中德能源与能效合作
Energiepartnerschaft
DEUTSCHLAND - CHINA

Supported by:

Federal Ministry for Economic Affairs and Climate Action

on the basis of a decision by the German Bundestag

Sino-German Energy Transition Project

Decentralized Flexibility and Integration of Renewable Energy

Experiences in Germany and Outlook for China

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

dena German Energy Agency

Legal Information

Publisher:
Deutsche Energie-Agentur GmbH (dena)
German Energy Agency
Chausseestraße 128 a
10115 Berlin, Germany
Tel: +49 (0)30 66 777-0
Fax: +49 (0)30 66 777-699
E-mail: info@dena.de
Internet: www.dena.de

Authors:
Tim Mennel, dena
Hrvoje Brlecic Layer, dena
Lisa Strippchen, dena
Anders Hove, GIZ
Wenyun Qian, GIZ

Date:
8/2022
All rights reserved. All use of this publication is subject to the approval of dena.

Please quote as:
Deutsche Energie-Agentur (Publisher) (dena, 2022) “Decentralized Flexibility and Integration of Renewable Energy”

The report “Decentralized Flexibility and Integration of Renewable Energy” is published by the German Energy Agency (dena) as part of the Sino-German Energy Transition Project. The project supports the exchange between Chinese government think tanks and German research institutions to strengthen the Sino-German scientific exchange on the energy transition and share German energy transition experiences with a Chinese audience. The project aims to promote a low-carbon-oriented energy policy and help to build a more effective, low-carbon energy system in China through international cooperation and mutually beneficial policy research and modelling. The project is supported by the German Federal Ministry for Economic Affairs and Climate Action (BMWK) as part of the Sino-German Energy Partnership, the central platform for energy policy dialogue between Germany and China on a national level. From the Chinese side, the National Energy Administration (NEA) supports the overall steering. The Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH leads the project implementation in cooperation with the German Energy Agency (dena) and Agora Energiewende.

Content

Summary: harnessing flexibility can overcome VRE grid challenges

Distributed generation plays an increasingly important role in the energy transition. With Germany aiming at a renewable energy share in its net electricity consumption of 80% by 2030, up from 45% in 2021, small-scale renewable energy sources connected to the distribution grid must contribute a larger share of national energy output alongside large-scale sources such as onshore and offshore wind.

So far, most of Germany's distributed generation consists of solar PV installations, both rooftop and small-scale ground-mounted installations. Other small-scale technologies include biomass, biogas, and small-scale hydro generation. By 2021, Germany had 2 million rooftop solar PV installations, approximately 15% of the country's total solar PV capacity.

Though solar helps reduce carbon emissions by replacing electricity from fossil fuels, its variable output creates technical challenges for the distribution grid, most notably thermal overloads of network devices, violation of voltage limits, backfeed issues, and phase imbalances. Fluctuating feed-in of renewable energy can lead to general generation adequacy and stability problems on the system level, especially as Germany phases out more conventional generation that can provide firm capacity and ancillary services.

Flexibility measures are the key to solving these distribution network problems and enabling distributed energy to play a full role in replacing conventional plants in the system. For the distribution grid, flexibility refers to the increased use of electricity storage, mostly batteries, and demand side management (DSM).

Electricity storage: On the distribution grid level, batteries are the most relevant technology. Batteries can perform load shifting, as well as a broad range of grid services, including balancing power, spinning reserves, and blackstart capacity. Behind the meter, batteries can contribute to the increase of self-consumption and the improvement of power quality for the customer.

DSM: Typical technologies providing DSM on the distribution grid level are household appliances such as air conditioning or heat pumps or business appliances such as cold stores or chemical processes. Metered customers can use DSM in market appliances to optimize their electricity procurement strategy and reduce power bills. Moreover, distribution grid operators can engage in load control contracts with providers of decentralized DSM to manage grid congestion and reduce costs for all customers.

The activation of flexibility entails changes to electricity sector regulation. In the liberalized EU electricity system, network operations are unbundled from generation and trade, and they are subject to regulatory oversight, in particular for grid investments. The EU and member states will require further regulatory changes to realize the potential of storage and DSM:

First, grid regulation must **enable smart grid investment** such as grid company communication and control technologies, which are a prerequisite for the activation of flexibility. This should include modern smart meter technologies as well as gateways that enable all consumers and prosumers to participate in real-time load control programs enabling the use of flexibility by network operators, potentially managed by third-party aggregator companies.

Second, flexibility asset owners need a suitable framework for the **remuneration of flexibility**. Ideally, payment for decentralized flexibility should fully reflect its value to the system in avoiding grid or generation investment. This should include the introduction of flexibility markets or innovative ancillary services that put load control and batteries at the disposal of the distribution network operator (DNO). Dynamic grid fees would incentivize the use of flexibility for congestion management.

Third, regulators must **further encourage aggregation of decentralized flexibility** through market data transparency and market access. Independent aggregators can enable decentralized flexibility by prosumers and small business, for wholesale and balancing markets. Thus, decentralized flexibility can contribute to load shifting and system stability.

Germany can offer useful lessons for China even though the regulatory regimes differ. China has seen a surge in distributed generation over the past decade, with distributed solar PV surpassing 100 GW in 2021, dominated by industrial installations. Industrial customers are ideal for decentralized flexibility given their greater sophistication compared to households and access to energy service companies.

We suggest to accelerate both energy storage and DSM: grid problems such as the violation of thermal limits of network devices, voltage, and backfeed issues are likely to challenge Chinese distribution grids once localities reach high penetration rates of solar PV. Activating flexibility offers an opportunity to address these challenges. Distribution grid operators should use electricity storage as well as DSM to manage congestion problems. **This will require incentivizing distributed flexibility with appropriate remuneration.**

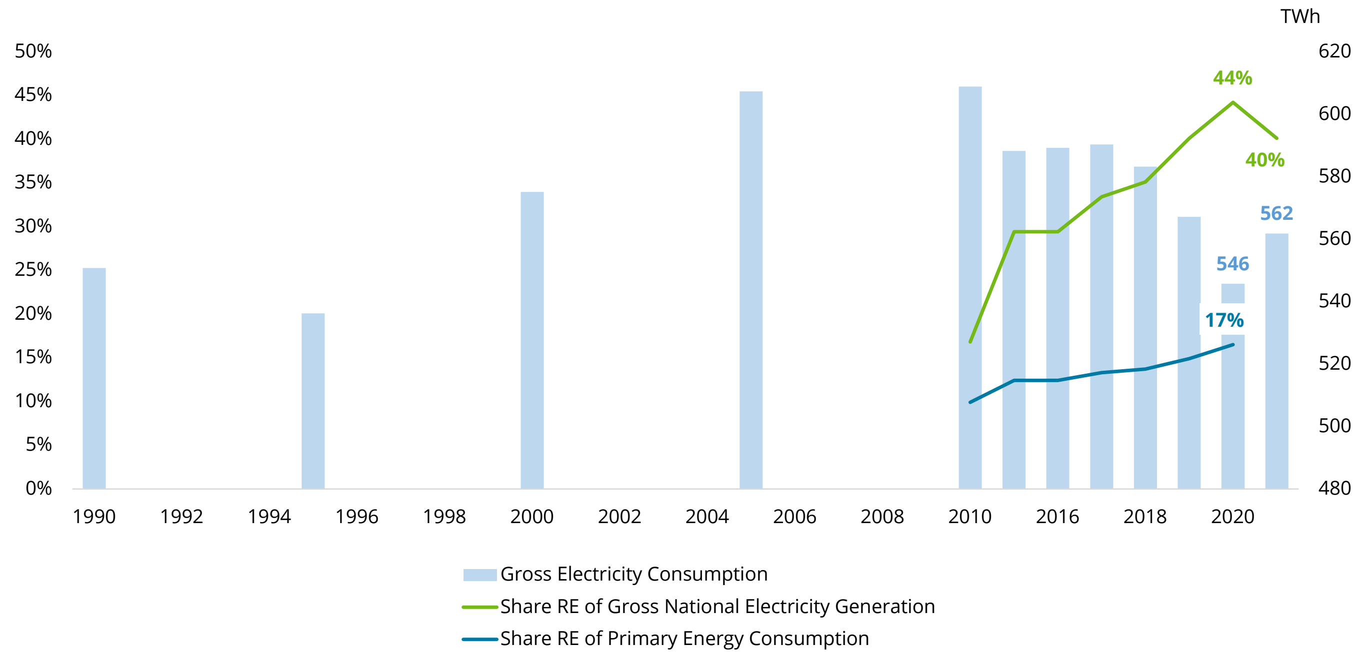
1 Distributed generation and decentralized flexibility in Germany

Renewable energy generation based on wind and solar PV reached 45% of Germany's electricity generation in 2021, and will likely surpass 80% by 2030, even as Germany electrifies transport, industry, and heating. Distributed generation will make a significant contribution. As the installed capacity of wind and solar PV rises, the system needs flexibility measures to balance variable renewable output. On the distribution grid level, small-scale electricity storage and DSM can contribute to the stability of the grid. Due to their increasing importance and value, recent German and EU legislation has focused on boosting both distributed generation and decentralized flexibility.

The role of renewable energy in the primary energy consumption of Germany is increasing, reaching 17% in 2020. Renewable energy has gained particular importance in electricity supply over the past two decades. In 2021, the renewable share of net power generation had reached about 45%, up from less than 4% in 2000.

In contrast, renewables play a minor role in the consumption sectors today. In the mobility sector for example, oil and oil products provide 90% of the energy.[1] Fossil fuels also account for a large share of energy use in the industry and heating sector. With increasing electrification via heat pumps, electric vehicles, and production of hydrogen, along with improved efficiency, the consumption of fossil fuels will decrease in those sectors. In consequence, electricity consumption will rise over the next two decades, even as the variable renewable share also rises.

Figure 1 Share of RE in total primary consumption and electricity generation



Source: AGEB, March 2022

Current gross annual electricity consumption in Germany is about 500 TWh. According to the 2021 government coalition agreement, Germany's electricity load may rise to 750 TWh in 2030 due to the contribution of electrification.[2]

Meeting a large fraction of this increased electricity consumption with renewable sources entails a major expansion of renewable energy installed capacity. As of 2021, Germany had 138 GW of renewable capacity installed capacity: 64 GW of onshore and offshore wind power and 59 GW of solar PV. The most common technologies for PV are rooftop solar systems and open field solar.

Both wind and solar are variable energy sources, and their fluctuating feed-in poses challenges to the grid, such as overload or voltage problems. In contrast, dispatchable renewable energy sources such as hydroelectricity or biomass offer lower variability and easier dispatch without supplementary energy storage. Yet hydro and biomass have limited growth potential in Germany. In 2021, biomass and hydroelectricity contributed around 11% of Germany's generation, or 65 TWh. Biomass and hydro solutions will not be able to cover the exit and replacement of conventional sources. Most future renewable growth will come from variable wind and solar, necessitating greater focus on flexibility measures.[34]

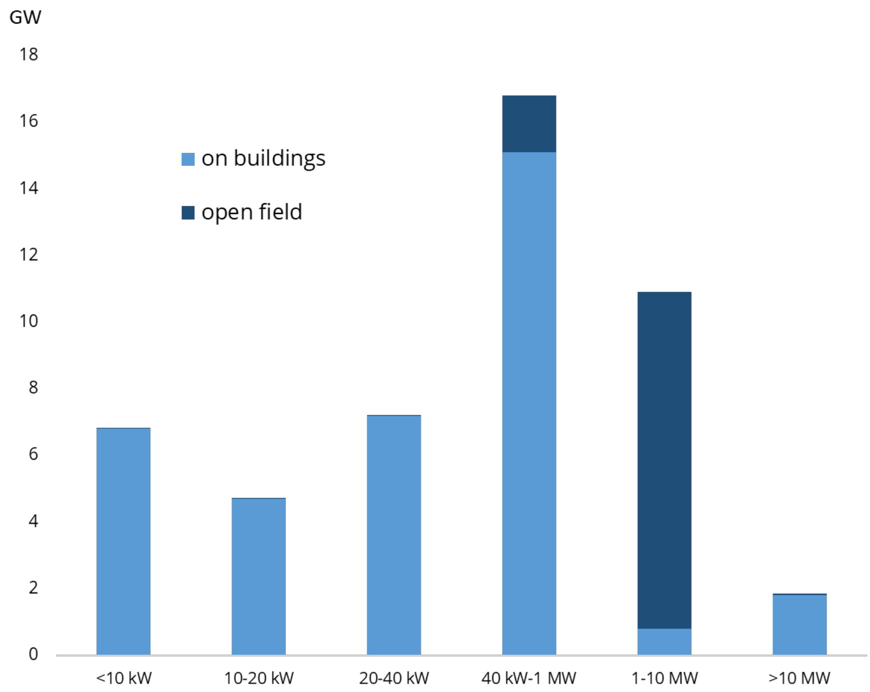
1.1 Development of distributed generation 2000-2022

Much of the renewable expansion of the past was due to large-scale installations connected to the transmission grid, which Germany defines as long-distance transmission at voltages above 220 kV. In a future low-carbon electricity supply system, more generation will be decentralized and used where it is produced. Private households and small businesses already operate renewable energy generation units, connected to the distribution network, the low- and medium voltage grid.

Prosumers are a class of distributed energy resource owners that both consume energy from distributed resources and feed a portion of output into the grid. The *energy community* is a similar concept, where neighbors nearby directly consume the generated electricity. There is no universal definition of small-scale PV. In this report, installations with a capacity of up to 1 MW are considered small-scale.

Distributed generation already makes up a major part of total capacity of renewable energy in Germany, most of which was solar PV. In 2021, Germany had roughly 59 GW of solar PV, located at roughly 2 million systems, 60% of which were smaller than 10 kW.[5] In 2019, Germany had 7.1 GW of PV below 10 kW, or almost 15% of the total installed PV capacity. The capacity of small-scale PV between 10 and 20 KW was about 4.7 GW in total, or a further 10% of the total. Open field PV contributes only small amounts to the installed capacity of small-scale PV.[6]

Figure 2 Installed capacity of PV in Germany by size



Source: Bundesnetzagentur, 2020

To use full the full potential of PV generation, innovative and integrative technologies such as floating PV or building-integrated PV will play a bigger role in the future.

Besides solar PV, a variety of other small-scale renewable energies are connected to the grid on low voltage levels. These include small-scale hydro, biomass, and biogas.[7] The role of biomass and biogas differs from distributed PV generation. Biomass is mainly used for flexibility. Biogas can not only generate electricity, but can also be fed into the regular gas network for heating. There are also decentralized generation systems based on fossil fuels, such as combined-heat-and-power (CHP) systems, often using methane gas.

1.2 Deployment of storage and DSM in Germany today

The transition from controllable electricity generation on high voltage level towards an energy system with variable generation both on the transmission and distribution grid level poses new challenges to the grid, especially on the distribution level. Short-term variation in renewable feed-in can cause network issues, such as overload, voltage problems, phase imbalance, and backfeed issues. These may compromise the thermal limits of grids. Additionally, new load patterns arising from increasing electrification, may cause new demand peaks, which can lead to grid congestion.

It is critical that prosumers assume a constructive role, contributing to the efficiency and stability of electricity supply, and reducing congestion costs or avoiding unnecessary investments in grid or generation assets. The key to achieving this role is the activation and provision of flexibility, investigated in this report. The two technical flexibility options are demand side management (DSM) and electricity storage.

DSM can help balance production and demand fluctuations by switching demand loads on and off, or regulating loads up or down. DSM used by the distribution network operator (DNO) can help to stabilize the grid, either via individual consumers, or via large numbers of consumers managed through a third-party aggregator. Depending on the type of device or load, DSM can relieve peaks in demand, compensate for large in-feeds from renewables, and reduce operation costs by opening new ways in planning of outages and reducing technical losses on the distribution networks via load shifting or interruptible loads.

However, Germany still has only limited application of DSM solutions. Electricity prices for small and regular sized consumers do not yet fully reflect the congestion and balancing costs of the grid. Aggregator services face various barriers to market entry. Additionally, many DSM technologies have only started to enter the market. Section 4.2 gives a few examples and pilot projects for illustration.

Decentralized electricity **storage** can serve as a technical flexibility tool and provide balancing energy for both transmission and distribution networks. Electrical storage can contribute directly to the integration of renewable energy.

Though many players are exploring innovative energy storage technologies, in Germany conventional battery storage is the most popular. Germany’s distributed energy storage systems have grown exponentially over the last two years as costs decline and product options expand. As of 2022, Germany had over 500,000 PV-storage systems installed, with a total storage capacity of about 4.4 GWh and storage output capacity of about 2.5 GW.[8] These storage systems can contribute significantly to the integration of distributed electricity by increasing the proportion of self-consumption and reducing peak loads and peak solar in-feeds.

Electric vehicle (EV) batteries are an emerging field with potential to help integrate distributed energy. In 2021, new EV registrations have increased to 680,000 with a total capacity of about 22.45 GWh and total output of 31 GW.[9] The government has announced the target of 15 million EVs in Germany by 2030. In the future, EVs will serve as a flexibility option. Bi-directional charging, which is still offered on only a few vehicle models, would allow EVs to serve as an electricity storage device. Private EVs are parked around 23 hours per day on average, giving them high potential to provide either grid services or storage of distributed renewable output. With the electrification of mobility, electric vehicles will play a more important role in providing flexibility and integrating renewable energy.

Using EVs as flexibility tool also poses a challenge for the grid operator. EV charging, storing, and discharging times currently lack predictability, especially at the smallest scales of a household or neighbourhood. The coordination of the vehicle charging is important to ensure that EV charging and discharging into the grid plays a beneficial role in overall system function.

1.3 German and EU policy targets for decentralized renewable energy and flexibility

The EU has set the goal of climate neutrality by 2050. Germany has even tightened its goals and strives for climate neutrality by 2045. These goals necessitate a major expansion of renewable energy, including distributed variable renewable energy. On the governmental level, the EU and Germany have recognized the role of distributed generation and the need for flexibility options for a successful energy transition. Even though the EU has not set specific targets for distributed generation or flexibility options, recent regulations include incentives and obligations for the installation of distributed energy systems.

On EU-level, the Renewable Energy Directive (RED II) introduced measures as part of the Clean Energy for All Europeans package. Regarding the expansion of rooftop solar, RED II includes the obligation for member states to use public and mixed private-public buildings for installations that produce energy from renewable sources. Moreover, RED II forbids discriminatory measures or conditions for energy communities:

“Member States shall ensure that final customers, in particular household customers, are entitled to participate in a renewable energy community while maintaining their rights or obligations as final customers, and without being subject to unjustified or discriminatory conditions or procedures that would prevent their participation in a renewable energy community, provided that for private undertakings, their participation does not constitute their primary commercial or professional activity.”[10]

The legislative package also includes provisions for flexibility services in the directive on common rules for the EU’s internal market for electricity and amending the Electricity Directive:

“Member States shall provide the necessary regulatory framework to allow and provide incentives to distribution system operators to procure flexibility services, including congestion management in their areas, in order to improve efficiencies in the operation and development of the distribution system. In particular, the regulatory framework shall ensure that distribution system operators are able to procure such services from providers of distributed generation, demand response or energy storage and shall promote the uptake of energy efficiency measures, where such services cost-effectively alleviate the need to upgrade or replace electricity capacity and support the efficient and secure operation of the distribution system.”[11]

Though Germany has yet to fully implement the EU measures, the new government has published new goals for the electricity generation sector, setting targets for 80% renewable energy by 2030 and climate neutrality as soon as coal capacity is fully retired, by 2038 or ideally by 2030. Distributed generation and flexibility will play an important role in this carbon-neutral electricity system. The coalition agreement of the new government announces plans to improve regulations for energy communities and distributed generation and introduce new mandates. These include the obligation to install rooftop solar on new buildings. The amendment of the renewable energy law sets new expansion targets for solar PV, and contains improvements of regulations for energy sharing. The coalition agreement also mentions instruments designed to improve storage and load management, though it does not outline specific measures:

“In order to incentivize the rapid expansion of generation capacity, we will evaluate existing instruments and examine competitive and technology-neutral capacity mechanisms and flexibilities. These include renewable energy, highly efficient gas-fired power plants with combined heat and power generation as part of the corresponding further development of the law, an innovation program, storage, energy efficiency measures, and load management.”[12]

Thus, Germany is currently scaling up distributed renewable energy, energy storage, and electric vehicles while policy makers are at the early stage of exploring regulatory options to ensure distributed energy plays a larger role in the energy system. As the following chapter will discuss, this poses challenges for the grid, and requires additional policies to support flexibility.

2 Technical challenges of electricity systems with high share of variable renewables

A high share of variable renewable energy in the energy mix leads to considerable challenges in electricity systems, in particular for distributed renewable energy connected to the distribution network. Challenges include the potential violation of thermal limits of network devices during periods of high feed-in as well as voltage problems and back-feed issues. Distribution network operators in Germany and other countries have assumed new responsibilities to tackle these problems. On the system level, high shares of renewable energy feed-in also contribute to the need for network expansion. The system also needs new sources of ancillary services as conventional power generation assets phase out.

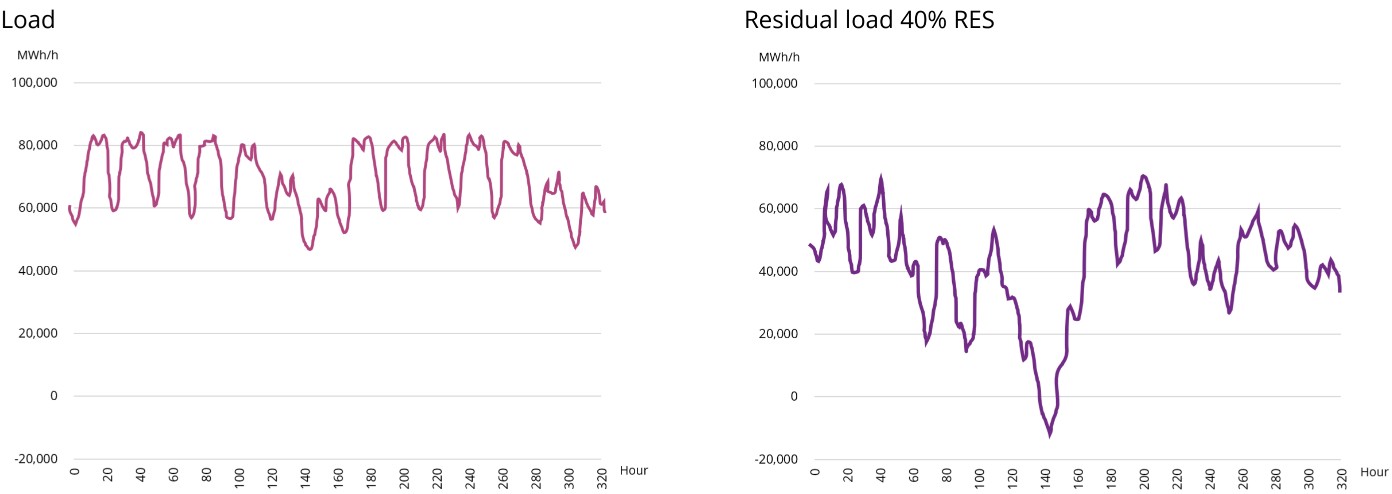
Existing electricity systems are designed to accommodate 20th-century power systems based on one-directional power flows from conventional, centralized, large-scale electricity production facilities to end consumers. Transmission grid operators focused on preventing failures at large generation plants or transmission lines, while distribution grid operators focused on planning and operating local grids to accommodate peak loads.

In the 21st century, the grid faces new challenges, especially the need to integrate high shares of central and decentralized variable renewable energy sources and electrification of heating, mobility, and industry. Ensuring reliability, stability, and safe operation of electricity systems requires new ways of thinking to adapt to and overcome these challenges.

2.1 Challenges in distribution grids

Growing shares of variable renewable energy (VRE) can pose challenges to the grid, especially at the distribution grid level. Residual load, defined as electricity consumption minus VRE generation, can decrease to almost zero and then increase significantly within a short period of either days or hours, as shown in the figure below.[13] In the case of solar PV, at the distribution level spikes in output can occur within seconds.

Figure 3 Flexibility requirements with high shares of RE – example load curves for two weeks during the winter in Germany



Source: Agora Energiewende, June 2022

On the consumer side, further electrification of end-use devices can cause temporary spikes of grid power demand and thus put pressure on the grid.[14] The distribution grid can face several technical issues posing a threat to supply reliability, stability, and safe operation. When unexpected power flows exceed the operational limits for power system equipment or violate voltage thresholds, serious damage or outages can occur.[15]

The first issue relates to a thermal overload via heating because of power in the network exceeding the power ratings of the system components.[16] The issue can affect grid cables or transformers, which are one of the most expensive components of the power system. Any severe overloading can cause damage or an outage if the grid operator does not or cannot respond immediately.

The second issue relates to changes in voltage, which could lead to a situation of voltage disturbance or even a voltage violation. Voltage disturbances can occur as long-term and short-term voltage variations, voltage flickers, and harmonic distortions. During a voltage violation, the system encounters voltage outside of the standard range specified by the regulatory authorities. Disturbances can lead to wear and tear in customer electrical appliances and grid equipment.

The third issue is backfeed problems. Backfeed is defined as power flows contrary to system design. Bidirectional power flows created by distributed generators can cause local voltage issues. In distribution grids not designed for bidirectional power flows, consumer-owned distributed PV systems could result in damage to the distribution system from backfeed.[17]

Over time, growing distributed energy in-feed will increase congestion in the distribution grid, and require active management, costly redispatch, and new grid investments.[18]

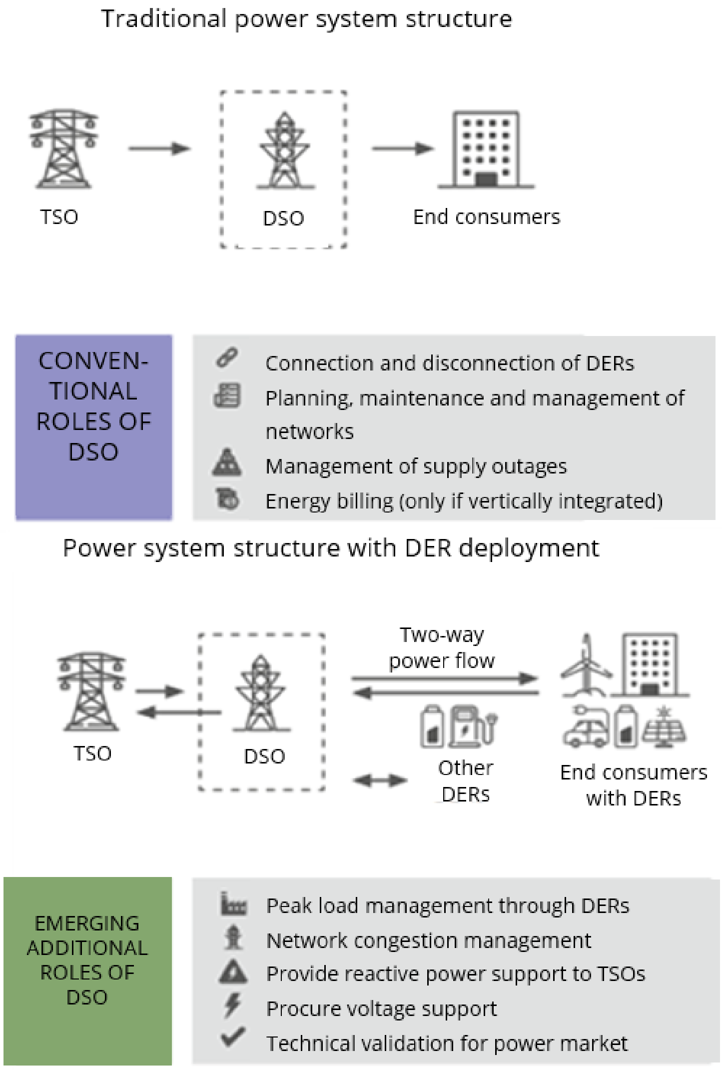
Today, on the operational side, the distribution network operator (DNO) can use load shedding and curtailment of VRE to solve network congestion problems, albeit with a cost to increased generation to replace the curtailed renewable output. Extending and expanding the conventional distribution grid can also accommodate increasing VRE in-feed.

Decentralized flexibility can help reduce or avoid the major costs associated with the challenges described above. The future electricity market will require adjusting traditional distribution grid planning and operation and therefore requires DNOs play new roles. DNOs effectively become distribution system operators (DSOs). Both load shedding and VRE curtailment should remain an exception, and investments in expanding the conventional grid should be avoided if less costly alternatives are available.

DSOs could deepen their role as active system operators, in addition to their role as network operators.[19] For instance, they could procure flexibility services from their network users, provide reactive power support to transmission system operators (TSO), by carrying out management of local congestion and non-frequency ancillary services such as voltage control, while TSOs take responsibility solely for frequency ancillary services.[20] Furthermore, a DSO can still engage in load shedding and curtailment of VRE. However, the DSO should apply the measure as a last resort, because it will inevitably lead to a distortion of the delivery foreseen under the wholesale market outcomes.

In any case, an appropriate regulatory framework is a prerequisite. The following figure compares the DNO role in traditional power system and a DSO within a system dominated by distributed renewables.

Figure 4 The new roles of the distribution system operators



Source: International Renewable Energy Agency (IRENA), 2019

Challenges on the system level

High shares of decentralized VRE on the local level have implications not only for the distribution grid but also on system level. Because their output coincides with that of central wind and solar plants connected to the high-voltage transmission grid, distributed wind and solar output aggravates existing congestion problems on the transmission grid. It means that transmission grid operations, including cross-border power exchanges, face new costs.

In Germany, policy makers and TSOs have worked for years to expand the power grid to reduce grid congestion, but grid expansion has lagged the expansion of wind and solar capacity. Germany's transmission plan aims to better connect regions with concentrated renewable sources, especially wind in the North, with regions of load centers such as the industrial clusters in the middle and on the south of the country. In 2015, Germany amended the Law on the Expansion of Power Lines, setting a regulatory framework for planned high-voltage transmission lines from Northern to Southern Germany, namely the SuedLink and SuedOstLink.[21]

Even when the new lines begin operation, Germany's transmission grid build-out is unlikely to keep pace with future wind and solar additions. Therefore, transmission expansion cannot serve the primary solution to ensuring system stability with high shares of wind and solar. To solve network congestion on the system level, redispatch based on flexible capacity—mainly gas-fired plants—plays an increasingly important role.

The term redispatch refers to the following practice common in Germany and its EU neighbor countries: If the evaluation of the schedule (or *dispatch*) resulting from market transaction by the TSO shows that bottlenecks are imminent or that there are short-term overloads, the TSO orders that the generators change their schedules (*redispatch*) to overcome the network congestion. The affected generators will be remunerated for this service under an administrative scheme.

The latest electricity market reforms initiated by the German federal government have expanded the scope of assets allowed to offer ancillary services, including balancing services. The Germany Bundestag enacted the reforms, known as Electricity Market 2.0, including a measure to promote the energy transition in the electricity sector. The government's aim was to strengthen competition between generation, demand, and storage while improving the incentives for flexibility. Germany also introduced safeguard mechanisms, including the network reserve and capacity reserve. These reserves refer to additional capacity outside the market available to the TSO when or if the wholesale or control energy markets are unable to supply sufficient electricity to meet the entire demand.

Prior to 2022, most observers did not expect Germany to activate the capacity reserve. However, Europe's gas supply crisis necessitated its activation to replace gas generation and save scarce fuel supplies for the heating sector.

Although available flexibility in the German electricity system is sufficient to guarantee system stability today, preserving system stability will become challenging in the mid- to long-term future due to the decreasing capacity of flexible conventional generation assets resulting from the planned phase out of nuclear and coal power. Therefore, the current government has announced plans for further electricity market reform to make more flexibility sources available. The reforms will likely give more weight to the role of decentralized flexibility assets such as DSM and batteries.

3 Flexibility for grid integration of distributed renewables

For two decades, electricity grid operators in the Germany and elsewhere have learned how to cope with the increasing share of variable renewable energy in the energy mix. While the basic setup of regulation and grid management in the liberalized market system provided a workable framework in the early stage of renewable expansion, higher shares of renewable energy will increasingly entail fundamental regulatory changes. These involve smart grid technologies and the activation of flexibility: With smart grid technologies, DNOs can use of storage and load control to manage congestion and avoid costly investments, for the benefit of all customers.

3.1 Flexibility as a remedy for problems on the distribution and system level

A combination of conventional and smart grid solutions can help address the challenges of integrating distributed and central renewables such as wind and solar. Conventional solutions include the construction of new infrastructure such as transmission lines and transformers, extension of existing infrastructure via additional cables and replacement of transformers, and optimizing geographic allocation of VRE additions based on available network capacity.

Smart grid solutions build on the use of flexibility in the system. These allow for improvements of the operational efficiency of the grid, management of VRE feed-in, and load controls. Based on information and control software, the grid operator can forecast and detect network congestion problems, including the violation of thermal limits, backfeed issues, and voltage problems. The grid operator can then activate technical remedies in the system.

As mentioned previously, there are two major flexibility technology options: storage and DSM. Electricity storage today can be provided by pumped hydro and batteries, and in the future by hydrogen. Demand side management (DSM) is provided today by appliances in industry and prospectively by small businesses and households.

A prerequisite for the use of flexibility by the network operator is the availability of smart grid technologies. Enabling and undertaking the investments into these technologies are key challenges of the energy transition in Germany and Europe. Currently, both the European Commission and the German grid regulator (BNetzA) are developing regulatory mandates and with the aim of enhancing the smart grid capabilities of EU and German networks.

The use of flexibility provided by storage and DR requires information, communication, and control technology in the grid, available to the grid operator, commonly called smart grid technologies. Smart grid technology includes the following basic elements:

- Communication such as mobile communications networks
- Smart meters enabling bi-directional communication
- Communication software regulating data exchange between devices and systems
- Control elements in all DSM devices

Only with smart grid technology integrated into the power system at all levels can decentralized flexibility play a full role in integrating decentralized renewables. In addition, smart grid technology has benefits for developing more functional and transparent electric power markets and enabling customers to monitor and reduce their own consumption and shift consumption to periods when more clean energy is available.

3.2 Flexibility in the distribution grid

Europe's electricity industry operates within a decentralized, liberalized market paradigm, governed by several EU directives and regulations. This paradigm mandates competitive markets for the generation and trade of electricity, while transmission and distribution remain regulated under administrative entities that control transmission and distribution tariffs. Generation and electricity trading are legally separated from transmission and distribution, a separation known as *unbundling*.

Unbundling has consequences for the use of flexibility: Network operators face strict limitations on the ownership and operation of electricity storage and the use of demand response. Since grid operators, including both TSOs and DSOs, cannot buy or sell electricity, this means they cannot fully operate a battery in the system, such as for load shifting or storing solar PV generation exceeding the load at a given point in time. Instead, network operators procure ancillary services and reserves from market participants to ensure network stability, which is the legal duty of TSOs and DSOs. Moreover, grid operators are allowed to technically intervene and control feed-in and feed-out into the grid in an emergency, provided all other options have been exhausted.

Germany has a well-developed ancillary services market. TSOs have a set of established competitive procurement procedures for several standard situations the grid may encounter. The most important instruments are balancing services, which encompass primary, secondary, and tertiary control reserves. Control reserves are distinguished by their activation times and availability. These are required to guarantee frequency stability in cases where market participants connected to the grid deviate from their scheduled grid use, thus endangering network stability. Other ancillary services on the system level include spinning reserves, voltage support, and black-start capacity.

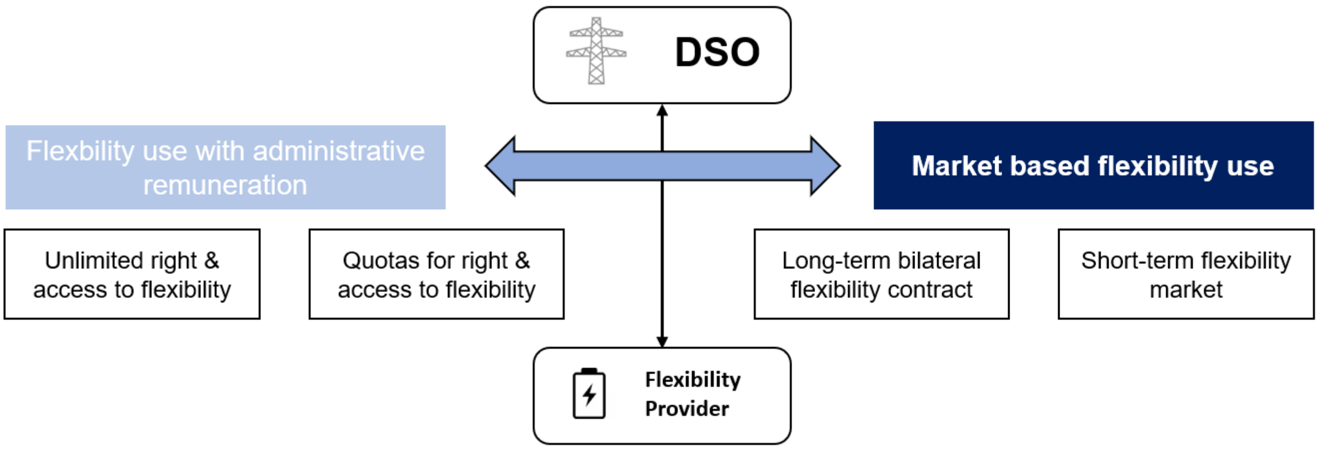
TSOs have several ways to monitor and manage their networks, in line with the needs of the traditional electricity supply model where generation assets are connected on the transmission grid level and distribution grids are designed to distribute electricity to consumers connected on lower voltage levels.

Today, thousands of small, distributed generation installations are connected to Germany's distribution grid, which changes the role of the grid operator. As explained before, the operator of distribution network should in the future be called distribution system operator (DSO), a term that seems better suited for the role needed in today's distribution grid.

Increasingly, DSOs must actively manage load and feed-in to stabilize the grid. Existing smart grid technologies, such as control devices for renewable energy installations are mandatory in Germany today. The introduction of smart meters in prosumer households will expand these possibilities.

Apart from the technological upgrades needed for the operation of a smart grid, the system needs a new regulatory framework to enable the distribution system operator to legally procure and use flexibility in the distribution grid. Several different models are under discussion or being piloted today, and these models differ in several respects. For example, different models feature different scopes and timing of DSO control of distributed generation or storage assets, and different remuneration schemes.

Figure 5 Alternative governance models for flexibility use



Source: Dena, 2022

Under administrative remuneration, a regulation defines the scope of flexibility and the regulator sets the applicable tariff for those providing flexibility. The scope of flexibility use can vary. At one extreme, under emergency conditions, the network operator may exert full control over the available flexibility such as storage and DSM. Another administrative scheme involves a quota system that limits the DSO's control rights to certain periods and capacity, such as 20% of a participant's battery storage capacity.

Competitive procurement of flexibility is an alternative where the DSO defines the specific scope of the required flexibility—such as an ancillary service—and sets up a tender with technical pre-qualifications. Both storage and DSM operators can then bid and sell their technical capability. There are different approaches with respect to the frequency and duration of the procurement: Under mid- to long-term contracts, the DSO purchases well-defined control rights of a flexibility asset for several weeks or months. In contrast, in a short-term flexibility market, flexibility is traded on platform with daily auctions.

German legislation today allows for some versions of the former model: Under the Energy Market Law, specific contracts between the DNO and energy users allow for individual, flexible grid fees to remunerate the provision of flexibility. The latter model, a flexibility market platform, has been intensely studied in the German federal government's SINTEG research program, that included both theoretical studies and pilot projects investigating different forms of flexibility markets. As of today, however, the German legislature has yet to introduce the legal framework for such anonymous platforms for the trading of flexibility, due to ongoing debate over the potential market abuse by rogue players in these platforms.

3.3 Aggregation of decentralized flexibility

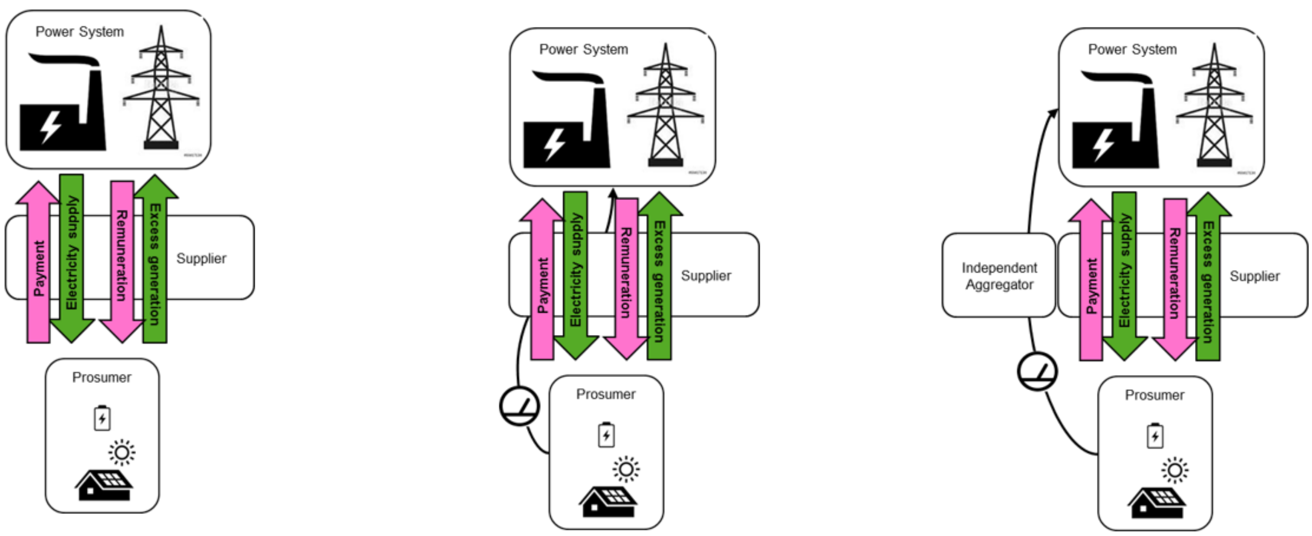
Because of the low compensation for feeding residential solar PV output into the grid, German households with PV have increasingly installed home batteries to raise the proportion of self-consumption. While this has some advantages from the grid's perspective, it is not ideal. Customer-sited batteries deployed purely for self-consumption can lead to irregular and unpredictable in-feeds, such as when a household has no electricity load on certain days or hours. In addition, distributed energy owners have barely begun to participate in demand response programs, partly due to the lack of a standard payment framework from the DSOs.

In addition, Germany's aggregator market is still in its infancy, even compared to neighboring countries such as France and Belgium. The term aggregator refers to a market role that engages in a contractual relationship with small providers of flexibility to harness their potential in the submarkets of the electricity system, sharing the gains of trade. Direct participation in wholesale and ancillary service markets is unrealistic for small consumers. The transaction cost, including time spent learning about and managing the energy flows from small systems, by far outweighs potential gains.

By bundling the potential of hundreds or thousands of prosumers with batteries and small businesses with DR potential, the aggregator enables their participation in electricity wholesale and ancillary service markets, in exchange for a flat or variable payment for participation. In principle, an energy supplier or market participant with many customers can fulfill this role.

Given the sluggish progress on aggregators, the EU in 2019 decided to establish the role of an independent aggregator.

Figure 6 Alternative models for aggregation of demand response



Supplier "integrates" prosumer into the power system

Supplier aggregates DR and sells it into into the markets

Alternatively, an independent aggregator can sell prosumer DR

Source: Dena, 2022

Directive 2019/944 defines the role of aggregators. Article 17 clarifies that aggregator can enter the market without consent from other market participants, aggregators cannot be required to pay compensation to suppliers or generators, and that grid and market operators must provide aggregators access to the required network data. This provision aims at avoiding obstruction by energy suppliers that might prefer to avoid allowing their consumers to participate in aggregation contracts. However, the directive also requires aggregators to notify suppliers about the aggregation arrangement so that the supplier can ensure reliable electricity delivery. The independent aggregator must also assume balancing responsibility, just like other market participants, to avoid dangers to system stability. These could result from unforeseen or uncoordinated activation of load controls that could cause distortions in the load forecast given to other market participants.

NEMO.spot, a German startup, is an example of an independent aggregator making decentralized flexibility available to the market.[22] The platform engages with prosumers and suppliers offering of flexibility, and with network operators for the use of flexibility. In this way, all parties can adjust their planning and operation accordingly and flexibility contributes positively to network stability.

4 The use of decentralized flexibility in German distribution networks

In principle, decentralized flexibility tools offer a variety of services to the grid. The use and advantages differ depending on the technology deployed. Today, Germany has an increasing number of flexibility assets, including batteries and DSM, but lacks a comprehensive market framework for flexibility. Instead, electricity storage and DSM have separate rules. Electricity storage faces some regulatory hurdles before it can play a full role—issues the new German government plans to address. As for DSM, grid operators have various direct load control methods, and there are some new market entrants into the DSM space, but deployment is low.

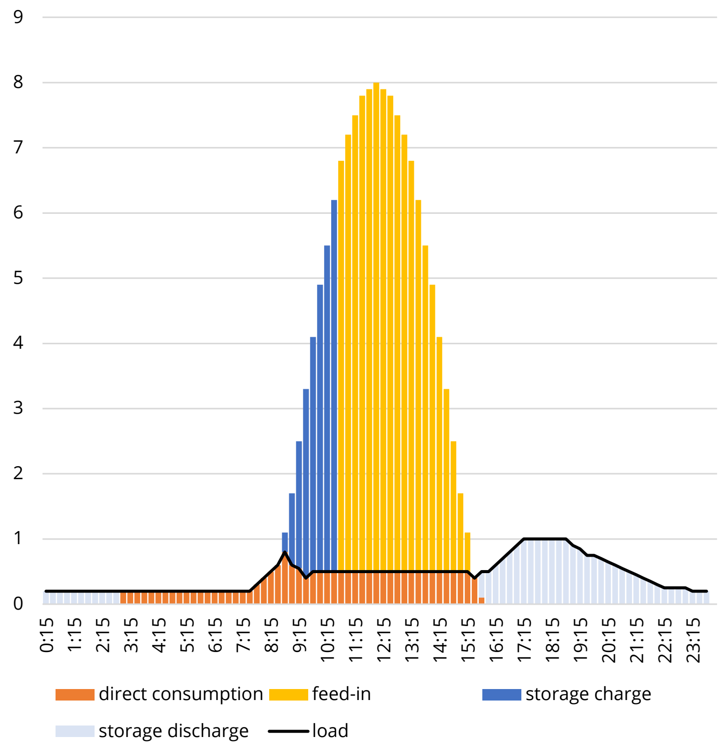
4.1 User-sited battery electricity storage

User-sited batteries have two operational methods that have different advantages and disadvantages for the customer and the power system. Batteries can either operate in the electricity market—for the German case, typically by maximizing self-consumption—or they can provide grid support. The two modes of operation may very well be inconsistent or even mutually exclusive, as price signals do not reflect the current situation of the distribution or transmissions grids.

The figures on the following page highlight the problem. A battery owned and operated by a prosumer will typically be used to increase self-consumption from a solar PV installation. Most consumers have insufficient battery capacity to absorb all output from the solar system. On the sunniest days, if the prosumer charges an under-sized battery until it is full, and if solar production continues once the battery has been filled, this results in a sudden increase in feed-in. In the summer, this could have an especially detrimental effect given that most solar PV installations in a given region are likely to reach their peak output at a similar time.

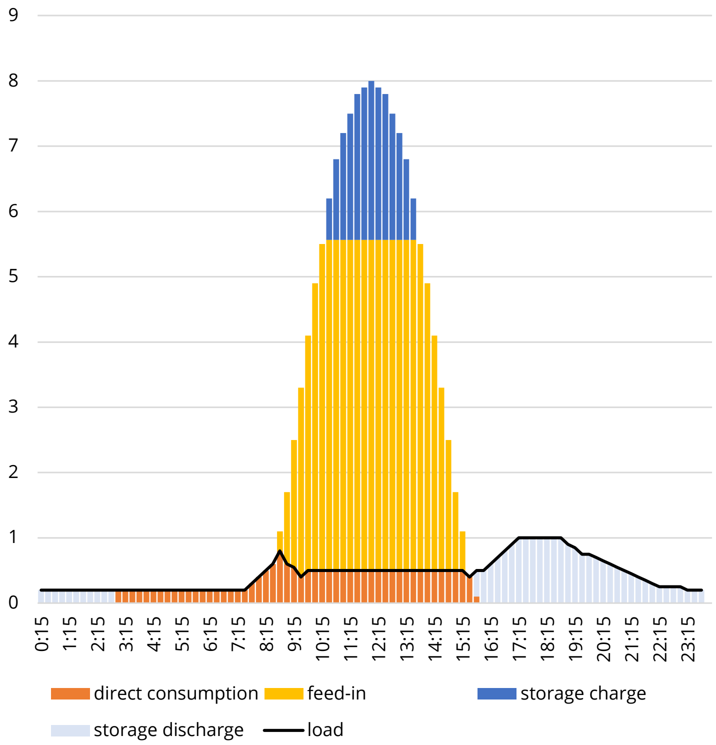
In contrast, if users have an incentive to operate batteries in a peak-shaving mode, this avoids any sudden spikes in feed-in when the battery is full, and reduces the maximum feed-in. This not only alleviates immediate grid problems, but can reduce the overall need for grid upgrades when scaled up across many prosumers within the region.

Figure 7 Prosumer battery used for increase of self-consumption



Source: adapted from Fraunhofer ISE: Aktuelle Fakten zur Photovoltaik (S.70)

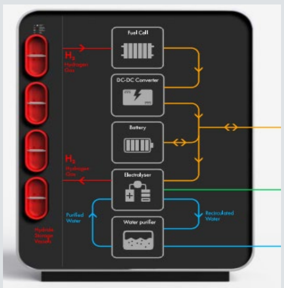
Figure 8 Grid-friendly use of prosumer battery



Source: adapted from Fraunhofer ISE: Aktuelle Fakten zur Photovoltaik (S.70)

This example shows that the technical availability of storage in the system does not itself resolve grid congestion, and may even exacerbate them. Regulatory and market incentives can incentivize or mandate grid-friendly battery operation.

Example: Prosumer hydrogen station



LAVO introduced integrated hybrid hydrogen batteries which combine rooftop solar and green hydrogen. The fuel cell is used to cover energy stored in the hydrogen back into electrical energy. The storage is able to cover an average household for two days.

4.1.1 Storage technologies and services

A variety of conventional electricity storage technologies is available on the market, include conventional technologies such as pumped hydro storage and battery storage. Each storage technology has its unique advantages and disadvantages. The most common type of small-scale electricity storage are batteries, which typically offer storage for seconds up to days.

Conventional batteries include lithium ion batteries, redox flow batteries, lead-acid batteries, and sodium-sulfur batteries. Those types of batteries are commercially available. redox flow batteries, lead-acid batteries, and sodium-sulfur batteries. These types of batteries are commercially available today. Batteries offer high round-trip efficiency but partly have the disadvantage of security risks due to high operating temperatures.

Double-layer capacitors are another type of conventional, commercially-available, and widely used electricity storage technology. When the capacitor is charged, a positive charge forms on one plate and a negative charge on the other, creating an electric field. Double-layer capacitors are an example of micro-storage, applicable for seconds and minutes. They offer high stability and performance, fast charging and discharging, as well as a long operational lifetime.

Small-scale hydrogen storage is an innovative storage solution, which is also applicable on decentralized level. It offers a long lifetime and is commercially available for residential applications. Hydrogen offers lower round-trip efficiency, but longer storage times.

Depending on its type, electricity storage can offer a range of services to the grid, including ancillary services, distribution infrastructure services, bulk energy services, customer energy management services, and off-grid services like in solar home systems and mini-grids. Some of those directly serve the integration of variable renewable energy. Technically, batteries are available today, their deployment varies depending on cost and regulatory considerations.

Table 1 Overview over services provided by batteries

Type	Scale	Application time	Service provided
Battery	Size ranges from micro-storage up to mid-scale storage (<100 kW-100 MW)	Applicable for seconds, minutes, hours, and days	Bulk energy services, Ancillary services (via aggregation), Distribution infrastructure services, Customer energy management services, Off-grid
Flywheel	Small scale storage (1-10MW)	Applicable for seconds / minutes	Distribution infrastructure services, Customer energy management services, Ancillary services (via aggregation)
Capacitor	Micro-storage (<100kW)	Applicable for seconds / minutes	Distribution infrastructure services, Customer energy management services

4.1.2 Regulatory issues

Electricity storage currently faces several regulatory issues affecting their profitability. Solving these issues will require a combination of incremental regulatory improvements and new, comprehensive regulatory frameworks, as discussed in section 3.

Network tariffs: After years of debate, Germany recently exempted electricity storage from network tariffs for charging if the electricity is fed back into the grid. A broader discussion focusses on how to incentivize grid-friendly deployment of storage with dynamic network tariffs.

Storage sited with utility-scale wind and solar: When storage is combination with a variable renewable energy installation, another regulatory issue arises concerning payment of tariffs. If the storage is located behind the meter, and the renewable output not separately metered, the battery must charge with renewable energy only. If storage were charged with electricity from the public grid, it is no longer defined as a renewable producer, and would lose any title to renewable supports such as renewable feed-in tariffs, renewable PPAs, or renewable guarantee of origin (GO). In other words, generation-sited storage cannot offer flexibility support to the grid without the installation losing economic benefits. This acts as a disincentive for offering flexibility to the DSO or to TSO even when it would be readily available at low cost, such as providing ancillary services. In turn, this also acts as a disincentive for combining renewable generation with storage.

Prosumer batteries: As explained in the introduction of this section, prosumers that own electricity storage typically seek to maximize self-consumption. Under net-billing schemes, excess electricity production is fed into the grid, for which prosumers receive only modest payments far below their own electricity supply tariff. Given Germany's high residential and commercial electricity prices, prosumers can pay back storage investments in a few years by saving on electricity purchases from their supplier. However, the disconnect between high power prices and low payment for feed-in to the grid effectively deters prosumers from offering flexibility and leads to the problem described in the beginning of this section. Clearly, regulatory incentives are required to encourage aggregation or remuneration by the DSO. Today, some restrictions to feed-in are included in legislation. Additionally, Germany has a public support program (KfW-Förderprogramm) which covers part of the investment cost of battery storage for prosumers with PV, and this program limits grid connection capacity to 50% of the peak capacity of the solar PV installation.

A more sophisticated regulation could enhance the usefulness of batteries for the grid. In the absence of a comprehensive flexibility market, these could include dynamic network tariffs or individual contracts between the DNO and the prosumer.

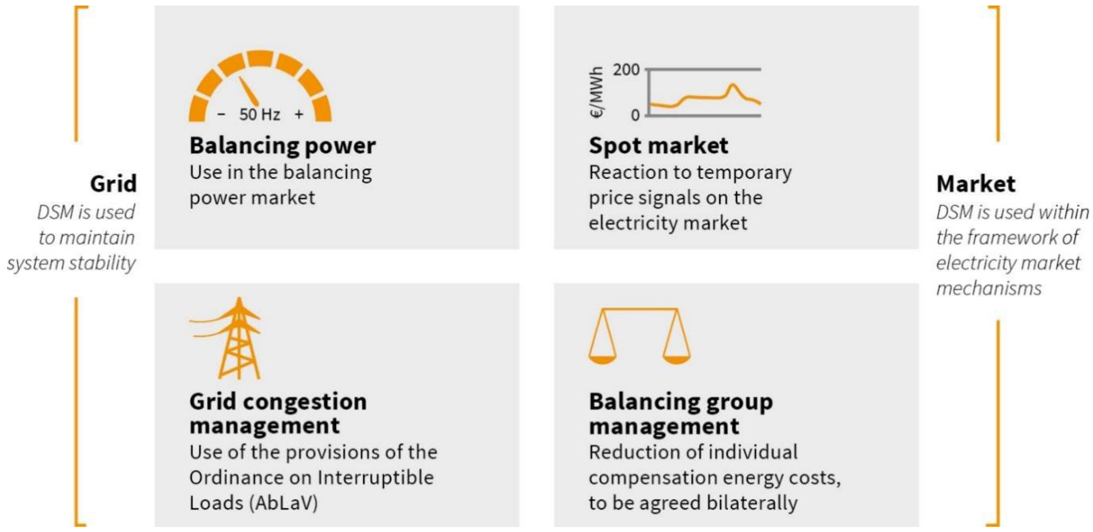
4.2 Demand side management (DSM)

Deployment of demand side management in Germany and in Europe has steadily gained attention in recent years. While European countries have already several DSM measures and are developing and piloting others, DSM makes a only minor contribution to load flexibility today.

Growth in DSM deployment will entail various technical, market, and regulatory conditions that future electricity market reform should provide. At a local level, for an energy system connected to a distribution electricity grid, DSM measures utilisation is in an early stage of development and has significant untapped potential. Future flexibility markets could offer an efficient way to utilise this potential.

This section gives and overview of technology options, use cases, regulatory issues and practical examples of DSM deployment with a focus on local distribution grids.

Figure 9 Grid and Market applications for DSM



Source: Dena, 2018

DSM offers benefits both from a grid and a market perspective. DSM measures can help to stabilize the grid and reduce operational and investment costs for the grid operator. DSM can also help consumers optimize their consumption behaviour and achieve financial benefits.

DSM measures include different ways of active or automated electric load management, either in response to an external price signal or under a contractually agreed load-control signal.[23] For both cases, DSM can involve a single consumer, an energy community, or a large number of consumers aggregated by a third party.

Some industrial consumers or larger commercial consumers may have sufficient incentive and sophistication to participate in DSM on their own. For smaller consumers, aggregation makes more sense.

Table 2 Application areas and end use sectors suited for DSM (own representation based on dena 2021[24] and Ffe 2021[25])

Industry	Service and Trade	Domestic appliance
Paper	Air-condition	Freezer / fridge
Chemicals	Air pressure / pumps / ventilation	Washing machine / dryer
Metal	Process cooling: cooling / fridges	Air-conditioner
Stone / Soil	Process heating: heating / hot water / oven	Hot water (electric)
Glass	Heating	Circulation heat pump (heat)
Machine construction	Data centres	Electric vehicle charging

DSM Platform - Airport Stuttgart: a pilot project of the airport operator

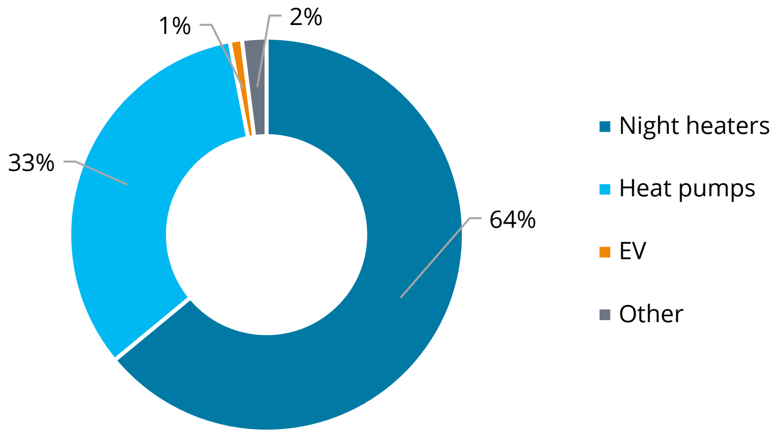
CONCEPT: a research project DSM real-time data platform BW for an integrated energy system solution for Stuttgart Airport. It aims to reduce peak loads and additionally market generation capacity as balancing energy to ensure the stability of the power grid. The project includes a block heating station, emergency power generator and Interruptable loads (cooling system and ventilation system). Interruptible loads are monetised by selling a control power by the virtual power plant from a distribution system operator. The project is a part of a larger research platform in which dena participates: Demand Side Management in Baden-Württemberg (more info: https://www.dena.de/en/topics-projects/projects/energy-systems/demand-side-management-in-baden-wuerttemberg/)

HIGHLIGHT: Reducing cost of the airport energy operation and enhancing security of supply.

For many years, DSO load-control agreements have allowed small consumers in Germany to contract with the DSO to remotely manage the electricity consumption of one or more of the customer's electrical devices, in exchange for a discount on grid charges. Data on load control agreements in 2021 show that around 83% of DSOs in Germany are using this DSM instrument to manage 1.8 million end-user devices. In exchange, DSOs have granted participants an average 57% reduction in the grid charges.[26] Night heaters account for two-third of load-control agreements, followed by heat pumps. To date, DSOs have not widely applied load-control agreements to EV charging, customer-sited energy storage, air conditioning, or other large devices. Stand-alone home cooling is uncommon in Germany today, though this will likely shift as a result of climate change and wider heat pump adoption.

As for the home battery storage market, where consumers typically pair batteries with solar PV for self-consumption, the absence of aggregation or market incentives has prevented participation in load-control services. This contrasts with other countries, where utilities have offered incentives for purchase of home batteries in exchange for load-control.

Figure 10 Application of load control agreements by DSOs in Germany in 2021 by shares of small consumer devices



Source: adjusted from BNetzA 2021

Appropriate load-control technology is a prerequisite for load control. In Germany, such technologies include simple timer switches with a programmable time pattern for load control, ripple control for carrying out load control through one-directional communication via grid or telecontrol, and more sophisticated bi-directional communication for load control via telecommunication networks. In case the of night heaters and heat pumps, on average 60% of load control employs ripple control technology, one third through timer-switch solution, while just 1% uses more advance bi-directional technology

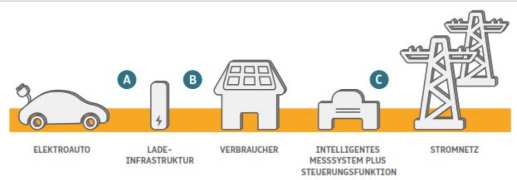
Apart from load control, more advanced DSM solutions are being tested on a local level. Several pilot project are underway, and they have already demonstrated technical and commercial viability. Application areas and use cases include integrated energy system solutions for consumers optimizing their energy consumption and production (such as for an airport or residential neighborhood) as well as intelligent charging and grid integration of electric cars and their batteries.

Vehicle2Grid: a pilot project of the technology company Mobility House

CONCEPT: an intelligent charging and grid integration of electric cars and their batteries enables vehicle owners to make economic savings on electricity costs (see the infographic of the concept below). Furthermore, vehicles can become providers of primary control power and help to stabilise the power grid. Technical part of the solution is a bidirectional charging capacity and a smart charging software that adjusts the charging plan of the vehicle according to price signals.

HIGHLIGHTS: electricity costs of the participating vehicles in a pilot project were approximately halved. In another pilot project it was demonstrated how V2G solution can contribute to stabilize the power grid and owners can benefit financially as part of the energy market. The project promotor has been granted a support for R&D of a smart charging technology in the framework of EU research and innovation programme Horizon 2020 (https://www.mobilityhouse.com/int_en/magazine/press-releases/eib-finances-the-mobility-house-under-innovfin-program.html).

CHALLENGES: It is essential to implement the second edition of the ISO standard 15118 (regulating communication between the charging station and the charging management device in the vehicle). In addition, the government should eliminate double taxation for the storage of renewable energy and simplify regulatory requirements for connections.

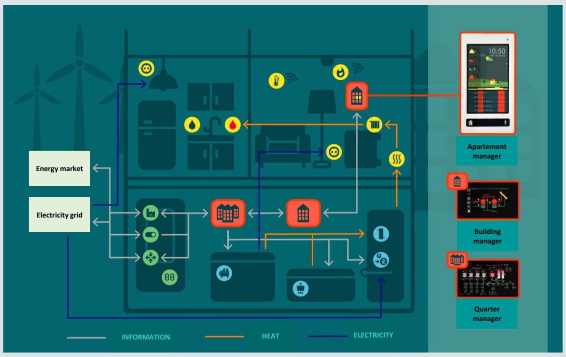


NPM V2G factsheet: https://www.plattform-zukunft-mobilitaet.de/wp-content/uploads/2020/10/201012_NPM_AG5_V2G_final.pdf Q: https://www.mobilityhouse.com/int_en/magazine/press-releases/vda-v2g-vision.html

WindNODE - ENERGY COMMUNITIES:

CONCEPT: testing solutions for aligning generation and consumption of renewable electricity in residential quarters, by practical implementation in a housing cooperative with six residential buildings and 224 apartments in Berlin, Germany. Technical concept includes a local heating network with a modulable CHP and additional peak load boilers. The buildings are equipped with smart building technology that continuously adjusts heat generation to heat demand. In addition, power-to-heat facilities, smart metering systems, and connections to energy industry platforms are installed which enables optimised conversion of a surplus power into heating energy, or on the other hand can support the grid by selectively feeding electricity in the grid. The project has been support through the funding program Schaufenster intelligente Energie - Digitale Agenda für die Energiewende (SINTEG) from the German Federal Ministry for Economic Affairs and Energy (BMWi, now BMWK).

HIGHLIGHT: The technology achieved a reduction in energy consumption of 24% compared to buildings of the same type.



Apart from suitable technical and commercial frameworks, wider deployment of DSM will require a more comprehensive regulatory framework.

An **EU framework** for enhancing the deployment of DSM by small consumers is still in development, but the EU has already identified its strategic goals and various conceptual designs. The 2019 clean energy package revised electricity market rules and paved the way towards integration of renewable energy production.[27] In this regard, the principles to create a national legal framework for demand side flexibility (DSF)—the term used in EU energy legislation and used here as equivalent demand side management (DSM)—and active participation of all energy consumers have been set by the EU Electricity Directive.[28] The regulations and principles define several specific topics and aspects important for the DSM.[29] Regulators established a priority list for the development of harmonized electricity rules by 2023, and included rules for DSF, aggregators, energy storage, and curtailment of distributed energy and renewables.[30]

The EU Agency for the Cooperation of Energy Regulators (ACER) has recently announced that it will submit non-binding Framework Guidelines to the European Commission by December 2022. These Framework Guidelines need to set out clear and objective principles for the development of a network code on Demand Response. The new rules will aim at enabling market access for demand response, and facilitating the market-based procurement of services by distribution and transmission system operators.

Aggregation is one of the important new roles in the new EU electricity market. The EU Electricity Directive defines this role as entities that engage in aggregation by combining multiple customer loads or generated electricity for sale, purchase, or auction in any electricity market. This service could be provided by suppliers or by independent aggregators.

Lastly, the EU Renewable Energy Directive includes provisions for renewable energy communities and for collective self-consumption (CSC),[31] where locally-produced electricity is shared between producers and consumers connected to the public distribution network, within the same geographical area.[32]

In its latest market monitoring report, ACER notes that implementation of rules for demand side flexibility and active participation of all energy consumers was still work in progress in most member states at the end of 2020.[33] Only Germany, Denmark, France, and Hungary had defined the main roles and responsibilities for aggregators, independent aggregators, active consumers and citizen energy communities (CECs)—defined as voluntary legal not-for-profit entities established at a local level for the purpose of energy generation, distribution, supply, consumption, aggregation, and storage—in their national legal frameworks and opened of their markets and products for system operators to these new entrants.[34]

An overview and the summary of main concepts and definitions important for the EU rules for the DSM are shown in the information box below.

The **German Electricity Market 2.0**, introduced in 2016, fosters active role of market participants through DSM on a commercial basis.[35] However, the framework for a significant deployment of DSM by small consumers is still a work in progress. Small consumers connected to a low-voltage grid have a right to participate in DSM through load control agreements with the distribution system operators. A problem arises from the fact that the government has not harmonized implementation of this solution with other regulatory incentives, such as indirect subsidies to batteries. The Energy Industry Law states that the Federal Government is authorized to specify by ordinance a framework for the reduction of network charges and the contractual arrangements, and to specify control actions.[36] Regulators are still debating more specific to harmonise implementation and to allow participation of other applications, such as EV charging or user-sited batteries.

Another critical issue for utilisation of untapped potentials of decentralized DSM is a roll-out **of smart meters and other digital technologies**. In Germany, policy makers have made some progress in designing a smart meter framework, but there are still hurdles to overcome. The Law on the Digitalisation of the Energy Transition and the IT Security Law govern this topic.[37] The law stipulates that as of 2017, the responsible metering point operators had to notify the Federal Network Agency and by June 2020, the operator must have installed smart meters on at least 10% of the metering points. After certification of smart meter gateway, in February 2020 the Federal Office for Information Security (BSI) gave the green light for DSOs to deploy intelligent metering systems (iMsys), an interface for connection to a communication unit.

To facilitate the process of digitalisation of the energy grid, in 2019, the Federal Ministry for Economic Affairs and Energy (BMWi) and the Federal Office for Information Security published the Standardisation Strategy for Cross-sector Digitalisation of the Energy Transition, an overall roadmap for energy digitsation.[38] In 2021, BMWi established a Gateway Standardization Committee to deal with the interoperability certification of smart meter gateways. Full implementation of smart metering technology will allow further deployment of dispatchable consumption devices, such as thermal energy storage or electric vehicles.

5 Application to China

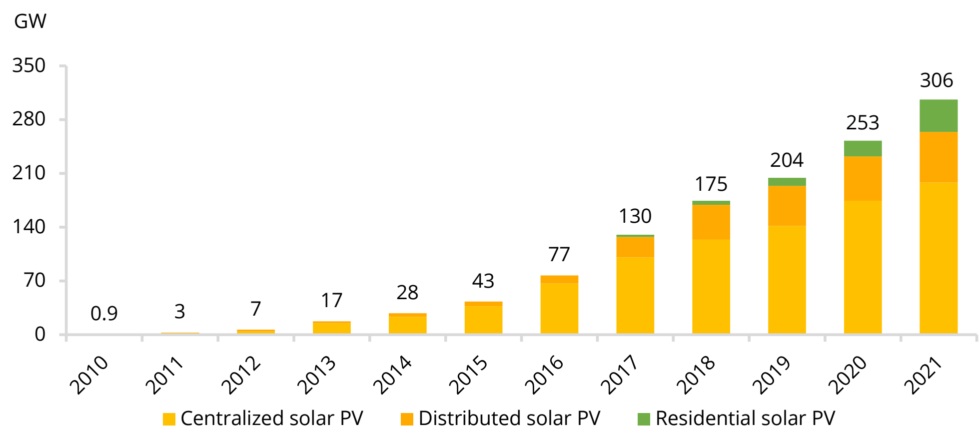
China's distributed and residential solar PV is growing rapidly. Recent policies have prioritized building storage together with utility-scale wind and solar projects and allowing participation of distributed PV and storage in energy markets. Although the grid can accommodate small-scale solar PV at low levels of penetration, at higher levels more demand-side flexibility will help avoid costly grid upgrades and curtailment. German experiences with distributed generation and distributed flexibility are likely to become relevant in China. Decentralized flexibility has a large potential to contribute to system and network integration of distributed generation. A supportive framework would build on present time-of-use prices and a framework of contracts between DNOs and flexibility assets owners to harness the flexibility for grid services.

5.1 Distributed generation in China

China's renewable energy sector has undergone a major shift over the past five years, adding both large-scale installations and distributed energy. Prior to 2019, the country's solar energy expansion concentrated in the more remote western and northern provinces, which contributed to high rates of curtailment to preserve system stability.[39] Renewable curtailment has fallen to low levels in most provinces due to a combination of factors, including administrative incentives, quotas for renewable uptake, limits on new renewables in provinces with transmission bottlenecks, and inter-provincial trading of renewables.

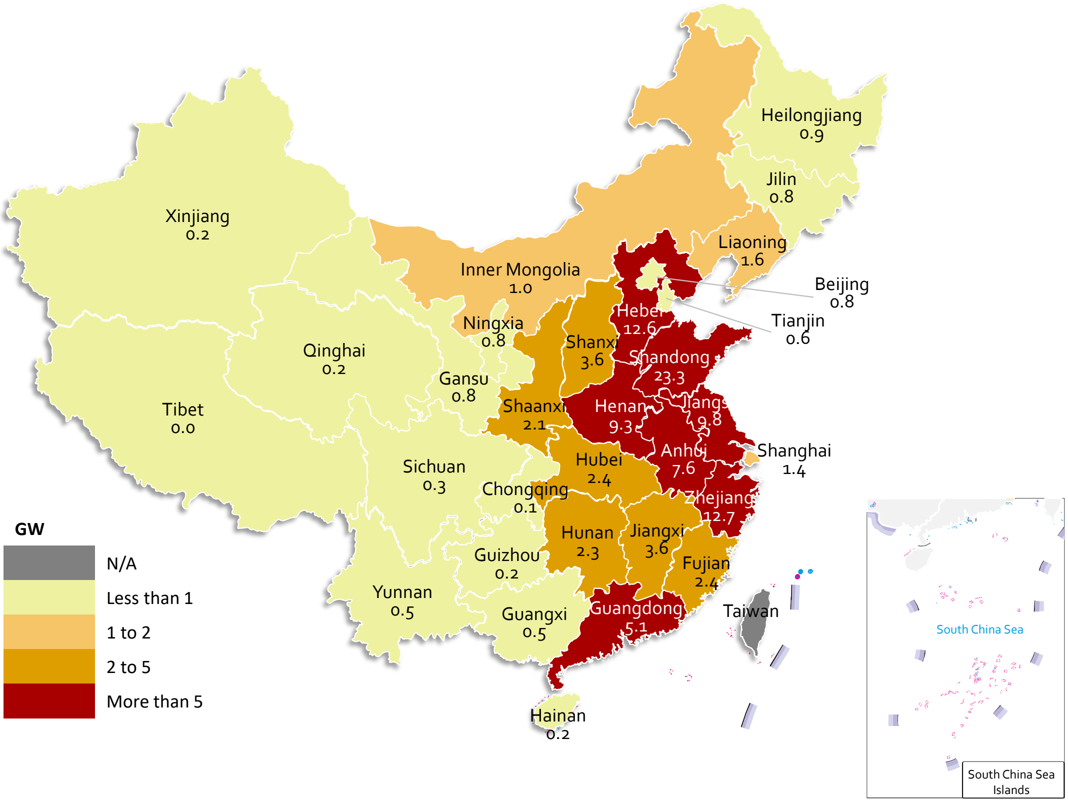
The share of distributed solar in China's total solar PV began to soar starting from 2016. There are several reasons for the shift to distributed solar. In May 2016, the National Reform and Development Commissions (NDRC) issued new guidelines on the size and management of distributed solar and removed provincial limits to new project approvals for distributed solar. Declining costs have also made distributed solar PV projects more attractive for developers.

Figure 11 China's PV capacity development by category between 2010 and 2021



Source: National Energy Administration, 2022

Figure 12 China's cumulative distributed solar PV capacity by province in 2021



Source: China Electricity Council , 2022

Distributed solar PV has been installed mainly in eastern and southern China, in regions with reasonably high solar resources and high electricity demand. China's strict land use regulations has made distributed solar PV projects attractive in more populous regions. In the 14th Five-Year Plan, Chinese policy makers signaled that the system will simultaneously expand central and distributed energy,[40] calling for eastern provinces to develop distributed energy to increase local energy self-sufficiency.[41] The plan also states that distributed energy and storage should fully participate in various markets.

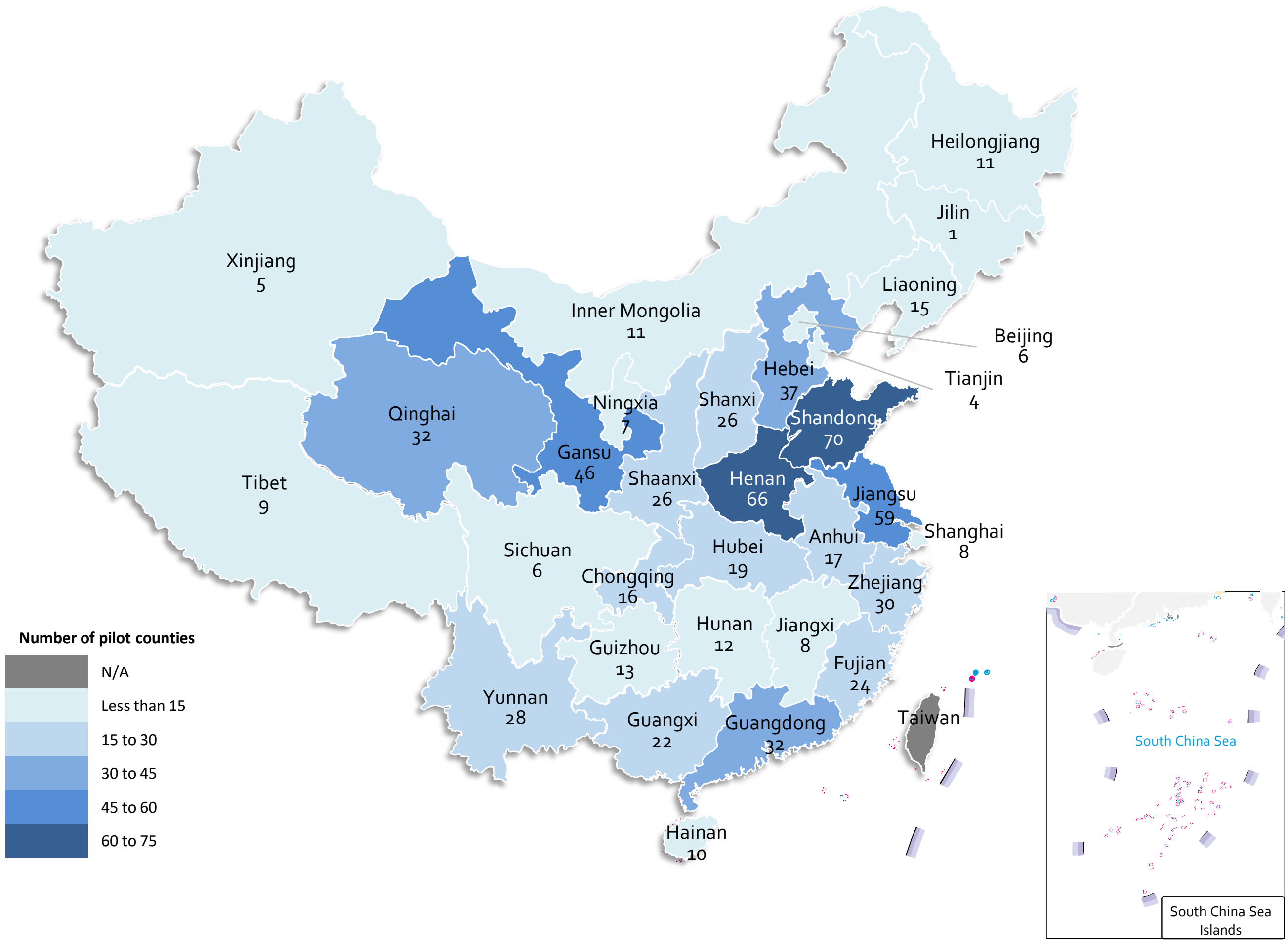
Distributed energy in China differs substantially from distributed energy in Germany, where distributed energy normally refers to VRE installations connected to the distribution grid. In China, the term *distributed generation* applies to many large-scale CHP plants co-located near loads.[42] Furthermore, distributed solar typically refers to multi-MW ground-mounted facilities near industrial areas.[43]

Rooftop solar is growing as a share of new installations, especially since the advent of county-level distributed solar pilots, but still accounts for a relatively small share of China's overall solar capacity.

In contrast to Germany, residential solar PV is a new phenomenon in China. Nonetheless, ever since 2017, the number of installed rooftop systems has increased rapidly.[44] So far, much of this growth is due to China's Poverty Alleviation PV programme. Over the 13th Five-Year Plan period (2016–2020), the Chinese government invested over RMB 20 billion in the deployment of distributed solar in rural areas.[45] The Zero Emission Village project in Zhuangshang illustrates this initiative.[46]

NEA release the list of whole-county pilot in September 2021.[47] The list includes 676 counties in 32 provinces. Eligible counties need to have ample rooftop area and incentive to exploit rooftops to install PV panels. The policy requires that government buildings need to have more than 50% of the space available to install PV panels, while the requirement is 40% for public buildings, 30% for factories, and 20% of the total rooftop area of rural residential buildings.[48]

Figure 13 Provinces with Whole County Solar PV Pilots



Source: National Energy Administration, 2021

Example: Residential PV and Energy Storage in China

The Zero Emission Village in Zhuangshang, Shanxi province, is a model project to deploy distributed PV and energy storage in rural areas. With a total installed capacity of 2 MW, many of the village's households are now equipped with solar panels, energy storage, and smart inverters and can both supply power to the rest of the village and sell surplus electricity to the country's main grid company, State Grid Corporation of China.

5.2 Distributed storage

Thus far, development of distributed solar has not been accompanied by an increasing deployment of user-side energy storage. Due to safety concerns and lack of clear standards, policy makers have restricted the development of user-side energy storage in China. As of 2021, there were only 31 standards in effect or under development for the energy storage industry, as compared to over 100 industry standards in place for EVs. In April 2021, a large lithium-iron-phosphate battery caught fire at a shopping mall in Beijing, further intensified safety reservations.[49] Based on the cautious language towards customer-sited storage included in the 14th Five-Year Plan for a Modern Energy System, which clearly prioritizes generation-side and grid-side storage over user-side storage,[50] it appears unlikely that user-side storage will become more widespread in the near future.

Pairing rooftop PV and energy storage could be especially beneficial for China's commercial and industrial consumers, due to the higher electricity prices paid by these users as well as their exposure to wholesale electricity costs after October 2021, when policy makers liberalized retail electricity prices. Policy makers are likely to target industry parks for further development of rooftop solar, making it logical to pair solar with storage to reduce peaks in net load. Nonetheless, many obstacles still hamper this development. Industrial park consumers interviewed in a recent GIZ study cited a combination of economic concerns and the lack of a government mandate as the leading reasons for the overall low motivation to combine PV with energy storage.[51]

Recent developments in China, such as the widening of the time-of-use (TOU) price differences in 2021 could improve the economic value of distributed storage.[52] Establishing time-varying prices and wider peak-to-through ratios, as outlined in the policy, can provide a greater incentive for reducing peak loads and will make distributed storage more attractive.

In 2021, China's NDRC announced several important policies to remove administrative regulations on power prices. The NDRC issued a policy notice in July 2021 suggesting that retail electricity prices should have higher ratios between the peak rate and trough rate—specifically, that the ratio should be at least 4:1 in regions where the generation difference between peak and trough is higher than 40%.[53] Before its implementation, an NDRC policy in October announced that commercial and industrial users would switch from regulated retail price schedules to market-based contracts from 2022.[54]

The enlarged TOU price has made storage more attractive to renewable generators and distributed renewable installers. In 2021, GIZ studied the investment returns of self-owned distributed solar PV, either on a stand-alone basis or paired with energy storage in various Chinese cities.[55] The result shows that in Nanjing and Hangzhou when the commercial tariff peak-trough ratios increased to 4:1, the IRR of Nanjing's distributed solar PV would increase to 23.80% and that of Hangzhou would increase to 19.19%.

For residential customers, electricity prices include tiered pricing based on monthly or annual consumption levels. In 2011, NDRC adopted a policy aimed at encouraging electricity conservation. The policy required each household to have one power meter and created an electricity price premium for households consuming more electricity than the district average. The pricing policy, known as ladder pricing, keeps prices unchanged for 80% of customers, but creates a 2nd and 3rd tier of residential customers in the 80-95% percentiles and 95-100% percentiles of local district monthly or annual average household power consumption, charging higher retail prices for these tiers.[56]

However, the tiered pricing approach provides no incentive to reduce peak consumption, and users may only be switched to the higher rate after they have exceeded the threshold towards the end of a measurement period—such as late in the year, when the opportunity to reduce peak consumption has already passed. Although residential electricity accounts for a small overall share of national electricity consumption, summertime cooling is a major factor driving peak load growth in most urban areas, and also causes strain for older distribution grids in rural areas. Urban cooling loads have grown by a factor of 5x since 2000, and represent up to 50% of summer electricity load peaks in major cities.[57] Electrification of transportation and heating will exacerbate the problem, increasing the importance of introducing time-based pricing signals for residential consumers.

5.3 Centralized storage

In the policy that issued in 2021 on multi-energy complementarity, NEA emphasized on renewable energy pairing with storage.[58] Until June 2022, 19 provinces have issued policies for renewables to pair with storage. Typical requirements specify storage equal to 10% of peak output, with 2-hours storage capability. In other words, a 100 MW wind plant would have 20 MWh of storage.

Figure 14 Provinces with storage requirement for renewables

Source: GIZ 2022

NDRC and NEA issued another policy in May 2022 encourage storage to participate in the mid-to-long term and spot market. [59] The policy aims to use storage as a peak regulation and generation resources through contracts for peak and trough hours. In addition to these policies, the Implementation Scheme for the Development of New Energy Storage (2021-2025) mentions establishing an energy storage development fund that aims for a 30% reduction of the costs per unit of battery storage by 2025.[60]

5.4 Demand-side management

In recent years, China has experienced power shortages in summer and winter. To guarantee the daily power consumption for residential users, a policy known as orderly consumption measures would apply to energy-intensive and emission-intensive consumers as well as commercial lighting. It requires industrial consumers to reduce power consumption at the peak time period, or shift loads to other times.[61] The power rationing measures apply to Energy administrators in China have long realized the importance of demand-side management.

When there's a power shortage, the power demand of the following users have priority:[62]

- Public sector and government that maintain national security and social order;
- Security load for enterprises that may experience personnel injuries or machine damages if there's a power outage, such as hazardous chemical producers and mines;
- Hospitals, financial institutes, and schools;
- Utilities, such as heating, cooling, and energy providers;
- Residential and agriculture users;
- National key projects and military enterprises.

The power consumption of the following users shall be limited: [63]

- Non-compliance projects;
- Elimination and restriction enterprises in the industrial restructuring catalogue;
- Enterprises with energy consumption per unit higher than the national or local mandatory energy consumption limit;

- Landscape lighting and illumination;
- Other energy-intensive and emission-intensive enterprises.

China launched DSM pilots in four cities in 2013, namely Beijing, Tangshan, Suzhou and Foshan.[64] By 2021, nine provinces within the State Grid region have issued supporting policies for DSM. Among these provinces, Shandong, Zhengjiang, Gansu planned to allow DSM to participate in the spot market, whilst northern Hebei allows it to participate in the ancillary service market.[65] In recent years, market is playing more important role in allocating demand-side management resources, and market participants are growing more diversified, with policies encouraging residential, retailors, aggregators, storage, and EV charging to participate in the market, though this is still largely a vision for the future.[66]

The 14th Five-Year Plan sets a target of DSM providing 3-5% of the maximum load in 2025.[67] Currently, there is no public data on the percentage of peak load subject to DSM, and it is unclear how government officials will monitor this target or how frequently results will be available. One possibility is to measure the volume of load-control contracts signed by industry with the local grid companies. In this case, the 3-5% target would apply to a capacity amount, but not to the actual volume of peak load shifted.

5.5 Coal plant flexibility

According to a 2021 policy target, China aims to retrofit 200 GW existing coal power plant capacity for increased flexibility and thereby add 30-40 GW of system adjustment capacity.[68] By the end of 2019, China had retrofitted 57.8 GW coal power plants, only around 25% of the 13th Five-Year Plan target of 220 GW.[69]

The slow investment return is the one of the main reasons for the lack of incentive for coal power retrofit. According to the China Energy Information Platform, current costs for coal power plant retrofit are around RMB 500-1500/kW.[70] However, the coal power prices can only fluctuate 20% above the baseline price,[71] and almost all power is traded on monthly and annual bilateral contract markets, with limited spot market trading in certain pilot provinces. The lack of a spot market that could provide short-term incentives for flexibility substantially reduces the incentive for flexible operations or investment in flexibility. Insufficient compensation for the provision of ancillary services is another reason for the reluctance for coal power plant retrofit.[72]

5.6 Ancillary service markets

Ancillary services such as frequency regulation, voltage control and black start help maintain the secure and stable operation of the electric grid. Ancillary services markets are especially important as variable renewable power grows in importance on electric grids. In China, ancillary services often includes ramping plant output up or down to follow load, sometimes also called peak regulation—a major difference from Europe, where spot markets would perform this function. Previously, China's power system provided only limited funds for ancillary services, and effectively required coal plants to pay one another for such services. Starting in 2018 reforms have established ancillary service market pilots, starting with Northeast China, focused on peak regulation.[73] China's ancillary services markets initially limited participation to coal-fired generators, but more recent policies call for opening up ancillary services markets to renewable energy, batteries and the demand side.

NEA issued two new policies regarding ancillary service by the end of 2021.[74] The policy allows more diversified entities to trade in the ancillary service market, including new types of storage, EV charging networks, aggregators and VPPs. Services already traded in the spot market shall not be included in the ancillary service market. The policy also implicitly states that for inter-provincial and inter-regional trading, the contract should include responsibility and compensation for ancillary services. According to the policy, there are two ways for ancillary service providers to recover costs.[75] The first through a fixed compensation fee, determined by provincial energy administrators. The alternative is through a market-determined price.

Table 3 Funding sources for demand-side management in China[76]

Province	Funding sources for DSM
Jiangsu	Peak Tariff
Zhejiang	Surpluses from power purchase in Inter-regional spot market; exploring market-based sharing mechanisms
Shanghai	Historical seasonal tariff differential of summer
Henan	Included in the T&D prices approval
Hunan	Provincial power Company
Hubei	Power price difference corresponding to Three Gorges' incremental generation capacity
Shandong	Emergency: share the cost according to related national regulations Economical: Clarify when the spot market is operating continuously
Tianjin	Special funding for demand-side management
Chongqing	High water period consumes the price difference of the additional power purchase during the valley period in Sichuan
Shaanxi	Annual surpluses from power purchase in Inter-regional spot market
Guangdong	Shared by users in the region with power demand

5.7 Relevance of German experience

The German experiences with distributed generation and subsequent grid problems, as explained in section 2, are likely to become relevant in China once the expansion of small-scale solar PV passes a critical threshold. With future distribution grids absorbing ever-higher levels of feed-in, avoiding violations of thermal limits of networks and voltage problems will require careful planning and new regulatory incentives. Grid expansion is one potential solution, but in many cases this represents the most costly approach. Curtailment of renewable feed-in preserves grid stability but wastes clean energy and directly affects the economic case for distributed renewable energy deployment.

Distribution-level flexibility from batteries and DSM measures can make a significant contribution to the solution of the grid problems, but requires regulatory support. It is important to note that the technical availability of flexibility in the network is not a sufficient condition for congestion management: As explained in this report, depending on whether consumers or aggregators program user-sited batteries for minimizing grid impacts versus maximizing self-consumption, such batteries can either help or harm network stability. Flexibility in the market, such as for the purpose arbitrage by load shifting, is not necessarily beneficial for the network. To harness the potential of flexibility for distribution and transmission grids, regulatory change is required: Regulation must allow distribution network operators to engage in contracts with providers of flexibility to make it available for decentralized congestion management and further ancillary services. Moreover, it must enable aggregation of decentralized flexibility assets to make it available to the transmission grid operator.

Smart grid elements are a prerequisite for the use of decentralized flexibility. These allow grid operators to monitor and control their networks. Regulatory measures to implement these reforms in China are likely to differ from the German experience in many details, owing to the different structure of the electricity supply industry. Regulators must ensure, however, to include an adequate incentive for grid friendly use of flexibility assets. To some extent, such incentives can be provided by dynamic grid fees that make consumption and feed-in expensive for the prosumer during times of congestion. However, the direct use of flexibility by the distribution network operator via load resp. feed-in control is more effective. To make it work economically, however, the DSO must remunerate flexibility asset owners for their grid services. Without such incentives, potential prosumers will have inadequate incentive to deploy distributed renewables paired with storage and to operate it in a manner optimal for both the grid and various user values such as reliability and clean energy consumption.

Without suitable incentives for investment and operation, the market for storage investment could be seriously distorted—for example, resulting in excess investment in generation-sited storage that results in higher distribution grid costs to manage in-feed of distributed PV. Provided a suitable framework is introduced, decentralized flexibility has a large potential to contribute to system and network integration of distributed generation, most notably small-scale solar PV, and thus to a successful Chinese energy transition.

5.8 Suggestions for decentralized flexibility in China

To promote the integration of distributed renewable energy into networks, Chinese regulators should introduce regulation aimed at encouraging demand-side flexibility, including both DSM and storage.

Currently, due to the limited availability of market-based incentives, DSM in the Chinese context is usually considered as a cost. Most DSM program participants are industrial customers who participate in peak shaving programs and receive payment in return. While reformed time-of-use rates will incentivize commercial and industrial customers to do more, there are presently limited real-time signals around flexibility, and those price signals that exist are focused on peak shaving, rather than flexibility as such. Further, residential consumers have no incentive to contribute to reducing system peaks, either by modifying consumption or operating user-sited storage to benefit the needs of the grid. Since residential and commercial heating, cooling, and EV-charging loads are likely to grow increasingly important as a factor driving peak load growth, more real-time signals are needed to incentivize such consumers—and their property managers, for large buildings in urban areas—to participate in DSM, either directly, or through aggregator service companies.

Policy makers should incentivize deployment of smart grid elements into the distribution grid to allow the monitoring and control of flexibility assets.

For over a decade, most Chinese cities have deployed smart meters for residential, commercial, and industrial customers. However, these first-generation meters are focused on remote monitoring, billing, and payment, rather than on real-time load control and monitoring. Further, meters have limited ability to enable real-time signals to customers about peak load events or opportunities to participate in demand response. In the current decade, smart grid devices should be deployed throughout the grid, including particularly for customers with valuable demand response loads such as controllable HVAC, heat pumps, EV chargers, or large data processing loads.

To the extent practical, grid operators should share information from smart grid monitoring with flexibility asset owners aggregators to assure they can participate in any market for grid-friendly flexibility services.

China's present electricity system is characterized by low levels of public data. Whereas the current daily load and generation profiles are widely available in most advanced economies, such information is considered sensitive in China. Without real-time pricing information, customers and aggregators have no ability to respond to grid needs. Without data on present loads and prices, customers and investors have no visibility on whether investment in new flexibility assets, such as storage or controllable loads, would be economically attractive. Administratively-set prices, such as TOU, can provide only a partial signal about the value of flexibility or peak shaving, where the grid's needs are likely to change on a daily and even minute-by-minute basis.

Remuneration for flexibility, whether determined by real-time congestion values or via administrative formula, should reflect the true cost of network use and the value of avoided grid investment costs.

As the discussions in Germany have made clear, increased deployment of renewable energy at all levels results in a greater demand for flexibility, and this implies that the value of flexibility is rising over time. Although some reforms in China have enabled payment for certain types of flexibility, the main participants in peak shaving so far are generators and large industrial customers, and many such payments are determined by static administrative measures.

As the penetration of renewable energy rises, and as urban heating and cooling loads increase as a share of peak load, it is critical to provide remuneration to all market participants who can provide flexibility services. To the extent practical, payment for demand-side services should avoid discrimination between flexibility provided by different customer classes, aggregators, generators, or energy suppliers.

Dynamic grid fees are one way for DSOs to incentivize flexibility. Direct load control batteries and other demand-side devices for congestion management purposes. This use of flexibility should be strictly based on a contract between the DSO and the asset owners to avoid a distortion of investment incentives.

Finally, the government should establish a regulatory framework for the role of the aggregator.

China's recently-issued five-year plans incorporate numerous references to aggregator services, but for the most part there are few ways for aggregators to engage customers today, due to the absence of real-time price signals. Specific regulations must enable aggregators to harness the flexibility of decentralized flexibility on the system level by allowing them to engage into contracts with final consumers, and earn returns from providing flexibility services to the grid and generators.

List of figures

List of tables

References

[1] “AG Energiebilanzen legt Bericht für 2021 vor,“ AGEB, 28 March 2022, at https://ag-energiebilanzen.de/ag-energiebilanzen-legt-bericht-fuer-2021-vor/.
[2] “Mehr Fortschritt Wagen,” SPD, Grüne & FDP, December 2021, at https://www.bundesregierung.de/breg-de/service/gesetzesvorhaben/koalitionsvertrag-2021-1990800.
[3] “Flexibility Technologies and Measures in the German Power System,“ dena, January 2021, at https://www.energypartnership.cn/fileadmin/user_upload/china/media_elements/publications/2022/Flexibility_Technologies_and_Measures_in_the_German_Power_System.pdf.
[4] “Assessing power system adequacy in Germany and Europe, and lessons for China,“ dena, April 2022, at https://www.energypartnership.cn/fileadmin/user_upload/china/media_elements/publications/EnTrans/Assessing_power_system_adequacy_in_Germany_and_Europe_and_lessons_for_China.pdf.
[5] Harry Wirth, “Aktuelle Fakten zur Photovoltaik in Deutschland,“ Fraunhofer ISE, 17 July 2022, at https://www.ise.fraunhofer.de/de/veroeffentlichungen/studien/aktuelle-fakten-zur-photovoltaik-in-deutschland.html.
[6] “EEG in Zahlen – 2019,” Bundesnetzagentur, 2020, at https://www.bundesnetzagentur.de/SharedDocs/Downloads/DE/Sachgebiete/Energie/Unternehmen_Institutionen/ErneuerbareEnergien/ZahlenDatenInformationen/EEGinZahlen_2019_BF.pdf?__blob=publicationFile&v=3#:~:text=EEG%20in%20Zahlen%202019%201%20Vorwort%202%2F83%2031.12.2019,%28Anzahl%29%207.222%20602%2015.122%2011%2028.363%201.467%201.868.1561.920.943.
[7] Dr. Harry Wirth, “Aktuelle Fakten zur Photovoltaik in Deutschland,“ Fraunhofer ISE, 17 July 2022, at https://www.ise.fraunhofer.de/de/veroeffentlichungen/studien/aktuelle-fakten-zur-photovoltaik-in-deutschland.html.
[8] Jan Figgener et al, “The development of battery storage systems in Germany: A market review (status 2022),” 15 March 2022, at https://arxiv.org/abs/2203.06762.
[9] Jan Figgener et al, “The development of battery storage systems in Germany: A market review (status 2022),” 15 March 2022, at https://arxiv.org/abs/2203.06762.
[10] “Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources,” European Union, accessed on 15 July 2022, at https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2018.328.01.0082.01.ENG&toc=OJ:L:2018:328:TOC.
[11] “Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on common rules for the internal market for electricity and amending Directive 2012/27/EU,” European Union, accessed on 15 July 2022, at https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32019L0944.
[12] “To dare more Progress – Alliance for Freedom, Justice and Sustainability. Coalition treaty 2021 – 2025 among the Social Democratic Party of Germany (SPD), Alliance ‘90/The Greens, and the Free Democrats (FDP),” originally published in German as “Mehr Fortschritt wagen - Bündnis für Freiheit, Gerechtigkeit und Nachhaltigkeit. Koalitionsvertrag 2021 – 2025 zwischen der Sozialdemokratischen Partei Deutschlands (SPD), BÜNDNIS 90 / DIE GRÜNEN und den Freien Demokraten (FDP)”, Deutsche Bundesregierung, accessed on 15 July 2022, at https://www.bundesregierung.de/resource/blob/974430/1990812/04221173eef9a6720059cc353d759a2b/2021-12-10-koav2021-data.pdf?download=1.
[13] “Flexibility Technologies and Measures in the German Power System,“ dena, January 2021, at https://www.energypartnership.cn/fileadmin/user_upload/china/media_elements/publications/2022/Flexibility_Technologies_and_Measures_in_the_German_Power_System.pdf.
[14] “Unlocking the Potential of Distributed Energy Resources: Power system opportunities and best practices,” International Energy Agency (IEA), May 2022, at https://www.iea.org/reports/unlocking-the-potential-of-distributed-energy-resources.

[15] Luhmann et al, “An approach for cost-efficient grid integration of distributed renewable energy sources,” Eng. Sci., pp.447-452, 01 December 2015, at https://www.semanticscholar.org/paper/An-Approach-for-Cost-Efficient-Grid-Integration-of-Luhmann-Wieben/35f7b0a3f90a6618566a015ce25f91de79668956.
[16] Iweh et al, “Distributed Generation and Renewable Energy Integration into the Grid: Prerequisites, Push Factors,Practical Options, Issues and Merits,” Energies, 29 August2021, at https://doi.org/10.3390/en14175375.
[17]“Unlocking the Potential of Distributed Energy Resources: Power system opportunities and best practices,” International Energy Agency (IEA), May 2022, at https://www.iea.org/reports/unlocking-the-potential-of-distributed-energy-resources.
[18] “Innovation landscape brief: Future role of distribution system operators,” International Renewable Energy Agency (IRENA), 2019, at https://cms.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Feb/IRENA_Landscape_Future_DSOs_2019.ashx?la=en&hash=9B2EBAC2A99DAA6AB85FF98E93F34BE930EEF78A.
[19] “Flexibility Technologies and Measures in the German Power System,“ dena, January 2021, at https://www.energypartnership.cn/fileadmin/user_upload/china/media_elements/publications/2022/Flexibility_Technologies_and_Measures_in_the_German_Power_System.pdf.
[20] “Innovation landscape brief: Future role of distribution system operators,” International Renewable Energy Agency (IRENA), 2019, at https://cms.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Feb/IRENA_Landscape_Future_DSOs_2019.ashx?la=en&hash=9B2EBAC2A99DAA6AB85FF98E93F34BE930EEF78A.
[21] “Flexibility Technologies and Measures in the German Power System,“ dena, January 2021, at https://www.energypartnership.cn/fileadmin/user_upload/china/media_elements/publications/2022/Flexibility_Technologies_and_Measures_in_the_German_Power_System.pdf.
[22] “NEMO.Spot. Flexibilitätshandel der nächsten Generation”, EnergieDock, accessed on 19 July 2022, at https://www.energiedock.de/technologie/nemo-spot/
[23] “Industrial Demand Side Flexibility in China. German Experiences – Status Quo and Potential in China – Policy and Market Recommendations,“ dena, August 2019, at https://www.dena.de/fileadmin/dena/Publikationen/PDFs/2019/190830_Industrial_Demand_Side_Flexibility_report_final_dena.pdf.
[24] “Flexibility Technologies and Measures in the German Power System,“ dena, January 2021, at https://www.energypartnership.cn/fileadmin/user_upload/china/media_elements/publications/2022/Flexibility_Technologies_and_Measures_in_the_German_Power_System.pdf.
[25] “Regionale Lastmanagementpotenziale Quantifizierung bestehender und zukünftiger Lastmanagementpotenziale in Deutschland,“ Ffe, 17 December 2021, at https://www.netzentwicklungsplan.de/sites/default/files/paragraphs-files/Regionale_Lastmanagementpotenziale_DE_0.pdf.
[26] “Monitoringbericht 2021 der Bundesnetzagentur und des Bundeskartellamtes,“ Bundesnetzagentur, 01 December 2021, at https://www.bundesnetzagentur.de/SharedDocs/Pressemitteilungen/DE/2021/20211201_Monitoringbericht.html.
[27] “Clean energy for all Europeans package,” European Commission, May 2019, at https://energy.ec.europa.eu/topics/energy-strategy/clean-energy-all-europeans-package_en.
[28] “Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on common rules for the internal market for electricity and amending Directive 2012/27/EU,” EU, 05 June 2019, at https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019L0944
[29] “Regulation (EU) 2019/943 on the internal market for electricity,” EU Sources Online, 14 June 2019, at https://www.europeansources.info/record/regulation-eu-2019-943-on-the-internal-market-for-electricity/.
[30] “Commission Implementing Decision (EU) 2020/1479 of 14 October 2020 establishing priority lists for the development of network codes and guidelines for electricity for the period from 2020 to 2023 and for gas in 2020,” EU, 14 October 2020, at https://beta.op.europa.eu/en/publication-detail/-/publication/360fd436-0ead-11eb-bc07-01aa75ed71a1/language-en/format-PDF.

[31] "Collective self-consumption: producing and consuming renewable energy locally," eDF, accessed on 20 July 2022, at https://www.edf.fr/en/the-edf-group/supporting-our-clients-on-a-daily-basis/collective-self-consumption-producing-and-consuming-renewable-energy-locally.
[32] "Directive (EU) 2018/2001 of the European Parliament and of the Council," EU, 21 December 2018, at https://www.europeansources.info/record/directive-eu-2018-2001-on-the-promotion-of-the-use-of-energy-from-renewable-sources/.
[33] "Electricity wholesale markets monitoring in 2020," ACER, 2020, at https://www.acer.europa.eu/events-and-engagement/news/electricity-wholesale-markets-monitoring-2020-further-action-needed.
[34] "Energy communities," European Commission, accessed on 20 July 2022, at https://energy.ec.europa.eu/topics/markets-and-consumers/energy-communities_en.
[35] "Electricity Market 2.0- An electricity market for Germany's energy transition," Bundesministerium Energie und Klimaschutz (BMWK). (2015a), 31 July 2015, at https://www.bmwk.de/Redaktion/EN/Artikel/Energy/electricity-market-2-0.html.
[36] "Energiewirtschaftsgesetz (EnWG)," 13 July 2005, at https://dejure.org/gesetze/EnWG.
[37] "The digitisation of the energy transition," Bundesministerium Energie und Klimaschutz (BMWK), at https://www.bmwk.de/Redaktion/EN/Artikel/Energy/digitisation-of-the-energy-transition.html.
[38] "Roadmap for smart energy grids of the future," Bundesministerium Energie und Klimaschutz (BWMK), 29 January 2019, at https://www.bmwk.de/Redaktion/EN/Pressemitteilungen/2019/20190129-roadmap-for-smart-energy-grids-of-the-future.html.
[39] Froggatt et al, "Decentralised Energy: A Global Game Changer, " pp.47-62, Decentralised Energy — a Global Game Changer, Decentralised Energy, London: Ubiquity Press January 2020.
[40] " "十四五"可再生能源发展规划的通知, 发改能源[2021]1445 号," National Development and Reform Commission and other eight ministries, 21 October 2021, at https://www.ndrc.gov.cn/xxgk/zcfb/ghwb/202206/t20220601_1326719_ext.html.
[41] "十四五"现代能源体系规划 [14th Five-Year Plan for Modern Energy System]," National Development and Reform Commission (NDRC), National Energy Administration (NEA), 22 March 2022, at https://www.ndrc.gov.cn/xxgk/zcfb/ghwb/202203/P020220322582066837126.pdf.
[42] Froggatt et al, "Decentralised Energy: A Global Game Changer, " pp.47-62, Decentralised Energy — a Global Game Changer, Decentralised Energy, London: Ubiquity Press January 2020.
[43] "Economics of Urban Distributed PV in China," Gesellschaft für Internationale Zusammenarbeit (GIZ), July 2021, at https://www.energypartnership.cn/fileadmin/user_upload/china/media_elements/publications/2021/Economics_of_Urban_Distributed_PV_in_China_EN.pdf.
[44] "Impact of China wholesale power price reform on economics of distributed storage and PV," Gesellschaft für Internationale Zusammenarbeit (GIZ), February 2022, at https://www.energypartnership.cn/fileadmin/user_upload/china/media_elements/publications/2022/Impact_of_China_wholesale_power_price_reform_on_economics_of.pdf.
[45] "Impact of China wholesale power price reform on economics of distributed storage and PV," Gesellschaft für Internationale Zusammenarbeit (GIZ), February 2022, at https://www.energypartnership.cn/fileadmin/user_upload/china/media_elements/publications/2022/Impact_of_China_wholesale_power_price_reform_on_economics_of.pdf.
[46] "一个村庄的"碳中和"探索," Xinhuanet, 24 August 2021, at http://www.sx.xinhuanet.com/2021-08/24/c_1127788450.htm
[47] "国家能源局综合司关于公布整县（市、区）屋顶分布式光伏开发试点名单的通知, 国能综通新能[2021]84 号," National Energy Administration, 8 September 2021, at http://www.gov.cn/zhengce/zhengceku/2021-09/15/content_5637323.htm.
[48] "关于报送整县(市、区)屋顶分布式光伏开发试点方案的通知," National Energy Administration, 20 June 2021, at https://www.163.com/dy/article/GDKCHPIK05372EVQ.html.
[49] "China's Battery Storage After the Explosion," Energy Iceberg, 21 April 2021, at https://energyiceberg.com/chinas-battery-storage-after-the-explosion/

50 "十四五"现代能源体系规划 [14th Five-Year Plan for Modern Energy System]," National Development and Reform Commission (NDRC), National Energy Administration (NEA), 22 March 2022, at https://www.ndrc.gov.cn/xxgk/zcfb/ghwb/202203/P020220322582066837126.pdf

51 "Impact of China wholesale power price reform on economics of distributed storage and PV," Gesellschaft für Internationale Zusammenarbeit (GIZ), February 2022, at https://www.energypartnership.cn/fileadmin/user_upload/china/media_elements/publications/2022/Impact_of_China_wholesale_power_price_reform_on_economics_of.pdf.

52 "进一步完善分时电价机制的通知[Notice on Further Improving the Time-sharing Tariff Mechanism]," National Development and Reform Commsission (NDRC), 26 July 2022, at https://www.ndrc.gov.cn/xxgk/zcfb/tz/202107/t20210729_1292067.html.

53 "国家发展改革委关于进一步完善分时电价机制的通知, 发改价格[2021]1093 号," National Development and Reform Commission, 26 July, 2021, at https://www.ndrc.gov.cn/xxgk/zcfb/tz/202107/t20210729_1292067_ext.html.

54 "关于进一步深化燃煤发电上网电价市场化改革的通知, 发改价格[2021]1439 号," 11 October 2021, at https://www.ndrc.gov.cn/xwdt/ztzl/jgjzgg/zcjd/202110/t20211027_1301157.html?code=&state=123.

55 Anders Hove et., al, "Economics of Urban Distributed PV in China," GIZ, July 2021, at https://www.energypartnership.cn/fileadmin/user_upload/china/media_elements/publications/2021/Economics_of_Urban_Distributed_PV_in_China_EN.pdf.

56 "关于居民生活用电试行阶梯电价的指导意见," National Development and Reform Commission, 2011, at https://www.ndrc.gov.cn/xxgk/zcfb/tz/201111/t20111130_964836.html.

57 Mechthild Wörsdörfer et, al., "The Future of
Cooling in China," International Energy Agency and Tsinghua University Building Energy Research Center, June 2019, at https://iea.blob.core.windows.net/assets/9212903b-e310-48d4-96fa-3eaf7ddf56d9/The_Future_of_Cooling_in_China.pdf;
"北京电网负荷突破 2000 万千瓦 北京电力全力确保度夏期间电网平稳运行, " People's Daily Online, 4 August 2020, at http://bj.people.com.cn/n2/2020/0804/c14540-34205049.html.

58 "关于推进电力源网荷储一体化和多能互补发展的指导意见, 发改能源规[2021]280 号," National Development and Reform Commission and National Energy Administration, 25 February 2021, at https://www.ndrc.gov.cn/xxgk/zcfb/ghxwj/202103/t20210305_1269046.html?code=&state=123.

59 "关于进一步推动新型储能参与电力市场和调度运用的通知，发改办运行[2022]475 号," National Development and Reform Commission and National Energy Administration, 24 May 2022, at https://www.ndrc.gov.cn/xxgk/zcfb/tz/202206/t20220607_1326854.html?code=&state=123.

60 " "十四五"新型储能发展实施方案, 发改能源[2022]209 号, " National Development and Reform Commsission and National Energy Administration, 29 January 2022, at http://www.gov.cn/zhengce/zhengceku/2022-03/22/content_5680417.htm.

61 "有序用电管理办法, 发改运行[2011]832 号, " National Development and Reform Commission, 21 April 2011, at https://www.ndrc.gov.cn/fzggw/jgsj/yxj/sjdt/201104/t20110428_987489.html?code=&state=123.

62 "有序用电管理办法, 发改运行[2011]832 号, " National Development and Reform Commission, 21 April 2011, at https://www.ndrc.gov.cn/fzggw/jgsj/yxj/sjdt/201104/t20110428_987489.html?code=&state=123.

63 "有序用电管理办法, 发改运行[2011]832 号, " National Development and Reform Commission, 21 April 2011, at https://www.ndrc.gov.cn/fzggw/jgsj/yxj/sjdt/201104/t20110428_987489.html?code=&state=123.

64 "关于公示电力需求侧管理城市综合试点工作首批试点城市名单的通知, " Ministry of Finance and National Development and Reform Commission, 31 October 2012, at https://www.ndrc.gov.cn/xwdt/tzgg/201211/t20121101_959730.html.

65 Su Nan, "这个领域市场化能不能再快点？｜聚焦新型电力系统(9), " China Energy News, 9 April 2021, at https://mp.weixin.qq.com/s/9jCeIY_m1l3fJZY7ywMW4Q.

66 "我国电力需求侧管理的成效及面临的新形势," Power Price Research Frontier, 7 February 2021, at https://mp.weixin.qq.com/s/nOQtPJGY9wX0AT4yNDR6nw.

[67] "十四五"现代能源体系规划 [14th Five-Year Plan for Modern Energy System]," National Development and Reform Commission (NDRC), National Energy Administration (NEA), 22 March 2022, at https://www.ndrc.gov.cn/xxgk/zcfb/ghwb/202203/P020220322582066837126.pdf

[68] "关于开展全国煤电机组改造升级的通知, 发改运行[2021]1519 号," National Development and Reform Commission and National Energy Administration, 29 October 2021, at https://www.ndrc.gov.cn/xxgk/zcfb/tz/202111/t20211103_1302856_ext.html.

[69] Zhu Yan, "目标规模超 2 亿千瓦，完成率仅 1/4 左右，煤电灵活性改造为啥这么慢? " China Energy News, 19 June 2020, at https://mp.weixin.qq.com/s/xW7c84Spf3CAahCNxCMr0Q.

[70] Zhao Ziyuan "煤电灵活性改造按下"加速键"," China Energy News, 10 November 2021, at https://baijiahao.baidu.com/s?id=1716011080837820708&wfr=spider&for=pc.

[71] "关于进一步深化燃煤发电上网电价市场化改革的通知, 发改价格[2021]1439 号," 11 October 2021, at https://www.ndrc.gov.cn/xwdt/ztzl/jgjzgg/zcjd/202110/t20211027_1301157.html?code=&state=123.

[72] Zhao Ziyuan "煤电灵活性改造按下"加速键"," China Energy News, 10 November 2021, at https://baijiahao.baidu.com/s?id=1716011080837820708&wfr=spider&for=pc.

[73] "完善电力辅助服务补偿(市场)机制工作方案," National Energy Administration, 15 November 2017;
华北电力辅助服务市场建设方案(征求意见稿) [Establishment Plan of the North China Power Ancillary Services Market (Draft for Public Comment)]," North China Energy Regulation Bureau, March 20, 2018.

[74] "电力并网运行管理规定, 国能发监管规[2021]60 号," National Energy Administration, 21 December 2021, at http://zfxxgk.nea.gov.cn/2021-12/21/c_1310391369.htm;
"电力辅助服务管理办法, 国能发监管规[2021]61 号, " National Energy Administration, 21 December 2021, at http://zfxxgk.nea.gov.cn/2021-12/21/c_1310391161.htm.

[75] "电力辅助服务管理办法, 国能发监管规[2021]61 号, " National Energy Administration, 21 December 2021, at http://www.cnenergynews.cn/guonei/2021/11/10/detail_20211110110475.html.

[76] Zhao Xiaodong, "需求侧资源潜力挖掘的实践," NRDC Workshop on Flexibility, 19 July 2022.

Website

Wechat

www.energypartnership.cn