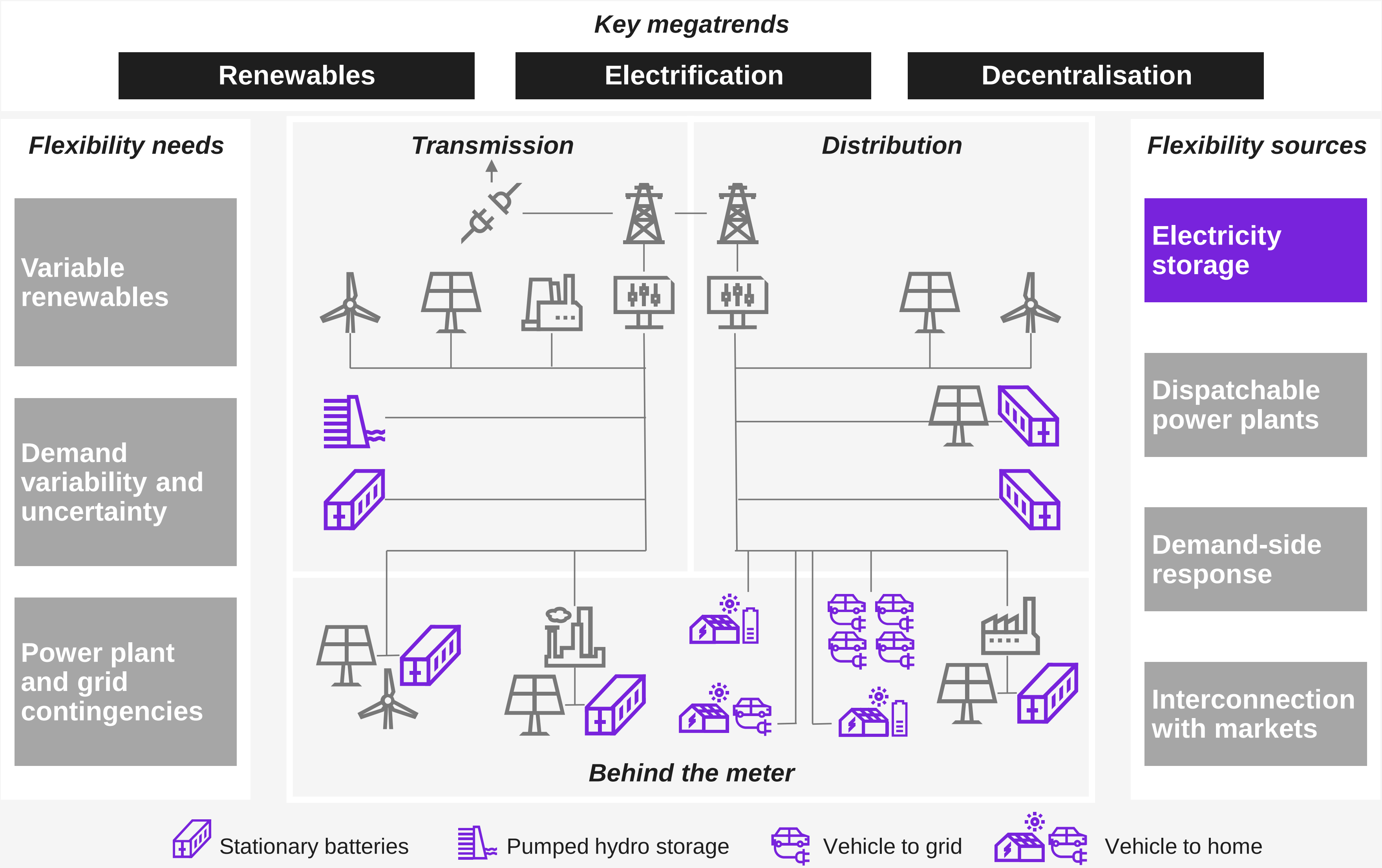
Transformation of energy systems requires additional flexibility sources, driving momentum for electricity storage solutions

Illustrative; non-exhaustive

Power systems are under strain due to:
- Increasing electricity demand
- Widespread penetration of variable renewables
- Aging grid infrastructure

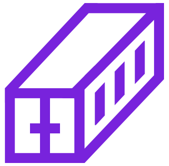
1.2 Electricity systems shift

The role of electricity storage in the energy system transformation
Power system flexibility management

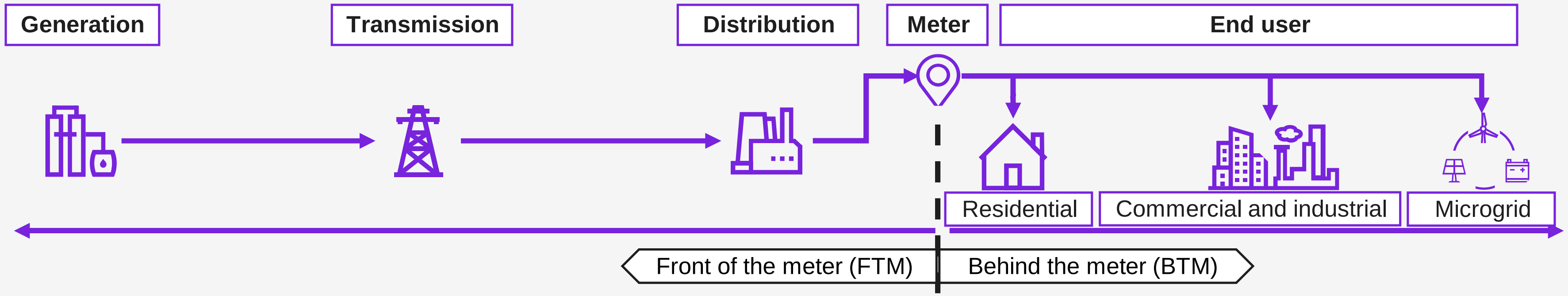


Note: Flexibility management can also be optimized by perfecting models for forecasting output from variable sources, fine-tuning market regulations and refining the design and power systems
Source: Kearney and Kearney Energy Transition Institute analysis

Electricity storage provides four main types of services to the grid and end users



The role of electricity storage projects



1 Energy and capacity services

Shift energy supply and demand over time where needed

- Capacity firming
- Energy arbitrage
- RE curtailment minimization[1]
- System electric supply capacity

2 Transmission / distribution services

Reduce / delay the need for T&D network upgrades

- Distribution loss reduction
- Distribution voltage support
- Transmission congestion relief
- Transmission/distribution upgrade deferral

4 Customer-level services

Ensure affordable, continuous, and reliable supply for end customers

- End-user peak shaving
- Power quality
- Reliability and resilience
- Time-of-use bill management
- Smart consumption maximization

3 Ancillary services

Fast and accurate shifts in supply and demand under normal and emergency operations

- Black-start capacity
- Contingency reserves
- Frequency-responsive reserves
- Ramping reserves
- Regulating reserves
- Voltage support

The definitions of different types of services, along with alternative terminologies employed in the literature, are available in Appendix.

[1] Renewable energies

Note: It should be noted that the definitions can vary significantly from country to country.

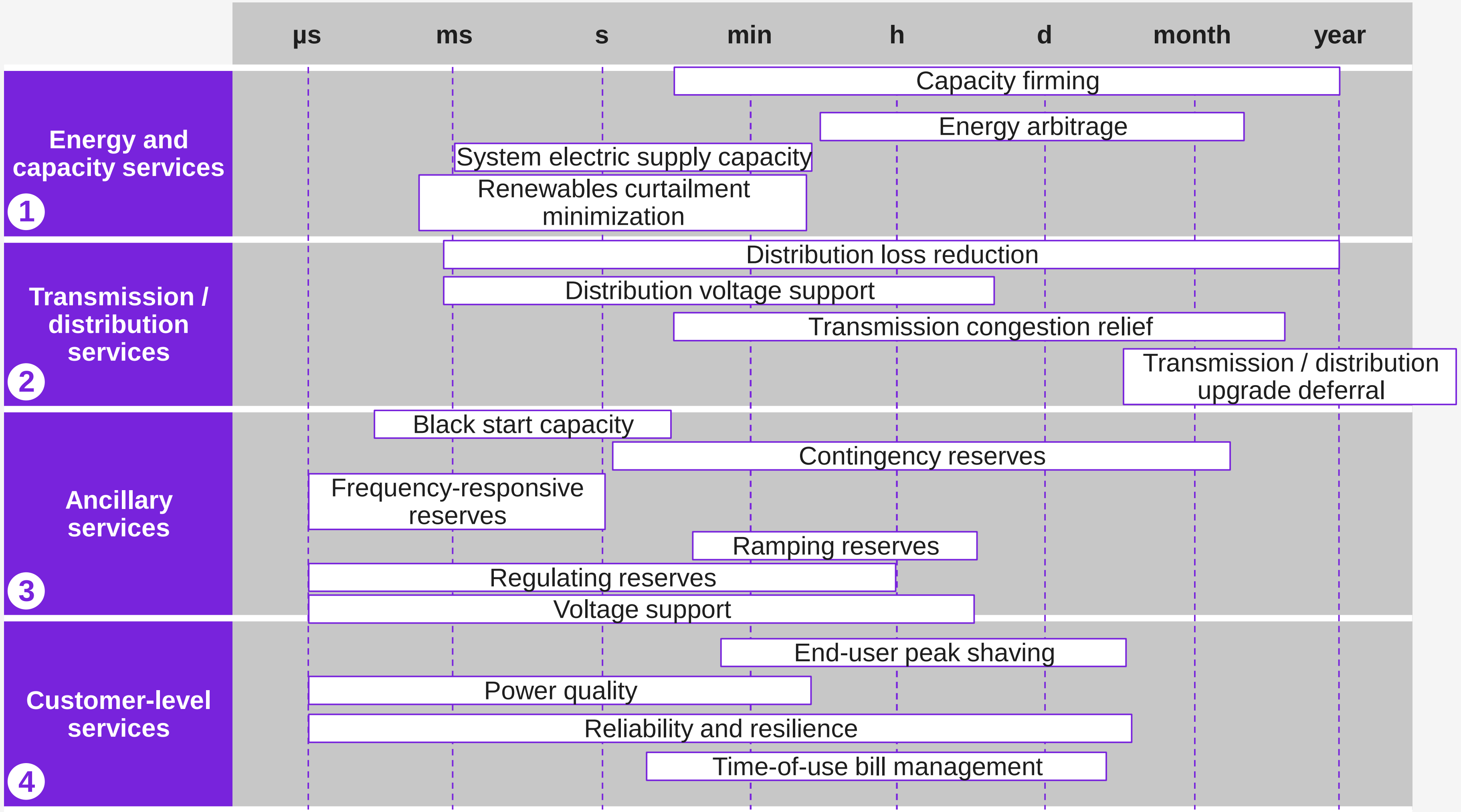
Sources: IRENA, 2019, Innovative Ancillary Services: Innovation Landscape Brief; IRENA, 2020, Electricity Storage Valuation Framework: Assessing system value and ensuring project viability; NREL, 2019, An Introduction to Grid Services: Concepts, Technical Requirements, and Provision from Wind; E3 Analytics, 2023, Scaling-up Energy Storage: Technology and Policy; P. Wei et al., 2023, “Progress in Energy Storage Technologies and Methods for Renewable Energy Systems Application,” Applied Sciences; M. Katsanevakis et al., 2016, “Aggregated applications and benefits of energy storage systems with application-specific control methods: A review,” Renewable and Sustainable Energy Reviews; Kearney Energy Transition Institute analysis

Each type of service includes a variety of applications tailored to the grid's and end users' needs

Note: This is a graphical representation of a generic concept which outlines that storage solutions can address these applications in theory but may or may not be the most practical and robust solutions available at hand

1.3 Electricity storage role and applications

Applications depending on output duration and location on the grid



Note: µs corresponds to microseconds and ms to milliseconds.
Sources: IRENA, 2019, Innovative Ancillary Services: Innovation Landscape Brief; E3 Analytics, 2023, Scaling-up Energy Storage: Technology and Policy; Kearney Energy Transition Institute analysis

Electricity storage technologies contribute to energy and capacity services in multiple ways

1 Energy and capacity services
2 Transmission / distribution services
3 Ancillary services
4 Customer-level services

1.3 Electricity storage role and applications

Electricity storage contribution to energy and capacity services

Electricity storage is used for load leveling over various time scales. Typically, electricity is stored during periods of low demand and discharged during peak demand periods to reduce the peak/off-peak amplitude (for daily, weekly, and seasonal demand), while limiting the need of peak plants.

Capacity firming encompasses:

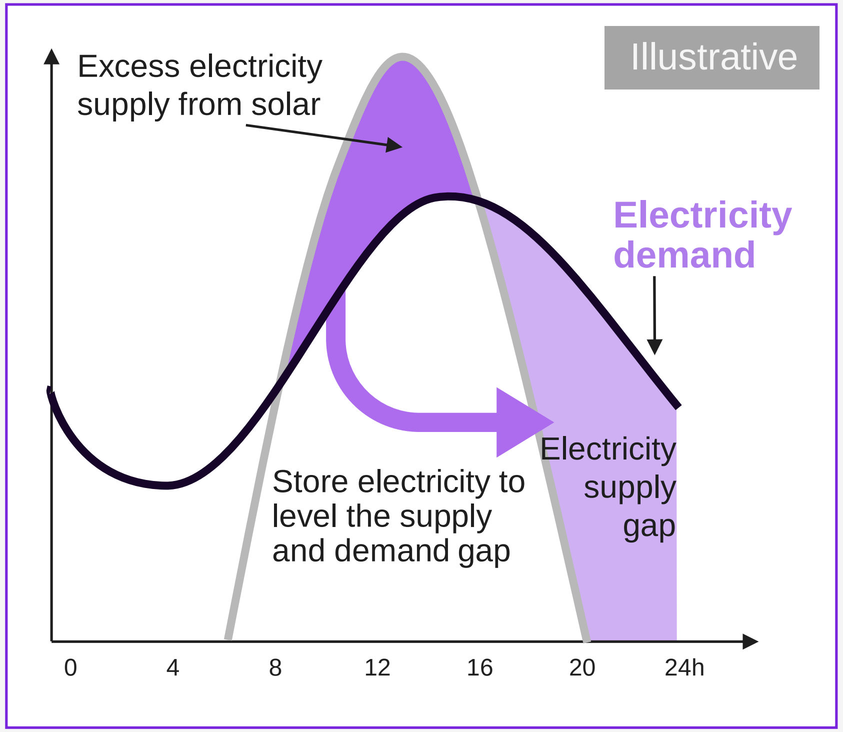
- **Optimizing power fleet operations**
- Deferring/avoiding transmission and distribution infrastructure upgrade
- Supplying isolated areas with electricity

Besides the capacity firming, electricity storage provides additional benefits, including:

- **Energy arbitrage:** taking advantage of an electricity price difference in the wholesale electricity to buy energy at low price and sell it at high price
- **RE curtailment minimization:** avoiding curtailment of variable RE sources[1]
- **System electric supply capacity:** providing the system with peak generation capacity.

Daily solar PV output with storage vs. demand

kW



[1] Renewable energies
Sources: Kearney Energy Transition Institute analysis

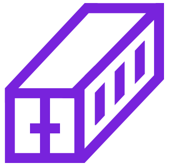
Electricity storage technologies provide various solutions to transmission and distribution services

1 Energy and capacity services

2 Transmission / distribution services

3 Ancillary services

4 Customer-level services



1.3 Electricity storage role and applications

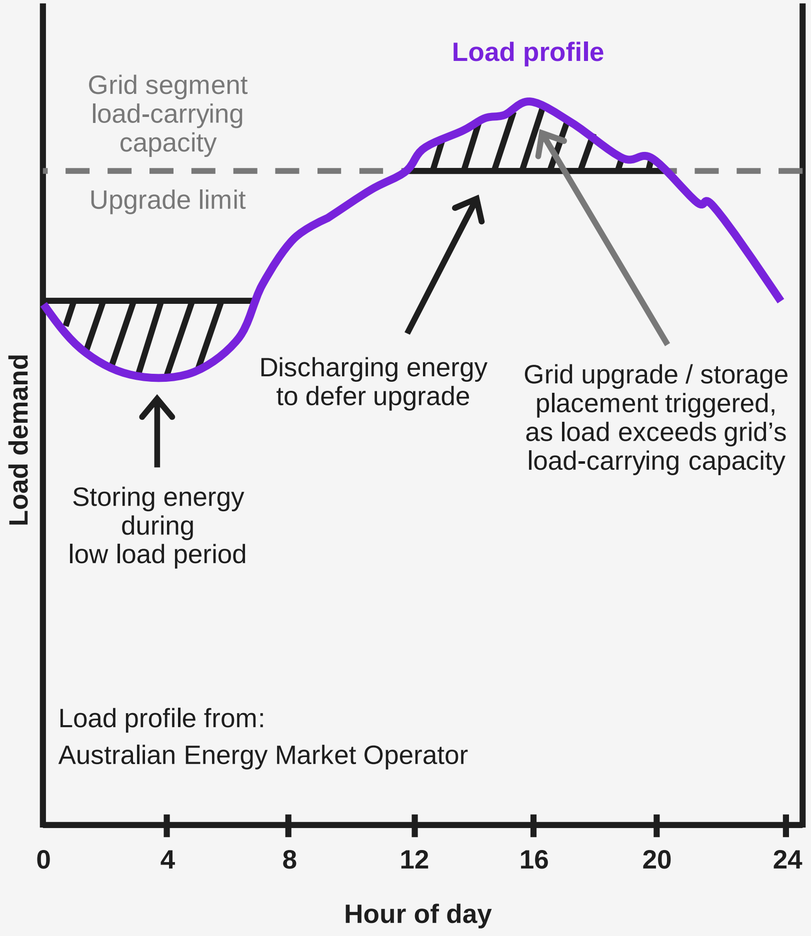
Electricity storage contribution to transmission and distribution services

Electricity storage technologies' role in T&D services consists of:[1]

- **Distribution loss reduction:** performing capacity / voltage support, reducing the impacts of the loss of a major grid component
- **Distribution voltage support:** maintaining the voltage profile within regulatory limits
- **Transmission congestion relief:** steering either the supply or demand and postponing / avoiding the necessity to increase lines in grid segments nearing capacity
- **Transmission / distribution upgrade deferral:** with EU electricity consumption projected to surge by 60% by 2030, the existing 11 million kilometers of grids are ill-prepared. **By supplying power during peak loads, these systems can delay or prevent the need to expand power transformers**, prolonging their lifespan and proving more cost-effective than alternatives. Charging should occur during low-load periods like night-time, while discharging should coincide with peak demand hours.

T&D upgrade deferral – congestion instance based on load demand[1]

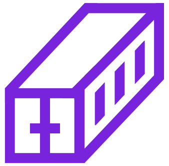
kW



[1] Transmission and distribution

Sources: M. Katsanevakis et al., 2016, "Aggregated applications and benefits of energy storage systems with application-specific control methods: A review," Renewable and Sustainable Energy Reviews; Kearney Energy Transition Institute analysis

Electricity storage technologies contribute to ancillary services in various ways



1.3 Electricity storage role and applications

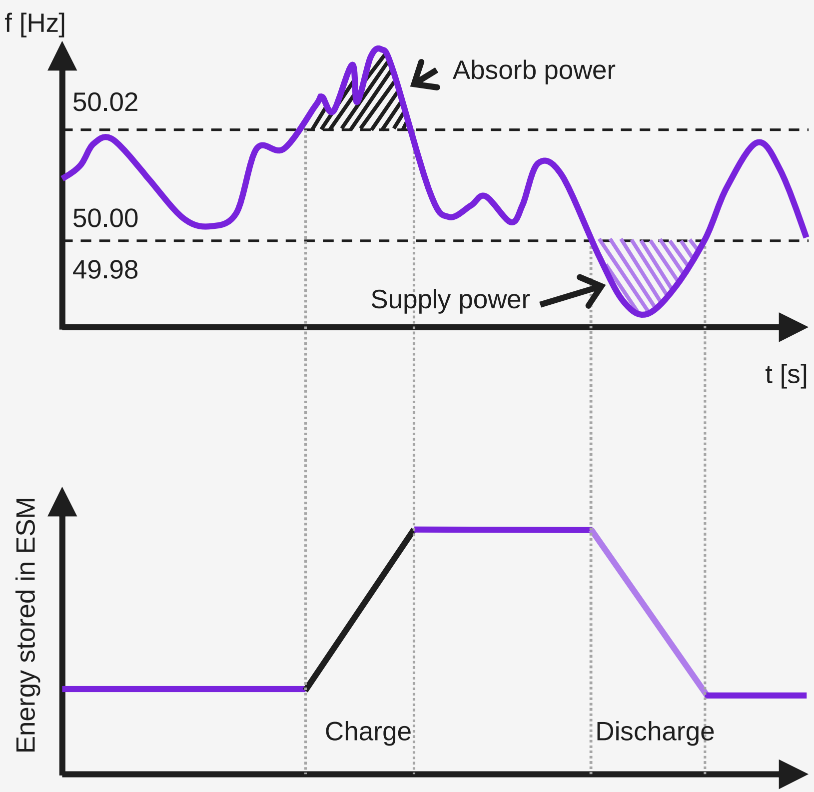
Electricity storage contribution to ancillary services

The system's frequency and voltage need to be maintained within technical limits to avoid instability and blackouts and to ensure continuous service. Ancillary services encompass:

- **Black-start capacity:** initial power supply to restart a power or gas grid after a full blackout
- **Contingency reserves:** reserves used to address power plant or transmission line failures
- **Frequency–responsive reserves:** reserves that act to slow and arrest the change in frequency via rapid and automatic responses that increase or decrease output from generators
- **Ramping reserves:** immediate or automatic mechanisms that increase or decrease output to maintain frequency and voltage continuously within electricity network standards
- **Voltage support:** Storage can be used for active and reactive power injection to sustain voltage

Frequency regulation with electricity storage

Hz, kW



The electricity storage system is charged or discharged in response to an increase or decrease, respectively, of grid frequency. This approach to frequency regulation is a particularly attractive option due to its rapid response time and emission-free operation.

Sources: E. Yosef et al., 2019, "Battery Energy Storage Applications: Two Case Studies", IEEE; Kearney Energy Transition Institute analysis

Electricity storage technologies provide multiple solutions to customer-level services

1 Energy and capacity services
2 Transmission / distribution services
3 Ancillary services
4 Customer-level services

1.3 Electricity storage role and applications

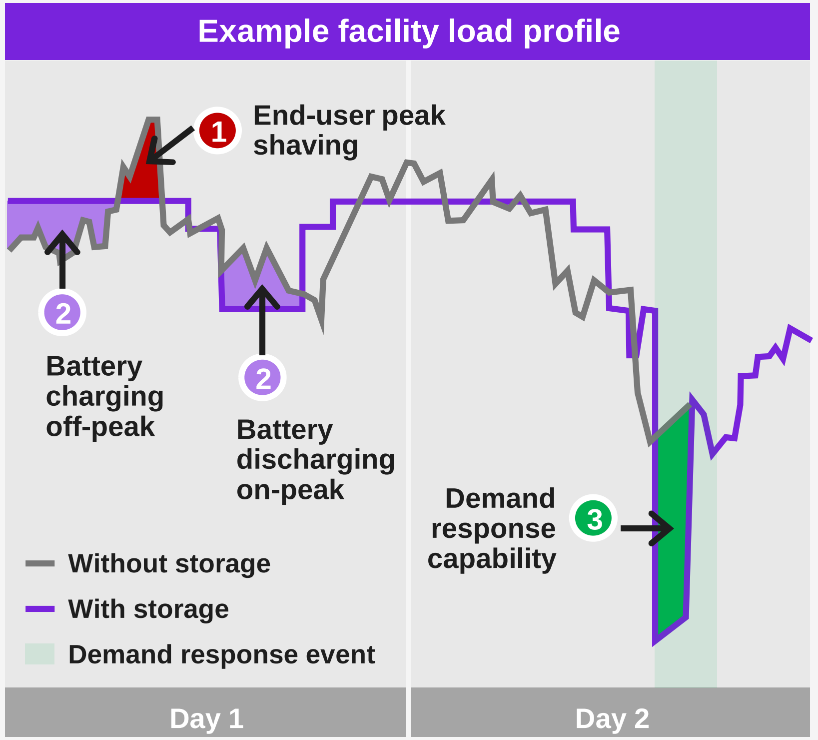
Electricity storage contribution to customer-level services

An electricity storage system can transform energy usage at a site, consisting of various services:

- **End-user peak shaving:** electricity storage systems respond effectively to market signals, enhancing flexibility, **providing solutions in demand charge management by reducing associated costs.**
- **Reliability and resilience:** substituting the network in case of interruption
- **Time-of-use bill management:** electricity storage systems **enable savings by storing power when grid prices are low and using it when prices are high, while also storing renewable energy for later use.** This can be supported by participating in demand response programs without disrupting critical equipment.[1]

Electricity storage system provides various value streams – facility load profile example

kW



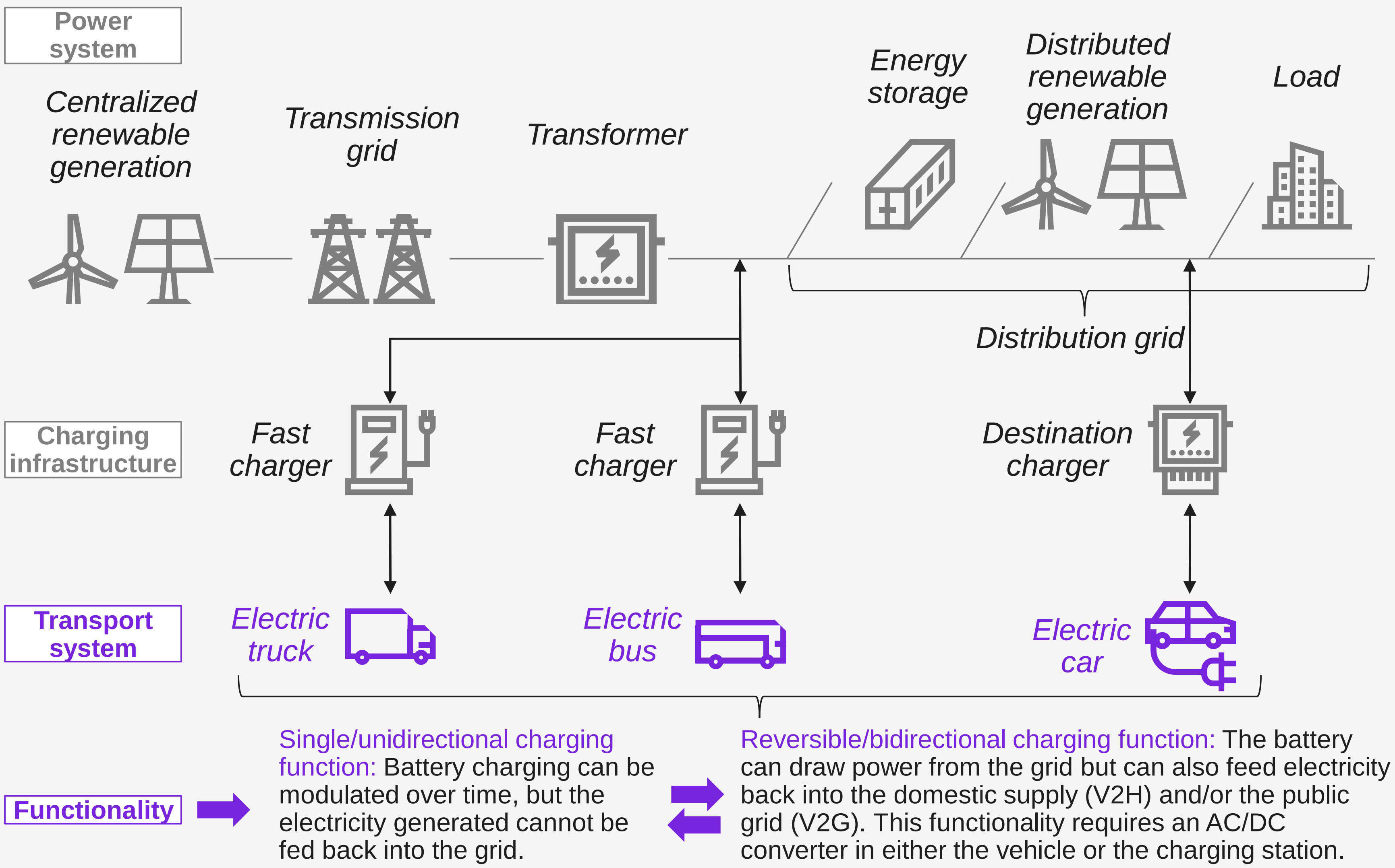
[1] Demand response programs are offered by many utilities for energy consumers to enroll in and receive money back for reducing their energy demand, at the utility's request, during peak periods of demand and under-supply. Common examples of reduction include turning up the temperature on a thermostat to reduce the air conditioning load, turning off certain lights, or shifting the time of use of some energy-consuming devices out of the peak demand period. The load avoided for a single facility may be small, but when many customers participate, it creates a meaningful energy demand reduction for the utility.
Sources: ENEL, 2023, Unlocking the full value stack for battery storage; Kearney Energy Transition Institute analysis

Growing electric vehicles adoption is intertwined with the transformation of energy systems

Vehicle-to-everything (V2X) is a term used to describe the general concept of a vehicle connected to its surrounding environment. It encompasses, among others, vehicle-to-grid (V2G) and vehicle-to-home (V2H).

1.3 Electricity storage role and applications

Integration of electric vehicles into the power and transport sectors



Sources: Zhang et al., 2024, Sustainable plug-in electric vehicle integration into power systems; RTE, 2019, Integration of electric vehicles into the power system in France; Kearney Energy Transition Institute analysis

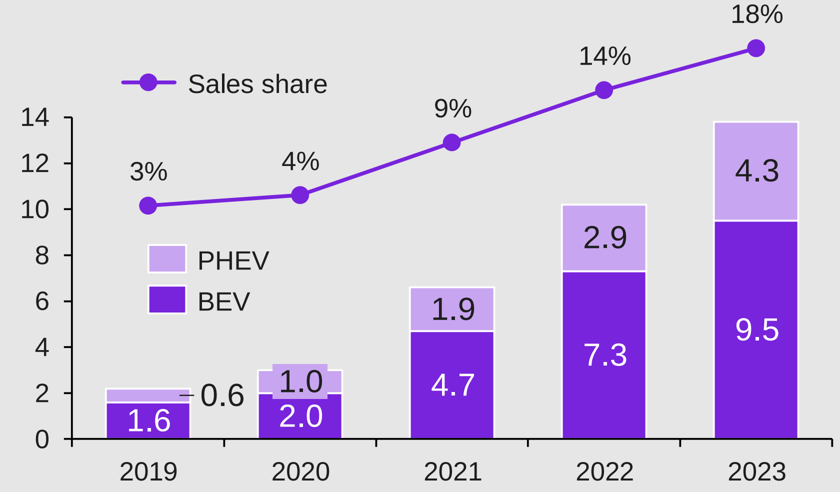
The global electric vehicle fleet is set to grow twelve-fold by 2035 under stated policies scenario of IEA

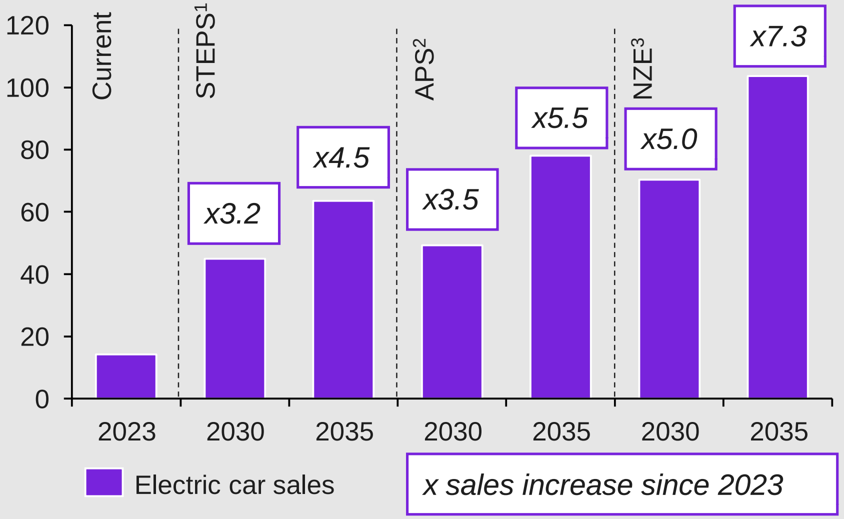
– Electric car sales neared 14 million in 2023, 95% of which were in China, Europe, and the United States.
– Nearly 1 in 5 cars sold in 2023 was electric.

1.3 Electricity storage role and applications

Electric car registrations and sales share evolution

Million, 2019–2035





[1] IEA's Stated Policies Scenario
[2] IEA's Announced Pledges Scenario
[3] IEA's Net Zero Emissions Scenario
[4] Original equipment manufacturer

Notes: PHEV to plug-in hybrid electric vehicle and BEV corresponds to battery electric vehicle. The share of sales represents the number of BEV and PHEV registrations compared to total car sales.
Sources: IEA, 2024, Global EV Outlook 2024; REN21, 2024, Renewables 2024 Global Status Report; Kearney Energy Transition Institute analysis

Main drivers of development

Growing attention of consumers for the energy transition and decarbonization:

– Consumers are increasingly adding sustainability and environmental impact criteria as a driver in their purchase decision.

Automotive OEMs fully embracing the e-mobility revolution[4]:

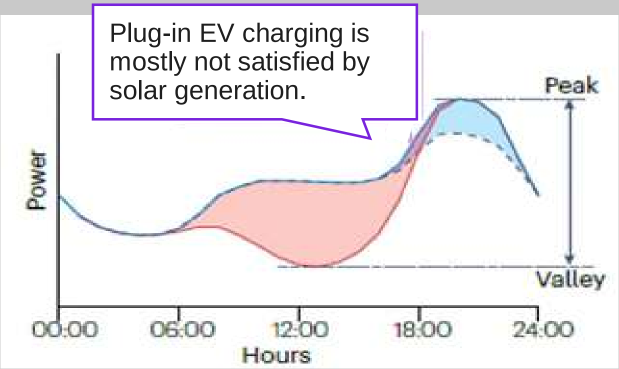
– A wide range of electric vehicles (EVs) is coming on the market, with growing battery power and enhanced charging speed, with the cost of batteries continuously falling.
– The largest OEMs are setting significant target (50%+) for their EV sales over the next years.

Governments' support for e-mobility with regulatory frameworks and incentives on EV purchase and infrastructure development:

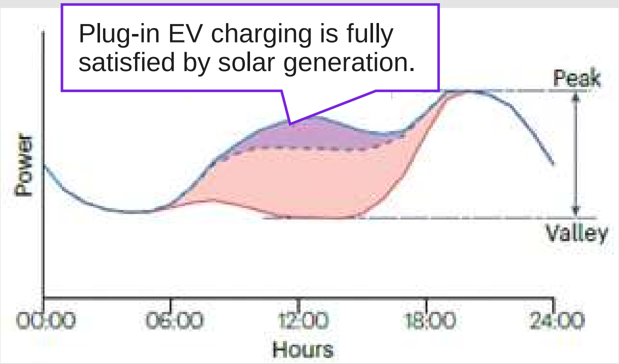
– Targets promoting electric vehicles continued to lead in road transport, with a total of 74 countries with such targets by the end of 2023.
– Additionally, 18 countries announced new policies supporting EV uptake in 2023.

EV charging patterns have an impact on the grid, such as increasing demand, affecting renewable penetration, or accelerating grid reinforcement

In **uncoordinated charging** scheme the EV battery starts charging immediately when it is plugged in or after a fixed start delay chosen by the user.

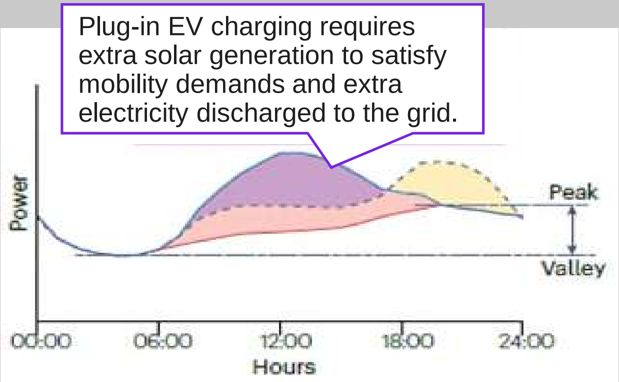


Smart charging allows plug-in electric vehicles to consume more electricity when renewable generation is high. Additional case for dynamic charging when rates are set for the time of the day (i.e. no variation on day-to-day basis)



- Base load curve
- Total load curve
- Net load curve
- PEV discharging
- Solar generation
- PEV charging
- PEV charging + solar generation

Smart discharging can transfer electricity from time periods with high renewable generation to time periods with low renewable generation, which further flattens the net load profile and promotes renewable generation consumption.



Sources: Zhang et al., 2024, Sustainable plug-in electric vehicle integration into power systems; Kearney Energy Transition Institute analysis

Example