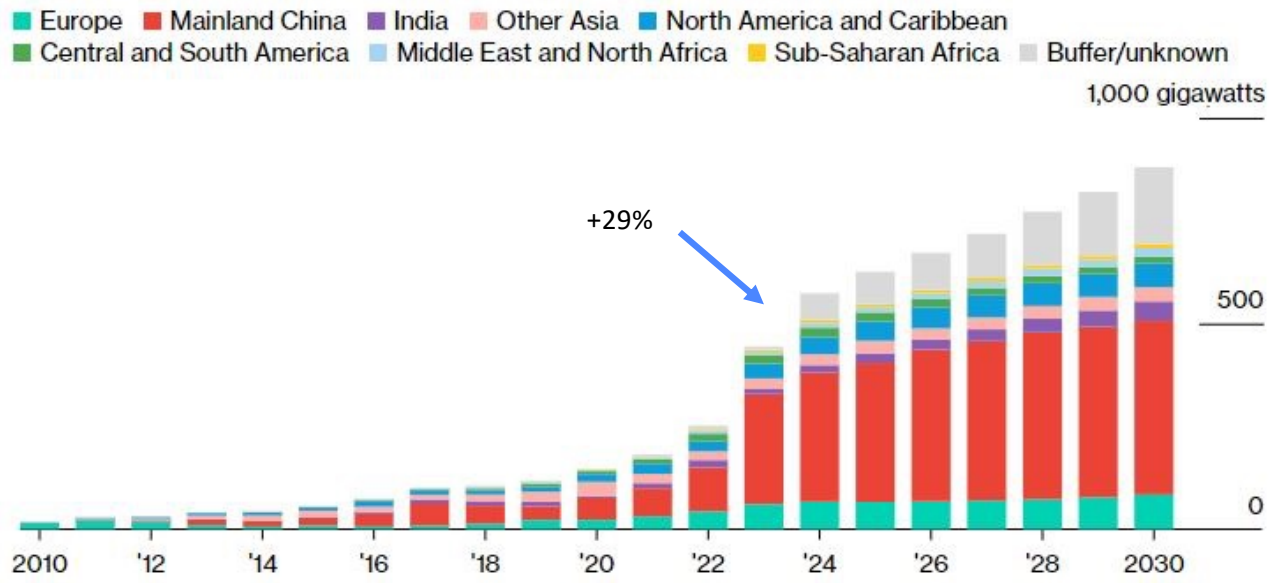
Installing the 2nd TW of PV Capacity

- >520 GW PV Installation
  2023: +76 % YoY
  2024: +29 % YoY
- 37 Markets with >1GW added PV capacity
- 11 ctUSD/Wp: Cheapest PV Modules ever
- 1.1 TW Polysilicon supply,
  783 GW Product Capacity
- PV and ESS combined
- Margins:
  - Under pressure across the PV value chain
  - Competition is intense
  - High module inventory

Global PV installation, expected in 2024 [GW]



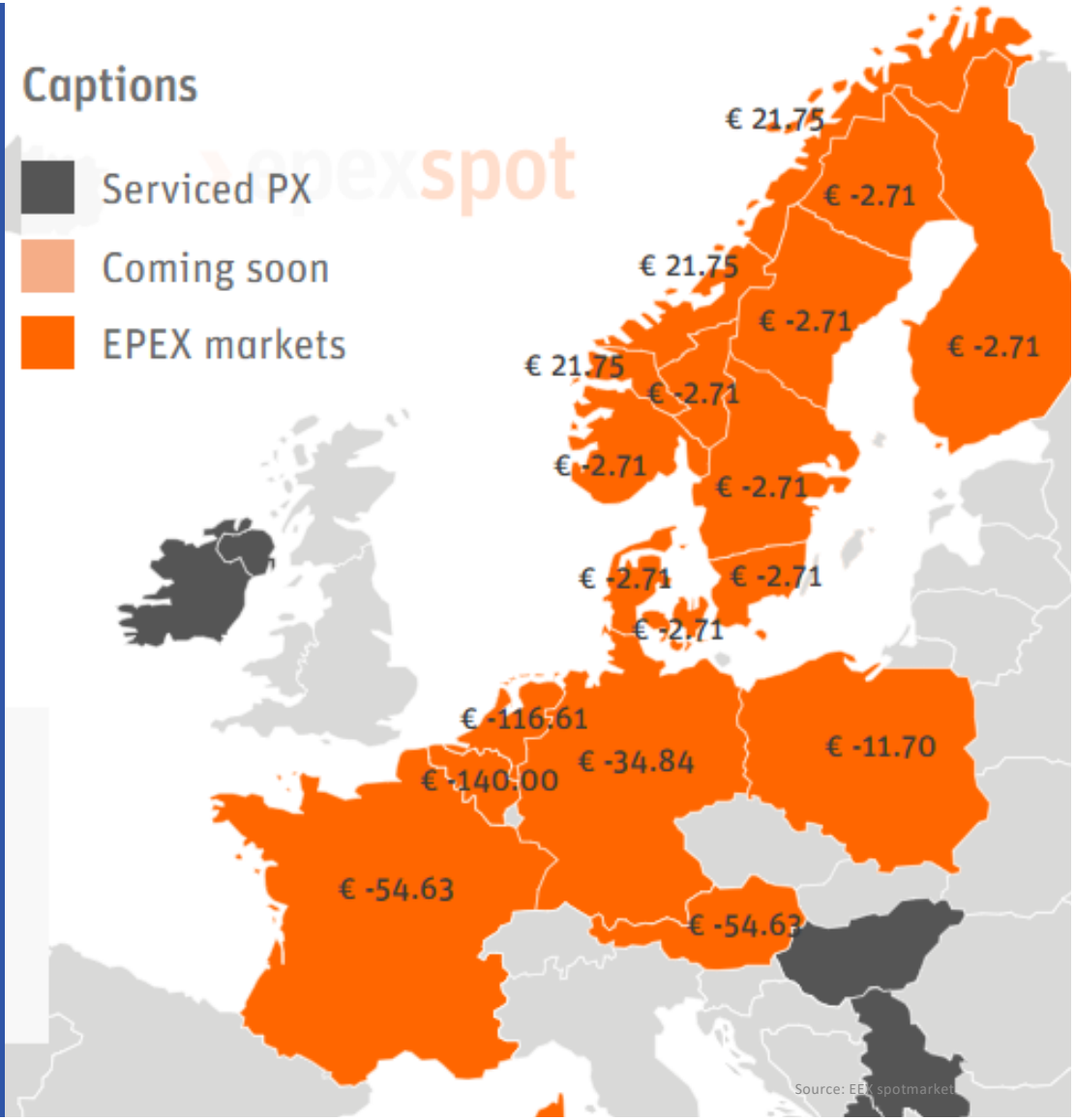
However, deep integration of variable renewables, particularly solar energy, into the power system presents challenges.

Source: BNEF, Q1 2024

Curtailment:
Introduction and Perspectives

PVPMC Workshop
August 22nd, Copenhagen, DNK

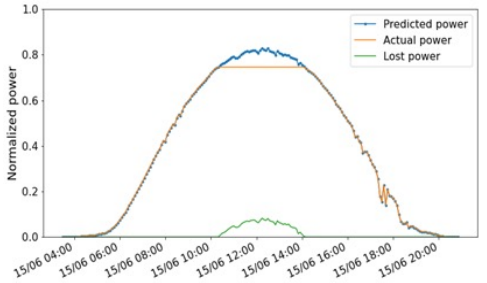
Jürgen Sutterlüti et. al.
j.sutterlueti@gantner-instruments.com

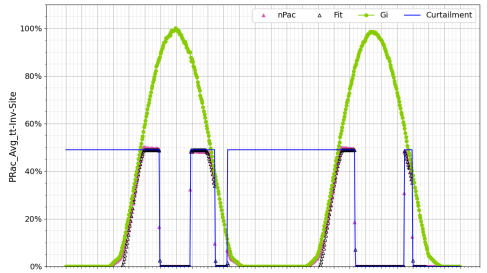


What is Curtailment?

Definition:

- Curtailment refers to the deliberate reduction or limitation of output from photovoltaic (PV) systems, typically at the request of grid operators.
- Occurs when the electricity supply exceeds demand or when the grid is unable to accommodate additional electricity due to technical or economic reasons.
- Key Causes:
  - Overgeneration: When PV output exceeds grid demand.
  - Grid Congestion: Transmission or distribution lines are unable to carry more power.
  - Market Conditions: Low electricity prices make it economically unviable to sell additional PV power.
- Who Initiates the Curtailment of Assets?
  - In most countries, the local **distribution system operators (DSO)** and the national **transmission system operators (TSO)** are responsible for initiating, executing, and sometimes remunerating the required curtailment measures.
  - Example: In 2020, the German grid operators paid 761 million Euros to compensate power producers for curtailed electricity generation.





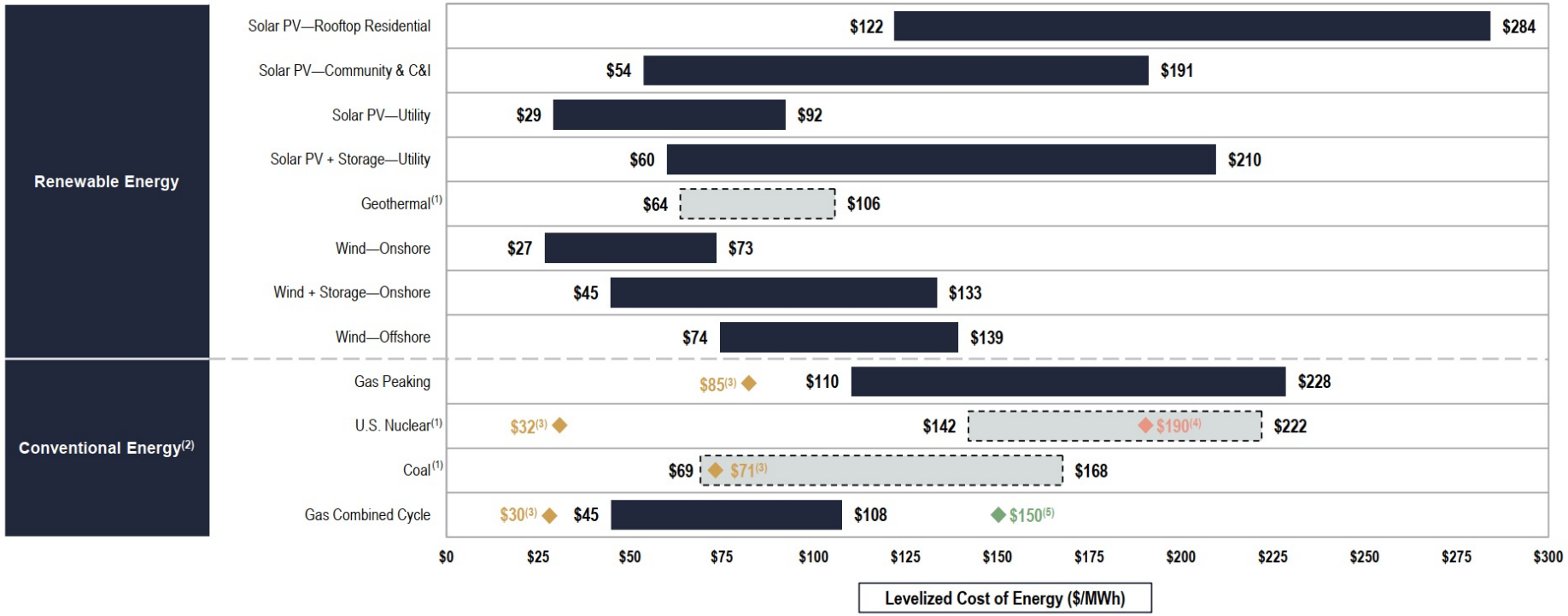
Source: BNA, GER link

Typical Patterns of PV Curtailment

- Temporal Patterns:
  - Midday Peaks: High curtailment typically occurs during midday when solar output is at its maximum, especially on sunny days.
  - Seasonal Variation: Higher curtailment rates in spring and early summer due to increased solar generation combined with lower electricity demand.
- Geographic Patterns:
  - Regional Curtailment: More common in regions with high solar penetration, such as California, Germany, and parts of China.
  - Remote Areas: Curtailment often occurs in remote areas where grid infrastructure may not be able to handle large amounts of PV generation.
- Frequency:
  - Curtailment events are more frequent during weekends and holidays when electricity demand is lower.

In most cases, the underlying cause for curtailment
is not the variability of renewable energy generation,
but rather the inability of current electricity grids to
transport the excess electricity from renewables to consumers.

Renewable Energy generation remains cost-competitive with conventional generation technologies under certain circumstances

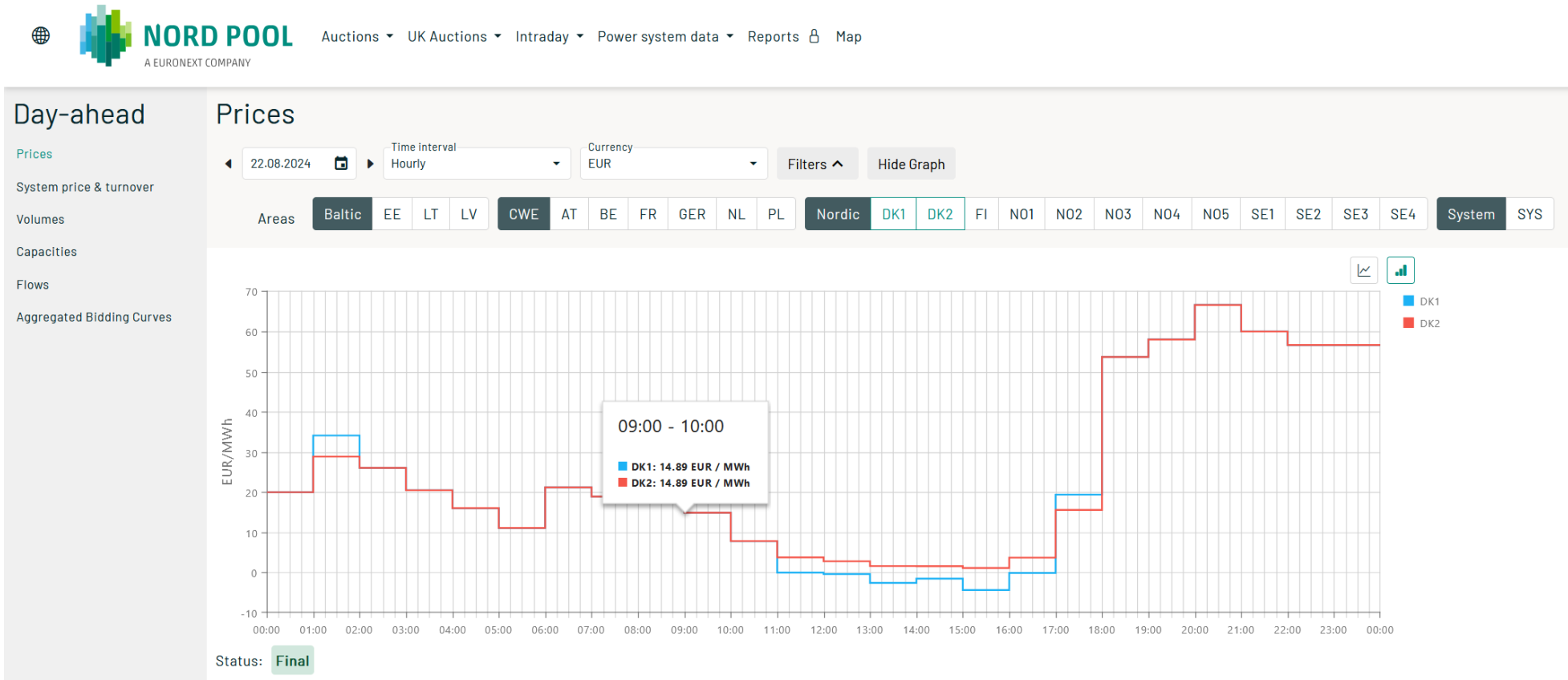


You can have a competitive LCoE but still a poor business case.

Source: Lazard LCoE Analysis, V17, Statement adapted from Adam Jensen, DTU

Observations from the Electricity Market

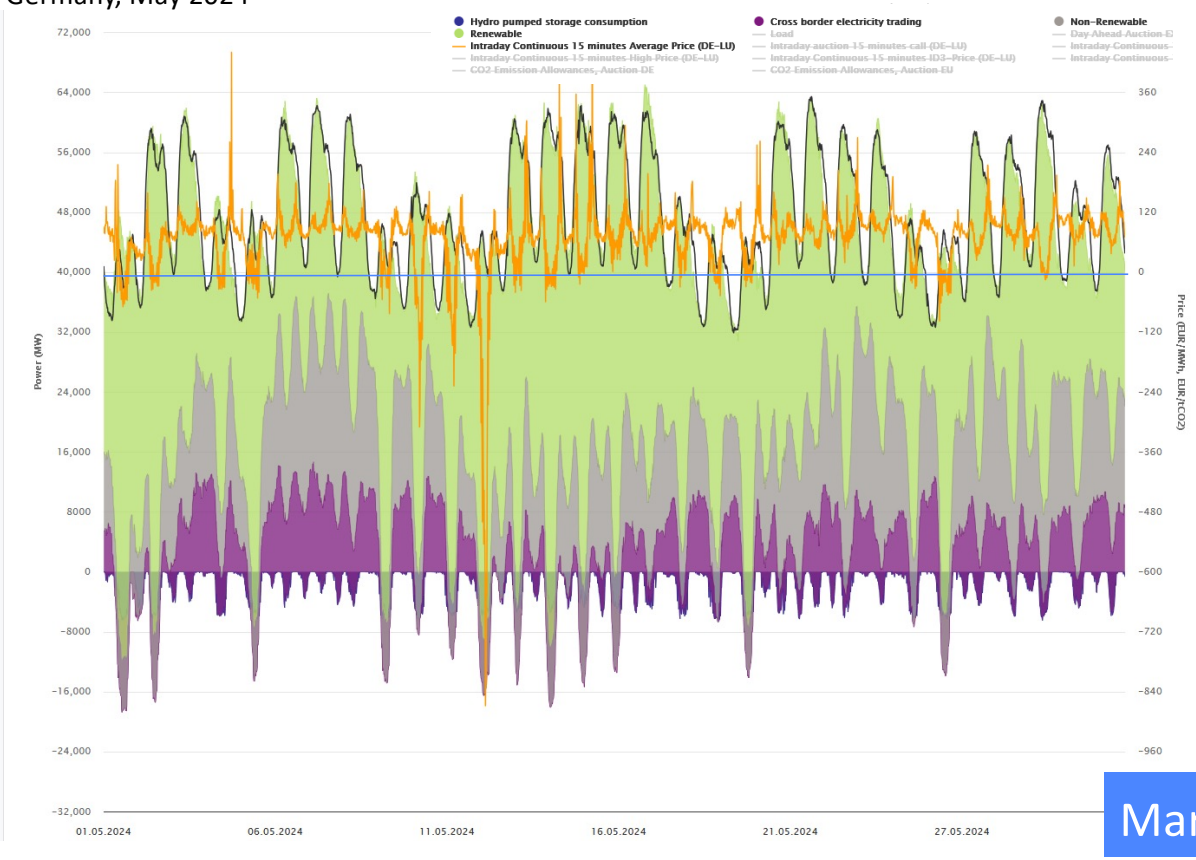
Day-ahead prices – Nord Pool, Zones: DK1 & DK2



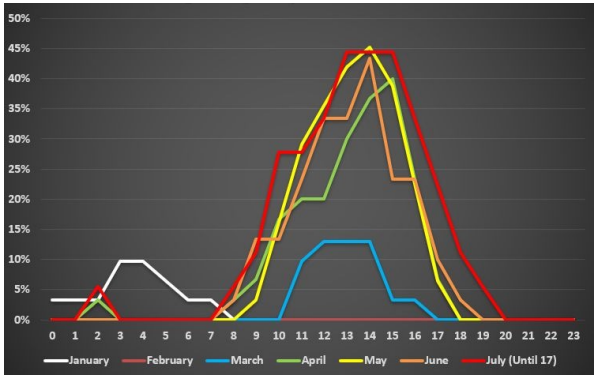
Source: Nordpool data, Link

Electricity production and spot prices

Germany, May 2024



Netherlands, 2024
Percentage of Negative prices

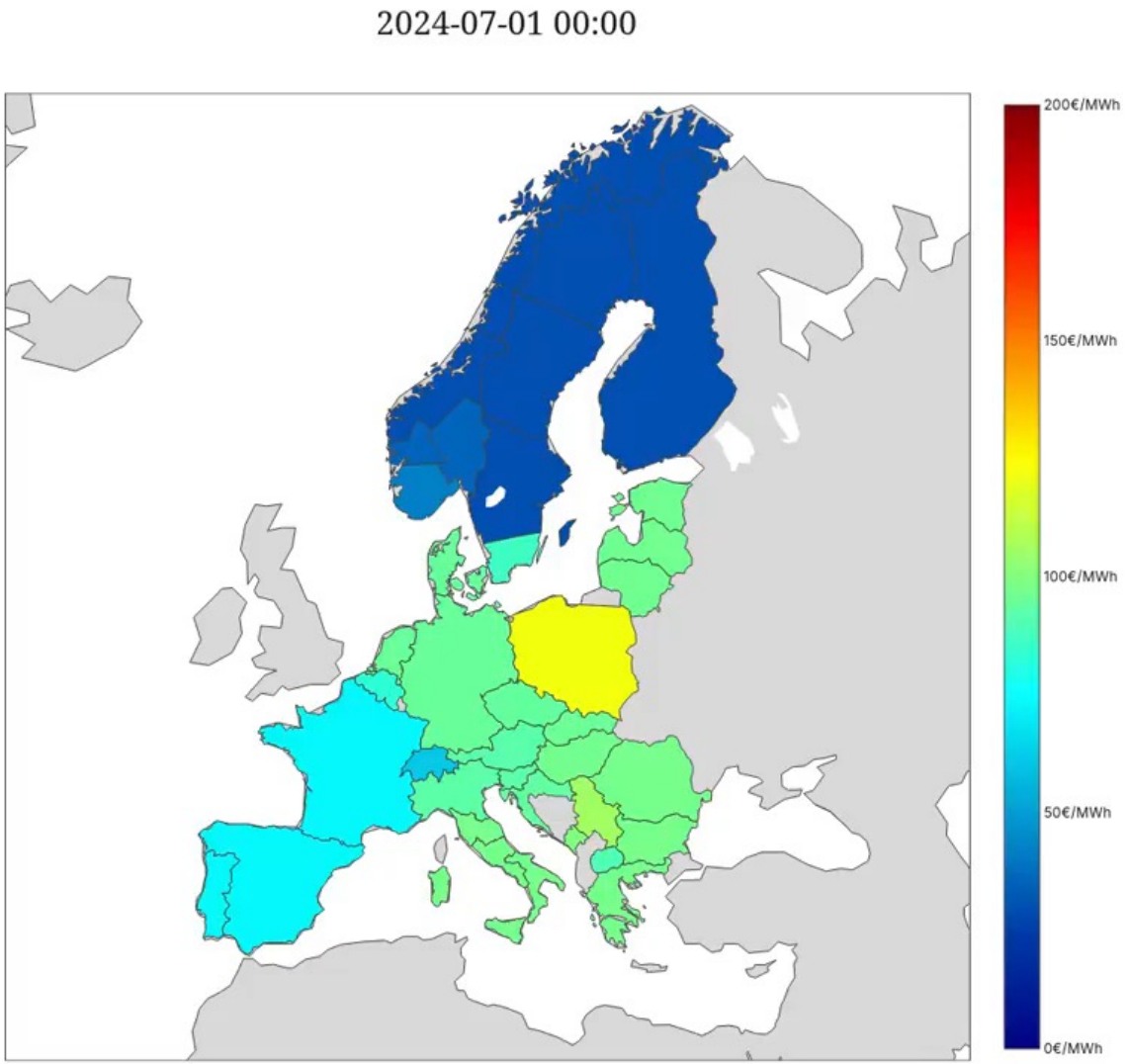


Market (spot) prices are volatile.

Source: Energy charts, accessed: Aug. 17th, 2024, link; Resolution: quarter-hour; GEM Energy Analytics, Julien Jomaux,

Europe electricity prices

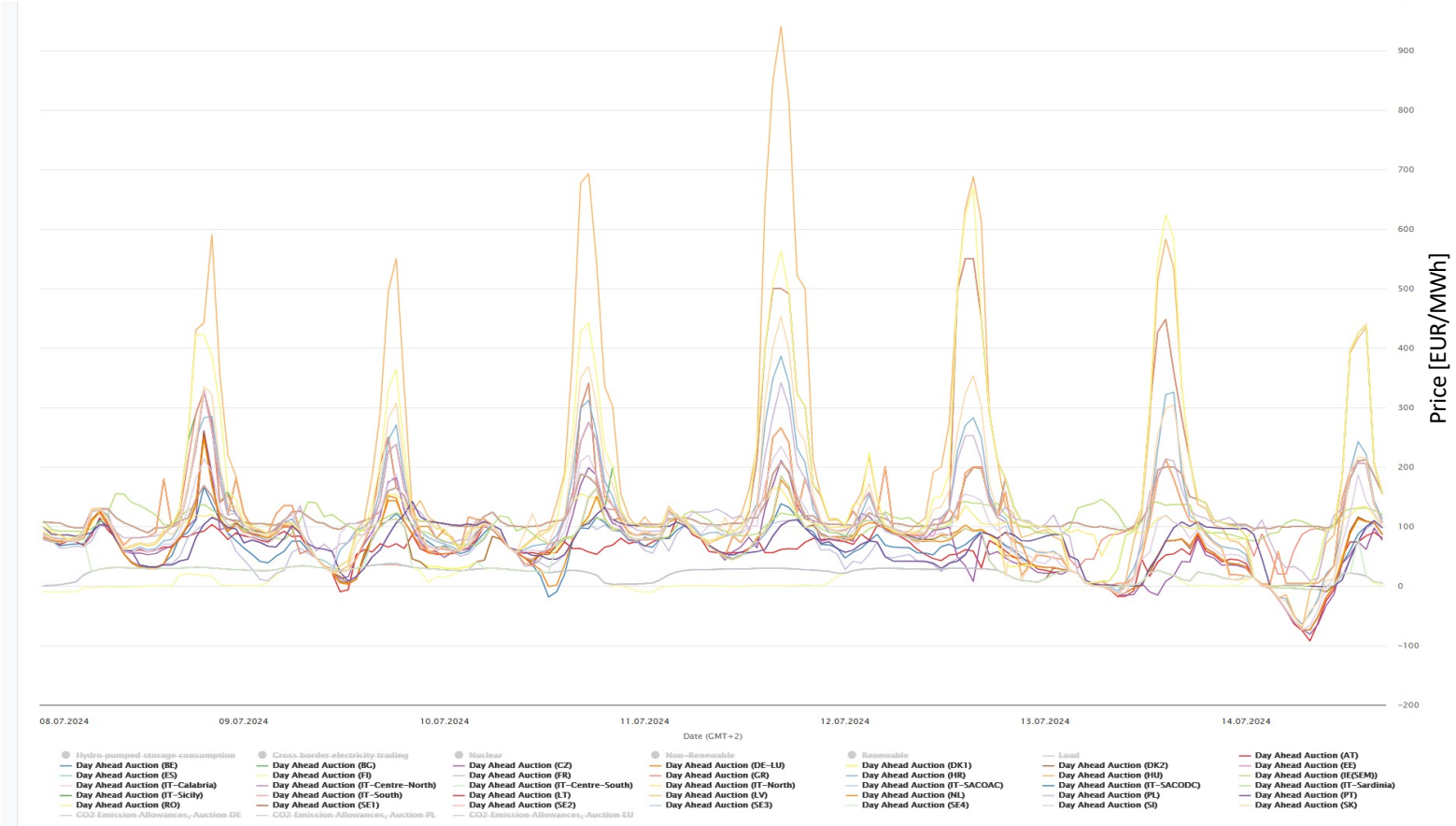
- Day ahead hourly spot price
- July 1st, till July 23rd, 2024
- Range capped at €200/MW



Source: intermittent.energy, Range capped at €200/MW

Spot prices EU, Week of 8th of July

7 days with very high prices in some EU countries during peak hours.



Reaching 500+ €/MWh, even getting close to 1000 €/MWh.

Source: Energy charts, EU accessed: Aug. 17th, 2024, link; Resolution: Hourly

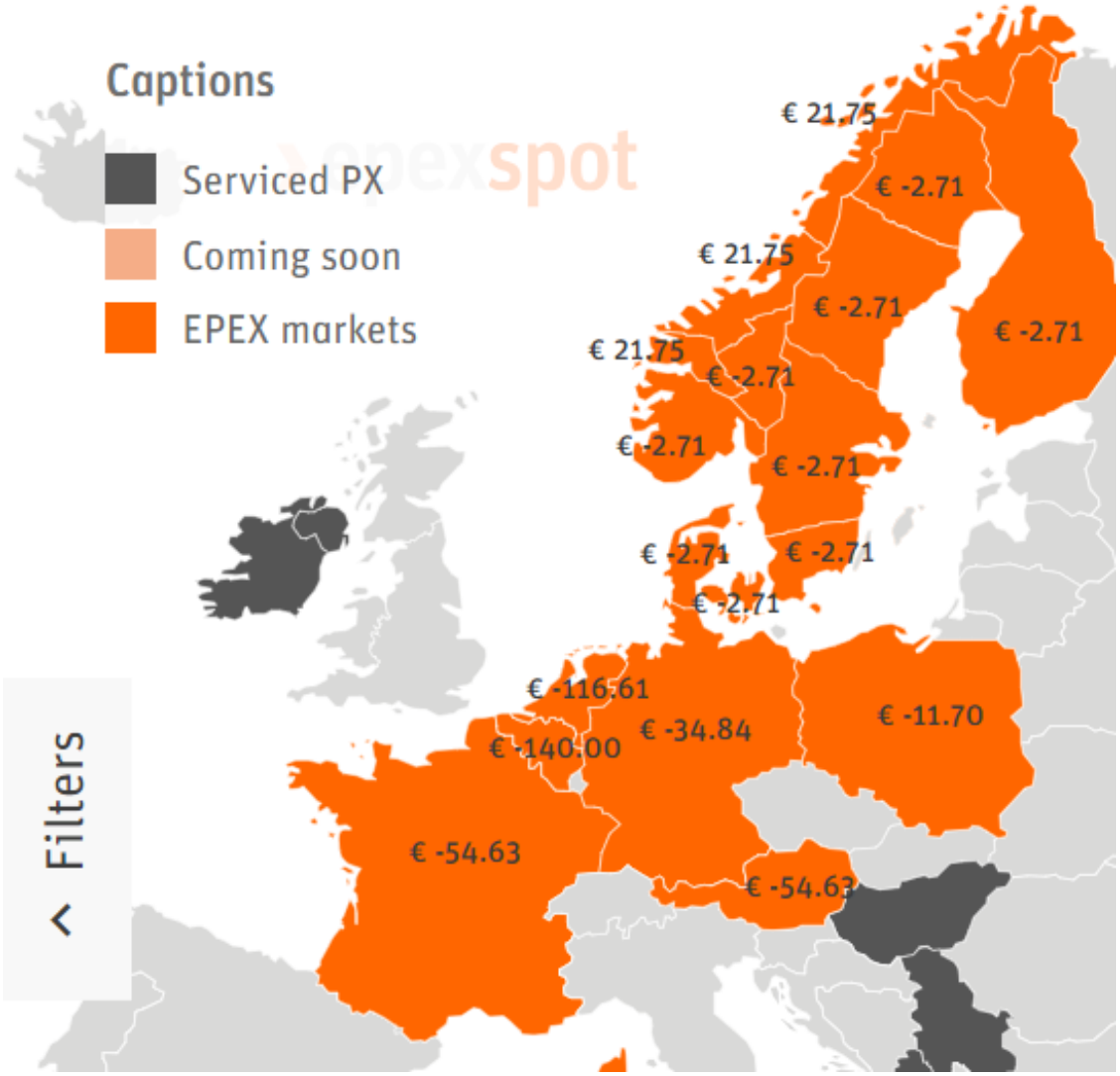
Fighting to export

Prices on 6 July at 3 PM

Reason for negative Prices:

- It is impossible to reduce generation or to switch off
- Revenues from subsidies and support schemes
- Contract with a fixed remuneration
- Revenues from ancillary services
- Expensive to switch off
- Electricity is not the sole output

Maximal production is different from maximal value.



Source: Adapted from GEM Energy Analytics, Julien Jomaux, link

European PPAs

- 2024 remains on course to be a record year for renewable power purchase agreements in Europe after buyers secured 30 TWh/year in the first six months of the year
- While demand for green power remains healthy from corporates and industry, falling power prices and sticky capital costs have challenged the supply side.
- Commodity Insights' models indicate an average gap of Eur20/MWh between developers' cost recovery needs and expected wholesale capture prices in Spain and Germany over the next 10 years.

European renewable PPAs set for another record year

Activity in Europe's power purchase agreement market remained high in H1 2024. Break-even estimates for 10-year PPAs eased due to lower capex and higher long-term capture price expectations, boosting merchant tail revenue projections, according to analysts at S&P Global Commodity Insights.

PPA market snapshot (H1 2024)
S&P Global Commodity Insights PPA database

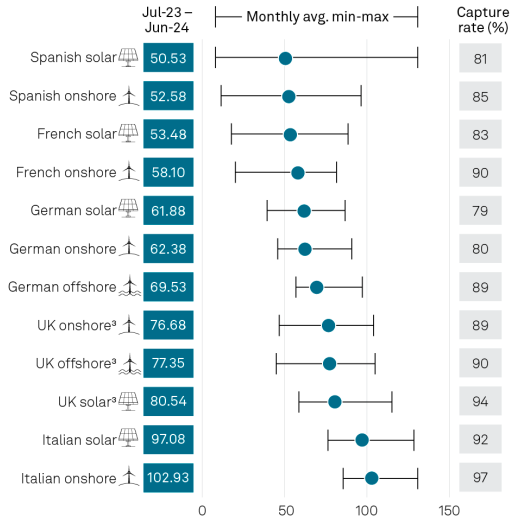
Deals	Power	Solar	Onshore	Offshore
221	30.2 TWh/yr	6.7 GW	2.8 GW	2.2 GW

Break-even estimates for 10-year PPAs by S&P Global Commodity Insights
Average forecast price (Eur/MWh)[1]
40 60 80 100 120

	Spain	Germany	UK	Sweden	Neth.	France	Norway	Finland	Italy	Poland
Solar	40	59	89	118	89	67	113	118	43	74
Onshore wind	71	86	83	71	78	92	67	80	88	71

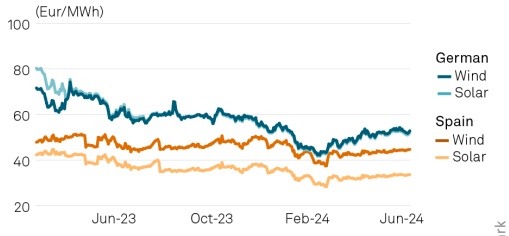
1) Pay as produced standard PPA 2026-2035 to recover new build, operating and financing costs. Merchant tail revenue assumptions based on Commodity Insights capture price, GO price forecasts 2036-2045. Ranked by PPA capacity volumes since 2018.

Platts Renewable Capture Prices across Europe²
(12-month rolling average, volume-weighted in Eur/MWh)

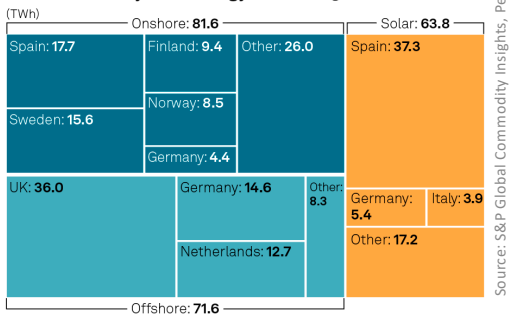


2) Expresses capture price as % of wholesale market price
3) Converted from GBP/MWh

Platts Pexapark Indices for 10-Year PPA (pay as produced)



PPA volumes by technology, market (grand total)

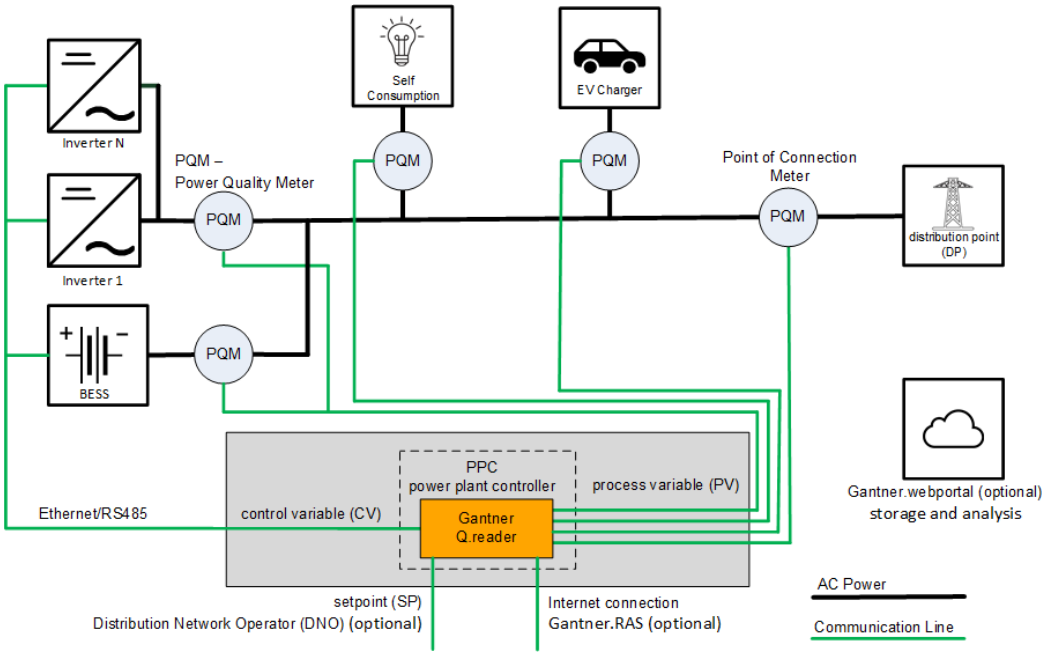


Source: S&P Global Commodity Insights, Pexapark

Key Element
PV and BESS Plant Controller

Typical Control features:

- Multi feeder, distribution point support
- Absolute production, power gradient constraint
- Voltage, Reactive power, power factor control
- Frequency control (Feed-in, consumption)
- Data logging
- Browser-based HMI
- Remote configuration, access
- VDE-AR-N 4110, 4120, 4130, IEC 61724-1, IEC 60870
- 1Hz / 1min response

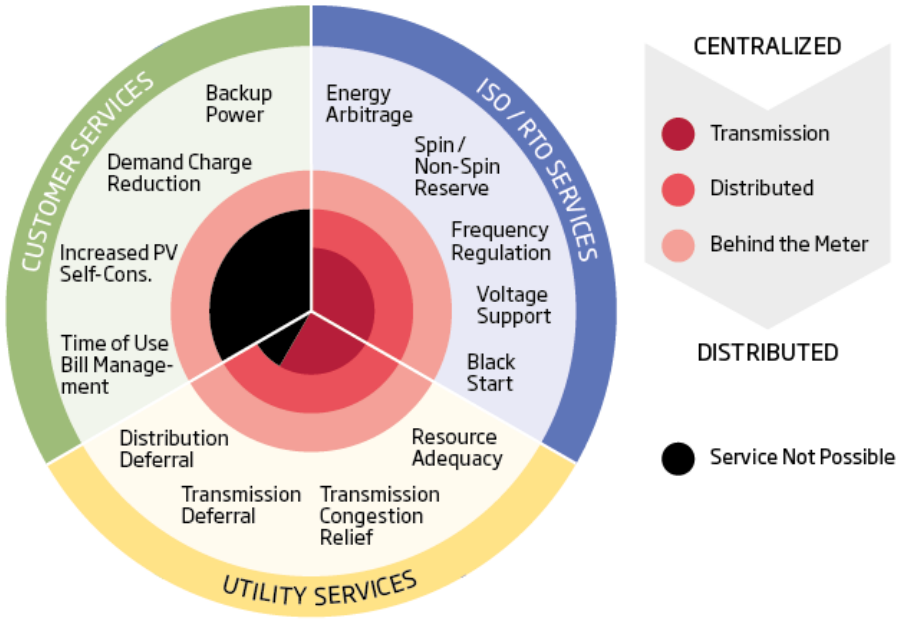


TECHNOLOGY ISN'T INTERESTING UNTIL ITS TECHNOLOGICALLY BORING

The Way Out - Strategies to Mitigate Curtailment

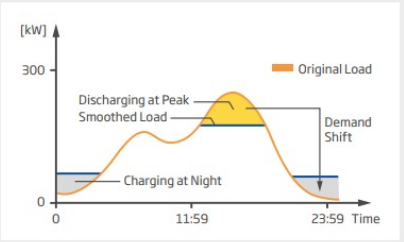
- Grid Modernization:
  - Enhanced Transmission Capacity: Upgrading grid infrastructure to handle higher volumes of PV electricity.
  - Advanced Grid Management: Utilizing smart grid technologies to balance supply and demand better.
- Energy Storage Solutions:
  - On-Site Storage to Avoid Loss of Energy
  - Battery Storage: Storing excess PV generation for use during non-peak solar periods.
  - Pumped Hydro and Other Storage: Leveraging alternative storage technologies to balance grid supply.
- Flexible Demand Management:
  - Demand Response Programs: Encouraging consumers to shift their energy use to times of high PV generation.
  - Dynamic Pricing: Implementing time-of-use rates to incentivize electricity consumption during high-generation periods.
- Sector Coupling:
  - Electrification of Heating and Transport: Using excess PV electricity for electric vehicles and heat pumps to absorb surplus generation.
  - Green Hydrogen Production: Converting surplus electricity into hydrogen for use in industry, transport, and heating.

Batteries can provide up to 13 services to three stakeholder groups



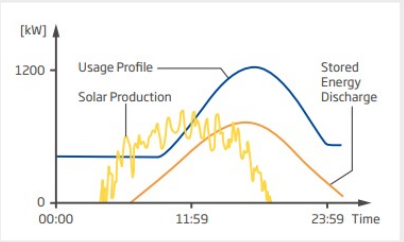
Peak-shaving and Demand

Manage stored power during different load periods and provide it during periods of high demand. This improves economics for peak load times and shift power to lower tariff times.



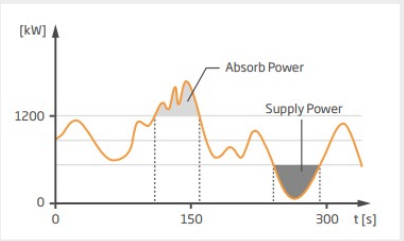
Renewable Integration, Solar/Wind Time Shifting

Smoothing the output and controls ramp rate of renewable sources like wind and solar power for a more stable power curve. Allows also time shifting to the user power profile.



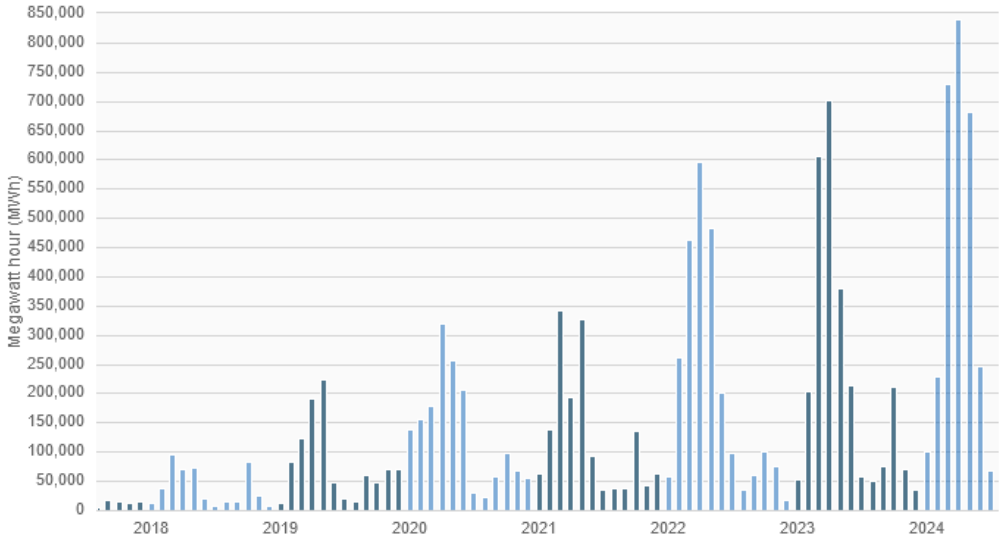
Frequency Regulation

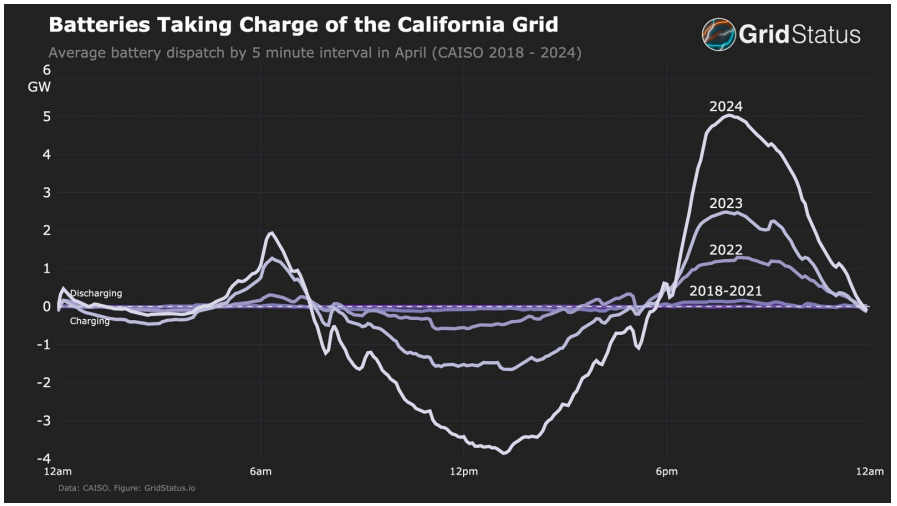
Absorbing and injection of power can be controled to keep grid frequency with dedicated limits.



Source: Gantner Instruments, RMI

Wind and solar curtailment, California





A business case for Batteries …

Source: CAISO, Updates as of 8/6/2024, Link: Grid Status link

Possible Services

Price Signals for Consumers

There are **several ways** to design a price signal for consumers. This includes, for example:

- Static or Dynamic Time-of-Use Tariffs (ToU)
- Self-consumption
- Flexibility Markets
- Flexibility Grid Connections

Source: LetsFlex, Solar Power Europe

Challenges for the PV community – Some thoughts

- PV System designs for less Curtailment constraints
- Ramp rates: more accurate prediction of the weather and production
- Model PV and Storage in combination

- Will Power at STC remain an important value?

- Curtailment Impact on Return of Investment in PV+Storage Projects:
  - Reduced Revenue, Underutilization of Assets
  - Increased Financial Uncertainty
- Consider Price trends and its uncertainty in the business model

WILL CURTAILMENT REMAIN THE LAST OPTION BECAUSE IT'S THE MOST POWERFUL?