WHITEPAPER

100 PERCENT RENEWABLE ENERGIES FOR GERMANY

BATTERY STORAGE AND THE ENERGY TRANSITION

Created by Hans Urban, M.Sc. Eng., on behalf of Solar Promotion GmbH

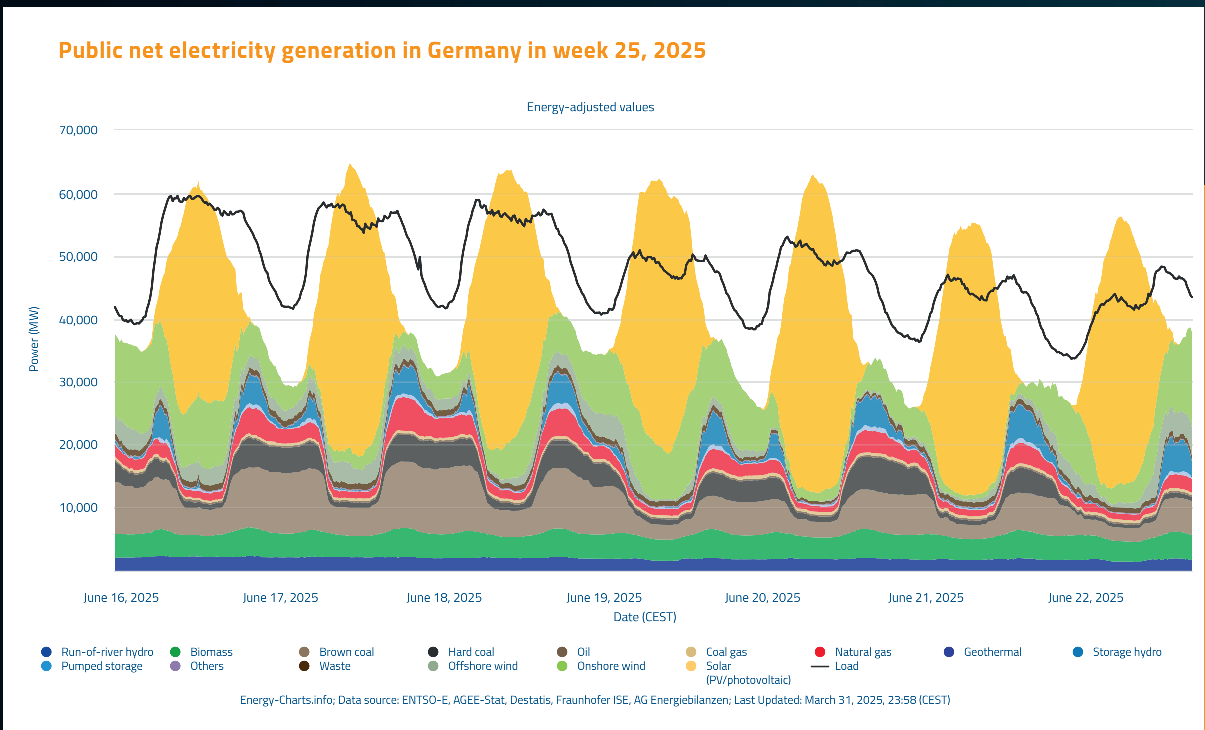
EXECUTIVE SUMMARY

CAN WE EXPECT A BATTERY STORAGE TSUNAMI?

More than a year ago, Montel, a news platform, reported data on grid connection requests for battery storage systems in Germany. The combined capacity of 161 gigawatts surprised many storage industry players, prompting talk of a ‘battery storage tsunami’ in the media.

Since then, the reported numbers have been rising steadily. PV Magazine and the battery podcast Geladen (Charged), amongst others, mentioned 240 to 340 gigawatts at the start of 2025, and on August 29, 2025, PV Magazine and the platform Regelleistung Online (Balancing Power Online) revealed that the connection load waiting for approval exceeded 500 gigawatts.

In view of these figures, it should be abundantly clear that there is a mismatch between the demand for grid connections and the practical and systemic possibilities of battery storage implementation. In fact, 500 gigawatts of storage capacity would be several times the typical Ger-man grid load of approximately 60 to 80 gigawatts. (See fig. 1)



At the same time, an electricity system largely based on intermittent renewable sources of energy such as wind and sun depends on sufficient storage capacity. Providing enough storage is the only way of ensuring that generation and consumption can always be harmonized.

It is a given that the success of the energy transition rests on dynamic growth in storage, which introduces a host of new questions:

- How many storage devices do we actually need; how many make sense?
- Where should these storage devices be located?
- How can they be integrated into the existing grids?
- Who is going to build these storage devices?
- Who is going to pay for, and who is going to operate these storage devices?

The storage transition heralds a new chapter in the energy transition. It brings new challenges, many unanswered questions – and no doubt plenty of opportunities for adding value and creating successful, future-proof business models.

This white paper examines the growing significance of battery storage systems for Germany's energy transition. The relevance of battery storage technologies is illustrated by several practical examples of large-scale battery systems: A project implemented by Schoenergie shows how large-scale battery systems can provide grid-forming capabilities and extended system services, such as black starts. Fenecon's battery storage project at Bad Wörishofen thermal baths focuses on adding sustainable value and using electromobility batteries. With 100 MW of output and 238 MWh of capacity, ECO STOR's Bollingstedt project showcases how large-scale battery systems can be operated in a grid-friendly way by using informed operating strategies.

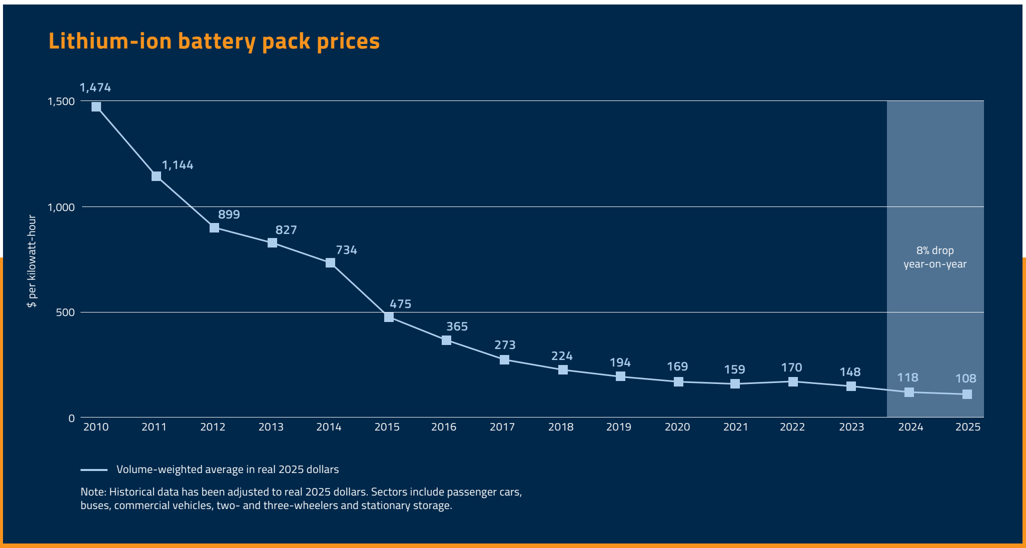
This white paper also describes various storage and business models, ranging from commercial storage systems to large, grid-connected systems, and then goes on to discuss the current regulatory and infrastructure challenges for grid connection, amongst other issues. The final analysis shows that battery storage is key for a climate-neutral and stable energy system, and that it is increasingly profitable – even without government funding. Readers will gain an overview of technological developments, read about use cases and learn about strategic actions recommended for investors, grid operators and energy companies.

THE ENERGY TRANSITION NEEDS STORAGE

Renewable energies have seen dynamic growth over the last few years. Today, around 60 percent of electricity in the German grid is renewable, mostly from wind and solar (see fig. 1, page 2). Renewable energy has thus become an integral part of Germany's energy supply. Fighting the climate crisis requires our ongoing commitment to decarbonization. To drive the electrification of the heating and mobility sectors in particular, the rapid expansion of renewables must continue.

Since 2024, the south of Germany in particular has experienced more and more periods where the generation of electricity from PV exceeded total consumption from the grid. Right now, only few PV installations can be curtailed or actively managed. As a consequence, the oversupply generated during peak production periods causes negative electricity prices, thereby burdening the state budget through the redistribution mechanism under the German Renewable Energies Act. For a number of years, wind power production in northern Germany has faced a comparable scenario. Temporary renewable energy surpluses contrast with periods when wind and solar alone are not enough to cover consumption, thus requiring fossil fuel backup. These effects demonstrate that more energy storage is a prerequisite to decarbonizing our energy supply further by shifting to renewables.

When renewable energy accounted for 50 to 60 percent of the supply, integrating it into the grid was relatively easy. Exceeding this rate, however, will only work if we have suitable energy storage. Short-duration energy storage devices to cover daily cycles are particularly important, but to balance out seasonal fluctuations, we also need long-term storage capacity. Battery storage systems are ideal for storing energy for a few hours. Technological progress, especially the mass production of battery storage cells, has caused battery costs to plummet by 90 percent over the last 15 years. Battery storage is now profitable for many use cases, including the provision of buffer storage for the power grid.



Source: BloombergNEF (2)

MARKET DEVELOPMENT AND CHALLENGES

BATTERY BUFFER STORAGE FOR INTRADAY CYCLES

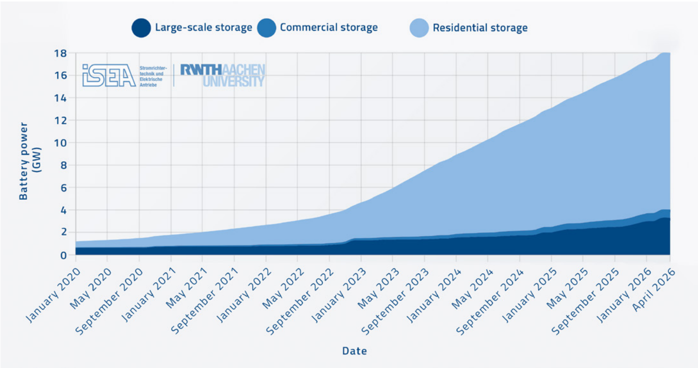
The challenges and opportunities for short-duration battery energy storage are reflected in the Fraunhofer Institute for Solar Energy Systems ISE Energy-Charts (see fig. 1, page 2). On typical summer days, each day follows a similar cycle, with solar power generation frequently being above the load curve in the middle of the day. When, during morning and evening hours, power generation is low, pumped-storage and gas-fired power plants bridge the gap. In the grid of the future, battery storage will play a growing role in energy buffering. This will lead to decreased fossil fuel use, with renewables taking their place. To drive up the share of renewables in the power grid beyond 60 percent, the expansion of generation capacity will have to go hand in hand with the dynamic expansion of storage.

Large-scale grid energy storage is not the only form of storage that is set to grow, though. Residential and commercial storage systems are already being used to store electricity for self-consumption. This is already the case in many prosumer systems, where PV self-consumption is boosted through the integration of storage devices. This development is not immediately apparent from the Fraunhofer ISE's Energy-Charts generation and load curve (fig. 1, page 2), as it exclusively documents measured and billed energy flows.

The Battery Charts by RWTH Aachen University (fig. 3 and 4) show that the expansion of battery storage systems in Germany has mostly happened outside the grid, in what is commonly referred to as the prosumer segment. The growth curves of cumulated battery power and total storage capacity illustrate that the market is currently dominated by residential storage systems.

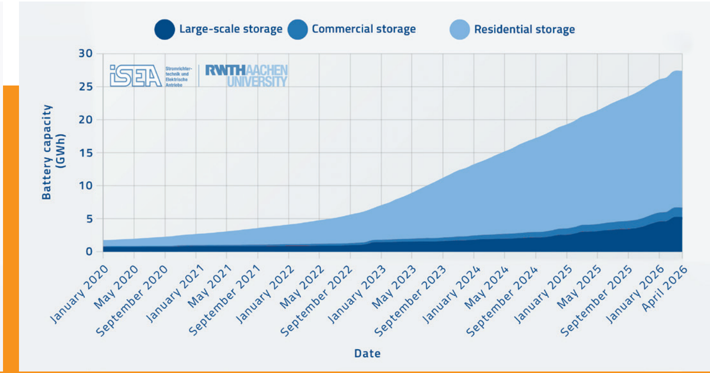
Commercial storage systems frequently fulfil a similar function to that of residential storage systems, i.e. the intermediate storage of electricity generated by photovoltaics. Their growth has been slower than that of the residential segment though, which can be attributed to the lower electricity tariffs for commercial and industrial companies.

Development of battery power across different storage segments



Source: RWTH Aachen, RWTH Aachen University, Chair for Electrochemical Energy Conversion and Energy Storage Systems (Battery Charts) (3)

Development of battery capacity across different storage segments



Source: RWTH Aachen, RWTH Aachen University, Chair for Electrochemical Energy Conversion and Energy Storage Systems (Battery Charts) (4)

HOW MANY LARGE-SCALE STORAGE SYSTEMS DO WE NEED?

Over the past few months, Germany has experienced significant political debate regarding the future trajectory of electricity usage. While there is agreement that rise of sector coupling will lead to a marked increase in power demand, how quickly this will happen remains the subject of controversy. To estimate future storage requirements, we must first consider future power consumption. The proportion of renewables in the future energy mix and their intermittent feed-in rates are also significant considerations.

However, to reliably determine the future need for large-scale storage systems, modelling alone is not enough because there are several other developments that will make our power system more flexible, reducing the need for battery storage:

- European electricity trading
- Electrolysis and Power-to-X
- Flexible electricity tariffs for private and commercial consumers
- Flexible end users (e.g. Section14a of the German Energy Industry Act)
- Smart residential and commercial storage systems used as swarm storage
- Smart charging of electric vehicles
- Flexibility models involving electric vehicles (V2G)
- Optimization of RE plants (e.g. PV with East/West inclination)
- Curtailment of RE systems

These examples show that large-scale storage systems will not be the only option for ensuring the flexibility needed to match generation and consumption within the power grid.

That being said, large-scale storage systems offer universal flexibility and have many advantages over other ways of providing flexibility: Electrolyzers, for example, can be used during periods of oversupply, but as long as conversion back to electricity is not possible, this will be a one-way street. Energy buffering through swarm storage systems and electric vehicles (V2G) can work in both directions. However, these solutions cannot be managed nearly as dynamically as large-scale storage systems, and they also cannot offer additional system services, such as grid-forming, reactive power or black starts.

The conclusion is that the energy transition needs large-scale storage.

BATTERY STORAGE PAYS ITS OWN WAY

The high cost of battery storage is frequently cited as a significant downside of the energy transition. The comparisons used in such arguments are usually biased and overlook the considerable costs the climate crisis will incur, and even ignore the economic effects of our dependence on energy imports; cost remains central to the debate, though. It is, by now, common knowledge that the cost per kWh of solar and wind power is lower than that of any other energy source. But what is the cost of continuous renewable energy supply?

To answer this question, it is important to emphasize that almost all battery storage systems are financed and constructed by private companies without government assistance Battery storage is now financially viable in the open market due to plummeting renewable energy prices during oversupply and rising fossil fuel prices during low supply. This is helped even more by spreads in the pot price, which finance the operation of storage devices, as well as by certain system services like primary and secondary balancing power. The continued price erosion for storage technologies also contributes to enabling these free market models.

Yet, the fact that these storage systems can operate without funding from electricity consumers is even more notable. Several economic studies have shown that battery storage systems can actually dampen prices in the electricity market. The rise of storage devices also ensures that renewable energy can be put to better use even during times of oversupply. A study by GEEC – Global Energy and Environmental Consulting, commissioned by ECO STOR GmbH showed that this could take the burden off the government's RE budget and – in the long run – off the tax budget.(7) This has sparked considerable interest among private investors in financing and implementing such storage projects even without public funding. The business models can vary depending on the use case.

USE CASES AND BUSINESS MODELS FOR LARGE-SCALE BATTERY SYSTEMS

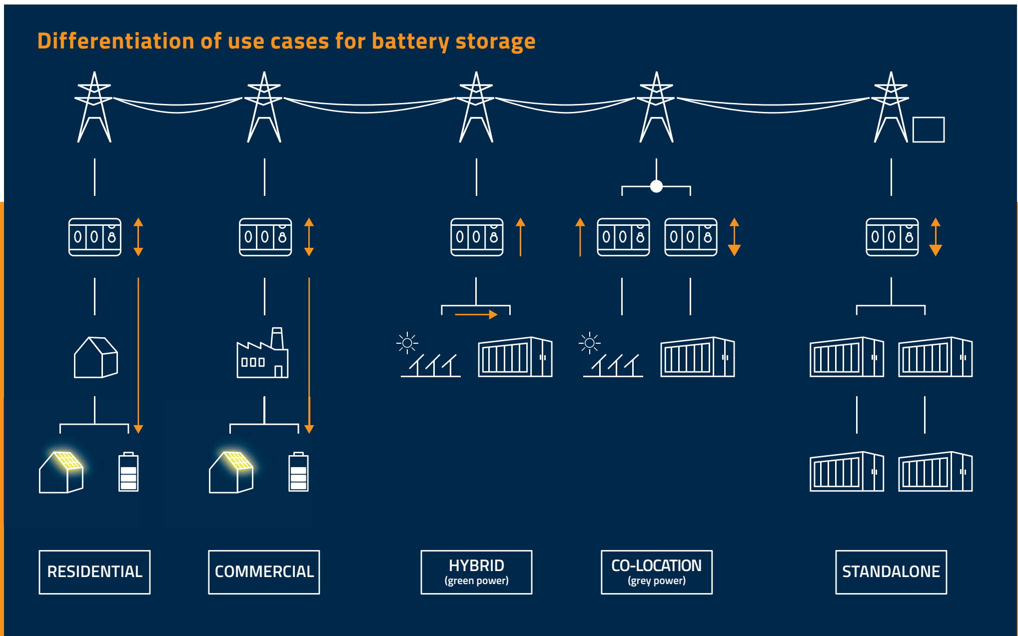
The chart below (fig. 5) depicts the different use cases for battery storage. Storage devices integrated into prosumer systems are shown on the left side – these are generally residential or commercial storage systems, whose main purpose is to boost the share of self-consumption of electricity from photovoltaic installations. They can also be used for other applications, such as peak shaving, or to benefit from variable electricity tariffs. Even though new regulatory approaches (such as the MiSpeL concept) could make this type of storage more relevant for the grid in the future, this document will not explore them in more detail. MiSpel stands for market integration of energy storage systems and charging points. It is a 2025 draft by the German Federal Network Agency, which revises the funding conditions for electricity from battery storage or charging points under the Renewable Energy Sources Act. One of the aims is to permit subsidies for so-called mixed storage devices, such as large-scale battery storage systems and co-location projects, under certain conditions.

The large-scale battery segment mainly comprises grid-connected systems that, rather than being assigned to an individual customer system, are operated via their own dedicated grid connections. The right side of the chart (see fig. 5) shows an example of a stand-alone battery system, which will generally be set up at a suitable grid connection point, independently of a specific renewable energy system. To its left, the gray electricity storage is shown as a co-location storage system sharing the grid connection with a PV system.

Hybrid green electricity storage systems are based on an entirely different model: They are configured to charge only electricity from renewable energies, and do not use grid electricity for charging. Because of their as of yet limited profitability, such storage devices have mostly been used under the funding framework of innovation tenders by the German Federal Network Agency.

However, various concepts for a more flexible power allocation are under discussion for the future, for example, the use of complex measurement concepts or scheduled power allocation.

What the future will bring
Each of the operating models for energy storage shown here is tied to specific business models and has its own challenges. Chapter 6 will discuss these aspects in more detail.



Source: Engineering Office Hans Urban (5)

APPROACHES AND BEST PRACTICES

Based on initial research into finished or construction-ready projects, three best-practice examples for storage expansion in Germany have been selected to illustrate how grid integration and system-serving capability can combine to effectively optimize the integration of renewable energies. They also show what technological developments the future may bring.

EXAMPLE PROJECT 1

Project name	Battery Storage Site in Föhren (Rhineland-Palatinate)
Manufacturer	SCHOENERGIE
Output, capacity	21 MVA, 55 MWh
Grid operator	Westnetz
Commissioning	2025
Specifics	SUREVIVE: Subsidized project for extended system services

The example project by Schoenergie, a project developer and systems provider of photovoltaics and battery storage solutions, is a large-scale storage system in Föhren, which went into operation in 2025. The storage system is co-located with a 21 MWp PV farm and connected to a joint transformer station. In addition to buffering renewable energies, the project's aim is to provide additional grid stability, and to test the system in real-life operation. Unlike most common large-scale storage systems, this battery storage system can operate in grid-forming mode, allowing it to supply power system inertia, reactive power and synthetic inertia, effectively replacing synchronous machines. It is based on SMA's innovative frequency converter technology, which has recently been certified for the provision of these grid-forming characteristics. The entire storage system can perform black starts, and in the case of disruptions, can start up the transformer station as an off-grid system to form an autonomous emergency unit.

With this innovation, even the last remaining advantages of fossil fuel power plants can be replaced by renewable energy in the future. This strenghens the efficiency and stability of energy supply while reducing the need for grid expansion.

As outlined in this white paper, public funding is not required – meaning that neither consumers nor taxpayers bear the costs of battery storage systems. This creates a strong case for private sector investment. That said, this project did receive research funding, despite the absence of a clear refinancing framework for the additional services described above within the electricity market. One reason for this is that key system services – such as grid formation, black start capability, system inertia, and reactive power – are not yet assigned a defined market value in Germany. Nevertheless, these services are essential for ensuring stable grid operation. This project therefore presents potential remuneration mechanisms that could support cost-recovering operation in the future.

(1) Schoenergie GmbH

EXAMPLE PROJECT 2

Project name	Bad Wörishofen thermal baths
Manufacturer	Fenecon
Output, capacity	736 kW each, 1288 kWh each, total: 3864 kWh
Grid operator	Stadtwerke Bad Wörishofen utilities
Commissioning	December 2025
Specifics	Adding regional value and optimizing sustainability through regional production and use of mobility batteries

Companies implement battery storage projects in order to integrate renewable energies and drive the energy transition. Designing storage systems to be as sustainable as possible is part of such a strategy. Fenecon, a battery storage manufacturer, has shown that it is possible both to produce storage devices in Germany and to use German inverter technology.

Despite plummeting costs in recent years, battery cells still add a great deal of value. Nevertheless, industrial-scale production has not yet become established in Germany. To achieve a sustainable value chain under these conditions, Fenecon builds its large-scale battery systems from EV battery blocks. As discussions about the use of second-life vehicle batteries are ongoing, Fenecon is focusing on new batteries. While the large-scale battery systems installed in Germany so far just have a capacity of few GWh, the market for vehicle batteries has reached almost 100 GWh in 2025 alone. Experience has shown that, for various reasons, a relevant share of these batteries are not used, and sometimes have to be recycled, incurring costs. This may be due to minor mechanical damage or shifts in the market. In all cases, these batteries are technically flawless and in perfect working order.

Fenecon's project illustrates that it makes sense to exploit the potential of these high-quality batteries for the large-scale battery market to save resources and money.

The Bad Wörishofen project

In the last few months, the Bad Wörishofen thermal baths have been equipped with state-of-the-art energy infrastructure. Timeless Planet, a project developer specializing in holistic energy solutions for commercial and industrial clients, covered the car part with solar modules. The photovoltaic installation has an output of 1.34 megawatts.

Three Fenecon Industrial L Storage Systems with a total storage capacity of 3.864 megawatt hours and an output of 736 kW each were installed to enable the efficient use and intermediate storage of solar power. The system also features 28 charging stations for electric vehicles and its own substation, which connects the energy infrastructure to the external grid.

(2) Timeless Planet GmbH & Co KG

EXAMPLE PROJECT 3

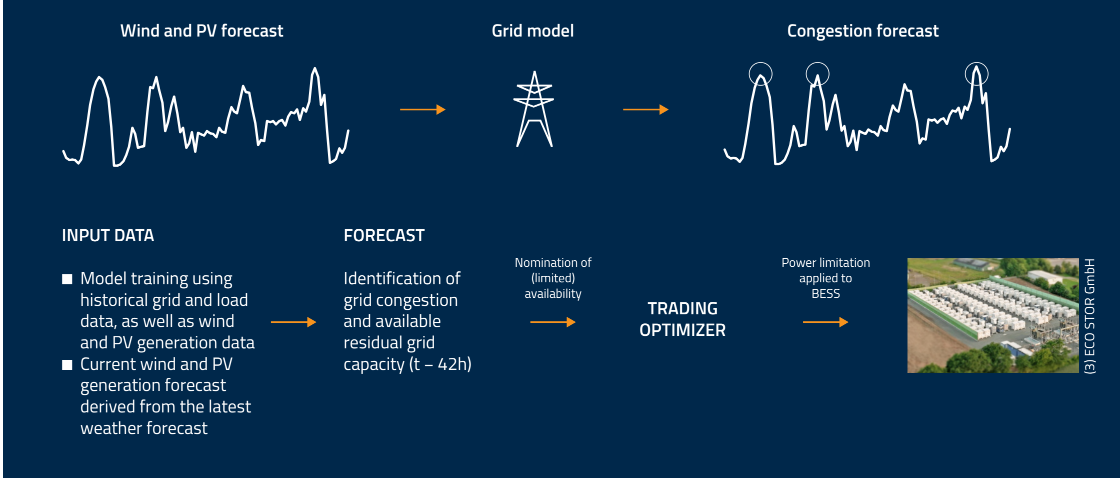
Project name	Bollingstedt
Manufacturer	ECO STOR GmbH
Output, capacity	100 MW, 238 MWh
Grid operator	SH Netz
Commissioning	2025
Specifics	Maximum grid-friendliness and minimum burden on the grid thanks to a proactive operating concept for grid-friendly operation

ECO STOR has grown into one of Germany's largest battery storage system project companies within just a few years. Following numerous projects in the double-digit range, Bollingstedt was not just the largest German storage power plant realized in 2025 (100 MW and 238 MWh) but also the first German project based on a standardized pipeline involving several storage devices in the three-digit output and capacity range. However, the decision to present this project was not guided by its size and associated importance for the storage transition in Germany, but by other criteria:

Bollingstedt in northern Germany has a major surplus of renewable power, mainly from wind power and many PV installations within its grid area. The obvious solution was to install a storage system for the intermediate storage of intermittent energies to achieve high system-serving capability, while the burden on the regional grid was to be kept to a minimum. Back then, there was a lack of forecasts and real-time grid burden data, leading ECO STOR to create a digital twin model of the grid area, incorporating local RE installations. The model combines weather and generation data from wind and solar with historical load values, enabling it to predict grid load realistically. This makes it possible to determine in advance how much electricity can be fed into the grid without causing congestion. At times of high feed-in from renewables, the storage system automatically reduces its discharge rating.

According to initial calculations, the restricted operation of the storage device used in Bollingstedt reduced the earnings from storage device operation by approximately 2 percent. By comparison, static feed-in constraints would significantly reduce the ROI while providing less benefit for the grid operator. ECO STOR and SH Netz, the grid operator, are expecting to gain insights from the modified operation. These should help them to optimize the system further and to develop a model for future variable volumetric grid charges.

Congestion management using a digital twin



Source: ECO STOR GmbH (6)

ADDITIONAL PROJECTS

Large-scale battery systems are a key component of a future climate-neutral and reliable energy supply. If renewable energy expansion targets are matched by an equally dynamic growth in battery storage, this will enable us to replace more and more fossil-based power plants, or keep some as backup. When planning for this scenario, we must not forget that battery storage will also have to take on extended system services such as power system inertia, synthetic inertia and black start capability. Even if a large share of future battery storage systems will be decentralized, preferably located in the vicinity of large PV installations, meeting the demand for these system services in particular will require large storage units. These will have to be situated near exceptionally high-performing grid nodes.

The obvious conclusion is to continue the transformation by erecting these kinds of battery storage units near the sites of existing power plants. The higher the grid power output is in comparison with the output of the battery storage system, the less relevant the question of optimal grid integration or grid-serving operation becomes at these locations.

Another benefit is the ability to operate backup power plants near battery storage systems at these locations. When combined with battery storage, a gas-fired power plant can make a much higher contribution to grid stability and to the electricity market during potential 'dark doldrums'.

When searching for suitable projects, we identified the following recent examples of this type of large-scale battery storage at the location of former power plants:

- Project Gundremmingen, RWE AG, (400 MW, 700 MWh, commissioning in 2028)
- Project Phillipsburg, EnBW Energie Baden-Württemberg AG, (400 MW, 800 MWh, commissioning in 2027)
- Project Boxberg, LEAG Clean Power AG (100 MW, 137 MWh, commissioning in 2026)

As the publicly available performance data for these projects, specifically at the time of commissioning, is not conclusive, we have not selected any of these projects yet.

(4) RWE AG

(5) TransnetBW

(6) LEAG Clean Power GmbH

CONCRETE RECOMMENDED ACTIONS

GRID CONNECTION AND GRID INTEGRATION – THE CHALLENGE

To enable the dynamic expansion of storage systems, a key challenge still needs to be overcome: Every storage device needs a suitable grid connection. The past few years have seen a huge wave of grid connection requests, which grid operators are struggling to process due to limited resources. Insincere connection requests, immature project registrations and a host of multiple registrations have exacerbated the situation, leading to a negative attitude among grid operators. Some operators have resorted to approving grid connections only for those storage devices that they themselves deem to be grid-serving. However, the absence of a neutral, universal definition for grid-serving capability complicates the distinction. In principle, every battery storage system is system-serving, which makes it indispensable because it enables the integration of renewable energies and ensures a stable power supply.

It should be noted, however, that storage devices can ease the burden on the grid during certain periods, while increasing the burden during others. Just like any power plant and any consumer, the grid is the basic infrastructure on which every storage device relies. Providing this will remain with the grid operators.

System value vs. grid value

Market and grid value
(= system value)

- Day-ahead market
- Balancing energy
- Imbalance energy
- Future capacity market?

Grid services in a broader sense

- Balancing power/ ancillary services
- Inertia
- Black start capability
- Reactive power provision

Grid services in a narrower sense

- Impact on redispatch and grid expansion

Study commissioned by ECO STOR et al. (7)

Current challenges:

For grid operators

- Enabling grid connection for storage devices

For regulators and the German Federal Network Agency

- Promoting grid-friendly operation of future storage devices through dynamic and volumetric management of grid charges

For investors and storage system operators

- Proactively optimizing the grid-friendly operation of storage systems and coordinating it with grid operators
- Promoting agreements on the operating mode through suitable flexibility connection agreements (FCA): contract between system operator and grid operator on the conditions under which the system is operated in a grid-friendly way

Only then can storage devices contribute more to stabilizing the power system of the future, and the costs of energy systems and grids for the national economy can be reduced.

CONCLUSION

What types of storage systems will be built in the future,
and where can we find the best opportunities for successful business models?
To answer this question, please refer back to fig. 5, which shows the different use cases for storage systems. The left side of the chart shows prosumer storage devices for residential and commercial applications (see fig. 5). These will continue to evolve. They allow companies to boost their share of renewable power, specifically from PV installations. The plummeting costs of storage components, extended use cases such as electromobility for fleets, and even heavy-duty transport, are key factors.

Most analysts agree that stand-alone batteries shown on the right currently offer the best return potential for investors and storage system operators, even though the details of this assessment keep changing. Planned changes to the design of grid charges will have a significant impact. One of these potential changes is the introduction of AgNES (General Grid charge System for electricity), a process designed by the German Federal Network Agency. This will involve an extensive reform of the rules according to which the costs for the operation and expansion of the power grids in Germany are distributed among grid users. These projects depend on finding a location with an approvable layout and – above all – sufficiently sized grid connections and binding approval by the grid operator. This is a limiting factor. When it comes to these types of storage devices, investors will want to know, above all, how much the business models – and thus the ROI of the storage device – could be limited, or even eliminated, by static or even dynamic output limitations imposed by grid operators.

Gray energy storage systems are co-located on a site with RE installations and share a single grid connection. This type of storage system comes with a time advantage in joint approval processes and, above all, a cost advantage when a grid connection is shared. However, the cost advantages are outweighed by a lower ROI because the grid connections usually have to be overbuilt. Frequently, these types of storage projects fail because approval for the output capacity at the grid connection is denied.

Co-located green energy storage systems, including hybrid configurations, place relatively low demands on grid connection infrastructure. However, they have also delivered comparatively modest ROI. For this reason, their deployment has largely been limited to the funding framework of innovation tenders. Some operators are hoping to be able to switch operating models at a later point.

In summary, it can be said that when it comes to storage, the answer is no longer 'yes' or 'no'. Ever longer phases of negative electricity prices have made PV installations unprofitable when operated without storage. Consequently, the message is: 'PV with storage – or no project at all'. At the same time, the rapid expansion of grey storage systems could be moderated if new PV installations were systematically equipped with integrated storage, or if existing installations were retrofitted accordingly.

References/Appendix
(1) BloombergNEF, for source see figure
(2) www.energy-charts.de, for source see figure
(3) www.battery-charts.de, for source see figure
(4) www.battery-charts.de, for source see figure
(5) Chart: Ingenieurbüro Hans Urban
(6) Chart: ECO STOR GmbH
(7) Study on behalf of ECO STOR GmbH:
https://neon.energy/Neon-Netzdienlichkeit-Gro%C3%9Fbatterien.pdf

Image sources
(1) Schoenergie GmbH
(2) Timeless Planet GmbH & Co KG
(3) ECO STOR GmbH
(4) RWE AG
(5) TransnetBW
(6) LEAG Clean Power GmbH

“Accelerating Integrated Energy Solutions” – that is the goal of The smarter E Europe, Europe’s largest alliance of exhibitions for the energy industry. The aim is to create a future-oriented energy world by shining a spotlight on renewable energies, decentralization and digitalization as well as cross-industry solutions from the electricity, heat and transport sectors for a sustainable 24/7 energy supply.

The smarter E Europe brings together the four exhibitions Intersolar Europe, ees Europe, Power2Drive Europe and EM-Power Europe. The exhibitions take place annually at Messe München.

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Hans Urban holds a degree in Electrical Engineering (Dipl.-Ing.) from the Technical University of Munich (TUM) and possesses decades of experience in executive positions within the solar industry. Since 2017, he has operated as an independent consultant specializing in renewable energy and e-mobility, advising solar and storage companies, regional utility providers, and municipalities. His mission is to convey complex technical topics in a well-founded, objective, and accessible manner.

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