ENERGY

Flexibility, Not Capacity, Will Decide Renewable Energy's Future

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Renewable energy has succeeded in overcoming its cost challenges, but systemic flexibility will be critical to its value in the future. Across the globe, countries have stepped up efforts to decarbonize energy production in recent times. Companies have set up wind and solar farms, which are relatively inexpensive and quick to build. By the end of 2025, renewable energy had become the world's main source of electricity.

However, renewable energy has become so abundant that it is cannibalizing its own value. Large amounts of renewably-generated electricity enter power grids at the same time, depressing prices when demand is low and reducing producer revenues when their output is highest. These spikes have triggered unprecedented volatility in wholesale electricity prices. Consequently, despite the sector's past success and future importance, there is an increasing risk that investments in renewable energy could dry up if the issue is not addressed.

Green subsidies and price guarantees address the problem's symptoms rather than the causes, leaving the mismatch between electricity supply and demand unresolved. Ensuring system-wide flexibility has become critical to tackling the problem. As we show in this article, market-based flexibility solutions change how and when electricity is consumed, stored, and moved, which will help renewable energy to regain its value.

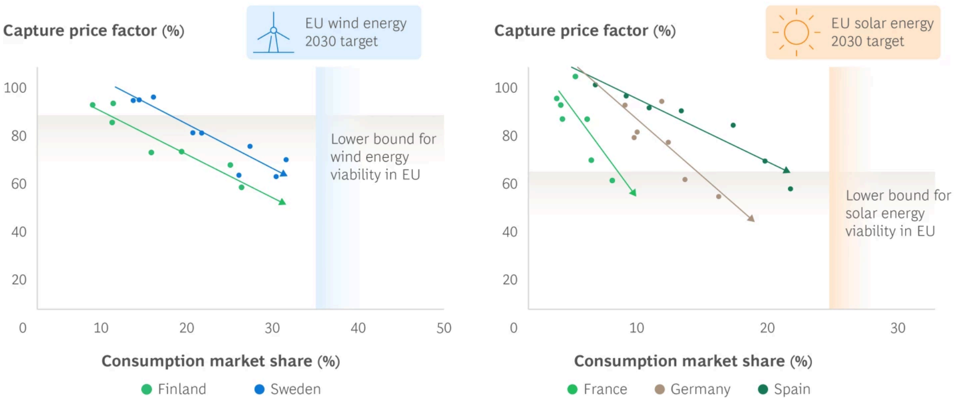
The Rise in Renewables Results in Market Value Cannibalization

Renewable energy faces a novel challenge today. Once it accounts for a large share of a country's electricity output, its market value often falls below renewable energy producers' breakeven costs, threatening their financial viability. (See Exhibit 1.) This situation also occurs in areas that generate a great deal of wind or solar power but do not use much electricity locally, especially in markets where prices are set at specific grid nodes.

EXHIBIT 1

Renewable energy's value in Europe has fallen below its investment cost as market penetration has risen

Restoring value will be critical to reduce reliance on subsidies and attract investments to the sector in the future.



Sources: ENTSO-E; EurObserv'ER; BCG analysis.
Notes: Capture price and market share data are for the period January 2019 to November 2025. Capture price = annual volume-weighted average wholesale price based on hourly prices and generation profiles. Market share = wind or solar generation share of total annual consumption in a market (not necessarily equivalent to the country total). Viability thresholds are calculated based on the ratio between average wholesale prices in 2024 and 2025 and minimum levelized cost of electricity (LCOE) by EurObserv'ER (2024) in core EU markets. Wind energy and solar energy target ranges for 2030 are as per ENTSO-E 10-year network development plan.

Studies show that wind energy value factors in the worst-hit European markets have fallen to between 0.55 and 0.65, meaning that wind power producers earn only 55% to 60% of the average annual prices in the power market. Solar power value factors have fallen to between 0.45 and 0.65. Meanwhile, negative price hours in some European countries have more than doubled from around 200 hours in 2020 to over 500 hours in 2025, mostly when renewables were generating power. The net result: In the European Union, value cannibalization, measured by the difference between the annual average wholesale price and the capture price, reduced producer revenues by over $14 billion in 2025.

This erosion in value is caused by several factors. Wind and solar farms, which are weather-dependent, usually produce electricity at the same time as other renewable energy producers in the same region. When the supply of renewable power is high but demand is low, market prices fall as do the renewable energy producers' realized revenues.

Distributed generation further complicates the issue. Customers with rooftop solar panels may not only cover their own needs during the day, they can also feed the excess power to the grid, reducing the demand for utility-scale generation. Monetary incentives for distributed generation, such as feed-in-tariffs and net metering, can further exacerbate the financial challenge for utilities.

Even when there is demand, a grid must be able to physically move electricity from where it is generated to where it is needed. However, bottlenecks reduce renewable energy's value in areas of oversupply. This forces renewable energy suppliers to curtail production. But when curtailment isn't an option, energy prices can become negative. That is, suppliers have to pay customers to buy their electricity.

The impact of lower prices and curtailed production has hit the renewable energy industry hard. Producers are seeing their revenues fall; new players are being forced to accept lower contract prices; and guaranteed offtake at fixed prices is becoming unlikely as subsidy budgets balloon. Fixed-price power purchase agreements shield producers from falling returns, but new ones are being signed at discounts and the offtakers of existing agreements carry the cost of value erosion on their balance sheets. Even in the US, where this situation has not affected the industry yet, renewable energy's eroding value has started posing the same risk.

These factors have triggered a vicious circle: The faster a country wishes to build a decarbonized power sector, the higher is the risk of value decline—and the less financially attractive it is to make fresh investments in renewable energy.

Tackling the Value Trap with Systemic Flexibility

Flexibility in managing when and where electricity is consumed, stored, and moved is emerging as the optimum way of bridging the gap between supply and demand in a renewables-dominated power system. Doing so strengthens affordability, reliability, and sustainability of electricity supply at the same time, making it a solution that advances all dimensions of the energy trilemma rather than trading them off against one another.

Systemic flexibility is needed across every timeframe, from seconds to seasons, but data shows that tackling daily and weekly volatility will have the most impact and is also the most challenging issue to solve. (See Exhibit 2.)

EXHIBIT 2

Systemic flexibility has become critical as renewable energy's share continues to rise

In Finland, wind energy's 60% penetration requires the grid to adjust by 30% of average demand over a week

Sources: ENTSO-E; Fingrid; BCG analysis.
Notes: Based on data from Finland on hourly demand and wind power capacity factor data between January 2019 and December 2025. (P#) = percentile of flexibility need. Flexibility need = the difference in residual load between consecutive time intervals such as hours, days, weeks, months, and winter/summer periods. Variation = the standard deviation of residual load fluctuation and high/low and extreme cases as 90% and 1% probabilities of the fluctuation.

In the shortest timeframe of seconds and minutes, system operators can ensure efficiency by carefully integrating flexible energy sources into grids. New hardware—such as grid-forming inverters, batteries, flexible reserve supply capacities, smart consumption management tools such as dynamic pricing, and flexibility arrangements—will be needed. This must be combined with better forecasting and analytics as well as the adaptation of new customer tariffs and market rules to ensure flexibility.

For short cycles of a day, batteries as well as virtual power plant (VPP) solutions, which combine distributed supply, demand, and storage, will dominate. Batteries have proven to be efficient in balancing the daily cycle in California's power markets, for instance, where they meet much of the demand after sunset. Similarly, in South Australia, where rooftop solar panels supply roughly half of all homes, excess midday generation recently pushed transmission-level demand below zero. The Australian Energy Market Operator directed AGL Energy's Torrens Island battery to discharge and then remain at a minimum state-of-charge, so it could instantly absorb surplus solar power if required. This clearly demonstrates how grid-scale batteries can stabilize intraday imbalances as renewable energy penetration deepens.

Using batteries to store electricity can increase demand when prices are low, thereby increasing renewables' value. In several countries, the economics for battery trading support arbitrage-based models that shift consumption from high-price hours to low-price periods.

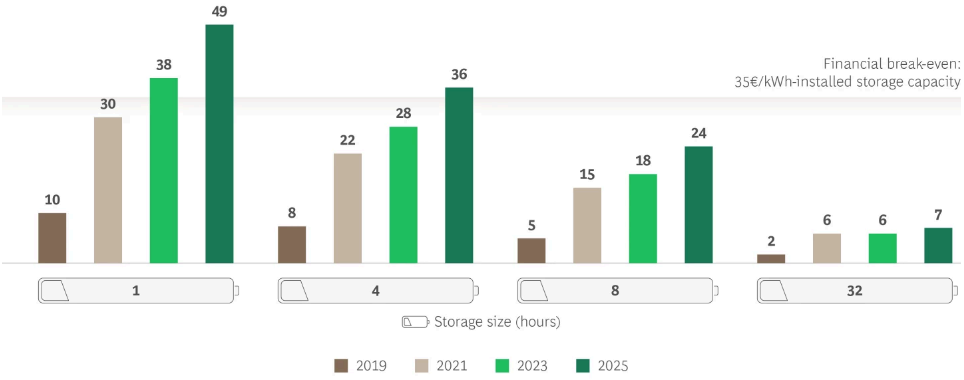
In countries where customers are exposed to volatile energy prices, VPP solutions will mushroom. These solutions, which pool distributed resources, offer a business opportunity for incumbent utilities too, with BCG recently estimating the potential market for VPP solutions at over $58 billion in 2026.

For medium timeframe flexibility, from a day to one or two weeks, no scalable solutions exist other than pumped hydro where it is available. Current storage technologies are too expensive or limited to provide prolonged flexibility at scale, and price spreads are not yet wide or persistent enough to justify investments. (See Exhibit 3.)

EXHIBIT 3

Battery storage can offset short-run variations in renewable energy, but currently is financially feasible only for periods of up to four hours

Net profit from day-ahead market arbitrage in Germany (2018–2025)[1]
(€/kWh-installed storage capacity)



Source: BCG analysis.
Notes: Net profit reflects only energy arbitrage assuming perfect foresight, 90% round-trip efficiency, and €1/MWh degradation cost. Other battery energy storage system revenue streams have been excluded.
[1]Assumes investment cost of €200/kWh, annualized with 8% weighted average cost of capital over a 10-year lifetime.

However, BCG analysis shows that weekly volatility will increase significantly as the share of renewables in electricity generation rises. Consequently, business models and technologies that can provide weekly flexibility will increasingly become more valuable. These solutions will combine many approaches, such as shifting industrial consumers' demand, power-to-heat techniques, and, eventually, hydrogen or synthetic fuel pathways. This will require market designs that reward duration and capacity, rather than short-term responsiveness, by providing the right price signals.

The week-to-a-month timeframe presents another challenge during the dark doldrums (*Dunkelflaute* in German), when there is little wind and sunlight during high-demand periods. Conventional generation must be used, leading to high prices and high emissions. Reducing industrial demand and providing more flexible bidding options is also necessary to tackle the issue. Conversely, in periods of low demand and plenty of wind or sun, renewable energy's value tumbles, making it necessary to boost demand by large volumes to absorb the excess supply.

At the seasonal level, supply and demand imbalances affect renewables to a smaller extent. Winds are stronger in winter, matching the high demand for heating in countries in high latitudes during the cold season. Similarly, the high solar energy output during summer months can cater to the spike in air-conditioning needs in warmer regions. However, annual variations in output have system-level consequences because there can be a 10% difference in output between high- and low-wind years.

Yet relying on weather conditions can be risky. If renewable energy supply grows faster than demand—as has occurred with wind in Finland and solar in Spain—it's bound to lose value. The main reason is that storing renewable power for long periods isn't feasible. Currently, grid operators deal with seasonal output swings by giving fossil fuel plants a capacity payment for being available whenever needed, raising electricity prices but not renewables' revenues.

How Finland Is Building Flexibility

In Finland, where wind energy accounted for around 27% of electricity generation in 2025, there has been an unprecedented increase in price volatility in a previously predictable wholesale market. Wind energy producers, which depend on market prices, have experienced fluctuating revenues and declining returns.

Finland's response has been to ensure flexibility. To manage short-run flexibility, many players have invested in improved forecasting, automation, and market integration tools. The power system operator has created new ancillary service markets to incentivize the creation of reserve capacities that can help with system balancing. Battery energy storage systems (BESS) have emerged as a critical tool, while hydroelectric and nuclear power are also playing a role in load balancing across different time horizons.

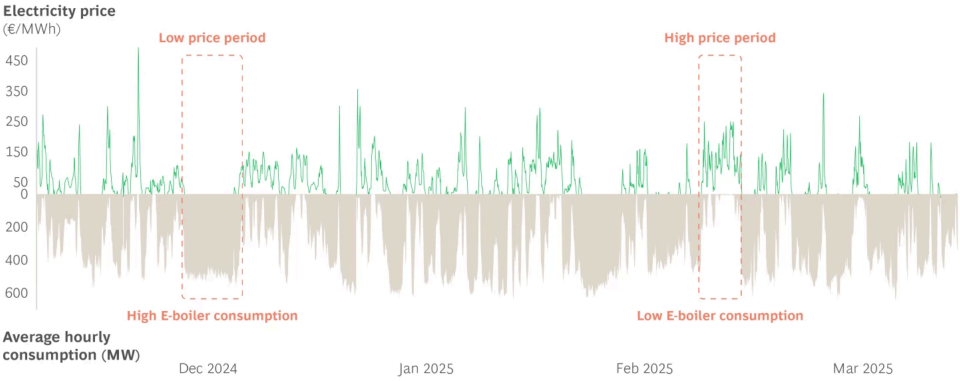
Another key response has been to install electric boilers (E-boilers) for heat production. By the end of 2025, almost 3,000 MW of E-boiler capacity—25% of the system's peak load—had come on line. The boilers are connected to city-wide district heating systems and provide heat generation and storage as well as industrial steam generation.

Adding E-boilers is light on balance sheets, but offers grids much-needed flexibility, and data shows they are financially viable. When prices are low on windy days, the E-boilers' power usage peaks. During high-price periods, the boilers are switched off even as legacy gas and biomass boilers take over. (See Exhibit 4.)

EXHIBIT 4

Finland has integrated electric boilers into district heating systems, turning heat production into a flexible electricity load

E-boiler demand rises with low electricity prices and high renewable energy generation, and falls with high prices and low generation, creating system flexibility



Sources: Fingrid, BCG analysis.
Note: E-boiler electricity consumption is an hourly average based on minute-level data.

Finland's E-boiler additions are driven by the market. For heat producers, adding an E-boiler to a natural gas-based system provides risk hedging between volatile electricity prices and stable biomass prices. While the business case currently enables around 50% heat electrification, going beyond that will become possible with heat storage. Integrating the power and heating markets will provide Finland the ability to absorb excess power and restore renewable energy's value.

Ensuring a Future for Renewable Energy Globally

Every country that has invested in renewable energy must focus on creating system-wide flexibility in the future. That will require changes in how power markets are designed, how electricity networks are planned, how storage and demand players participate, and how policy frameworks allocate risks and rewards. Leaders can adopt one or more of these measures.

Plan renewable and battery investments to maximize system value, not volume.

Until now, most renewable energy investments have been driven by capacity targets, subsidies, and project-level economics rather than system value. Planning for system value means timing, locating, sizing, and designing generation assets to reflect their contribution to the system's needs. This can be done by taking into account factors such as the future demand volume and profile, existing generation facilities, and predicted grid congestion levels.

Value maximization entails prioritizing projects that reduce system balancing costs even if their standalone levelized costs may not be the lowest. It can be achieved by locating smaller wind farms close to demand and positioning solar panels so they generate more power during the evening demand peaks. The process requires integrating power system modeling, locational price signals, and grid investment plans into licensing decisions rather than treating transmission and load balancing problems when they arise.

Investments in battery energy storage systems also should be guided by system economics rather than capacity targets. Grid-scale batteries create the greatest value when located at constrained nodes, sized to match prevailing intraday imbalance patterns, and operated so they reduce curtailment, price volatility, and balancing costs. As renewable penetration rises, BESS will be essential to maintaining grid stability, so it is best to plan the deployment as a core component of the grid flexibility toolkit.

Actively manage renewable assets, curtailing output when necessary.

Curtailment is usually framed as a waste rather than as a rational decision. However, in grids with a high percentage of generation of renewable power, the ability to curtail output when the value is low can reduce balancing costs, preserve reliability, expand renewable penetration, and prevent grid stability issues. It requires closer integration between generation, storage, and grid operators so that curtailment decisions can be optimized at the system level.

Curtailment is one aspect of the process of actively managing assets and treating them as resources whose output and availability can be adjusted in response to system conditions. It needs real-time telemetry, automated dispatch systems, and contractual frameworks that will allow grid operators to respond to price and system signals without incurring financial penalties. As forecasting, bidding, and scheduling improve, system operators can deploy curtailment more strategically, reducing imbalance costs and stabilizing the grid. That operational discipline will give renewable energy producers clearer signals and greater predictability, enabling them to curtail economically and reduce exposure to negative pricing.

Catalyze demand-side flexibility.

Unlocking demand-side flexibility requires digital infrastructure, dynamic pricing, aggregation platforms, and the regulatory acceptance of demand as a system resource. Many industrial users, commercial buildings, data centers, electric vehicles, and heating systems possess inherent load flexibility, allowing them to shift consumption across hours. By responding to real-time price signals or grid conditions, ramping up when renewable supply is abundant and scaling back when it tightens, they effectively convert demand into a balancing resource. Coordinated at scale, these flexible loads can absorb excess renewable generation, reduce curtailment and imbalance costs, and stabilize prices across the system.

The trick lies in enabling consumption to respond to price signals in near-real time while aggregators bundle flexible loads into market resources. Regulatory clarity around data access, performance verification, and compensation will be essential to create systemic capacity. The binding constraints aren't technical; they are coordination, incentives, and trust.

Create rules that incentivize flexibility.

Flexibility won't emerge automatically; it's a function of market design. Many countries possess flexible technologies but fail to use them because markets have been designed for inflexible, central thermal generation. Shifting to flexibility involves redesigning the wholesale, balancing, and ancillary service markets so that quick responses, locational availability, and flexibility durations are properly priced into the equation.

Flexibility also requires the lowering of entry barriers, so that storage, demand response, and hybrid assets can compete on an equal footing with traditional generators. It demands scarcity pricing and open access for non-traditional actors such as aggregators and consumers. Similarly, retail markets and distribution grids must be reformed. Managing grid constraints in systems where a large percentage of customers have become electricity producers demands new skills, licenses, and remuneration schemes for grid operators as well as redesigned retail tariffs for customers.

Build for flexibility.

This pertains to the ability to manage power variability across seconds, hours, days, weeks, seasons, and extreme events. It includes the optimal use of conventional generation capacities, grid and market interconnections, a mix of short- and long-duration storage systems, and institutional arrangements that preserve options under uncertainty.

Long-term flexibility is often discounted in energy market frameworks because its value is probabilistic and system-wide rather than commercial and project-specific. The result is over-investment in short-term solutions and persistent exposure to weekly and seasonal mismatches. Delivering system-wide flexibility requires a shift from optimizing for expected conditions to building resilience and options. In practical terms, this means valuing assets and policies that may be used infrequently but are critical during extreme events, such as prolonged low-wind or no-sun periods. Thus, planning frameworks must incorporate tail risks, climate variability, and strategic reserves into investment decisions.

Embrace volatility.

The new world of electricity is by its very nature volatile. Creating flexibility will be a lucrative business opportunity for electricity producers, consumers, and storage operators. It requires a new mindset and fresh capabilities, but technologies are available and renewable energy producers are keen to fight cannibalization. The goal isn't to eliminate volatility, but to industrialize the response because that's how reliability and returns can be achieved in a high renewable energy system.

The era of treating renewable energy projects as standalone infrastructure is over. Wind and solar power projects are commercial investments whose returns depend on the realities of the power system, such as the prices producers can earn and whether power grids can deliver output when needed. Renewable power capacity must therefore be planned and financed as part of an integrated power market and energy system that incentivizes more flexible resources. Expanding and modernizing power grids are imperatives, as is designing markets that reward value—not volume. Tomorrow's energy transition winners won't be countries that add the most amount of renewable energy, but those that extract the most benefit from the renewables they do produce.

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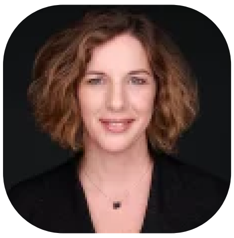

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