flexibility schemes, direct price support can be an effective investment stimulus by improving revenue perspectives for storage operators.

In particular, our policy simulations suggest that a percentage mark-up on discharging prices can be particularly effective in expanding storage capacity, especially for early-stage technologies and does not endanger the system-friendliness of storage activity. When being combined with competition-based capacity payments, the support framework can successfully balance efficiency against fiscal risks without creating double funding. In terms of the specific design, sufficient consideration should be given to promoting infant storage technologies with the potential to provide new forms of system services, particularly in the area of long-duration storage. Finally, alongside measures to support power-to-power storage, further instruments are required to encourage storage solutions that focus on the direct use of stored energy (power-to-heat, power-to-chemicals).

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