Electricity storage

A booming sector of technology

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About the FactBook: Electricity storage

This factbook intends to cover technologies that can store electricity for future use (mainly in the form of electricity but also heat, chemicals, fuels, etc.). Based on this definition, the FactBook aims to summarize the status of the electricity storage industry, covering both current and emerging technologies. It outlines the market status and its evolution, offering insights into the costs associated with electricity storage. The report delves into the battery value chain and examines the business models surrounding electricity storage services. Additionally, it provides a global perspective on existing policies. Lastly, it discusses the environmental and social impacts of electricity storage technologies.

About the Kearney Energy Transition Institute

The Kearney Energy Transition Institute is a nonprofit organization that provides leading insights on global trends in energy transition, technologies, and strategic implications for private-sector businesses and public-sector institutions. The Institute is dedicated to combining objective technological insights with economic perspectives to define the consequences and opportunities for decision-makers in a rapidly changing energy landscape. The independence of the Institute fosters unbiased primary insights and the ability to co-create new ideas with interested sponsors and relevant stakeholders.

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Executive summary

	The need for electricity storage	Achieving supply and demand balance in power systems, complicated by renewables and the phase-out of dispatchable plants, is a key driver for electricity storage. Many applications such as network reinforcement, primary reserves, etc. add further impetus to momentum for electricity storage solutions.
	Electricity storage technologies	Electricity storage encompasses five main categories: electrical, electrochemical, mechanical, thermal, and chemical storage, each with distinct advantages and limitations. Research and development aims to optimize batteries and develop new solutions for better energy density.
	Status and future market development	Global electricity storage capacity reached 276 GW by 2023, led by pumped hydro storage at 184 GW and lithium-ion batteries at 78 GW. The demand for lithium-ion batteries is driven by mobility applications, with China leading global investments, with significant growth expected.
	Costs of electricity storage	Investment costs, comprising 70–98% of overall expenditure for electricity storage, are crucial for market adoption. Experience curves show decreasing costs with increased capacity, with Li-ion cells exhibiting the fastest decrease, expected to reach USD 75–870/kWh by 2040.
	Battery value chain, from mining to recycling	The battery storage value chain, involves four main stages: mining, raw material processing, component production, and application/recycling. Increasing mineral demand, driven by EV batteries, could pose supply constraints, prompting EV and battery manufacturers to secure raw materials.
	Business models in electricity storage	Electricity storage profitability depends on diverse business models leveraging grid utilization and price arbitrage, though revenue gaps often exist due to undervalued services. Maximizing profitability involves stacking income streams from multiple applications, with revenue potential varying internationally. Electric vehicles can also participate in the electricity system through business models such as demand-side response, behind-the-meter support, and market trading.
	Policy and regulation for electricity storage	Policies supporting electricity storage include setting targets, offering financial incentives, and guiding investment through roadmaps. Globally, investment in grid-scale battery storage surged to more than USD 20 billion in 2022, with continued growth expected, fueled by governmental targets and supportive policies. Moreover, 74 countries had targets to promote electric vehicles.
	Environmental and social impact	Assessing the environmental impact of electricity storage is complex, with factors like technology and end-of-life scenarios to consider. Integrating renewables with storage can reduce greenhouse gas footprints, but various technologies have diverse impacts including land use, water consumption, and social effects, often underreported.

1. The need for electricity storage

The need for electricity storage

Scope definition:

This FactBook intends to cover technologies that are applicable in the stationary storage and mobility sectors and can store electricity for future use, mainly in the form of electricity but also heat, chemicals, fuels, etc..
The consumer electronics segment is not covered in this report.

Henceforth, "electricity storage" will be used in this FactBook instead of "energy storage" to reflect this focus.

Operating power systems requires balancing supply and **demand, which constantly fluctuates.** Traditionally, power systems are balanced by modulating the output of the power plants when in operation and demand side management. **Further, the projected phase-out of fossil fuel plants and the increase of variable power sources can pose challenges to resilient electricity supply, stable grid, etc.**

The rise of variable renewables increases system flexibility needs, as shown by residual load variations. **Other factors, like growing electricity demand and aging infrastructure, also affect supply and demand**, necessitating improved flexibility management of the power system.

Energy system transformation demands new flexibility sources, boosting the importance of electricity storage. **Storage solutions**, using electrical, electrochemical, mechanical, thermal, and chemical means, **help shift supply and demand, reduce the need for network upgrades, ensure reliable and affordable supply, and transform energy usage at the customer level.**

The transformation of energy systems is also closely linked to the growing adoption of electric vehicles, with the global **EV fleet** expected to **increase twelve-fold by 2035. EV charging patterns significantly impact the grid** by increasing demand, influencing renewable energy integration, and accelerating the need for grid reinforcement.

Smart EV charging provides power system flexibility, reduces the need for extensive grid upgrades, and supports additional electricity demand. Furthermore, the evolving relationship between EVs and electricity networks, particularly through vehicle-to-grid (bi-directional flow/smart charging) applications, enhances grid stability.

Various properties characterize the electricity storage process, which **involves withdrawing electricity from the grid, storing it, and returning it at a later stage.** It consists of two dimensions: the power capacity of the charging and discharging phases, which is the ability of the storage system to withdraw or inject electricity instantaneously from or into the grid; and the energy capacity of the storing phase, which measures how much energy can be stored and for how long.

As a consequence, **the uses of electricity storage vary, depending on the combination of the power rating and discharge time of a device, its location within the grid, and its response time.**

Electricity storage enables stationary storage, mobility, and consumer electronics applications

Scope definition:

This FactBook aims to cover electricity storage technologies applicable in **stationary storage and mobility sectors**.

1.1 Electricity storage definition

Stationary storage

Stationary storage refers to **technologies connected to the power grid** (front of the meter) and **premises of the customer** (behind the meter) as well as serving off-grid standalone systems

- Energy and capacity services
- Transmission and distribution services
- Ancillary services
- Customer-level services

Mobility

Mobility applications include the use of **batteries** to store energy and allow travel through **transportation systems**.

- SUVs
- Average-size cars
- Small cars
- Buses
- Trucks
- Trains
- Boats
- Planes/ drones
- Two-/three-wheelers
- Smart charging

Consumer electronics

Consumer electronics include the use of **batteries** to store energy for portable **electronic devices**.

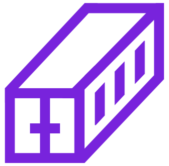
- Other electronics
- PCs
- Phones

Yearly demand of batteries storage per segment[1]

Segment	Year	Demand
Stationary storage	2017	1 GWh
Stationary storage	2023	93 GWh
Mobility	2017	71 GWh
Mobility	2023	780 GWh
Consumer electronics	2017	65 GWh
Consumer electronics	2023	212 GWh

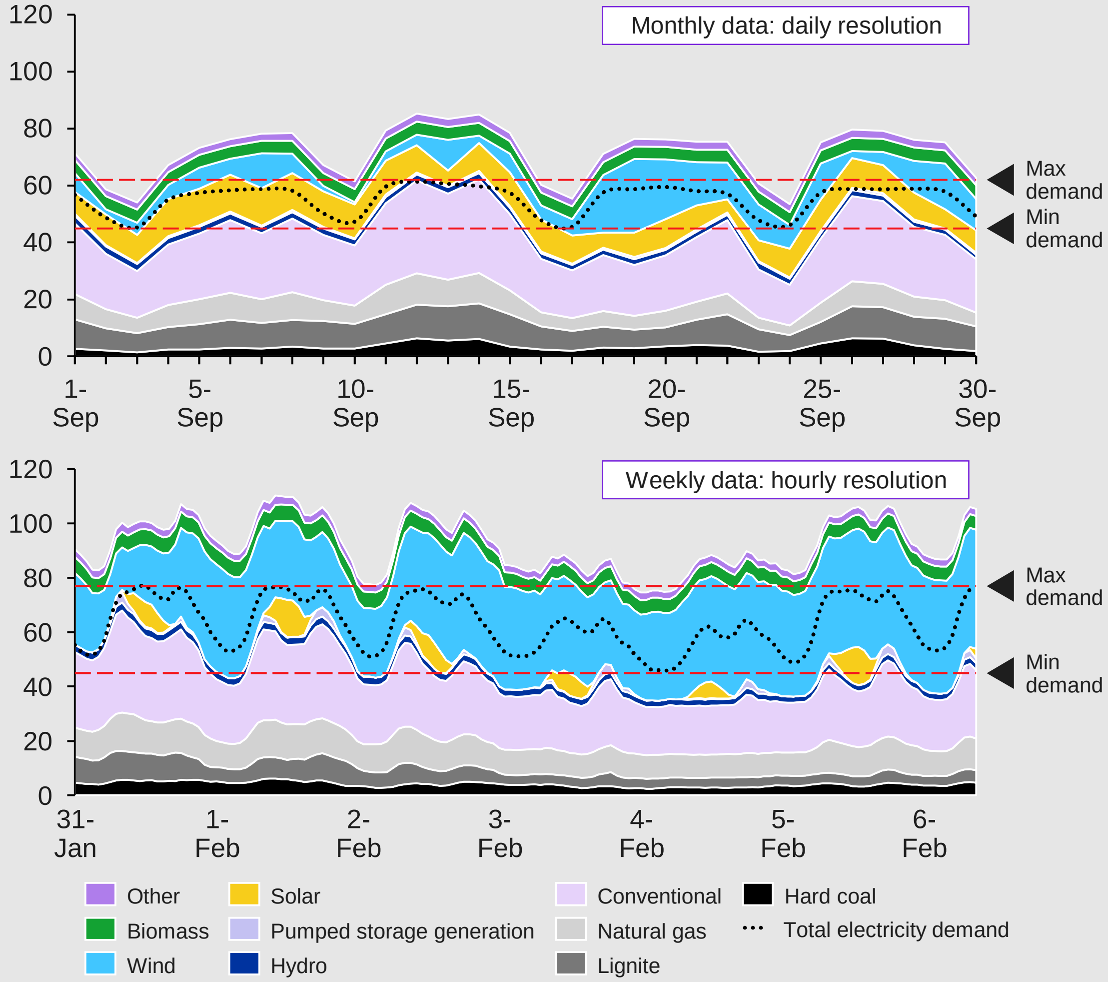
[1] Illustrative example of battery-only demand, yearly demand reflects what comes into the market; this excludes other type of storage.
Sources: IEA, 2024, Global EV Outlook 2024; E3 Analytics, 2023, Scaling-up Energy Storage: Technology and Policy; Kearney Energy Transition Institute analysis

Traditionally, power systems are balanced by modulating power plants output and demand side management



Monthly and weekly load and supply curve in Germany, by technology

GWh/h, Sept. 2023 – Feb. 2024



Difference between demand and generation corresponds to exports / imports

Electricity storage is crucial because of the inherent imbalance between electricity supply and demand, as depicted by the load and supply curves.

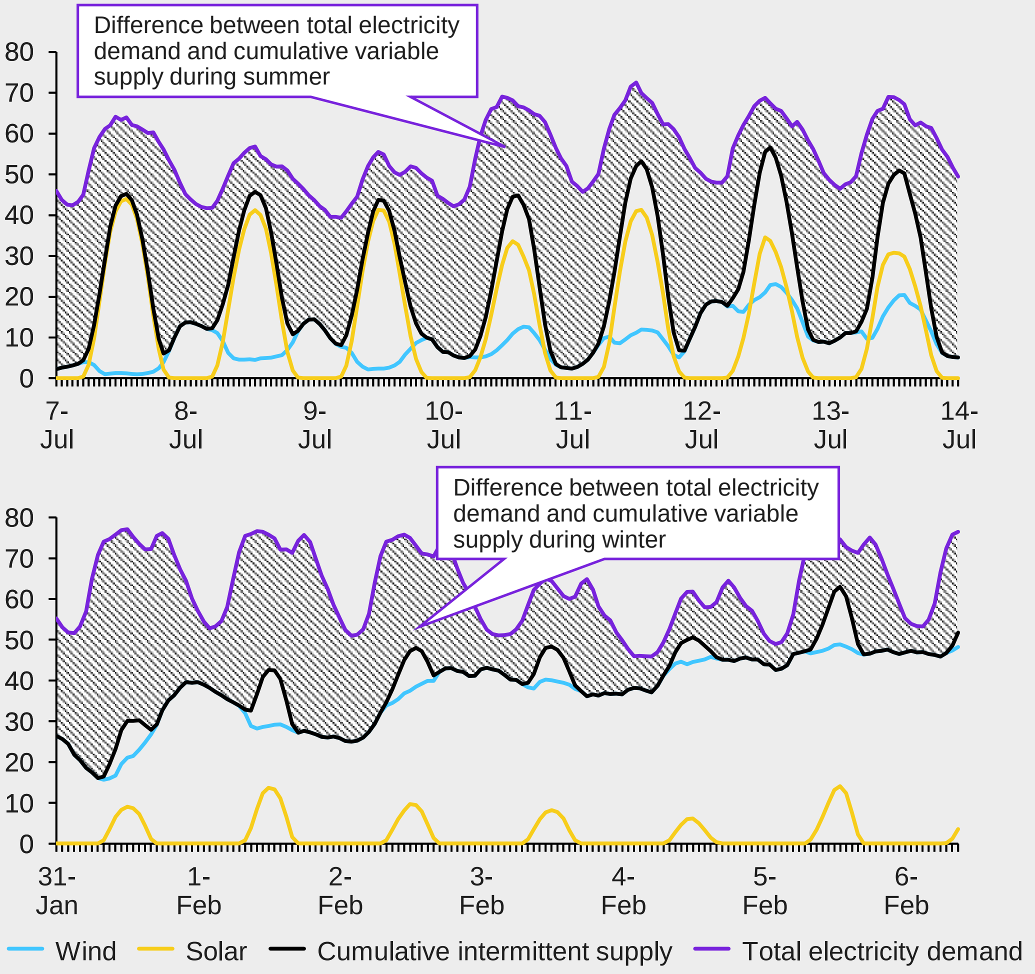
- **Matching supply with demand: Electricity storage captures excess power when supply exceeds demand and releases it when demand exceeds supply.** This balances the grid, ensuring reliable electricity supply and preventing shortages, curtailment during peak hours and blackouts.
- **Integration of renewable energy:** Solar and wind energies are variable, meaning they generate electricity according to weather conditions. **Electricity storage enables the storage of surplus renewable electricity generated during times of high production for use when production is low.** This maximizes the utilization of renewables and reduces reliance on fossil fuels.

1.2 Electricity systems shift

Sources: Agora Energiewende, 2024, Power generation and consumption monthly data; Agora Energiewende, 2024, Power generation and consumption weekly data; Kearney Energy Transition Institute analysis

To reach a higher penetration of wind and solar photovoltaic electricity, power and electricity flexibility are required

Wind and solar generation vs. consumption in Germany
GWh/h, Jul. 2023 – Feb. 2024



Wind and solar introduce variability and uncertainty on the supply side. Their output varies according to daily and seasonal patterns, and weather conditions. Output is therefore:

- Less reliably predictable (notably harder to forecast than demand)
- Limited ability to ramp up production in real-time (resource availability, e.g.: wind speed, irradiance)
- Subject to steep ramp changes

The variable output of wind and solar increases the need for flexibility. The residual load variations on the graph illustrate the need for flexibility.

Wind and solar make a limited contribution to the flexibility of the power system due to uncertainty surrounding their production reliability in meeting peak demand, also known as capacity credit. The capacity credits of wind and solar range between 5% and 55%.[1]

[1] In reality, this means that of the 9,900 GW of installed wind and solar capacity predicted by 2030 (IRENA's under 1.5 °C scenario), only 495 GW will be available to power operators as part of the pool of flexibility resources. However, capacity credit varies by region and solar and wind regional grid penetration levels.

Sources: Agora Energiewende, 2024, Power generation and consumption weekly summer data, Agora Energiewende, 2024, Power generation and consumption weekly winter data; J. Ssengonzi et al., 2022, "An efficient method to estimate renewable energy capacity credit at increasing regional grid penetration levels," Renewable and Sustainable Energy Transition; Kearney Energy Transition Institute analysis

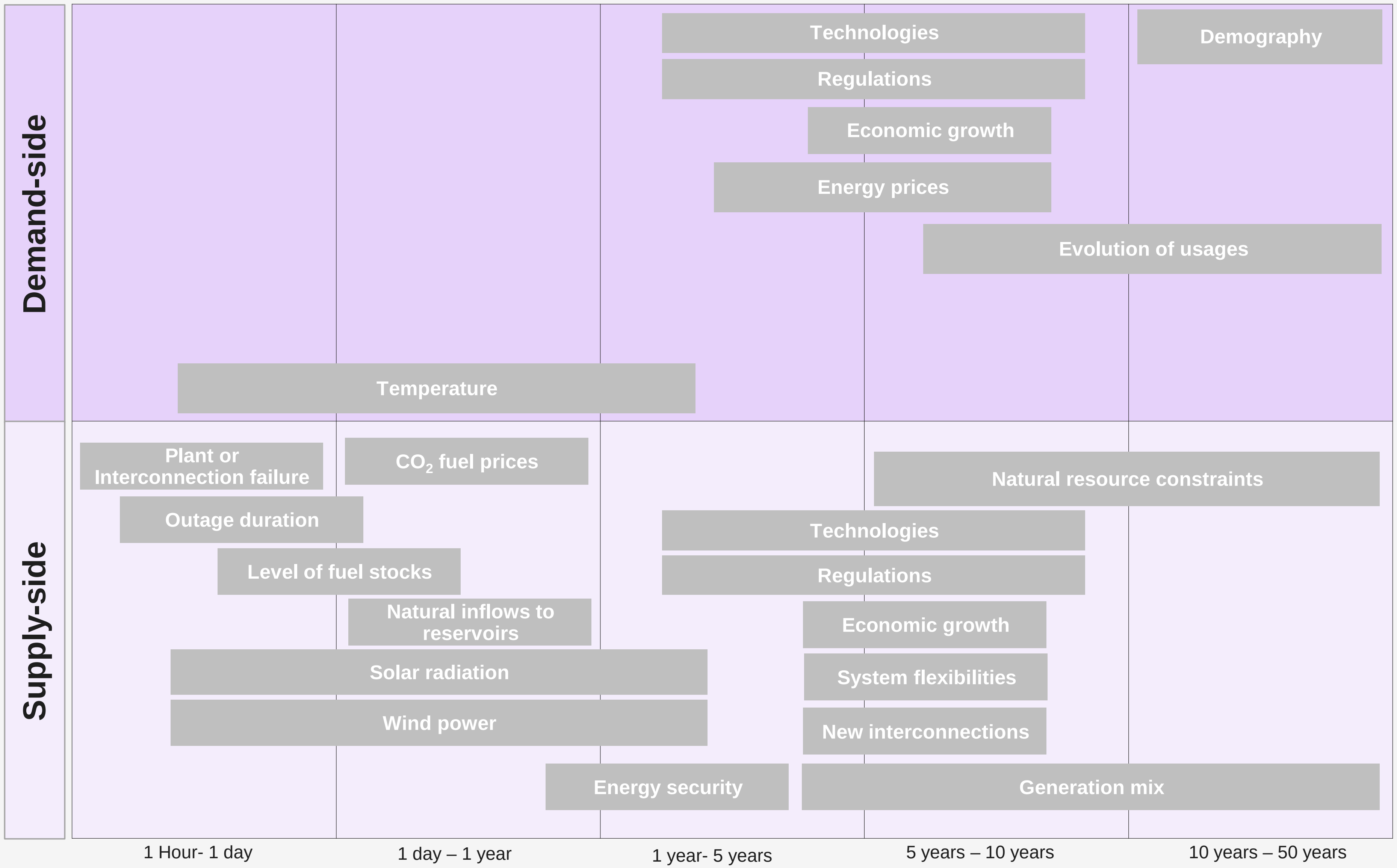
Power supply and demand is impacted by multiple factors at various time scales

Power supply and demand management faces multiple complexities and uncertainties.

1.2 Electricity systems shift

Key factors impacting supply and demand at different time scales

Illustrative



Sources: Adapted from Ecole Polytechnique, 2020, “Electrical Grid”; Kearney Energy Transition Institute analysis