BloombergNEF | PYLONTECH

Scaling the Residential Energy Storage Market

November, 2023

Contents

Section 1. Executive summary

93GW/ 196GWh

Cumulative residential energy storage capacity in 2030

78%

New home solar systems that have batteries attached in Germany

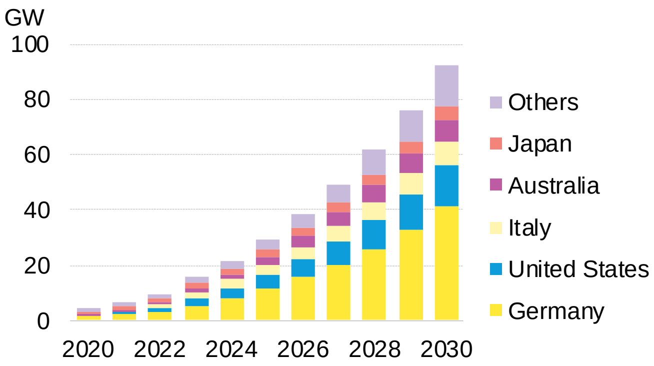
6.2x

Cumulative residential energy storage market size in 2030

The residential battery storage market is rapidly growing, and many governments subsidize consumer adoption of batteries to accelerate the smooth integration of large amounts of solar into power grids. However, there are several questions remaining about choice of products, the structure of the industry which will deliver the storage capacity, and the policies and business models which will allow residential battery owners to capture part of the value of the grid flexibility they provide. This report examines the state of the industry at the end of 2023.

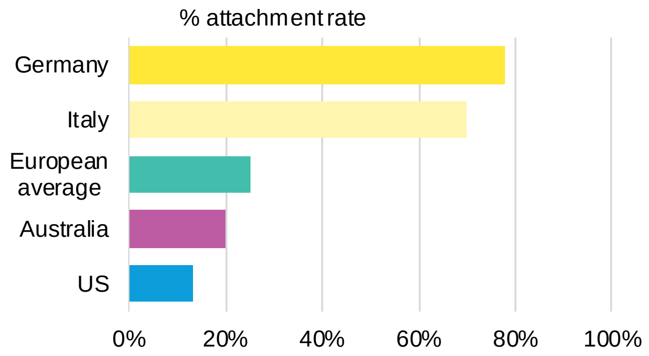
- **Battery storage** is an important enabler of the energy transition, and residential batteries are a major part of that (Figure 1). Already in Germany and Italy, over 70% of new home solar systems have batteries attached, to shift the use of daytime solar power generated to the evening (Figure 2). Encouraging customer uptake will also help smoothen major fluctuations in electricity demand between day and night, as well as support local grids that are becoming congested.
- **Customers** have different, but often overlapping, concerns about product selection, depending on whether they are primarily driven by resilience concerns, a desire to increase solar self-consumption, or to reduce their bills. Across the board, they are mostly concerned with ensuring that the battery capacity is appropriate and having the ability to accurately track how the system operates.
- **Installers** typically have different concerns. For installers, reputation and continued recommendations are crucial, making factors like safety a critical priority. The average consumer does not know how to assess other important features such as battery safety and quality, and relies heavily on the installer for guidance.
- **Products** on the market are now lithium iron phosphate (LFP) batteries, which are safer as well as less expensive than the previously dominant nickel manganese cobalt (NMC) batteries. It is becoming more important for installers and residential storage providers to offer targeted products in each market.

Figure 1: BNEF cumulative residential energy storage forecast



Source: BloombergNEF. Note: Based on BNEF's 2H 2023 Energy Storage Market Outlook (web | terminal).

Figure 2: Residential battery to solar attachment rates in 2023, selected markets



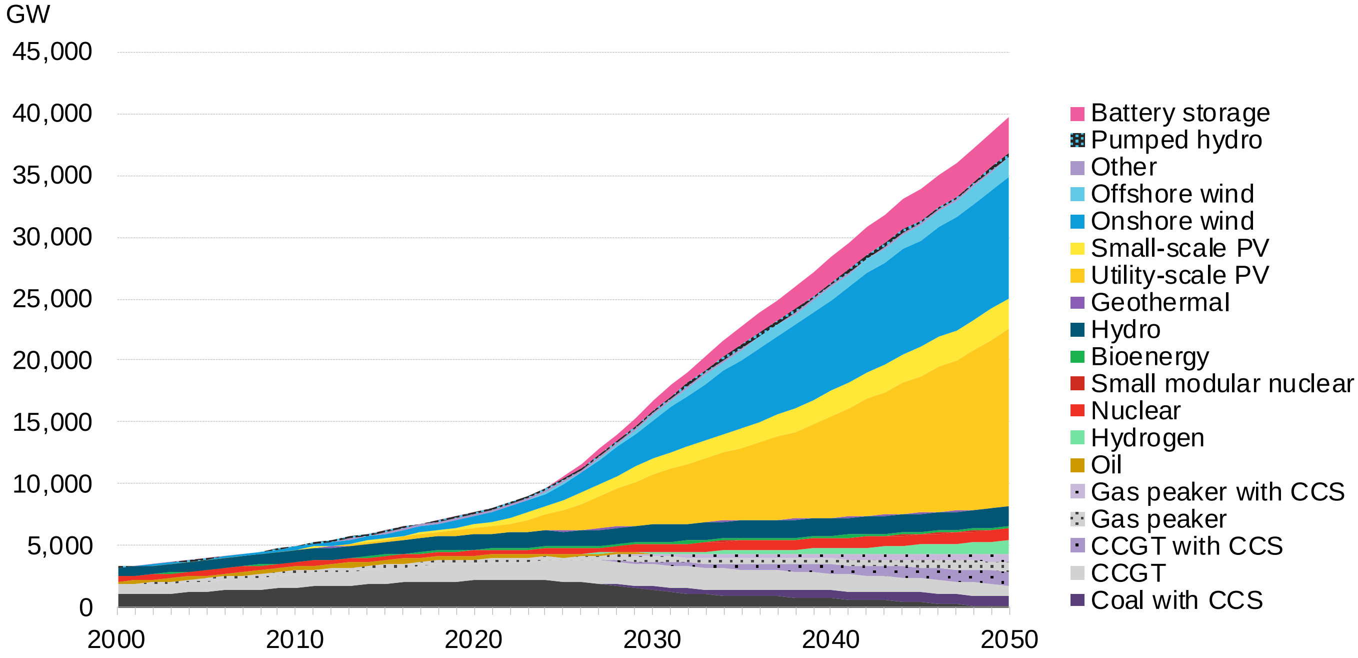
Source: BloombergNEF, SolarPower Europe, LBL, Otovo, Sunwiz. Note: Europe = EU average including Italy, Germany.

- **The value chain** is evolving, as residential energy storage providers that integrate hardware components and software into a final product for the customer face fierce competition. These are increasingly focusing on their competitive advantages in downstream areas of the value chain like aggregation and energy trading, while partnering with established component manufacturers that can make components at scale and at reasonable cost, but cannot offer downstream services as efficiently in new markets.
- **Challenges** to further uptake of batteries include poor economics without subsidies and an inexperienced installation industry in many markets where batteries are new. Consumers can be put off by lengthy wait times, lack of good data on actual performance of the system, and other negative experiences. Some of these problems will be resolved with time and industry maturity.
- **Opportunities** to drive uptake of batteries, and their usefulness to the overall grid system, can be accelerated by improving business models that reward battery owners for their services. These include more sophisticated time-of-use electricity tariffs and virtual power plant business models that participate aggregated residential batteries in flexibility markets. Emerging local flexibility markets look to be an apt opportunity, because they are designed to reward small, distributed energy resources in specific locations.

Section 2. Why build residential batteries?

Electricity storage is a key component of almost any reasonable pathway to net-zero greenhouse gas emissions. BloombergNEF models a pathway to take the world to net-zero emissions by 2050, using solar, wind and battery backup (Figure 3). This requires 722GW of batteries to be installed worldwide by 2030, up from 36GW at the end of 2022, and 2.8TW of batteries by 2050. (See *BloombergNEF New Energy Outlook 2022* (web | terminal).

Figure 3: Cumulative installed power capacity in BloombergNEF's Net-Zero Scenario



Source: BloombergNEF. Note: CCS is carbon capture and storage. CCGT is combined cycle gas turbine.

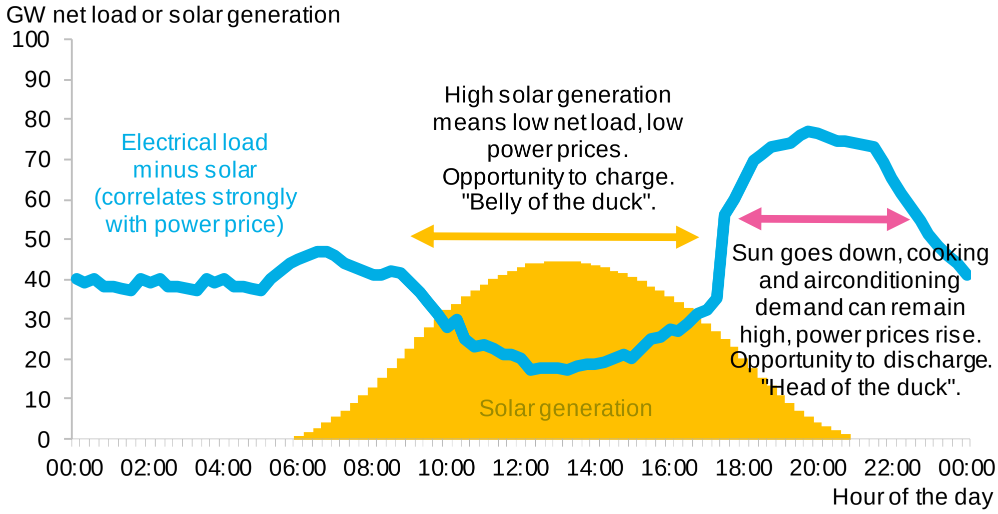
Residential batteries are expected to be a major contributor to the storage capacity needed to shift electricity demand to timeslots of high renewable electricity generation.

When customers use residential batteries to increase their solar self-consumption, they also help to reduce overall power price volatility

At the household level, the battery charges in the daytime when solar power is generated in excess, and discharges later when there is typically higher demand. These charge and discharge patterns benefit customers that want to increase their solar self-consumption. They can also lower consumer bills, assuming that consumers are on time-of-use tariffs.

The benefits of these charge and discharge patterns translate to power markets by flattening out the overall load or the ‘duck curve’ which emerges at high solar penetrations (Figure 4). Examples of this ‘duck curve’ already exist in many markets like Hawaii and California in the US, South Australia, and even on a sunny day in the Netherlands or Spain.

Figure 4: The 'duck curve' that emerges in power markets at high solar penetrations



Source: BloombergNEF

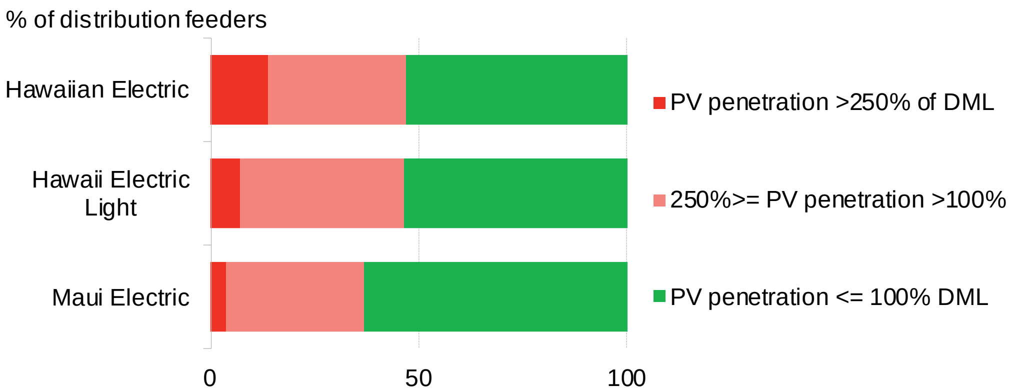
Residential batteries also have some important benefits for local grids, helping to resolve challenges presented by rapid growth of distributed energy resources such as residential solar and electric vehicles (EVs).

Residential batteries can also reduce strain on distribution grids caused by uptake of rooftop solar and electric vehicles

Thousands or even millions of residential solar systems and EV chargers will connect to grids that were not built to support high instantaneous loads like EV charging or electricity flowing in the opposite direction when residential solar systems send power back to the grid. In Hawaii for example, reverse power flow occurs in more than half the substations (Figure 5).

As these local grids become congested and strained, grid operators need to find new ways to manage voltage and thermal issues or upgrade the grid to avoid future ones. One alternative for grid operators making large investments in the grid is to use flexible distributed energy resources like residential batteries, though the structures for compensating owners for providing flexibility

Figure 5: Hawaiian Electric PV penetration as a percentage of daytime minimum load

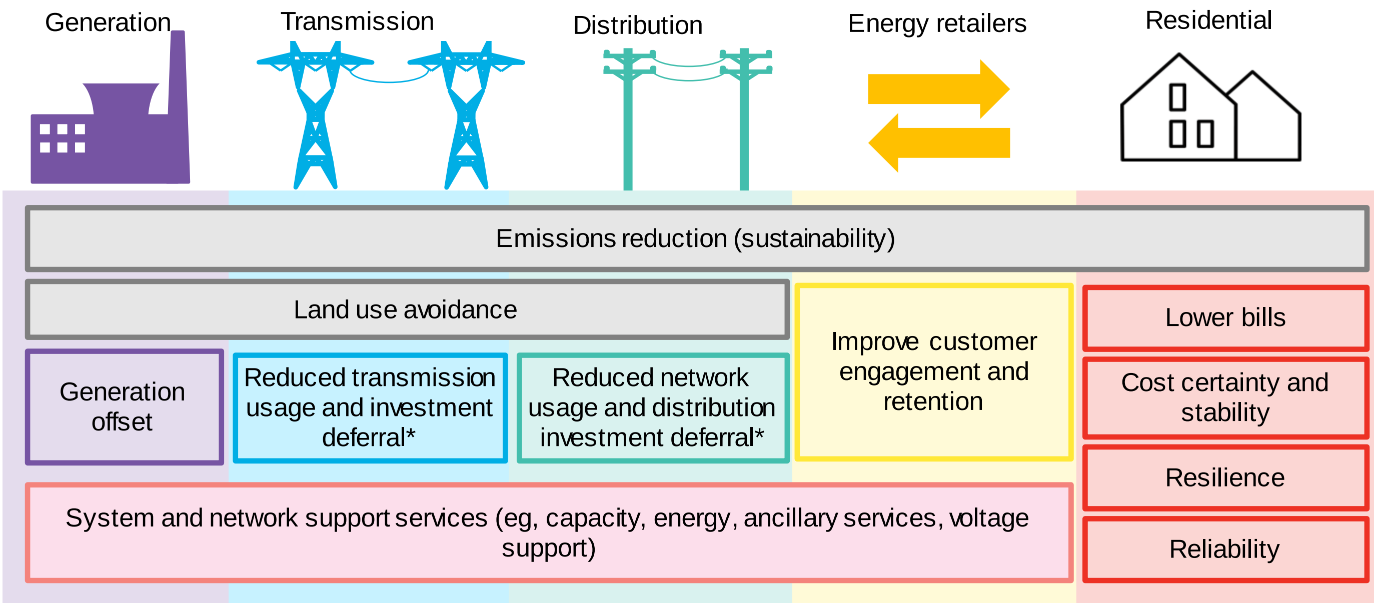


Source: Hawaiian Electric. Note: DML = Daytime minimum load.

In a future where flexible distributed energy resources play a more active role in supporting the grid, residential batteries could have an advantage over other flexible distributed energy resources such as electric vehicles, smart heat pumps and grid-connected thermostats. Residential batteries do not require consumers to actively change their behavior and adjust comfort in the home if the grid requires such a change during critical hours. Batteries can be programed to automatically respond and discharge, while changes to other distributed energy resources in the home may lead to minor changes in home temperature or travel patterns, or adjustments to the schedules of individuals.

Policy decisions about how to support residential battery uptake should consider these benefits to the wider power system in addition to benefits to individual customers (Figure 6). Even though residential batteries today may not provide a clear economic benefit to the individual, they should be an essential part of long-term planning and can play a key role in decarbonization.

Figure 6: Benefits of residential batteries



*Source: BloombergNEF. Note: *transmission and distribution investment deferral are location-specific. Size of boxes does not correlate with size of benefit. This figure does not illustrate costs of batteries, for example grid exports can generate a cost that networks take on – some of these may be embedded in how the export rules and tariffs are designed.*

Section 3. History and background

The global residential battery storage market has grown quickly in recent years. Progress has been concentrated in a few leading markets including Germany, Italy, Japan, the US and Australia. Combined, BloombergNEF expects these five markets to represent around 88% of cumulative residential battery storage capacity installed globally by the end of 2023.

Uptake in other markets today is limited by economic viability. Growth in the next five years will be driven by both economics and policy: battery costs will fall, and countries will support the use of batteries to manage rooftop solar and EV growth.

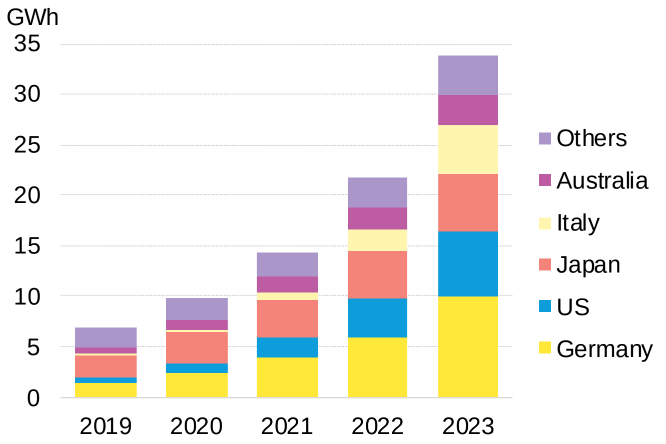
3.1. Market overview

BloombergNEF expects over 15GW/34GWh of cumulative residential battery capacity to be installed globally by the end of 2023 (Figure 7). Leading markets will be Germany, Italy, Japan, the US and Australia, accounting for 88% of cumulative residential battery capacity installed by the end of 2023, with a similar share of new installations expected in 2023 (Figure 8).

Uptake in major markets has been driven by supporting policies such as subsidies and mandates. Rising consumer interest in increasing solar electricity self-consumption and back-up power has also played a role, but batteries are still too expensive for most consumers to purchase without some form of support. As a result, cumulative residential battery capacity in all other markets combined will be less than 1.2GW/2GWh by the end of 2023, due to the relative lack of supportive frameworks.

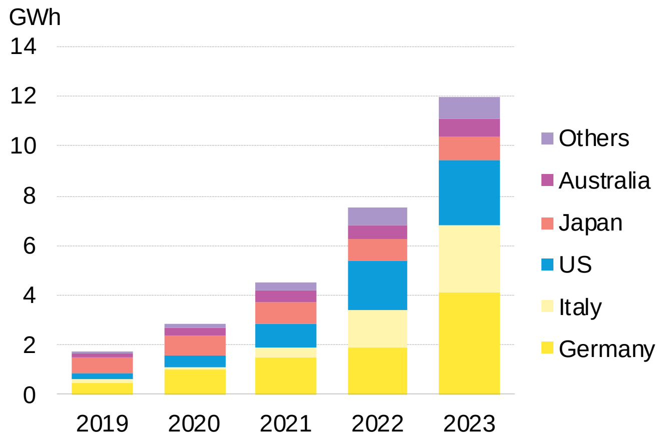
Demand in other markets will rise over time as battery costs fall and governments phase out policy mechanisms like feed-in tariffs and net metering, which pay consumers for excess solar generation. When such policies are phased out, consumers become more inclined to install batteries to ensure that they maximize self-consumption of solar generation.

Figure 7: Cumulative residential battery additions by region



Source: BloombergNEF

Figure 8: Annual residential battery capacity by region



Source: BloombergNEF

3.2. Drivers

Residential battery uptake in major markets began mainly as a result of battery storage subsidies. Other key factors that have driven uptake in some markets are the phasing-out of PV export frameworks, which reduces incentive to export excess solar generation, as well as customer interest in back-up power. Table 1 profiles the main policy decisions that have supported residential battery demand in the largest markets.

Table 1: Comparison of residential battery storage drivers across key regions

Country	Region	Storage subsidy schemes	PV export tariff
Germany	National level	KfW grant introduced in 2013, covered 30% of capex when introduced, gradually reduced	Feed-in tariffs, reduced each year to €0.0480/kWh in 2023
Italy	National level	Superbonus tax rebate since 2020, covered 110% of capex until scaled back in 2023 Tax rebate since 2018, covers 50% of capex	Net billing (exports from PV <500kW compensated at the wholesale power price, deductible from retail value of electricity consumed) to be phased out from 2024*
	Lombardy	Tax rebate since 2016, covers 50% of capex	
	Veneto	Tax rebate since 2019, covers 50% of capex	
US	Hawaii	Hawaii Battery Bonus, covers $850/kW of capex	Ended net metering in 2015
	California	Self-Generation Incentive Program rebate, worth $150/kWh to $1,000/kWh in 2023	Net metering payments, reduced in December 2022 with NEM 3.0
	Texas	N/A	
Japan	National level	$250/kWh grant, up to ¥37,000/kWh	Feed-in tariffs still available for new PV in 2023: • ¥16/kWh ($0.11/kWh) for PV systems below 10kW • ¥12/kWh for ($0.08/kWh) for rooftop PV between 10 and 50kW
Australia	National level	Home Battery Tax Relief, launched in 2023, tax deductions up to A$3,500 or 50% of system cost for new battery systems	Varies by region (below)
	Victoria	Interest-free loan, up to A$8,800 ($5,606) in 2023	Feed-in tariff depends on retailer, averaging A$0.054/kWh in 2023, time-of-use feed-in tariffs are also available
	New South Wales	Empowering Homes program, interest-free loan, up to A$14,000, closed July 2022	Feed-in tariff depends on retailer, averaging A$0.076/kWh in 2023, time-of-use feed-in tariffs are also available
	Australian Capital Territory	ACT Government's Next Generation Energy Storage (Next Gen), offered A$3,500, or 50% of capex, ended in 2023	Feed-in tariff depends on retailer, averaging A$0.076/kWh in 2023
	South Australia	Home Battery Scheme, worth A$500/kWh, up to A$6,000 per system. Ending in 2023	Feed-in tariff depends on retailer, A$0.085/kWh in 2023
	Queensland	Queensland Government Battery Rebate ended in 2019	Feed-in tariff depends on retailer, averaging A$0.066/kWh in 2023
	Northern Territory	Home and Business Battery Scheme, grant of A$450/kWh, up to A$6,000	Standard feed-in tariff rate is $A0.0913/kWh

*Source: BloombergNEF. Note: Green = major drivers supporting residential storage uptake. * = Italy's net billing will end on Jan 1, 2024, for new PV systems, while existing systems need to progressively switch to a scheme with a lower compensation of around €100/MWh depending on time of production and region by the end of 2024. Japan's PV export tariff is for 10 to 50kW PV systems.*

Germany

Germany was the earliest major residential battery market. In May 2013, the government launched a subsidy scheme administered by development bank KfW, providing grants to energy storage systems installed with new or existing solar systems below 30kW. This drove Germany to become the largest residential solar and battery market globally, and installations have continued at a steady rate even as the subsidy was reduced over the years. In 2022, attachment rates of batteries to rooftop solar were over 75%[1], one of the highest rates globally.

Growth was supported by subsidies for over a decade, but these subsidies have been slowly scaled back and are no longer a major driver. Instead, the market is now driven by customers seeking to increase self-consumption of onsite solar because they save over €0.30 per kWh for avoided electricity purchase from the grid while payment for solar exports is less than €0.05/kWh.

Italy

Italy became the second biggest market in 2022, representing over 20% of global additions in 2021 and 2022. The attachment rate of batteries to rooftop solar was 77%[2] in 2022, up from 11% in 2018. This followed the introduction in 2020 of an extremely generous "Superbonus" subsidy scheme, which covered 110% of costs related to all home energy improvements.

Italy's Superbonus scheme was a very generous subsidy to batteries, but the boom is probably over.

Uptake boomed after the 2020 introduction. This was followed by a sudden contraction after the Superbonus scheme was scaled back in early 2023. Unlike in Germany, the Italian government withdrew the support scheme quickly and the market has been unable to sustain growth without it.

BNEF expects uptake to remain modest. A 50% national tax rebate scheme still exists, and before the Superbonus was introduced, this already drove some installations across Italy. Regional subsidies are also available to consumers. In the Lombardy region for example, a 50% rebate on solar plus storage batteries has been available from 2016.

US

The US residential battery market is very fragmented, as state-level policies are the biggest determinants of uptake and can vary significantly.

California, Florida and Texas are the largest markets in terms of number of systems installed, with attachment rates ranging from 9% to 12% in 2022 and expected to rise sharply in 2023. Uptake in these markets is driven by demand for back-up power, as grid outages due to extreme weather events are becoming a serious concern for customers.

California in particular has become an extremely attractive market in the past year, with consumers encouraged to pair batteries with existing PV systems due to changes in solar net metering policies. Demand in California is also supported by the California Self-Generation Incentive Program (SGIP), which provides a subsidy between $150 to $1,000/kWh for a residential battery.

Despite being a smaller market in terms of number of systems installed, Hawaii stands out for having the highest attachment rates in the US. In 2022, around 96% of residential PV installations paired with batteries, as utilities only allow co-located systems to export to the grid. The incentive

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1 Based on estimates by SolarEdge, Enphase Energy and BNEF's assessment of installations from Germany's energy asset data register

2 Based on BNEF's assessment of installations from Italy's renewable energy association ANIE

for consumers to install batteries is made even stronger by the availability of targeted subsidies through the Hawaii Battery Bonus.

BNEF expects adoption rates in the US to increase in the next five years due to more frequent power outages, falling rooftop solar export tariffs, the introduction of time-based retail tariffs with evening peaks, higher peak demand charges and demand response payouts.

Japan

The residential battery segment is the largest energy storage segment in Japan, driven by subsidy programs that can provide up to ¥37,000 ($250)/kWh for new installations. Many Japanese households with solar panels are coming to the end of their original 10-year feed-in tariff contracts in the 2023-2030 period, and will therefore be paid much less (if anything) for solar exports, which means they have an incentive to increase self-consumption for an existing PV system.

Australia

Australia's growing residential battery market is spurred by soaring power prices and subsidies in several states, as well as resilience concerns. The attachment rate of batteries to new PV installations jumped to nearly 15% nationwide in 2022, from around 8% in 2021. Attachment rates are still relatively low compared to European markets, as the continued use of feed-in tariffs (export payments offered by retailers) is limiting uptake.

While most Australian solar owners receive a flat export payment, the introduction of time-varying rates by electricity retailers, starting in the state of Victoria, is promising for batteries. Under this option, these owners can be paid higher or lower amounts depending on the time of the day that solar electricity is exported to grid, potentially encouraging them to install batteries that allow them to store excess solar generated during the day and only export in the evening when prices are typically higher. Other states in Australia are likely to follow, starting with South Australia which has been exploring time-varying rates since 2020.

China

China's residential battery market has struggled to take off because China has relatively low electricity rates and limited concerns on energy supply resilience (low power outage rates).

China's household electricity rate averaged under 530 yuan ($0.076)/kWh in 1H 2023, equivalent to roughly 50% of average US household electricity prices and 15% of German household electricity rates. China's residential electricity rates are kept artificially low thanks to cross-subsidization from commercial and industrial end users. The low prices make customer-sited storage assets economically unattractive.

Losing power due to grid outages is also less of a worry for China's electricity consumers, leading to less value being placed on storage. We expect China's residential storage market to remain small by 2030 if no further incentives are made available.

3.3. Battery chemistry

The common choice for residential battery chemistry has changed over the years, with residential battery energy storage providers shifting from the use of lithium-ion batteries with nickel-based cathodes (nickel manganese cobalt or NMC, and nickel cobalt aluminum oxide or NCA) to lithium-iron-phosphate (LFP) batteries (Table 2). The main driver cited across the board was better safety, lower costs and longer cycle life.

China-based providers like Pylontech and BYD have prioritized the use of LFP batteries since entering the market, as this is the major chemistry choice in the Chinese market. Battery manufacturers from other regions, like Japan-based Panasonic and South Korea-based LG, have recently started offering residential energy storage systems using LFP batteries in 2023.

Major residential storage providers like US-based Tesla, Germany based E3/DC and UK-based Powervault have also started offering systems using LFP batteries in 2023, citing similar reasons. They previously sourced NMC batteries from third parties, but are also making a switch to LFP.

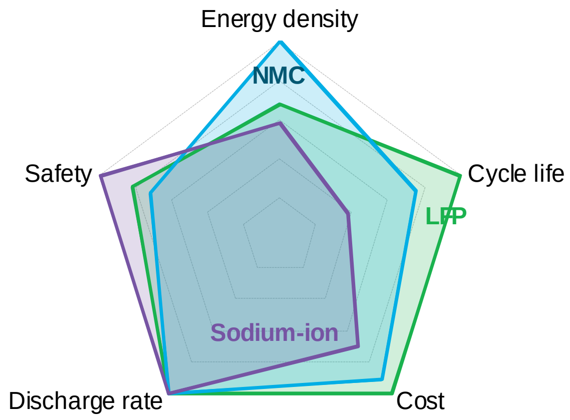
Table 2: Battery chemistry of major products by selected residential storage providers

Company	2017	2021	2023
Pylontech	LFP	LFP	LFP
BYD	LFP	LFP	LFP
Panasonic	-	NMC	NMC / LFP
LG	NMC	NMC / LFP	NMC / LFP
Tesla	NMC	NMC / LFP	NMC / LFP
Enphase Energy	LFP	LFP	LFP
Sonnen	LFP	LFP	LFP
E3/DC	NMC / NCA	NMC / NCA / LFP	NMC / NCA / LFP
Senec	NMC	NMC	NMC
Powervault	NMC	NMC	LFP

Source: BloombergNEF. Note: NMC = nickel manganese cobalt, LFP = lithium iron phosphate, NCA = nickel cobalt aluminum oxide. Green entries refer to newly launched products or chemistry changes. Grey entries refer to newly announced or upcoming products or chemistry changes.

LFP batteries outperform NMC batteries on three key metrics that are particularly important for residential energy storage systems: cycle life, cost and safety (Figure 9). Of the two other metrics that BloombergNEF compares across battery chemistries, energy density is where NMC batteries outperform, but this is less of a concern in residential applications, as weight becomes less of a concern once stationary storage systems are fully installed. The final metric, charging rate, is also less important in stationary, where fast charging is not a priority.

Figure 9: Illustrative characteristics for lithium-ion batteries and sodium-ion batteries



Source: BloombergNEF. Note: Shows expected metrics of mass-produced sodium-ion batteries.

The relative unimportance of energy density and charging rates is helping push the market share of LFP batteries for the residential and wider stationary storage segment. These metrics are a much bigger concern in electric vehicles, as increased weight reduces the range and speed of an electric vehicle and fast charging is an appealing feature for consumers (Table 3).

BloombergNEF expects a divergence in the chemistries used for these applications, with NMC and NCA batteries potentially keeping a hold on the electric vehicle market, while LFP becomes more dominant in the stationary storage segment. This will create more opportunities for battery manufacturers and residential storage providers making targeted products for the segment.

Table 3: Battery metrics and best-fit applications for lithium-ion batteries

Application		Energy density	Cycle life	Cost	Charge rate	Safety
Electric vehicles	Passenger EVs	Green	Yellow	Green	Green	Green
	Commercial EVs	Green	Yellow	Green	Green	Green
	Electric buses	Grey	Green	Green	Yellow	Green
	Two- and three-wheelers	Green	Grey	Green	Yellow	Green
Stationary storage	Utility-scale	Grey	Green	Green	Grey	Green
	Commercial	Grey	Green	Green	Grey	Green
	Residential	Grey	Green	Green	Grey	Green

Source: BloombergNEF. Note: Green = most important metric, Yellow = less important metric, Grey = relatively unimportant metric

Section 4. Residential energy storage products

Residential storage products have similar appearance regardless of brand, signifying the commoditization of these products. It is difficult for system providers to set themselves apart and grow brand awareness. This section summarizes and compares the main features that companies advertise for these products. We highlight the following features: battery chemistry and cell supply, back-up functionality, price, size, modularity, weight and footprint, warranty length and smart features.

We compare these features across the products of 8 residential storage providers that represent more than half the sales in the major residential battery markets.

4.1. Overview of products

Residential storage product features depend significantly on the markets they are being sold in (Table 4).

Providers typically offer much larger entry-level systems in the US and Australia, where the energy demand and typical customer-sited solar system size of an average home is larger than in Europe. Products in the US and Australia will also have bigger batteries to enable more hours of back-up when needed.

In Europe, providers offer the option for consumers to stack multiple modules in a system and achieve much larger systems. Nearly all residential battery products are modular, but there is an upper limit to how many modules can be safely stacked, and when there is an integrated inverter, that limits the maximum power output. Hence Table 4 shows a maximum system size for most of these modular models. Products that use an external inverter can increase both power and energy capacity beyond this.

Table 4: Overview of features in residential energy storage products

Company	Markets	Product (launch date)	Battery chemistry	Inverter setup	Minimum product size	Maximum scalable size	Warranty terms	Outdoor suitability
Pylontech	Europe North America	Force H3 (June 2023)	LFP	External	10.24kW 10.24 kWh	35.84kW 35.84 kWh	10 years 8,000 cycles	Yes (IP55)
BYD	Europe	Battery-Box HVM (September 2020)	LFP	External	7.65kW 8.28 kWh	20.45kW 22.08 kWh	10 years	Yes (IP55)
LG Energy Solution	Europe US	enblock S (October 2023)	NMC	External	5kW 10.6 kWh	14kW 35.4 kWh	10 years 70% EOL	Yes (IP55)
	Europe	enblock E (October 2023)	LFP	External	6.2kW 12.4 kWh	7.7kW 15.5 kWh	10 years	Yes (IP55)
Tesla	US Australia Europe	Powerwall 3 (September 2023)	LFP	Integrated	11.5kW 13.5 kWh	11.5kW 54 kWh	10 years	Yes (IP67)
Enphase Energy	US	IQ Battery 5P (May 2023)	LFP	Integrated	3.8kW 5 kWh	80 kWh	15 years 6,000 cycles	Yes (NEMA 3R)

Company	Markets	Product (launch date)	Battery chemistry	Inverter setup	Minimum product size	Maximum scalable size	Warranty terms	Outdoor suitability
Sonnen	Australia US	Evo (December 2021)	LFP	Integrated	4.8kW 10 kWh	14.4kW 30 kWh	10 years 10,000 cycles	Yes (IP56)
	Europe	Batterie 10 (June 2020)	LFP	Integrated	3.4kW 5.5 kWh	4.6kW 22 kWh	10 years 10,000 cycles	Yes (IP30)
E3/DC	Europe	S10 SE (August 2022)	Various	Integrated	3kW 5.25 kWh	4.5kW 11.2 kWh	10 years 80%	No (IP20)
Senec	Europe Australia	Home V3 (October 2019)	NMC	Integrated	5kW 9 kWh	5kW 9 kWh	10 years* 12,000 cycles	Yes (IP 30)

*Source: BloombergNEF. Note: PVS = PV with storage. * = Extendable to 20 years; EOL = end of life; Outdoor data refers to the rating of the product (the higher the IP value, the greater the resistance to water). Some products do not list a maximum power output capacity. Launch date shows initial launch of the product but list of features includes latest upgrades since.*

4.2. Consumer preferences

BloombergNEF spoke to installers in major residential energy storage markets (UK, Australia, Canada and Italy) to understand how consumers make decisions about installing residential batteries.

Installing solar at a home is typically an economic decision, where consumers are offsetting their energy bills with self-generated solar. Batteries, in contrast, do not always improve bill savings due to flat retail rate structures, unfavorable export tariffs and high cost of batteries. This means that consumers are typically seeking batteries for more specific product features.

BloombergNEF found that consumers are generally interested in installing batteries for three distinct, but sometimes overlapping reasons:

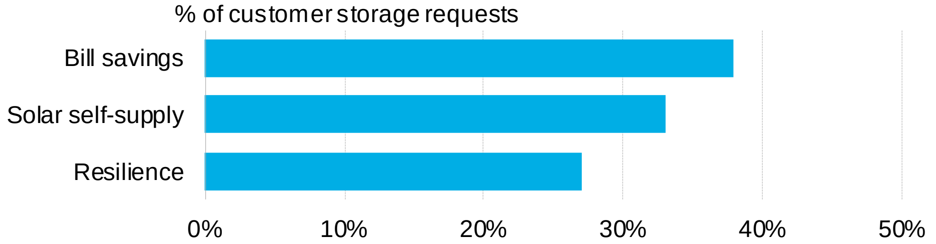
- **Bill savings:** Homeowners also simply install batteries primarily for economic reasons i.e., to reduce their energy bills. This is often dependent on homeowners having access to favorable electricity tariffs or subsidies to reduce battery system costs.
- **Solar self-supply:** Homeowners may also install batteries out of a desire to green their electricity consumption by increasing their solar self-supply. This may not always correlate with reducing their energy bills, and such customers may be willing to pay a financial premium to go green and support the energy transition.
- **Back-up power and resilience:** Homeowners often install batteries because they need or want resilience, i.e., to have back-up power and be able to operate off-grid. This is either because they are living in an area with an unreliable grid or face extreme weather events.

Our findings on customer motivations align with those from US solar marketplace EnergySage, which publishes a major report twice a year on the solar and storage market (here). The latest, in September 2023, found that in 1H 2023, just under 40% of US residential battery buyers bought storage primarily to make savings on their utility rates, while about 35% wanted to increase solar self-supply, and most of the remainder wanted back-up power i.e., resilience (Figure 10).

Customer motivations differ by market, as covered in Section 3.2. In markets where grid outages are common, like in parts of Australia, Japan and the US, resilience is often the reason for customers to buy a system. In markets where generous subsidies are available, like Italy, consumers that would otherwise not make the investment become more likely to install batteries to reduce their bills.

Other consumers motivated by increasing solar self-supply are generally early adopters that are green-minded or technology enthusiasts, and are more common in markets like the UK, where attachment rates are high (about 30%) not because of the need for back-up or availability of subsidies, but because higher-earning consumers can spend on batteries.

Figure 10: Motivations of US residential customers requesting battery storage quotes



Source: EnergySage, BloombergNEF

Another interesting finding of the EnergySage report, which may be unique to the US market, is that installers are highly loyal to certain brands of solar panels and inverters, with nearly 9 out of 10 installers offering only one or two inverter brands, and 3 out of 5 offering only one or two brands of solar panel. While storage numbers were not published, it seems likely that in the US, partnerships between technology providers and local operators will also be very important in market adoption, as firms learn to work with certain designs over time.

Survey results

BloombergNEF's conversations with installers suggest that the product features that are most carefully considered by customers are not always those that are most relevant to installers and most widely advertised by residential energy storage providers. In the sections below, we compare our findings for consumer preferences across all three types, and how they are different to installer preferences as reported in the EnergySage report.

Across the board, installers reported that consumers focused least on technical features such as battery chemistry, weight and size, performance metrics like round-trip efficiency or depth of discharge, and product certifications. Installers also reported that consumers discuss very little about safety of systems and have scored this as a less important criteria. This is not to say that safety is not an important feature to consumers, but rather, that consumers tend to trust installers regarding some of the more technical aspects of batteries like safety, with the assumption that warranties are the crucial factor to help ensure the reliability and performance of their purchases. Surveying installers means we also do not consider individuals who do not even consider a battery installation, for safety or other reasons.

Installers vs consumers: safety

Installers take responsibility for ensuring that the products they sell are safe and comply with relevant product certifications. Indeed, installers will quickly move away from a battery supplier if they have known safety issues in order to maintain customer satisfaction and guarantee security of their products.

Consumers today may not be very knowledgeable about safety of systems, and will not be able to choose between one product or another based on which they consider to be safer. The importance of safety to consumers could change with the growing occurrence of residential battery fires in markets like Germany and Australia. This will require more clarity and consensus of safety metrics between manufacturers, installers and consumers.

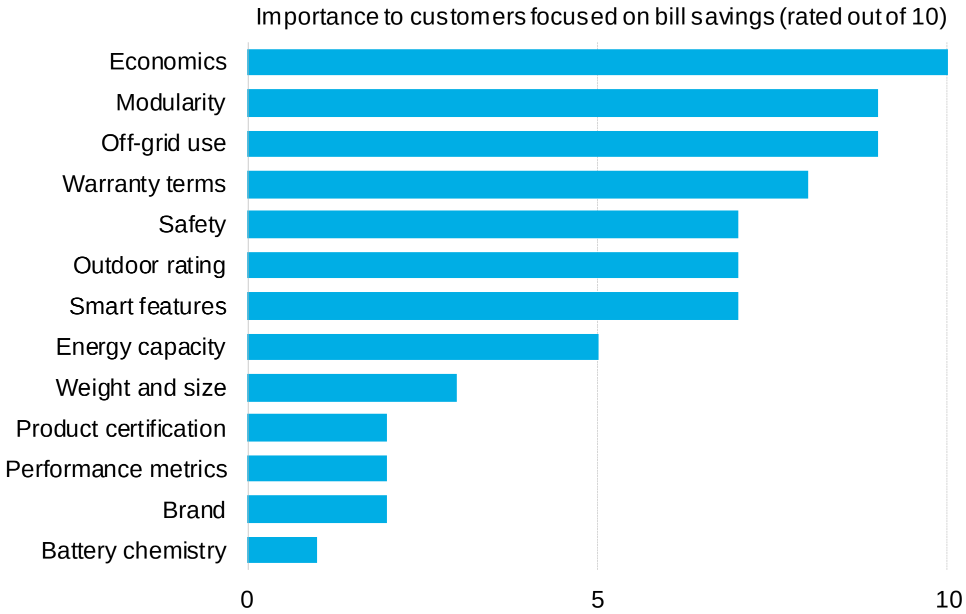
Bill savings

For consumers installing batteries for cost reductions or bill savings, economics were the most important concern (Figure 11).

The next most important criteria were modularity, warranties and off-grid use, once again. Regarding modularity and warranties, installers noted the importance of the ability to upgrade batteries as necessary in the future, ensuring that cost savings can be further optimized as energy use changes over the life of the installation.

Criteria such as smart functionality, branding and product certification were considered less important, as these customers were more comfortable installing the cheapest possible systems to ensure a return. Battery chemistry was also ranked particularly low compared to the two other customer types.

Figure 11: Importance of product criteria for consumers installing residential battery energy storage systems to make savings on bills



Source: BloombergNEF. Note: data from surveys of five installers operating across Australia, Canada, UK and Italy. Warranty refers to warranty length and cycle life. Economics includes price and payback period. Performance metrics refer to advertised round-trip efficiency and depth of discharge.

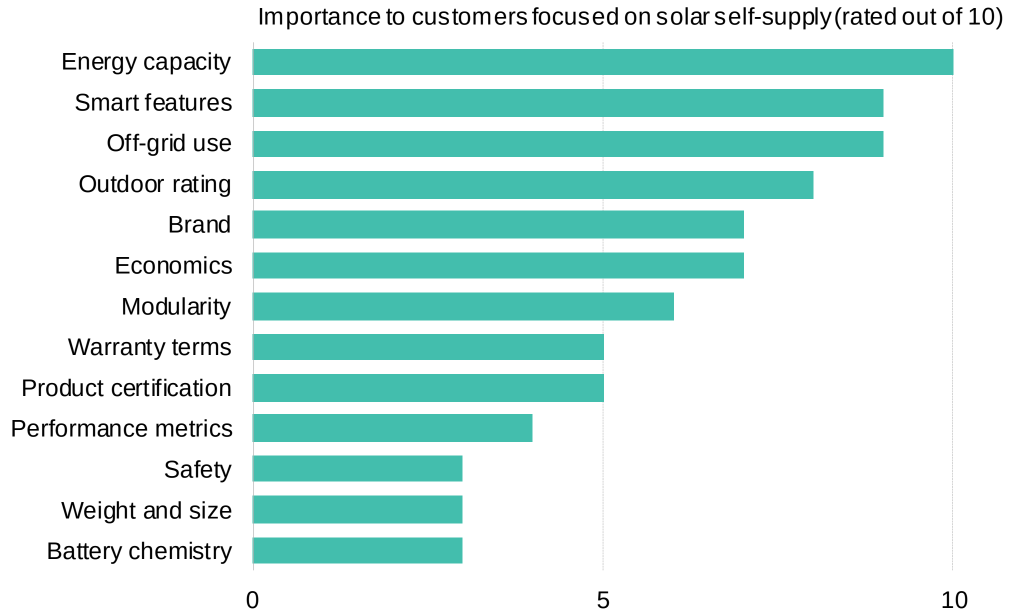
Solar self-supply

For customers focused on greening their power consumption, energy capacity, smart features and off-grid use are also the main priorities (Figure 12). Customers in this category are likely to be those that install batteries because they want to support the energy transition and can afford them. Such early adopters are more likely to be concerned about criteria that may be less important to the average customer or may not even be necessary for their own use.

According to installers surveyed, these customers are also more likely to be brand-conscious, favoring the installation of specific brands over others. Installers also noted that economics are more of a concern than for customers focused on resilience and off-grid use, although they do not necessarily expect to install batteries to reduce their overall costs versus relying on grid electricity or on solar alone.

Despite being early adopters, performance metrics such as round-trip efficiency or depth of discharge matter little to customers and are rarely brought up during the installation process. Battery chemistry also matters very little, suggesting that while these consumers may be more conscious of the transition, they are unlikely to be driven by marketing of batteries as nickel-free.

Figure 12: Importance of product criteria for consumers installing residential battery energy storage systems to increase solar self-supply



Source: BloombergNEF. Note: data from surveys of five installers operating across Australia, Canada, UK and Italy. Warranty refers to warranty length and cycle life. Economics includes price and payback period. Performance metrics refer to advertised round-trip efficiency and depth of discharge.

Battery buyers who want to operate off grid are not particularly concerned with price.

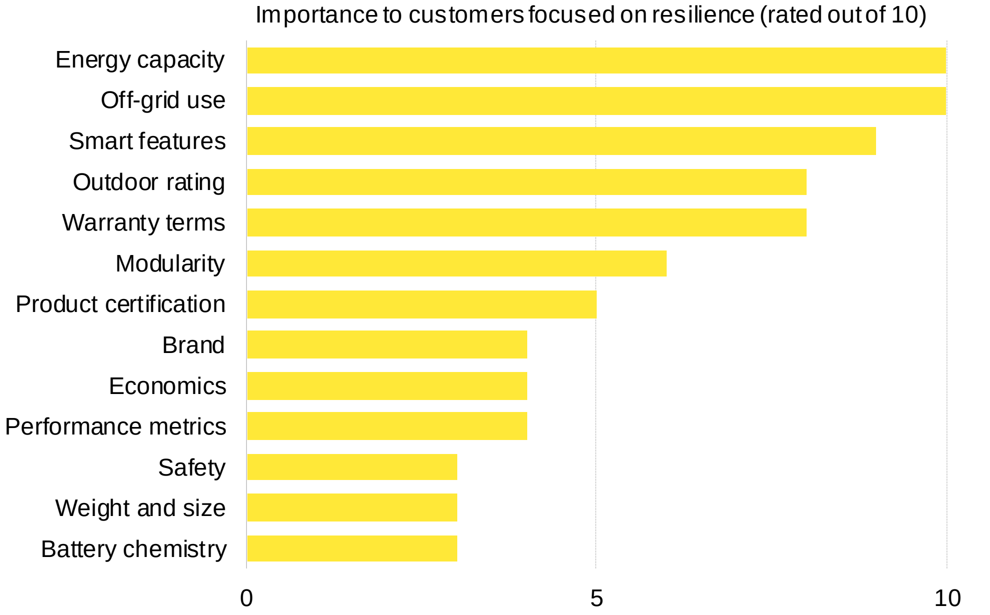
Back-up power and resilience

For consumers installing batteries due to resilience concerns, the most important criteria are the scope of off-grid use and energy capacity. For the latter, reducing use of grid electricity makes it crucial to have enough energy storage capacity to continuously operate the system during hours of low solar generation (Figure 13).

Other important criteria for this group were smart features, the outdoor rating and the warranty associated with the batteries. Smart features are especially important for these customers to be able to monitor as well as forecast their electricity use accurately. For customers that are not off-grid but install batteries for resilience, installers noted that smart features are still particularly important for them to be able to track when grid outages occur and how the system responds.

Resilience seekers are more common in the US, Australia and Japan, where storms and weather-related outages have been more frequent than in Europe, for example. Economics, referring to both system costs and payback periods, are less important to these customers as their priority is reliability, and they are willing to pay a premium.

Figure 13: Importance of product criteria for consumers installing residential battery energy storage systems for resilience purposes



Source: BloombergNEF. Note: data from surveys of five installers operating across Australia, Canada, UK and Italy. Warranty refers to warranty length and cycle life. Economics includes price and payback period. Performance metrics refer to advertised round-trip efficiency and depth of discharge.

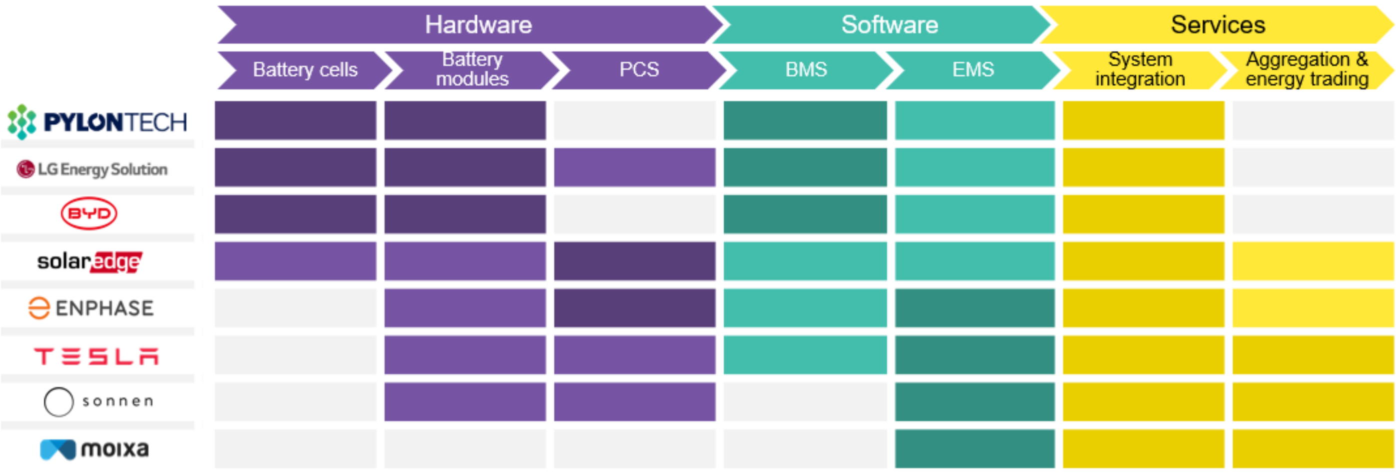
Section 5. Competitive landscape

5.1. Company overview

Residential energy storage systems integrate various components including battery cells, modules, power conversion systems (PCS), software i.e., battery management systems (BMS) and energy management systems (EMS), and other balance of plant items.

Integrating these components into a final product was previously limited to a small number of specialized storage providers like Tesla and Sonnen, but battery and other equipment manufacturers are increasingly moving down the value chain into system integration (Figure 14).

Figure 14: Select residential energy storage system providers by activity



Source: BloombergNEF. Note: PCS = power conversion systems (inverters). BMS = battery management systems, EMS = energy management systems. Darker shading indicates core business area.

5.2. Key trends

Competition from upstream is squeezing storage system providers

Residential storage system providers are facing intense competition from the other companies moving into system integration. As the residential energy storage market grows, battery and other solar equipment manufacturers are increasingly moving down the value chain, launching residential energy storage products of their own and gaining market share.

Since the start of 2019, battery and solar equipment manufacturers such as Panasonic, Sofar Solar, Jinko Solar and Canadian Solar launched their first residential energy storage products, adding to competition from other established battery or solar equipment manufacturers like BYD, Pylontech, LG and Trina Solar, all of which also offer integrated residential storage products. Companies from other verticals, such as automaker Toyota, have also launched residential battery products in the past two years, adding to competition from other automakers like Nissan and industrials like Eaton.

At SNEC International Photovoltaic Power Generation and Smart Energy Conference & Exhibition in Shanghai in May 2023, the number of companies displaying residential storage products surpassed BNEF's bandwidth to count (there were more than 35). Many solar component manufacturers were looking for new products and markets to enter, and residential batteries are one of them.

Storage system providers are focused on competing downstream

Residential storage system providers facing competition can expand into new markets or other areas of the value chain, but this requires large amounts of capital.

The handful of storage system providers that have successfully attracted such capital have shown a trend: rather than expand upstream into battery cell manufacturing, they tend to double down on downstream areas where they have leverage, either in their local market or in new markets. One strategy is focusing on developing a strong local network of certified installers, which allows storage providers to access the market expertise of installers that have experience with local permitting rules, incentives, retail rates, language and marketing resources.

Another strategy is developing software for aggregation and energy trading, which allows companies to develop new business models beyond just focused on the end-customer. This strategy requires deep expertise of local energy markets. It is generally difficult for competing battery or solar equipment manufacturers to gain a clear advantage in this area of the value chain due to the level of local expertise required.

Table 5: Major investments in or acquisitions of residential battery storage providers

Investor	Target	Deal type	Details
TEPCO	Moixa	Strategic investment	The 2017 strategic investment in UK-based storage provider Moixa by Japan-based Tokyo Electric Power Company Holdings helped support Moixa's expansion into the Japanese residential energy storage market, at a time where UK market was yet to take off. By the end of 2019, Moixa was managing more than 10,000 residential batteries in Japan and announced plans to raise additional capital and expand into Europe, Australia and the US.
Lunar Energy	Moixa	Acquisition	The 2022 acquisition of Moixa by US-based Lunar Energy is expected to help increase the deployment of Moixa's GridShare software. Lunar Energy will use Gridshare to manage batteries and other distributed energy resources in its virtual power plants across Europe, Japan and the US.
EnBW	Senec	Acquisition	The 2018 acquisition of Germany-based storage provider Senec by ENBW, a utility based in the same country, helped the former gain market share. Senec was the fastest growing storage provider in Germany in 2019, rising to become the third largest provider. It also launched a successful expansion into the Australian market in late 2019. Other key focus areas for EnBW and Senec were to in-source all software development and services.
Shell	Sonnen	Acquisition	The 2019 acquisition of Germany-based storage provider Sonnen by Royal Dutch Shell also helped the latter expand into new markets across Europe and the US. The relationship between both companies is set to end with Shell's potential sale of Sonnen due to a limited strategic fit between both companies.

Source: BloombergNEF

Partnerships between global companies are helping unlock growth

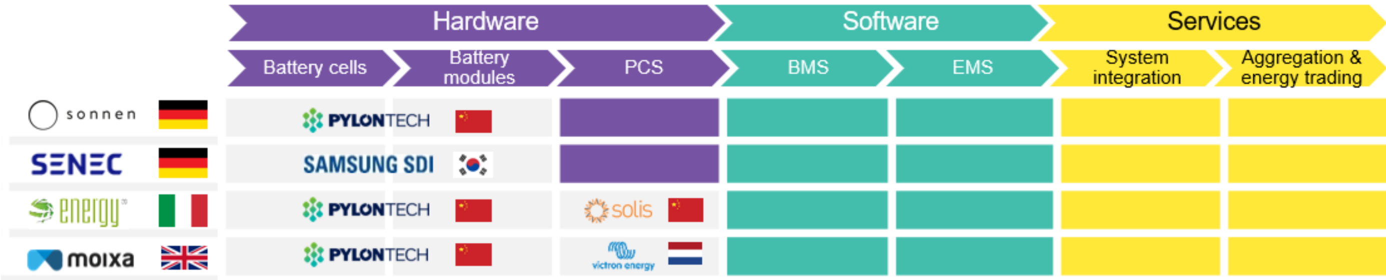
The difficulty that battery or other equipment manufacturers face in providing downstream services in new markets makes alliances with local partners necessary for success in the residential energy storage segment, especially as the space becomes more and more crowded with new products and brands.

Global cooperation is necessary for residential battery uptake to rise quickly

Established battery manufacturers like Panasonic, LG Energy Solution, BYD and Pylontech are active across most areas of the value chain, but are not expanding into downstream areas in every market they plan to sell their batteries. Many battery manufacturers rely on local partners instead, choosing to sell their batteries to local system integrators that may then brand the systems as their own (i.e., 'white-label' products). This can help battery manufacturers get a foot in the door and is particularly common in mature markets such as Germany where there are many well-established local storage providers with developed local networks and brand credibility.

The chart below profiles the major relationships across the value chain of leading local residential storage providers in Germany, Italy and the UK (Figure 15). Across the board, battery cell supply is outsourced and secured through partnerships with battery manufacturers from markets like China and South Korea, where there is enough manufacturing scale to keep battery costs low.

Figure 15: Select residential energy storage system providers by region and partnerships



Source: BloombergNEF. Note: Shading shows that the residential storage provider is active in that area of the value chain. Logos show where in the value chain the residential storage provider works with a partner and who that partner is. PCS = power conversion systems (inverters), BMS = battery management systems, EMS = energy management systems

Residential storage providers in Germany, where there is a stronger manufacturing base, tend to integrate further up the value chain. Sonnen also makes its own battery modules as well as inverters, while others like Senec and E3/DC only integrate inverters into their storage products while using modules from battery manufacturers.

The downstream areas of the value chain, such as aggregation and energy trading, remain a focus area for these residential storage providers looking to grow their business and extract value. Investments tend to be focused in this area, and storage providers without these capabilities are increasingly acquiring them. The most recent of such acquisitions was the purchase of software provider Cloud Computing by Italian storage provider Energy SpA in July 2023. Following the acquisition, Energy SpA noted plans to capture "opportunities that may arise from regulations regarding local energy exchange among different parties".

As residential batteries become smarter, responding to complex price signals and time-of-use tariffs, there will be more of a need for residential storage systems that have energy management systems and functionality that is tailored to a specific market. In California for example, complex NEM 3.0 rules have created an opportunity for residential storage systems that are specifically designed to capture value from that. For customers in California, US-based Enphase developed its IQ Battery 5P to take advantage of NEM 3.0 by self-consuming solar power and exporting power to the grid at optimal timeslots for maximum economic benefits.

Section 6. Case studies

Whether individual homeowners decide to buy a battery, and if so, whether they recommend one to their neighbors, depends on their experience. These case studies are real-word examples of the experience of consumers installing batteries, to shed light on what holds back battery deployment across Europe.

The case studies are of two homeowners in Europe, one largely motivated by money-saving thanks to Italy's tax credit system, and the other motivated to increase the self-consumption on existing solar panels. Both consumers are ultimately satisfied with their purchase, although the economics on the UK system do not look particularly attractive.

In both cases, and for other battery buyers BNEF has spoken with, the installer is a key player in the customer relationship and working with an experienced firm is extremely valuable.

Table 6: Summary of case studies

	Installation	Price	Savings/ revenue	Payback period
Veneto, Italy	21.3kWh Pylontech battery system with 9.5kW of solar panels and 7kW electric vehicle charger	€26,700 (including VAT)	Tax credit of 50% of capex amortized for 10 years About €2,900 in avoided electricity cost	7 years
Landford, UK	5kWh battery system added to 3.67kW of existing solar panels	£6,529 (including VAT)	Increased solar self-consumption targeted. Likely savings of less than £316 per year	>20 years

Source: BloombergNEF

6.1. Veneto, Italy – homeowner seeking bill savings

This Italian investment in PV and batteries is expected to pay back in seven years, thanks to Italy's 50% tax credit system, and continue to supply power long after that.

A single-family household with annual power use of 14.1MWh installed 9.5kW of PV panels connected to two inverters, at the same time as a 21.3kWh Pylontech battery system and a 7kW charging point for electric vehicles. One inverter is a 4kW string inverter and the other, a 6kW hybrid PV inverter. The home is fully electric, and no gas is used for water or space heating. The total capex for 9.5kW of PV, 21.3kWh of batteries and a 7kW electric vehicle charger was €26,700 including installation and VAT, with 50% of the cost amortized in annual instalments over 10 years. This helped inform the decision to make all the upgrades at once and install the very large system.

The battery was delivered in January 2023 by Italian firm Energy SpA, which is listed on the Euronext Growth Milan stock market, and its local partners. The installer estimates that the Veneto home would run on 63% solar with the battery configuration, saving the purchase of about 9MWh of electricity each year (Table 7). Assuming that this is correct, at an average avoided power price of €0.33 per kWh, the system would pay back within seven years and continue to save the homeowner money after that.

Table 7: Economics of a 2023 home electrification investment (PV and batteries) in Veneto, Italy

Year	1	2	3	4	5	6	7	8	9	10
Total electricity produced (kWh)	11,156	11,078	11,000	10,923	10,847	10,771	10,696	10,621	10,546	10,473
Total home electricity demand (kWh)	14,133	14,345	14,560	14,779	15,000	15,226	15,454	15,686	15,921	16,160
Direct self-consumption (kWh)	5,032	4,996	4,961	4,927	4,892	4,858	4,824	4,790	4,757	4,723
Self-consumption via battery (kWh)	3,933	3,862	3,793	3,724	3,657	3,592	3,527	3,463	3,401	3,340
Energy fed into the grid (kWh)	3,213	3,191	3,168	3,146	3,124	3,102	3,081	3,059	3,038	3,016
Energy purchased (kWh)	5,169	5,487	5,806	6,128	6,451	6,776	7,103	7,432	7,763	8,097
% self-consumption	80%	80%	80%	79%	79%	78%	78%	78%	77%	77%
% energy of battery in self-consumption	44%	44%	43%	43%	43%	43%	42%	42%	42%	41%
% of own energy generated (Autarky)	63%	62%	60%	59%	57%	55%	54%	53%	51%	50%
Electricity price, € per kWh	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33
Savings on bill	2,958	2,923	2,889	2,855	2,821	2,789	2,756	2,723	2,692	2,661
Tax deductions (50%)	1,335	1,335	1,335	1,335	1,335	1,335	1,335	1,335	1,335	1,335
Annual maintenance	0	-150	-150	-150	-150	-150	-150	-150	-150	-150
Initial capex	-26,700									
Annual cashflow	-22,407	4,108	4,074	4,040	4,006	3,974	3,941	3,908	3,877	3,846
Payback period	7 years									

Source: Energy SpA, adapted by BloombergNEF

6.2. Landford, UK – solar self-supply enthusiast

A recurring theme in the UK purchasing process was that the installer selected by Solar Together could not meet deadlines and cut corners on work.

A single-family house with two occupants and approximate annual electricity consumption of 5,300 kWh per year (mostly from a heat pump), with a 3.67kW west-facing PV system installed in 2011. In August 2022, the homeowners paid a £150 deposit to add batteries under the "Solar Together" aggregate purchasing scheme in the UK, under which local governments organized bulk build of highly commoditized residential solar and batteries through selected firms. The "Solar Together" scheme has had significant difficulties, partly related to labor shortages in the UK in 2022, and many of the selected installers have failed to deliver on their promises.

In October 2022, the homeowner received quotes for three products with different sizes – a 13.5kWh battery, a 5kWh battery, and a 3kWh battery. Looking at daily generation (often over 5kWh), the homeowner chose the 5kWh based entirely on size, as recommended by the installer.

The price was £6,529 (including VAT), with a monitoring system. A 25% deposit was paid in October 2022.

The battery was eventually installed in January 2023. The homeowner had been assured by the surveyor that installation up on the wall would be possible, but only one person turned up and since the battery weighed 59kg, it was installed low down on the wall. The original wiring was also much too tight behind the battery, causing the system to cut out and need to be rebooted. The first battery installed was dented and had to be replaced and completely rewired. For this, the homeowner finally managed to get in touch with an experienced individual at the installation firm. That individual has now moved to a different company.

The payback time for one UK system is almost certainly over 20 years, but the buyers are satisfied with the purchase.

The entire system was much more complicated and less integrated than it could be. However, the battery system has been working successfully, significantly reducing the home's grid electricity use. Import from the grid from April to September 2023 was 448kWh, compared with 1,034kWh for the same period in 2022. Figure 16 shows an early day of system operation, and it is visible that the battery charges from the sun and discharges in the evening as planned. There is not yet a full year of data to ascertain actual system savings, but the absolute best case of the six summer months being the same as the winter months and therefore the system saving 1,172 kWh per year at £0.27 per kWh would save just £316 per year – a payback time of over 20 years. The homeowners may add further solar panels on the east side of the house, or charge at times of low power price when time-of-use power tariffs become more common, but clearly this is not primarily a money-saving purchase.

Figure 16: Activity of Landford battery on February 8, 2023

Source: Homeowner, Solis Cloud, BloombergNEF

6.3. Challenges and takeaways

The economics for residential storage in Europe are often poor without substantial subsidies like Italy's Superbonus and tax credit schemes. However, many consumers in Europe are enthusiastic about the technology and keen to buy.

Challenges encountered by these consumers in their battery adoption process, and a summary of potential improvements to help uptake of residential batteries are:

- **Consumers are often put off by complicated installation processes, long wait times and poor customer service.** This is likely to improve in future as the market becomes mature, and companies level up. It is important for technology providers, local governments and other stakeholders to select and work with well-run installation firms, to avoid creating a poor reputation for the industry and themselves. Building up a competent installer workforce is also important because, as Section 4.2 found, consumers trust the installers to make the safety decisions and only stock products that will not cause problems.
- **Installers need more guidance from technology providers**. As found in Section 5.2 partnerships between technology providers and local operators are very important in market adoption, as firms learn to work with certain designs over time. More involvement from technology providers will also help reduce wait times and issues encountered in installations above.
- **Consumers want simpler and more accurate data on how systems perform.** One repeated pain point is a lack of data on expected performance such as household electricity consumption by time of day, which would enable the household to calculate exact savings. This will also help reduce concerns of consumers that believe installers may overstate the economic benefits of the system. However, the homeowners here did not find this a major concern, as they were motivated by subsidy (in Italy) and green consumption goals (in the UK).
- **Consumers prefer to make electrical home upgrades all at once.** Uptake will likely increase if providers offer multiple different technologies for a holistic electrification upgrade, and are able to provide maintenance and after-sales service for these technologies as well. The consumer wants to have one responsive point of contact for all their home electrification products, and may choose not to go ahead with a purchase if it requires multiple installations and multiple points of contact. This point of contact will ideally be responsive to customer concerns and provide reliable after-sales service.
- **Consumers want greater precision and accuracy in product offerings.** This includes installers providing honest advice on system sizing and product choice based on the current and expected future electrical load of the household and other factors. Consumers also stress the importance of having a modular or scalable product, and in most instances would benefit from the option to have smaller increments in module size increases, so as not to overpay for more capacity than they need, or to install a smaller system than is ideal. Installers should also correctly measure the space available for a new system, and consider best placement of solar panels, inverters, and batteries. Arrive at the site with the correct number of staff and all necessary equipment.

Section 7. Rewarding power system flexibility services

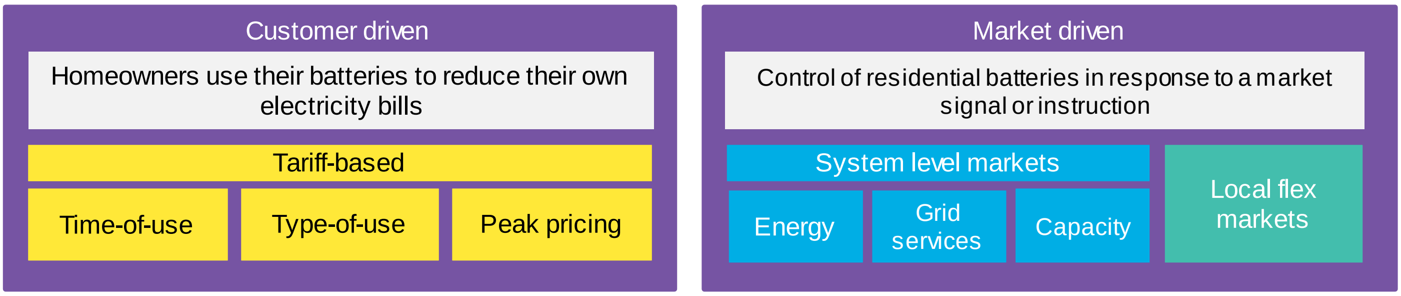
Although residential batteries can provide many power system benefits (see Section 2), the market structures for compensating homeowners for the flexibility their batteries provide are still nascent. This section explains the different ways residential batteries can help the power system, how homeowners are currently rewarded for this, and suggests potential improvements to encourage uptake as well as improve the impact of residential batteries can have on the grid.

7.1. How residential batteries can provide flexibility

There are two ways that residential batteries can provide flexibility to the grid (Figure 17).

- The first is **customer-driven**, where consumers that primarily want to reduce their bills or increase solar self-consumption can indirectly help the grid. For example, when consumers charge from solar and then supply the house when the sun goes down, they can help to flatten out the duck curve. Changing electricity tariffs to "time-of-use" rates, for example with cheaper power in hours of maximum solar generation when the "duck curve" has a belly (Figure 4), encourages more of this grid-supporting behavior and can incentivize battery adoption. Customers do not have to know anything about what is happening on the grid, but simply respond rationally to price signals. In many markets today, however, electricity is often priced at a flat rate per kWh for homes, so customers are not incentivized to act this way.
- The second is **market-driven**, where residential batteries participate in system level energy, grid service and capacity markets, or local flexibility markets run by distribution grid operators. This requires residential batteries to be aggregated into virtual power plants, as individual systems are generally too small to participate in markets on their own.

Figure 17: Ways that residential batteries can provide flexibility to customers and the wider power system



Source: BloombergNEF

Customer-driven – price signals encourage grid-supporting behavior

When customers use batteries to move excess rooftop solar generation from the day to the evening (when electricity demand typically peaks, as in Figure 16), the evening electricity demand that must be met by large power plants reduces. This flattens the net load curve and is good for both grids and carbon emissions, as high evening load is nearly always met by the least efficient, most polluting and most expensive fossil fuel plants (gas, coal or even sometimes oil). These fossil fuel plants are also expensive, so cutting their use also reduces the amount that the power system operator needs to pay for the system to work.

Many European countries still have flat tariffs for electricity, which disincentivizes both batteries and smart charging and discharging behaviors.

Homeowners are more likely to shift their electricity use in ways that benefit the power system if price signals are passed to them. In Europe, most retailers still offer flat electricity tariffs that do not reflect differences in wholesale electricity prices throughout the day. This does little to encourage customers to buy batteries that can shift their electricity use away from times of peak demand, when wholesale electricity prices are high. Green-minded customers or solar self-supply enthusiasts may install a battery anyway, but customers primarily interested in electricity bill savings are unlikely to do the same. Customers are even less likely to do so if there are feed-in tariffs or export tariffs that pay for exported solar generation, though these are increasingly rare.

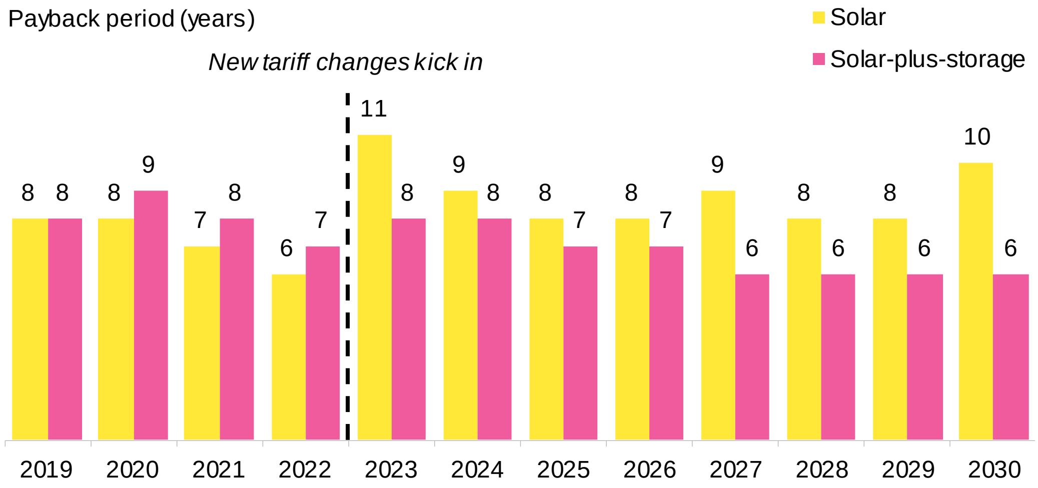
Introducing time-of-use tariffs that allow residential customers to benefit from differences in wholesale electricity prices during a day (a benefit that large electricity consumers and generators already have) can encourage the pairing of batteries and smart charging behavior. Other revisions to tariff structures (for example, charging fees to homeowners exporting solar to reflect their use of the grid) can also encourage batteries.

A prime case study is California, which gets about 21% of its electricity from solar and has a well-developed duck curve. All of this solar will now be compensated under the NEM 3.0 tariff structure change, which became effective in 2023 despite protests from the solar industry.

Under NEM 3.0, solar exports are compensated at the “avoided cost”, or ACC, which represents the long-term hourly value of a distributed energy resource (DER) for the utility grid, measured in $/kWh. The California Public Utilities Commission calculates these values every year. California already had time-of-use utility rates, which depend on utility and time of year. In 2022, an average solar owner received about $0.17/kWh during the day and $0.41/kWh in the evening for power.

The new proposed rate structure makes the payback period for home solar and storage shorter than for solar-only in California (Figure 18).

Figure 18: Payback period for California residential solar and solar-plus-storage in California, before and after NEM 3.0 changes to electricity rates



Source: BloombergNEF Note: More information in NEM 3.0 Will Not End California's Rooftop Solar Market *(web | terminal)*

BloombergNEF expects the California home solar market to slow a little. Permits for new home solar systems from data provider *Construction Monitor* show activity has remained strong in 2023, but most of these probably applied for interconnection before NEM 3.0 came into force. However, roof owners in California will continue to add solar and especially solar with storage.

Norway is another prime case study where time-of-use tariffs for most consumers have been linked to spot power prices since 2019. Consumers can look up the power price forecast for 12 to 36 hours, and decide when to do laundry – or they can automate the charging of batteries or electric vehicles for the periods when prices are lowest.

Time-of-use tariffs can be complex to administer and require smart meters to be installed.

What's holding back time-of-use tariffs?

Utilities frequently resist time-of-use tariffs because they are more complex to administer and require more sophisticated meters to be in place. There may also be a financial disincentive in markets where utilities are integrated across power generation and retail, meaning that some utilities may not want to implement measures that risk reducing electricity demand and utility revenues overall.

Market driven – customers give up some control

At the system level, residential batteries can participate in wholesale energy and capacity mechanisms, provide grid services such as frequency response, voltage control and some black start services (i.e., can bring the grid back online if it has gone down), though they are not always the best option for these grid services (Table 8).

Table 8: Grid service capability of distributed energy resources

Application				Wind	Utility-scale solar	Small-scale solar	Electric vehicles	Utility-scale batteries	Small-scale batteries
System level markets	Wholesale energy			●	●	●	●	●	●
	Capacity mechanisms			◑	◑	◑	◑	●	◑
	Grid services	Frequency	Fast	◑	✗	✗	○	●	◑
			Primary	◑	◑	○	○	●	◑
			Secondary	◑	◑	○	○	●	◑
			Tertiary	◑	◑	○	◑	●	◑
		Inertia		✗	✗	✗	✗	◑	○
		Voltage		●	●	○	✗	●	◑
		Black start		◑	○	✗	✗	●	◑
Local flexibility markets				○	○	●	●	●	●

✗ No capability ○ Poor suitability ◑ Limited capability ● Well suited

Source: BloombergNEF. Note: Not all markets distinguish between the various frequency applications.

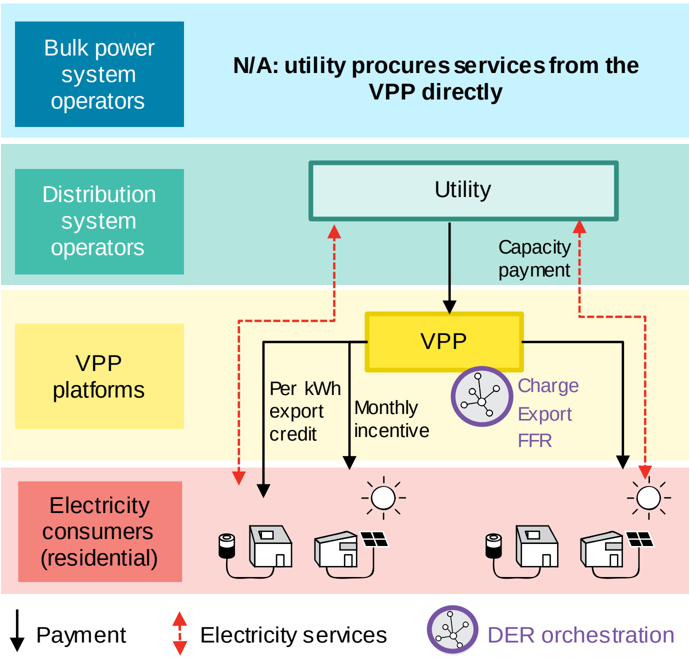
Residential batteries can also participate in emerging local flexibility markets, which are being formed by regional distribution grid operators. These local flexibility markets can be particularly suitable for residential batteries, due to the small minimum bid sizes, as well as the location-specific needs of these services.

The way that residential batteries are aggregated to provide flexibility changes depending on whether utilities in a market are integrated across power generation, system operation and retail, or whether markets are deregulated and competitive.

In vertically integrated markets like the Southwest and Southeast of the US, and many developing countries where there is no competitive wholesale market and a single utility is in charge of delivering energy to the end customer, battery owners may be enrolled in a program that is operated by an aggregator (or virtual power plant operator) who is in charge of dispatching that equipment to respond to what a utility needs (Figure 19). The utility then pays the battery owners for being part of the program.

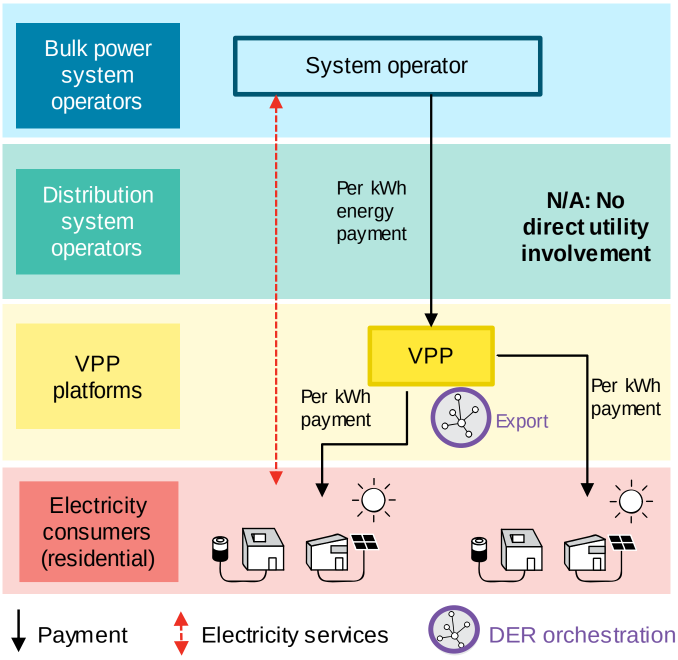
In competitive markets like the UK and Germany, distributed energy resources can access the wholesale market by being aggregated through a virtual power plant operator who bids that capacity and dispatches it into the wholesale market (Figure 20). A single residential battery cannot bid into the wholesale market, and would pay heavy associated fees to register in the market and install relevant metering. This mechanism typically requires that wholesale market rules are revised to ensure that these virtual power plants can access markets.

Figure 19: Illustrative operations of utility-integrated battery virtual power plant in vertically integrated markets



Source: US Department of Energy, BloombergNEF. Note: VPP = virtual power plant., DER orchestration refers to how the VPP platform manages the distributed energy resources (DERs) to deliver a specific service. Example in these figures are not comprehensive. FFR is Firm Frequency Response, a grid service.

Figure 20: Illustrative operations of residential batteries in a virtual power plant in a competitive market



Source: US Department of Energy, BloombergNEF. Note: VPP = virtual power plant., DER orchestration refers to how the VPP platform manages the distributed energy resources (DERs) to deliver a specific service. Example in these figures are not comprehensive. FFR is Firm Frequency Response, a grid service.

Market access

Market access rules define how distributed resources such as residential batteries can register and operate in wholesale energy markets. The absence of such rules is a major barrier to adoption of aggregation and virtual power plant business models, as many of the potential markets that aggregated resources can participate in were designed with large power plants in mind. Defining and implementing these rules is critical for the optimal participation of aggregated distributed energy resources on the grid.

The US Federal Energy Regulatory Commission (FERC) Order 2022, issued in September 2020, provides a strong framework outlining requirements that regulators or grid operators setting market rules must follow to encourage participation of distributed energy resources (DERs). This framework includes the review of eligibility criteria such as minimum size requirements, locational requirements, information requirements and metering requirements. It also outlines requirements for coordination between transmission grid operators, distribution grid operators, aggregators and local authorities.

BloombergNEF's assessment of how rules across key markets align with the FERC Order 2022 framework finds that California is currently one of the most advanced (Table 9).

In other competitive markets such as the UK, market rules for distributed energy resources have improved over the years, but are not coordinated across wholesale energy, grid service, capacity and local flexibility markets. While grid service and capacity have been open to aggregators for several years, the wholesale energy market is just opening. Still, other fine details such as metering requirements often limit actual participation of residential batteries.

Table 9: BNEF assessment of distributed energy resource market rules based on US FERC Order 2222 framework

Requirement	Subsection	California	UK	Italy	Australia	Belgium
Eligibility to participate	Participation model	(yellow)	(green)	(green)	(green)	(green)
	Technology requirements	(green)	(green)	(green)	(green)	(yellow)
	Double counting	(green)	(green)	(yellow)	(green)	(yellow)
	Aggregation size (100kW or less)	(yellow)	(yellow)	(green)	(yellow)	(yellow)
Locational requirements		(green)	(yellow)	(green)	(green)	(green)
Information requirements		(green)	(green)	(green)	(green)	(green)
Metering and telemetry requirements		(green)	(yellow)	(green)	(green)	(green)
Coordination		(green)	(green)	(yellow)	(yellow)	(yellow)

Source: BloombergNEF Note: Colors refer to BNEF assessment of compliance: green = compliant, yellow = compliance in progress. FERC = Federal Energy Resource Regulatory Commission.

7.2. The value of providing flexibility for homeowners

In this section, we consider where residential batteries are participating in energy markets, the challenges to participation, and the economic benefits that residential battery owners receive from having their batteries participate in various markets.

The most common applications that residential batteries are aggregated for are primary frequency response and capacity markets (Table 10). Residential battery participation in wholesale energy markets is less common as it requires complex rules to be developed around "double counting" (selling services in two markets at the same time). Participation in local flexibility markets is also uncommon, but only because not many exist today.

Table 10: Participation of residential batteries in energy markets across selected regions

Application			UK	Italy	Australia	Belgium
System level markets	Wholesale energy		Yellow	Grey	Green	Grey
	Grid services - Frequency	Fast	Yellow	Grey	Grey	Grey
		Primary	Green	Grey	Green	Green
		Secondary	Yellow	Green	Green	Grey
		Tertiary	Yellow	Green	Green	Grey
	Capacity		Green	Green	Grey	Green
Local flexibility markets			Green	Grey	Green	Grey

Source: BloombergNEF. Note: Residential batteries participate through aggregation rather than a single battery. Green = residential batteries are participating, Yellow = residential batteries are yet to participate but market rules are evolving, Grey = residential batteries cannot participate

BloombergNEF considers local flexibility markets to be the best opportunity for residential batteries. These markets require distributed energy resources to solve location-specific grid challenges. Although they are not widespread globally, their emergence as power markets transition will create significant opportunities for distributed energy resources like residential batteries to earn a return from the services they provide.

While power systems benefit from residential batteries being made available for grid services like frequency response, they are unlikely to be economically attractive in the long term. The major challenges include:

- Demand for frequency response and other grid services tend to be static, so building a long-term business model based on their value is difficult, as prices tend to drop steeply as new resources start to participate and eventually saturate markets.
- Metering and performance requirements for these services are often particularly challenging. Fleets of residential batteries may be unable to submit telemetry data as often as grid operators would prefer and may also be unable to operate continuously.

Residential battery participation in wholesale energy markets will depend on complex rules to be developed around "double counting". Double counting refers to a customer participating in more than one market mechanism at the same time, which, without proper verification, leads to them benefitting twice financially for the same energy delivered, for example. This may occur when a customer is enrolled in a bilateral utility demand response program, while that same capacity is registered with another aggregator that is bidding that same capacity into the wholesale market. Double counting rules try to avoid overpaying for system benefits delivered.

UK

In the UK, residential batteries can participate in wholesale energy, grid service, capacity and local flexibility markets.

- Participation of residential batteries in grid service markets has declined, following the move from Firm Frequency Response to a new suit of Dynamic Frequency Response services metering and performance requirements that do not suit residential batteries.
- Participation of residential batteries in the capacity market is typically led by retailers with large virtual power plant portfolios. These are mainly for demand response, where residential batteries play a small part.
- Access to the wholesale energy market will come from late 2024, following the October 2023 decision by UK energy market regulator Ofgem to allow access of aggregated distributed energy resources into wholesale energy markets.

Participation of residential batteries in UK frequency response markets goes back to 2018, when UK-based electricity retailer Social Energy (now rebranded to Levelise) became the first company in the UK to win contracts to provide firm frequency response with an aggregated fleet of residential battery systems. Social Energy was awarded further contracts to provide frequency response in the following two years, and by the end of 2020 was using 80% of its fleet of customer-sited batteries to provide 4MW of capacity for the firm frequency response service.

Frequency response markets are quite shallow, so when a lot of batteries participate, prices go down.

The scheme was quite lucrative for homeowners, as Social Energy passed on about 70% of revenues earned from frequency services to its customers, aiming to offer a faster payback for residential battery and solar owners. The company claimed in 2021 that these revenues helped drive £226 of savings per year for the average customer.

UK frequency response prices have declined since, as more and more energy resources participate in frequency markets and push down prices, reducing the value available to homeowners. As frequency response markets are limited in size and prone to such declines in price, this decline in prices is unlikely to reverse and value will need to come from elsewhere.

One possible value stream is the wholesale market, for which reforms are ongoing. To ensure that access to this market comes with value for customers, UK regulator Ofgem issued a decision that aggregators will not be liable for unexpected costs that energy suppliers face if aggregator actions result in lower-than-expected customer demand.

Ofgem expects the introduction of the proposed solution to lead to increased participation of aggregators and customers that can adjust their demand or generation in response to wholesale energy price signals. The proposed solution is expected to drive greater volumes of flexibility deployment, due to the lower costs imposed on aggregators, and therefore drive greater welfare benefits compared to the alternative.

Another key value stream in the UK will be local flexibility markets, which are emerging as regional distribution grid operators become more involved in grid management. The UK has one of the most mature local flexibility markets, as all six distribution network operators operate some form of local flexibility market. The markets accept all resources, including the aggregation of distributed energy, and have high participation of residential batteries. Products are largely uniform across distribution grid operators, with four standardized options (Table 11).

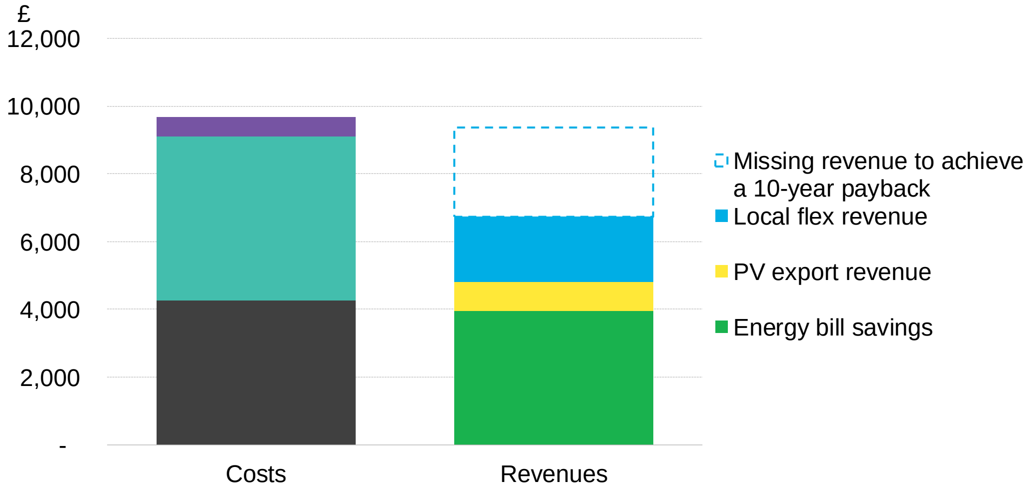
Table 11: Standard UK local flexibility market products

Name	Sustain	Secure	Dynamic	Restore
Need type	Pre-fault	Pre-fault	Post-fault	Post-fault
Use-case	The DNO knows with certainty where the network will be under strain and at what times, so contracts capacity for those predicted times.	The DNO predicts, with limited certainty, when a point on its network will be under strain and so contracts to have the option to activate local flexibility.	The DNO requires support for planned but temporary network constraints, for example planned outages for maintenance work.	The DNO must respond to an unplanned outage or fault, such as major equipment failure or lighting strike.
Minimum bid size	10kW	50kW	10kW	50kW
Availability payment	No	Yes	Yes	No
Utilization payment	Yes	Yes	Yes	Yes
Dispatch notice	Scheduled dispatch	Varies by DNO	Real-time dispatch	Real-time dispatch

Source: BloombergNEF, UK Power Networks Note: DNO = Distribution Network Operator.

BloombergNEF estimates that a UK residential solar and battery system would need an additional annual flexibility service revenue of at least £163 per kW per year to reach a 10-year payback, on top of energy bill savings and export revenues from a PV system (Figure 21). Annual local flex revenue of £47.50 per kW per year, consistent with UK Power Network's Sustain product payment, can contribute to that number. This assumes the system receives the local flex revenue every year over the lifetime of the PV and storage system, which is not guaranteed. Seven-year contracts are the longest guaranteed payments available today.

Figure 21: UK residential solar and battery system costs and revenues, including local flexibility payments



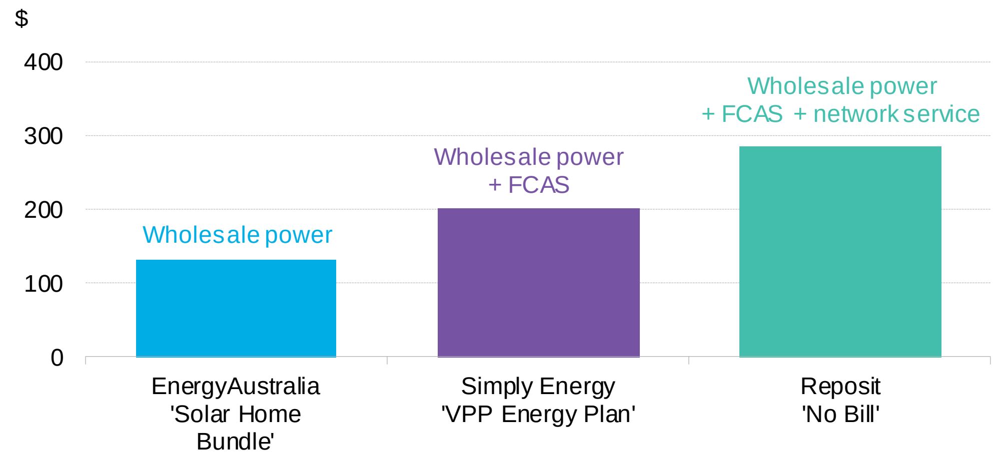
Source: BloombergNEF. Note: Analysis using Energy Consumption Optimization Model. Local flex revenue is £47.50 per kW per year – the value of UK Power Network's local flex contract. Modeled system was a 4kW PV, 2.6kW/7.2kWh battery, PV capex £4,275, battery capex £4,835, over a 25-year period from 2020. Battery replacement in year 15. See UK Local Flexibility Markets: A Case Study *(web | terminal).*

Australia

In Australia, residential batteries can earn revenues from the wholesale energy market, the grid services market (known as Frequency Control and Ancillary Service, or FCAS) and local flexibility markets.

The chart below summarizes the additional benefit that residential battery owners in Australia were quoted for agreeing to join virtual power plant programs. The offers across three retailers include a mix of three different flexibility markets potentially open to customers, with the retailer Reposit offering the most revenues for the most services, nearly an additional $300 a year (Figure 22).

Figure 22: Annual extra benefit to residential battery owner in New South Wales, Australia joining different virtual power plant programs



Source: BloombergNEF, Energy Consumption Optimization Model. Note: VPP = virtual power plant, FCAS = Frequency Control and Ancillary Services. Data based on 2022 prices.

The availability of multiple value streams can result in more potential value for customers. This can be a virtuous cycle, as more attractive offers can result in more customers and virtual power plant capacity, which in turn can be used to access more value streams.

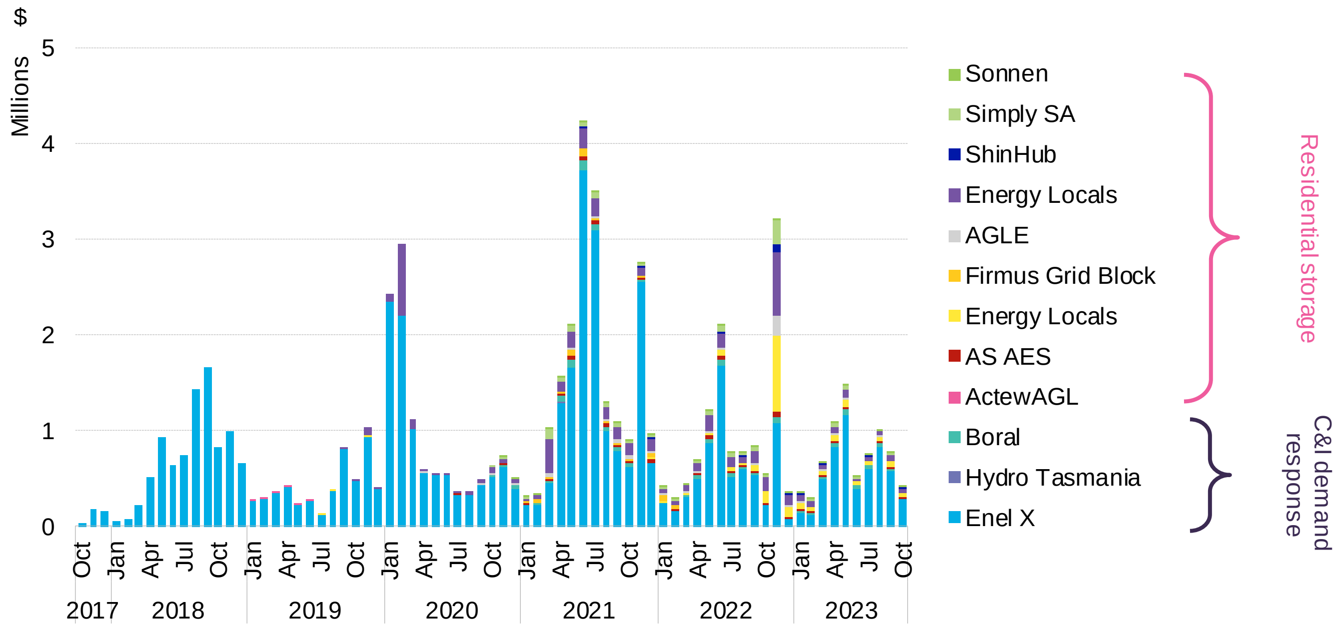
Crafting an effective customer offer is complex as grid service market revenues are uncertain

At the same time, offers need to present clear and compelling value to customers in an easy-to-understand package. Offering more services and revenues also comes with higher use of the consumer's battery, and operators need to ensure they do not cannibalize too much of their own profits in their efforts to attract customers. It is also important to provide simplified offerings, as most consumers find it hard to understand multiple options.

One major challenge for retailers making these offerings in Australia is that the frequency control and ancillary services (FCAS) market, thought to be the most lucrative source of value for virtual power plants in the country, has unpredictable revenues. Since 2018, about 40% of VPP FCAS earnings have come from just two outage events. These were from unexpected coal plant outages in 2021 and a breakdown in the South Australia-Victoria interconnector in 2020 (Figure 23).

The longevity of FCAS as a lucrative source of revenue is also uncertain. While competition from synchronous fossil fuel generation is falling as those plants are taken offline, Australia's fleet of utility-scale batteries is growing rapidly, and residential batteries will have to compete against these assets to serve FCAS demand. This creates complexity for retailers that need to be able to make firm offers to customers even with this uncertainty.

Figure 23: Australia monthly virtual power plant revenue from frequency control and ancillary service market by asset



Source: BloombergNEF, Australia Power Dashboard. Note: VPP = virtual power plant, FCAS = frequency control and ancillary services.

Italy

In Italy, residential batteries gained access to the grid services market through the launch of the Virtually Aggregated Mixed Units (UVAM) pilot project in November 2018. This created a new participation model for aggregators to provide manual secondary (mFRR) and tertiary reserves (RR) in 2019, followed by automatic secondary reserves (aFRR) in 2021.

For the first time in Italy, the UVAM pilot offered aggregated assets an availability fee (in euros/MW), in addition to the typical payments for energy dispatched (in euros/MWh). According to grid operator Terna, this added availability fee was introduced to help compensate demand-side resources that incurred fixed costs to install necessary monitoring and measuring equipment to participate.

Italy's UVAM pilot project for paying virtual power prices hit a snag in the energy crisis of 2022, when high wholesale prices destroyed returns.

The payment model helped encourage participation, but the capped availability fee of €30,000/MW/year limited the profitability for aggregators as prices rose during the European energy crisis. For many months during 2021 and 2022, wholesale energy prices were higher than the strike price, obliging aggregators to pay distributed energy resource owners more than they earned from the service.

Aggregators started to exit the pilot early as a result, slowing progress towards the development of a grid service market that includes distributed energy resources. This pilot and Italy's experience so far is a cautionary tale about the complexity of integrating residential batteries into power markets.

Belgium

In Belgium, residential batteries can be aggregated to participate in the recently opened capacity market, as well as provide grid services.

Participation of residential batteries in the grid service market was led in late 2022 by grid operator Elia, aggregating residential batteries from over 2,000 families in Flanders into a virtual power plant. According to Elia, the virtual power plant had made 6MW of capacity available by the end of 2022, meeting some of its requirement for 26MW of fast and flexible capacity.

Consumers were required to have a home battery and a smart meter to participate. The transmission system operator has stated that consumers notice virtually nothing as a result of their participation, and that they receive a remuneration depending on the market prices in the balancing market. This approach, where programs are directly led by grid operators, can benefit uptake.

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