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Small is Beautiful: The Great Potential of Distributed Renewables

Making Distribution Grid Integration in China Work.

国家发展和改革委员会
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Contents

Foreword

In the past few years, China has been leading the world's renewable energy (RE) development, accounting for 45 percent of new installations last year. By the end of June 2019, the total installed capacity of RE generation in China has reached 706.19 GW, accounting for 38.4 percent of the total power generation capacity of Chinese power plants. In 2018, wind and solar accounted for nearly 8 percent of total power generation. In some areas, the figure was more than 20 percent and RE can now be considered as one of the main sources of power supply.

The "Revolutionary Strategy for Energy Production and Consumption (2016-2030)" by the National Development and Reform Commission (NDRC) and the National Energy Administration (NEA) set a goal of non-fossil energy accounting for 20 percent of the country's total primary energy consumption by 2030. By the same time, non-fossil energy generation strives to reach more than 50 percent. The China Renewable Energy Outlook (CREO) of the Energy Research Institute (ERI) of NDRC and its China National Renewable Energy Center (CNREC) shows that the share of RE generation will be more than 86 percent in 2050, accounting for about 60 percent of the primary energy consumption.

At present, China's RE development and utilization is relatively concentrated in large-scale projects. How to further expand the field and model of distributed RE development and utilization in the future should be explored. China will continue to promote decentralized wind power development, fully advance distributed PV applications, accelerate the development and utilization of small- and medium-sized biomass and geothermal resources and expand the scale of RE application. Increasing distributed RE supply for local utilization will be a key driver for the energy production revolution.

Assessment and planning of integrating distributed RE need a solid foundation, a system approach, enhanced coordination and a dynamic manner based on local conditions and neighbouring balancing regions. It is very important to unlock demand side flexibility at distribution grid level in the power market reform by enabling more active customers that respond to changing electricity prices, either directly or through an aggregator. Distribution system operators (DSOs) play a key role in enabling these developments and in integrating distributed RE generation into the energy system.

Germany has gained a lot of experience in developing distributed RE in past years and we therefore believe that this joint report by the Germany Energy Agency (dena) and CNREC will contribute to a solution for a high penetration of distributed RE in China.

Wang Zhongying
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Executive Summary – China could benefit from distributed RE

Both China and Germany are committed to the Paris agreement within the United Nations Framework Convention on Climate Change (UNFCCC). The agreement not only acknowledges that the threat of global warming is real. For the first time, it also brings virtually all nations into a common cause to undertake ambitious efforts to combat climate change, “holding the increase in the global average temperature to well below 2 degree above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 degree above pre-industrial levels”.

In order to reach the agreed targets, a transition towards a more sustainable energy system based on renewable energies (RE) is required. With respect to the use and expansion of RE in Germany and China, their starting points are somewhat different. Since the beginning of its energy transition, Germany relied on a large number of smaller RE projects, mostly due the strong roots of the *Energiewende* within civil society as a grassroots movement, and also due to its high population density and the limited financial means prior to the EEG-support based on Feed-in-tariffs (FiT). China, on the other hand, so far has chosen the path of primarily building large RE plants, especially in its western regions.

China’s economic centres and thus its energy intensive consumers are primarily located in the coastal regions in the East. With the current approach and with respect to China’s target for non-fossil fuel to account for 50 percent of electricity production by 2030, large amounts of electricity from RE sources would thus have to be transported from the West to the East.

Recently, discussions about increasing the amount of distributed RE in the more densely populated eastern regions have come up in China in order to make optimal use of the natural resources in these regions and to increase system efficiency by reducing transport losses. But companies that want to construct distributed RE plants are faced with a great deal of uncertainty. One of the main challenges is the grid connection for their plants and in particular a lack of transparency regarding the technical and regulatory requirements that need to be met.

This report sheds light on the status quo of distributed RE in China (chapter 1) and relevant experiences from Germany and the EU are shared (chapter 2). They show that the use of highly distributed RE is technically feasible and can also be economically advantageous. An enabling regulatory framework is the precondition for this. Based on these experiences, the following suggestions to reduce obstacles for the integration of RE in China’s distribution grids are elaborated (chapter 3):

- Technical solutions for the integration of distributed RE have proven to be successful in Germany and can be directly transferred to China.
- Compulsory grid connection and priority dispatch of RE are the regulatory basis that needs to be introduced along with transparent grid codes and regulations that take into account a more active role of DSOs.
- The introduction of market structures based on the merit-order principle guarantees a cost-efficient integration of distributed RE.

1 China's lacks comprehensive and targeted rules for the integration of RE on distribution grid level

1.1 Current development conditions of distributed RE in China

Small-scale, distributed wind and PV are a very important form of RE applications in addition to large scale applications. Distributed generation close to the big consumption centres can significantly reduce transmission losses and as a consequence costs, which leads to an increase of the overall power system efficiency.

The development of **distributed PV** (i. e. projects with up to 6 MW, including rooftop PV) has experienced a rapid growth during the last few years thanks to a simplified administration process, the absence of capacity control and relaxed land-use policy. The overall installed capacity of distributed PV in China has reached 51 GW by the end of 2018. Driven by high subsidies, the share of household PV has increased since 2018, from less than 10 percent to more than one third of the total PV capacity. In certain distribution grids, high penetration of distributed PV has resulted in significant reverse power flow and even overloading of grid assets.

The deployment of **distributed wind** (i. e. projects with grid connection at less than 110 kV level) has gradually started since 2018, after new policies to encourage its development were released by the National Energy Administration (NEA). It is estimated that approx. 700 to 800 MW of distributed wind projects were built in 2018. The newly installed capacity of distributed wind projects is expected to exceed 1 GW in 2019, after the announcement of local plans on the development of distributed wind. However, its development still faces challenges, e. g. regarding investment and a lack of transparency and standardization with respect to grid connection requirements.

With the growth of distributed RE sources, the distribution grid operators are concerned about operating risks and upgrading needs. More transparent solutions and standard procedures are required for the planning of distributed RE and the estimation of hosting capacity of distribution grids.

1.1.1 Regulations and policies regarding the development of distributed RE in China

The "12th Five-Year Plan on Renewable Energy Development" and the "13th Five-Year Plan on Power Development" which were issued in 2010 and 2016 clearly stated that the development of RE should focus on the principle of **centralized development and decentralized utilization**. In 2013, the "Interim Measures on Distributed Power Generation Management" issued by the NDRC[1] comprehensively described the concept of distributed RE for the first time and clarified the specific method of project construction management, grid integration and operation management for distributed RE. In 2018, the NEA issued the "Distributed Power Generation Management Measures (Draft for Comment)" which further improved the scope of distributed RE on the basis of "Interim Measures for Distributed Generation Management" in 2013. The management measures encourage the full marketization of distributed RE, clarify the principles of investment, design, construction and operation, and encourage power trade between distributed RE and adjacent power users. For distributed wind and PV, the NEA has issued a number of documents to provide policy guidance and support. The relevant regulations and policies are summarized in Table 5 (see appendix).

[1] NDRC (2013)

1.1.2 Installation of distributed RE in China

Following the instruction from NEA and benefitting from a relaxed capacity control and auction-free policy, more and more provinces started to focus on promoting their local distributed wind projects. Several provinces and cities which are listed in Table 6 (see appendix) have published plans on distributed wind constructions and lists of distributed wind projects being approved by local governments. More provinces have released updated plans that contain more distributed wind projects. Some provinces, such as Henan, Shanxi and Anhui, show strong interest to support and to promote distributed RE development.

Distributed PV has enlarged the scale and started to show significant potential to replace coal power plants. The growth of distributed PV started in 2016 when strong economic incentives for the operation of distributed PV were added. Furthermore, the approval system changed to a registration system for distributed PV so that the overall process of the project could be significantly shortened by executing different tasks in parallel. Affected by the curtailment issues in the “Three North” region (Northeast China, North China, Northwest China), and with the advancement of the power system reform and the maturity of the distributed PV business model, from 2016 to the first half of 2018, China’s distributed PV showed explosive growth. The average growth rate reached more than 200 percent.

By the end of 2018, the cumulative grid-connected capacity of China's distributed PV was 50.62 GW, accounting for 29 percent of the total installed capacity of PV. These capacities are mainly located in the central and eastern regions. Zhejiang, Shandong and Jiangsu have the three largest capacities in the country with a cumulative grid-connected capacity exceeding 15 GW (more than 5GW each).

1.1.3 Standards for the integration of distributed RE in China

In order to standardize the distributed PV equipment to obtain controllability of active devices for system stability issues, the following requirements are demanded and defined through a series of standards (see Table 1). By comparing the standards of distributed PV with international ones, no significant difference is discovered. However, the standards are technology-specific; they are developed for distributed PV only and are not applicable to distributed wind at same voltage level of the grid connection point. For distributed wind, there are no specific standards drafted yet. In practice, it is therefore very difficult to know which standard applies to a specific RE project. Moreover, additional requirements for distributed RE are commonly demanded by the DSOs with regard to provision of system services. In comparison, it is rather structured in Germany or Denmark where requirements for distributed RE are standardized by capacity and voltage level of connection, regardless of the type of power source.

Technical requirements for grid the connection of distributed PV				
Serial number	**Technical Content**	**GB/T33593-2017 Distributed source grid-connected technology requirements (35kV and below)**	**GB/T19964-2012 Technical regulations for distribution power grid with PV integration (10kV-35kV public grid)**	**GB/T29319-2012 Technical regulations for distribution power grid with PV integration (10kV user side and 380V)**
1	**Active frequency Control**	Capable of adjusting active power according to frequency and dispatch order	Equipped with active power control system, emergency control and active power changing rate control capability	None
2	**Reactive voltage control**	Capable of adjusting reactive power of source, the input of compensation device, grid voltage adjustment. 380V grid-connected (voltage range: ±0.95 pu); 10/6/35kV grid-integration±0.98, participate in voltage regulation	Inverter dynamically adjustable (voltage range: ±0.95 pu); 10/35kV grid-integrated PV power plants (voltage range: ±0.98 pu), capable to participate in voltage regulation of grid	PV power system (±0.95 pu), the grid voltage is continuously adjustable
3	**Fault ride through**	Not necessary, minimum limit is 0.2pu	Necessary, require zero-voltage ride through capability	None
4	**Security and protection**	6/10kV demand side connected: refer to GB/T 29319-2012; 6/10kV public grid: refer to fault ride through requirements	High voltage adaptive: 1.1pu-1.2pu: brake opening≥10s; 1.2-1.3pu: brake opening≥0.5s;	<0.5pu: brake opening ≤0.2s; 0.5-0.85pu: brake opening ≤2s; 1.1-1.35pu: brake opening≤2s; ≥1.35pu: brake opening≤0.2s;
5	**Frequency adaptation/protection**	6/10kV user side: If the frequency is out of range 49.5Hz-50.2Hz, the power supply should be cut off in 0.2s	Within 50.2Hz-50.5Hz: keep operating for at least 2 min.	If the system frequency is out of range 47.5Hz-50.2Hz, the power supply should be cut off in 0.2s
6	**Dispatching automation system**	None	Have requirements	None

Table 1 Technical requirements for grid the connection of distributed PV

1.2 China's distribution grid, its load and operation conditions

1.2.1 China's distribution grid and the connection of distributed RE

The voltage level of the distribution grid in China ranges from 220 V for residential customers to 110 kV for city-level power transmission. The voltage level of the distribution grid is set in accordance with the relevant provisions of the current national standard "standard voltage GB / T 156-2007" (see Table 2). Depending on the load growth, the medium-voltage distribution grid can be lifted to 35 kV, and the high-voltage distribution grid can be lifted to 220 kV or 330 kV.

	Voltage level
Low-voltage	220 / 380 V
Medium-voltage	10 / 22 kV
High-voltage	35 / 66 / 110 kV

Table 2 Definition of voltage levels in China according to the national standard

For distributed PV, by May 2019 the installed capacity has reached 53.2 GW in the grid area of the State Grid Cooperation of China (SGCC) (see Figure 1).

Voltage level	Number of cases	Capacity [GW]
380/220 V	1,210,261	27.23
10 kV	10,808	22.46
35 kV	184	3.52

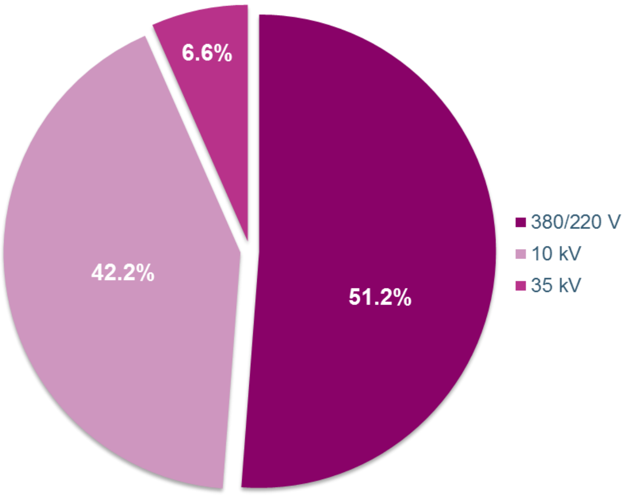

Figure 1 Distributed PV and their capacity shares in the grid area of SGCC by voltage level (May 2019)

1.2.2 China's current distribution grid dispatching and coordination mechanism

In recent years, more and more attention has been attracted to intelligent dispatch of the distribution grid. The smart power distribution grid is based on a flexible, reliable and efficient grid structure and a highly reliable and secure communication network. It can efficiently support self-adaptive fault-handling and self-healing, meet requirements of high penetration of distributed RE and integration of energy storage. It can also meet the user demand to improve power quality.

At present, there are still many challenges in China's distribution grid dispatch:

- Firstly, the construction of current distribution grid is not systematic and the asset utilization rate and economic efficiency are ignored to a large extent.
- Secondly, the assignment of dispatcher responsibilities is still not clear; the difference in management level between local villages and large cities is huge.
- Thirdly, auto-dispatch technology is still under development, Supervisory Control and Data Acquisition (SCADA) has not yet been widely implemented, and the quality of the distribution grid measuring technology is unsatisfactory which brings great difficulties for the smart dispatch. At present, the distribution grid dispatch is largely based on the dispatcher's experience.

Many strategies have been proposed to improve the reliability and operation quality of distribution grids. Due to the uncertainty of the information source of grid measurements and diversified needs of dispatch methods, there is a need for an integrated optimization strategy taking into account different time sequences (long term, medium term, long-medium term, super-short term and real-time). For distributed RE, the distribution grid dispatch generally aims to maximize the share of consumption of locally produced RE. The coordination between distributed RE, micro-grid and distributed energy storage should be fully balanced in the local area, to improve the reliability and economic usage of power supply and realize the efficient operation of the smart distribution grid.

From 2012, SGCC started the national project "Study on smart distribution grid optimal dispatch". The developed system has been successfully applied in Nanjing, where Youth Olympic Games were held in 2014. The related technology will be applied in other areas in the following years.

1.2.3 Main influences of the integration of distributed RE on the operation of China's distribution grid

With the development of distributed RE, energy storage technologies and micro-grids, the distribution grid gradually develops from the original "passive electric network" to an "active electric network", the operation and maintenance management of distribution grid thus becoming more complicated. A series of challenges have arisen such as reverse power flow, the increasing complexity of the protection technology and system, the lack of frequency support capability and islanding. Detailed explanation of these problems are as follows.

Reverse power flow

In contrast to the traditional top-down grid and power flow design, with the integration of distributed RE into distribution grids the power may flow from low-voltage to high-voltage level. This phenomenon is called reverse power flow. Among other, the power restriction is the main factor that affects the integration of distributed RE to the distribution grid. There were practical cases of the reverse power flow shown in a distribution grid with PV power generation. In the Spring Festival of 2019, the reverse power flow occurred in Jianshan substation which led to the maximum reverse power reaching 20 percent of the rated power of the main transformer causing serious security risks to the distribution grid such as automatic shut-down of equipment at lower voltage levels (see also chapter 2.2.1 and 2.2.2 for German experiences on this matter).

Increasing complexity of the protection system

The integration of distributed RE provides an auxiliary or reverse fault current to the protection devices, which will decrease the difference in actuation-time between the primary and backup protection. Therefore, the coordination between adjacent protection systems may be destroyed and could cause damages to the protection devices. Meanwhile, the adjustment of protection parameters becomes more difficult, since the level of fault current varies greatly in a different time period. If the setting value of protection is not adjusted with the operation state of distributed RE, the actuation-time limit of protection may be extended, and then break the coordination between the primary and backup protection.

Lack of frequency support capability of distributed RE

Distributed RE also reduces the system frequency support capability. At present, most distributed PV power systems operate in the maximum power point tracking mode (MPPT). Distributed RE currently only provides active power to the system according to the distribution of actual RE resources and is not required to provide adaptive adjustment capability under grid frequency fluctuation circumstances. In a power system with larger share of distributed RE that lacks the adaptive adjustment capability to system frequency and less regulated conventional power sources, system operation faces risks on stable frequency regulations and other ancillary services to ensure a safe operation. It is therefore very important that distributed RE and other controllable assets (e. g. demand side flexibility, energy storage) are enhanced and mobilized to support stable grid operation (see also chapter 2.2.1 for German experiences on this matter).

Islanding

When the distribution grid becomes electrically isolated from the rest of the power system, yet continues to be energized by distributed RE, it is referred to as islanding or islanded status. This may have several negative effects on the distribution grid. For example, the electrical devices operating under islanded status may be damaged due to the low power quality. Moreover, the live line may cause personal injury to the maintainer of power line. At present, the islanding detection of distributed PV power generation relies on the user-side inverters and fault disintegration devices, but the operation and maintenance on the user side is relatively weak, therefore once there is misoperation in fault disconnection devices, the islanding situation occurs easily.

Case example: Distributed PV in Haining

Haining is a city located in the north of Zhejiang province. Production industry is very strong in this province which leads to a good condition for distributed rooftop PV in industrial parks. At present, the grid-connected PV capacity in Haining reaches 570 MW. They include three utility scale PV power stations with a total capacity of 60 MW, 116 distributed PV power stations connected to the grid on the high voltage level with a total capacity of 290 MW, and 399 distributed PV power station connected to the grid at 380 V level with a total capacity of 180 MW. In addition, residential connections have reached a total capacity of 40 MW. In Jianshan district, the most critical feeder has embraced distributed PV plants with more than 100 percent of the transformer capacity.

During the spring festival period when the factories stop their production lines, reversed power flow becomes very significant in Haining. The reversed power flow has reached 20 percent of the capacity of the 220 kV/110 kV transformer. It has also resulted in reversed reactive power flow and increased voltage along distribution feeders. Power quality as well as islanding are also of concern. In addition, due to the fluctuations and uncertainty of the PV production, the operation of the distribution grid becomes complicated. Therefore, a pilot project is conducted in Haining investigating the aggregated control as well as virtual synchronous machine through PV converters.

1.3 Major challenges for distributed RE integration in distribution grid

1.3.1 Challenges in the near and medium term

- Planning management needs a more solid scientific foundation and enhanced coordination. The construction should be based on local conditions and demands.

- The administration process on connecting distributed RE are currently the same as for large-scale projects. The process of grid connection is significantly lagging behind the construction of distributed RE.
- The grid integration planning method, related parameters and boundary condition are not clear. There is no benchmark model and no uniform design guidelines.
- There is a lack of research and analysis on grid integration and design in industrial parks, poverty alleviation by means of PV power projects and other application scenarios.
- The standard system of grid integration has been established and is in line with international standards, but the application scenarios of the standard are not clear.

1.3.2 Challenges in the long term

The development of China's power market is very different from that of other countries. At present, the power generation capacity of China is sufficient, and the power supply and demand of China is generally well-balanced. Meanwhile, the progress of enhancing the grid structure both on transmission and on distribution level provides a solid foundation to secure the better operation of a power system that is still transitioning towards a less regulated power market. Applications of smart grid and energy internet will also increase the resilience of the system and enable innovative trading and products.

2 European experiences: Clear regulations and continuous improvement of technical standards are key

2.1 Germany's way towards 50 percent share of RE on national level

Germany's climate targets strive for a 65 percent share of RE in the electricity sector by 2030. With the progressing energy transition in Germany, RE in electricity consumption rose from 4.6 percent in 1990 to almost 38 percent in 2018 (see Figure 2).[2]

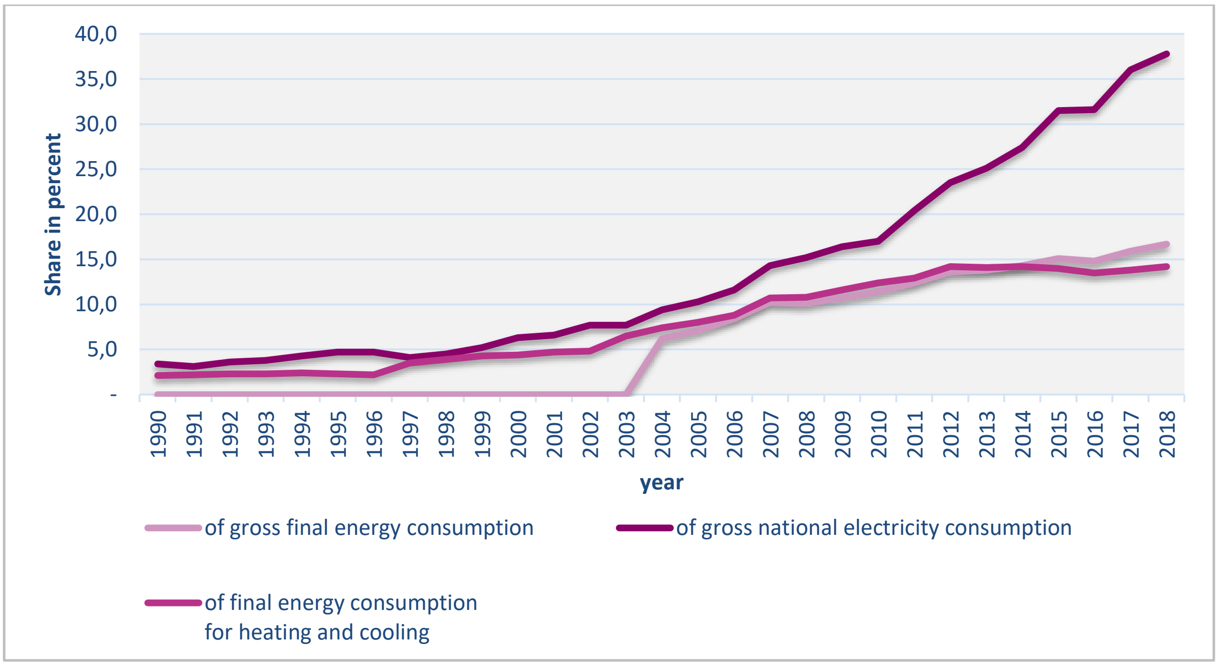

Figure 2 Shares of RE in energy consumption in Germany 1990 to 2018 [3]

Similarly, in the EU the amount of RE production increased by 64 percent between 2007 and 2017.[4] In the first half of 2019, 44 percent of the total electricity generation in Germany were provided by RE. In the months of March and June the share of RE in electricity generation was above 50 percent and the average of this year until November 2019 amounts to 46 percent.[5] This shows that Germany is on track to reach 50 percent RE and more in its electricity generation soon.

The progress is not evenly distributed across Germany; some regions already handle far higher shares. In the windy northern region of Germany, Schleswig-Holstein, wind energy regularly exceeds 100 percent. In 2017, RE reached a production of 156 percent of gross electricity consumption (in the region).[6] Schleswig-Holstein is one of the frontrunner regions in Germany concerning the expansion of RE capacities while it is sparsely

[2] UBA (2019)
[3] BMWi (2019)
[4] Eurostat (2019)
[5] SMARD Strommarktdaten (2019) and Statista (2019)
[6] Schleswig-Holstein (2019)

populated. So large amounts of the produced RE are being transported to other regions in Germany or Denmark.

98 percent of the German electricity grid are distribution grids (line kilometres).[7] The German distribution grid is owned and operated by around 900 distribution system operators (DSOs). The different voltage levels (see Table 3) are connected via substations and the high-voltage grid is connected to the transmission grid.

	Voltage level
Low-voltage	400 V
Medium-voltage	10 / 20 / 30 kV
High-voltage	110 kV

Table 3 Voltage levels in German distribution grids

90 percent of RE is fed into the distribution grid, virtually all PV power systems are connected to the distribution grid.[8] Figure 3 depicts the installed capacity of PV and onshore wind energy connected to the different voltage levels. More than half (55 percent) of PV energy is fed into the low-voltage grid. The distribution of onshore wind energy is similarly concentrated on the distribution grid, only a share of 4 percent of the wind energy capacities is connected to the high-voltage grid.

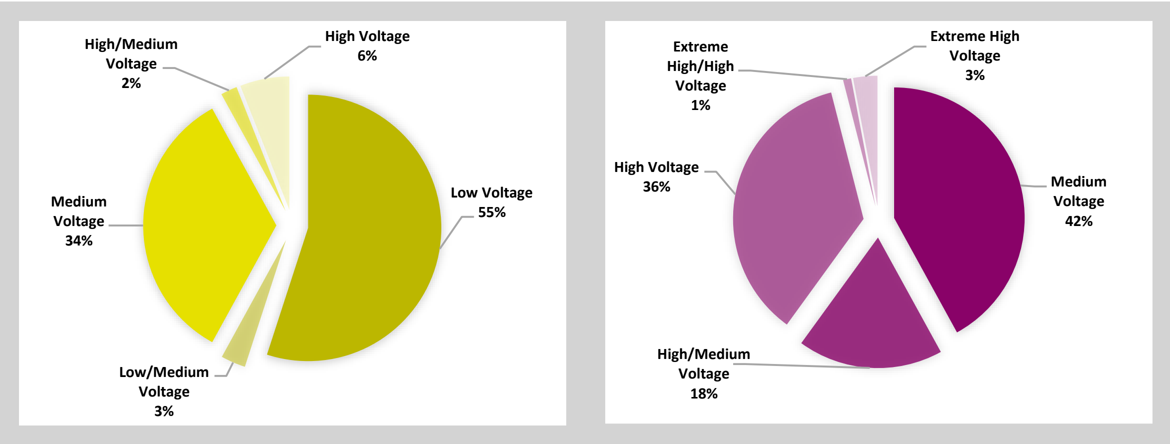

Figure 3 Installed capacity of PV energy (left) and onshore wind energy (right) by voltage level 2017[9]

2.2 How does Germany manage to integrate large shares of RE on distribution grid level?

The transformation to an energy system fully powered by RE is a difficult task, yet it is possible. As seen above, the share of RE in the German electricity sector has soared from below 5 percent to almost 50 percent in 20 years. Some German provinces produce more than 100 percent share of RE. As a part of the interconnected European grid system, Germany can also export electricity to neighbouring countries and vice versa

[7] Matschoss et al. (2018)
[8] Matschoss et al. (2018) and Fraunhofer ISE (2019)
[9] Bundesnetzagentur (2017)

receive imports in times of undersupply. The European and German electricity market is the basis for the integration of RE (see chapters 2.2.3 and 2.3). A secure and reliable power system even with a high share of RE is guaranteed by technical solutions as well as transparent and clear regulations.

Regulatory basis: Compulsory grid connection and priority dispatch are two main factors to enable RE integration in Germany

Two of the most influential regulations concerning the connection of RE systems are the **compulsory grid connection** and **the priority dispatch principle, which are based on the Renewable Energy Sources Act** (Erneuerbare-Energien-Gesetz, EEG):

- German DSOs must provide **compulsory grid connection** for RE. This means they are **legally required to connect RE** as quickly as possible to the most economical grid access point. This means that grid operators will choose the nearest access point that is also the most suitable in terms of voltage level. For rooftop systems up to 30 kW this is usually the grid connection point of the building. Furthermore, DSOs are obliged to expand grid capacities, if necessary, in order to integrate RE. The optimization, reinforcement and expansion of the network capacity are carried by the DSO, the costs are reimbursed via grid fees which get included in the electricity price. The RE operator bears only the costs for the direct line from the plant to the grid connection point (*shallow connection charge*).
- The electricity generated from RE sources is injected with the **priority dispatch principle** to the distribution grid, meaning that generally all produced electricity must be integrated by the grid operator.

Technically: DSOs check grid compatibility and improve the grid

When connecting new RE systems to the grid, a technical assessment (***grid compatibility check***) is carried out by the DSOs to determine whether the RE can be connected to the grid without dangerously exceeding the limits for voltage or current-carrying capacity. There are different ways to conduct grid compatibility checks. Supposing the low-voltage grids are already digitized, a computer simulation is the most efficient approach. Hereby, two extreme scenarios are included: One is maximum generation with minimum load, the other minimum generation with maximum load. A **permissible curtailment of RE of maximum three percent of the total produced electricity** is taken into account. If the grid can cope with these scenarios, the RE system can be connected. In case there is a negative assessment of the grid compatibility check, the DSO has to implement measures to secure the integration the RE electricity. There is a range of different options to optimize the grid for more RE to be integrated (see chapter 2.2.2)

The market structure guarantees a cost-efficient approach

The merit-order system of the German electricity market (see chapter 2.2.3) provides for a preferential integration of RE, which will lower the wholesale electricity price at the same time. It is an inherently cost-efficient approach, as those power generating facilities with the highest marginal costs will be pushed out of the market.

2.2.1 Transparent regulations and the right processes are key for a successful integration of distributed RE

With an increasing share of distributed RE, more power enters the distribution grid and significantly changes the role that the distribution grid plays in the whole electricity system. In Germany, there is now a growing amount of reverse current running from lower to higher voltage level (***reverse power flow***) if the electricity from distributed RE is not consumed locally.

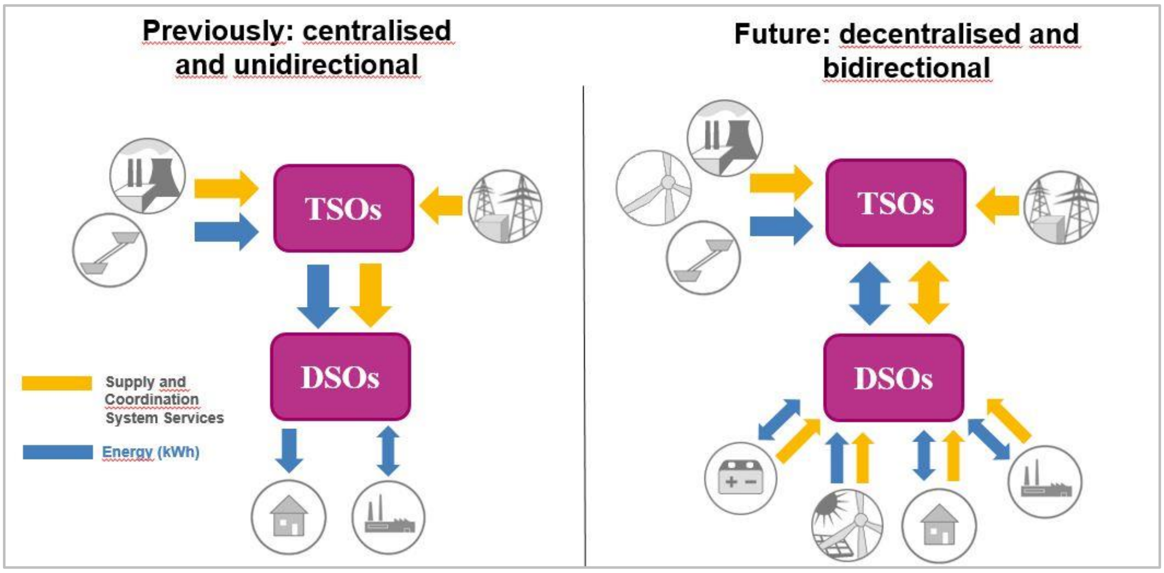

Figure 4 Distributed RE shifts responsibilities of TSOs and DSOs (own illustration)

As the grids were originally designed for a unidirectional flow, German system operators had to confront a range of technical and organizational challenges. Adapting to the challenges made for a change in the grid system and a shift in responsibilities of TSOs and DSOs (see Figure 4). With a number of regulatory and technical improvements, the issues can be kept under control. Regulations range from the European level down to technical grid codes ensuring the best technology is used. Key regulations are:

Regulation of grid operators: Incentive Regulation Ordinance

To prevent grid operators from using their position as natural monopolies and to secure a cost-efficient operation of the grid system, the so called **Incentive Regulation Ordinance** (Anreizregulierungsverordnung, ARegV) specifies the design of grid regulations. Based on the **German Energy Act** (Energiewirtschaftsgesetz, EnWG) and implementing European legislation, the incentive regulation requires **transparent calculation of grid fees** as well as **fair and equal access to the grid**. The **budget approach** as the underlying principle of the ARegV regulates the revenues of DSOs rather than their costs. This creates an incentive to lower the costs by achieving more efficiency. An **efficiency-benchmark**, that is in short an efficiency comparison of all DSOs, determines the revenues in a certain regulatory period. This “simulated” competition serves the purpose to keep the overall costs of the distribution system operation as low as possible.[10]

Regulation of grid operators: Directive on System Stability

Over-capacity and over-voltage are two issues that need to be addressed for an effective integration of a high share of RE. Until 2012, high penetration of low-voltage grids by solar panels created the danger of over-voltage leading to a frequency above 50.2 Hz in case of best weather conditions or grid disturbances. This would have led to an automatic disconnection of every PV plant from the grid. With the **Directive on System Stability** (Systemstabilitätsverordnung, SysStabV), DSOs were required to retrofit existing PV plants so that they **curtail generation successively** before being shut off at 51.5 Hz. More than 300,000 PV installations had to

[10] Matschoss et al. (2018)

be updated accordingly. Similar threats of other RE sources disconnecting at a frequency below 49.5 Hz were diminished by a revised version of the SysStabV in 2015. TSOs and DSOs are now given greater leeway to control the cut-off of generating capacities in case of urgency.

At a glance: Traditional management instruments for grid operators

There are four major instruments on the supply side that are available to the grid operators for the management of the grids (see Figure 5). The **curtailment of RE** is the last resort in this order after all other measures have been exhausted. 95 percent of lost revenues are compensated based on the so-called "hardship clause" (EEG 2017, section 15). Those measures are mostly utilized by TSOs. Currently only a fraction of the curtailment measures is performed by the DSOs. Yet, with an increasing share of RE posing particular challenges for the distribution grid, the role of DSOs is growing in importance.

The **priority dispatch principle** is used in several European countries to integrate and promote RE generation. The possibility of curtailment of RE is provided in the **feed-in management scheme**. DSOs and TSOs can curtail the output of power-generating systems in their area to guarantee grid stability. Since 2016, DSOs may take feed-in management into account in the planning of grid expansion. This is limited to 3 percent of the forecasted annual electricity per unit of an RE system.

1. **System-related measures such as switching operations in the grid**
2. **Market-related measures such as re-dispatch (ramping up and down of conventional power plants)**
3. **Contractual activation of reserve power plants for compensating a deficit of re-dispatch capacity**
4. **Curtailment of electricity from RE with financial compensation**

Figure 5 Instruments for grid management

Regulation of consumers: Incentivizing of self-consumption

Self-consumption of RE by prosumers (e. g. households or businesses with rooftop PV) is the most important element of the consumer-side regulation. By incentivising them to consume their produced RE directly, the transport need to higher voltage levels shall be reduced. In combination with battery storage, PV electricity can be fed into the grid when demand is high and power can be consumed from the batteries in times of grid constraints and scarce generation. In Germany, producers of PV pay a **reduced EEG-levy** when they self-consume a certain percentage of their RE production.

Outlook: Flexibilities offer great potential for cost-efficiency

New and fluctuating supply and demand patterns create challenges for grid operators. This complexity requires more flexibility. Fostering flexibility on the demand side in low-voltage grids is the purpose of §14a of the German Energy Act and the EU winter package (see chapter 2.3), which will allow and encourage the use of flexible electricity applications to maintain a stable system. Peak loads shall be circumvented in order to avoid excessive grid expansion needs.

Increased use of demand side flexibility as well as new storage options and coupling of electricity, heat and transport energy needs are seen as key to accommodating a large share of RE in the distribution grid in the future (see also dena-reports "Making money with smart electricity consumption"[11] and "Industrial Demand Side Flexibility in China"[12]). First regulations to harness the potential are already passed but implementation is slow. Progress in this field is expected in the next years due to experiences that were gained in national and European pilot projects.

Continuous improvement of grid codes necessary to incorporate new technical standards

Continuous improvement of grid codes guarantees the reliability of German distribution grids. German grid codes complement and realize the **Network Code Requirements for Generators** (NC RfG) by the EU. In combination with Technical Connection Rules (TCR) Low Voltage (VDE-AR-N 4100), TCR Medium Voltage (VDE-AR-N 4110) and TCR High Voltage (VDE-AR-N 4120), the NC RfG represents the applicable regulation for the German distribution level. For the low-voltage level, the application rule VDE-AR-N 4105 contains recently updated requirements for distributed RE.[13] The TCRs are regularly revised and updated to depict the latest technical innovations and conditions. New provisions that also address some of the challenges experienced in China (see chapter 1.3) include among others:

- **Dynamic Grid Support:** New power generating plants on the low-voltage level will have to remain on the grid during short voltage drops or increases to provide dynamic network support. Disconnecting from the grid could compromise grid stability. Plants will remain on the grid for an extended time during faults instead of switching off, which is called **fault ride-through**.
- **Feeding in reactive power depending on voltage (Q(U) control):** More power generating plants can be integrated in an existing grid depending on local circumstances, i. e. RE plants will now react to the voltage at the connection point and feed-in reactive power depending on voltage (Q(U) control). The method has proven successful to actively support maintaining the voltage and improving grid stability at the medium- and high-voltage level. This approach will now be expanded to the low-voltage level.
- **Active power output in under-frequency situations:** In case of under-frequency (insufficient power supply) power generating plants and accumulators/storage systems also at low-voltage level will have to feed-in power according to the grid operators' requirement in order to support the system.
- **Faster reaction of power generation facilities to frequency changes:** Initial response capacity by damping effect of rotating masses (inertia) will shrink. The new TCR High Voltage demands a more rapid adaptation of the active power from all power generating plants to react to frequency deviations. So far,

[11] dena (2018b)
[12] dena (2019a)
[13] VDE|FNN (2019)

a lack of frequency support capability is not yet acute in the German power system, but the new regulation provides for a partial solution to this prospective issue.

Based on the maximum requirements set in the TCRs, each DSO defines specific requirements for its own grid (so called Technical Connection Conditions, TCCs) which can be less restrictive than the TCRs if the grid conditions allow for it.

2.2.2 Technical solutions to allow for more RE in distribution grids

As long as the grid compatibility check remains positive, further distributed RE can be connected to the grid. When the assessment indicates need for action, the grid operator may take several technical measures to ensure the compliance with permissible voltage and current limits. To minimize costs and reduce the negative impact on citizens and the environment, measures usually follow the **GORE principle (Grid Optimization before Reinforcement before Expansion)** which prioritizes the improvement of existing grid infrastructure before building new lines. Only after exhausting the optimising and reinforcing potential of existing lines, the construction of new power lines may be considered. PV plants that primarily feed into the low-voltage level generally require other actions than onshore wind energy which are connected at the medium or high voltage level. Possible remedies and measures to avoid congestion and over-voltage differ greatly as the low-voltage level is mainly distributed with underground cables and high-voltage levels features regular power lines. All actions serve the purpose to limit curtailment to a minimum and help integrate a maximum share of RE. Table 4 shows various possible and common measures to improve the grid situation. As described in the table, many measures (such as replacing local distribution transformers) are already being used by German DSOs, others (such as the booster transformers) are currently being evaluated in pilot projects. Some of these options can be utilized for all voltage levels, others are more specific to a certain grid situation. In the following, the most frequently used measures or those with the highest potential will be explained in further detail while the table provides the full range of solutions.

Measures	Description	Evaluation
Grid Optimization		
Individual tap changing of distribution transformers	Manual adjustment of the voltage ratio to decrease voltage on low-voltage side and make available a larger range up to the higher voltage limit which can be used for additional RE facilities.	Risk of setting the voltage too low. Voltage could be adjusted seasonally. Only few DSOs make use of this option.
Wide-area control	Use control option between high- and medium-voltage levels to adjust voltage level for the complete supply area including low-voltage grids	Relatively cost-effective; for new substations it requires only a software update; used by several DSOs in Germany.
Reactive power feed-in	Contribution to maintaining the voltage range by inverters capable of providing reactive power	By supplying reactive power, voltage at the grid access point can be reduced by 1-2 percent.
Changing grid topology	Change in grid topology in low-voltage grids reduces resistance and thereby voltage drop	Can only be implemented for specific grid topologies.
Use of Intelligent Equipment		
Voltage regulator (so called “booster” transformers)	Use of voltage regulator to raise or lower voltage level of individual lines.	Multiple DSOs are testing the use of voltage regulators. Could be economically beneficial for low-voltage grids with long power lines.

Voltage regulated distribution transformers	Automatic adjustment of voltage ratio without interrupting power supply. Voltage in the medium-voltage grid can be increased while the low-voltage side is being kept constant.	Often seen as an easily applicate alternative to conventional grid expansion needs due to voltage problems. Majority of DSOs installed such transformers.
Grid Expansion		
Replacing local distribution transformers	Traditional local distribution transformers could be replaced and set up not only for maximum demand but also for maximum reverse flow.	Local distribution transformers are often the first point of congestion in a low-voltage grid. Replacing the transformer by a more flexible design is a frequent measure to accommodate more RE.
Segmenting local grid	Capacity of local distribution transformer can be increased by segmenting existing grid.	Relatively complex measure which also affects medium-voltage grid.
Laying parallel cables	Used when cross-section of cable is no longer sufficient. Larger cross-section decreases grid impedance, thus reducing the voltage drop.	Disadvantage of having cables with different lifespans leading to more frequent work for maintenance or replacement. Yet all DSOs in the survey made use of this measure.
Increasing conductor cross-section	Replacement of existing lines by ones with larger cross-sections.	Little willingness to switch from overhead lines to cables in the low-voltage grids. Time-consuming and expensive. Cables are rarely replaced before the end of their lifespan.
Grid Operation and Planning		
Grid monitoring	„Dynamic Line Rating" for high-voltage grid to optimize energy transportation capacity.	Line monitoring for low-voltage grids would require a grid-wide measurement of the low-voltage grid. Currently no planes for a roll-out of such a monitoring.
Feed-in management	Feed-in management under certain circumstances as an alternative to grid expansion in the high- and medium-voltage grid.	Simplified feed-in management for low-voltage level could serve similar purpose. So far, automatic curtailment on low-voltage level is only temporary.
Improved grid planning	Grid compatibility checks for every connection request.	Usual procedure to guarantee grid stability after connection of new plants.

Table 4 Overview of technical measures to manage distribution grids[14]

Technical solutions for the low-voltage level

The low-voltage distribution grid is characterized by high penetration of PV energy and the connection of most households and small businesses. Some of the most important measures that are being used on this system level are:

- The most common measure is the **laying of parallel cables** in the low-voltage grid, increasing the cross-section and thus reducing the voltage drop. This is one of the most obvious options for improving the grid system and the majority of German DSOs make use of this option. Including a second cable will be accompanied with the downside of extra excavation work.
- The local distribution transformers often are the first point of congestion for a low-voltage grid. **Replacing the local distribution transformer** with a more flexible design makes it possible to accommodate not only for maximum demand but also for maximum reverse flow. Often used as the first adaptive measure to integrate RE.

[14] Based on a survey by Bayer et al. (2017)

- Further intelligent power electronics are being used extensively by German DSOs, e. g. **voltage regulated distribution transformers,** which allow the voltage in the medium-voltage grid to be increased while keeping it constant in the low-voltage grid. The innovative element of this transformer type is that it will adjust the voltage ratio automatically without interrupting the power supply. [15] As soon as transformers need to be replaced, it is expedient to do this with a new voltage regulated distribution transformer.
- Due to the increasing amount of fluctuating feed-in of RE, the demand of **reactive power** is also growing**. PV inverters capable of providing reactive power** can contribute to maintaining the voltage range in low-voltage grids. It has been shown that with the use of inverters supplying reactive power, the voltage at the grid connection point of the RE plant can be reduced by 1-2 percent.[16] This helps considerably to prevent exceeding permissible voltage limits. According to regulation VDE-AR-N 4201 from 2011, all inverters must be capable of supplying reactive power. A dena–study on system services[17] further concludes that controllable supply of reactive power from RE inverters can be largely independent from the active power. This can relieve the transmission grid, which before regulated the exchange of reactive power in the distribution grid.
- **Smart management and control systems** can increase the maximum installed capacity of RE and reduce losses at the low-voltage level. In some cases, a significant raise in installed RE sources and improvement in the distribution grid could be observed following the **introduction of intelligent equipment.** New measurement and monitoring at vital points of the local grid increased feed-in capacity of RE by up to 17 percent. It also led to 20 to 30 percent less power loss and up to 40 percent fewer network outages.[18] However, even though such intelligent measures can be an integral part for the integration of RE, some DSOs consider these to be over-valued. Intelligent measures including monitoring and smart control mechanisms can provide a valuable additional benefit yet will not replace the general need for grid expansion measures in the long-term.

Technical solutions for medium- and high-voltage levels

Besides tools like replacing transformers and increasing cross-sections, there are some additional measures that are often applied in medium- and high-voltage grids.

- Installation of **phase-shifting transformers** in areas with high levels of grid congestion to reduce re-dispatch and curtailment of RE. Phase-shifting transformers are only implemented if a cost-benefit analysis (see also dena-report “Transmission Grid Planning in systems with high shares of Renewable Energy”[19]) shows that it is more cost-efficient than the costs of re-dispatch and congestion. Phase-shifting transformers can be installed for temporary use in already existing substations and be used elsewhere when the bottleneck was alleviated by the construction of new lines or other measures.[20]
- For open-air lines application of a more advanced monitoring system is a very cost-efficient approach. The so called **“Dynamic Line Rating”** (“Freileitungsmonitoring”) optimizes the line utilization by measuring the real-time temperature of the power lines either directly or through climate data. So on days with a cooling breeze, more energy can be transported than on calm days.

[15] Bayer et al. (2017)
[16] Bayer et al. (2017)
[17] dena (2014)
[18] Designetz (2019)
[19] dena (2019b)
[20] Agora Energiewende (2018a) und dena (2017)

- The German grid system operates under the "n-1 condition" dictating that the system must at any time be able to cope with the outage of one grid component. In practice this leads to a permanently reduced maximum load of power lines and transformers to hold available capacity for emergencies. **Real-time monitoring of the capacity utilization** (**"**Auslastungsmonitoring") can increase transmission capacity by 25 to 50 percent.[21] If an outage should happen, the feed-in will be reduced instantly to grid-compatible levels.
- Direct reactions to congestion situations can be facilitated by a "**Sensitivity Analysis**" which continuously identifies critically influential transformers based on the current status of the extra-high-voltage grid. Following the identification, power generation facilities connected on high and medium-voltage levels behind the detected transformers are curtailed to eliminate the congestion.

2.2.3 The German market design provides for an efficient integration of RE

The European Union's (EU) policy to create an internal market for electricity in Europe (see also chapter 2.3) sets the framework for the German power market design. Market price zones, where the same wholesale price applies are typically national in Europe. Exceptions are countries like Italy, Norway or Sweden which consist of several price zones. Within one market zone, the basic assumption regarding the grid status is the existence of a "copper plate" on which electricity can flow freely according to market and trading activities.

Key elements that characterize the European and German market design and that contribute to the efficient integration of RE are:

Energy Only Market

The German power market is an **"energy only market"** where only the actual dispatch of energy is paid and not the provision of capacity. Market-based transactions happen in time sequences from long-term contracts (typically 1 year ahead) to day-ahead trading and intraday trading with hourly and 15-minute products. Allowing to respond to updated generation forecasts, the intraday market is particularly important for integration of RE generation.

Merit-Order Principle

Electricity prices are determined by **the merit-order principle** which sorts bids from the cheapest to the most expensive until the forecasted demand is met. This ensures that the facilities with the lowest operating costs are deployed first. These will be RE sources which have marginal generation costs of almost zero. The mechanism ensures the integration of RE as well as a decrease of the wholesale electricity prices.

Balancing Markets

Real-time balancing of power and supply and thus the management of frequency, is ensured on the **balancing power markets**. Balancing power is distinguished in primary, secondary and tertiary balancing power which differ in their activation lead time (for detailed information on the German balancing power market see also the dena-report "Making money with smart electricity consumption"[22]).

Increasing amounts of variable RE sources such as wind and solar lead to an increasing demand for flexibility. Figure 6 highlights that the German power market is able to efficiently cover most of the flexibility de-

[21] dena (2016)
[22] dena (2018b)

mand. Since 2011, the calls for balancing power have decreased significantly. In the same time span, the intraday trading volume have dramatically increased, implying that short-term trading contributed significantly to addressing any demand/supply imbalances that became visible to market participants.

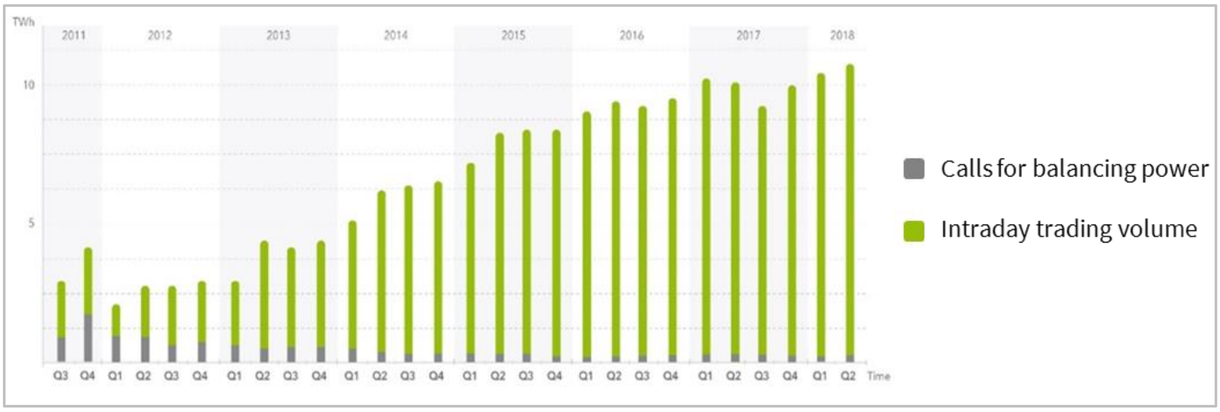

Figure 6 Development of demand for flexibility 2011-2018 (Source: Next Kraftwerke)

Challenges

This is not to say, that the integration of RE does not come with challenges. Despite the rising share of variable RE and a decreasing level of dispatchable baseload generation, the German system is one of the most stable in the world. High grid reliability and the integration of an increasing share of RE are thus not incompatible. But the geography of RE generation is quite different to the previous one based on coal and nuclear which leads to relevant grid extension needs. The required grid extension that is necessary to integrate higher shares of RE (particularly new transmission grids from North to South) is not progressing fast enough. The costs of grid stabilization and avoidance of bottlenecks are very high, with an upward trend. In 2018 they amounted to approximately 1.1 billion Euros.[23]

Multi-energy technologies like battery storage, Power to X-applications or demand side flexibility can be flexibility tools, thus reducing the pressure on the grid system and lowering the need for reinforcements. However, under current circumstances grid-oriented use of those flexibility instruments is often not profitable. In consequence, growing flexibility options of industry, business and private prosumers is mainly used in a user- or market-oriented way and not for grid-oriented measures like preserving voltage stability. In several large-scale smart energy showcase projects in Germany, various advanced market-based approaches for the flexibilization of the energy system are being tested as part of the Showcase Intelligent Energy Transition (SINTEG) program.

2.3 Common legislation within the EU supports standardized processes

The EU shapes the European Energy Union and mandates the framework under which national energy legislation and policy can be developed. In 2016, the European Commission presented a comprehensive legislative package (“Clean Energy for all Europeans”) supporting the EU energy targets for 2030 and 2050. Eight legislative acts covering the governance of the Energy Union after 2020, the design of the electricity market, and the market conditions for RE and energy efficiency are now entering into force latest 2021.

[23] dena/ewi (2019)

The design of the electricity market is defined in the “Directive on common rules for the internal market for electricity” and “Regulation on the internal market in electricity”, both of which have been revised in the “Clean Energy for all Europeans” package. In addition, a number of European grid and market codes define more detailed rules and guidelines for all European countries. The Directive sets out the key rules and principles relating to the organization and functioning of the European electricity sector. Main elements of the Directive are rules on consumer empowerment and protection, open access to markets, third party access to transmission and distribution infrastructure, unbundling rules, and independent national energy regulators. Main elements of the Regulation are general rules for day-ahead, intraday markets and balancing markets, rules on cross-border transmission capacity allocation, rules on resource adequacy and capacity mechanisms, principles for setting network tariffs, as well as general rules for the European cooperation bodies of TSOs and DSOs. In Figure 7, some of the main developments in the new European legislation are described.

Consumer-centric market model

- Consumers have strengthened rights and are enabled to make informed choices
- Vulnerable customers are protected
- Consumers can own generation or storage assets and offer their flexibility to the market
- Consumers can also act jointly e.g. as energy communities

Enabling demand flexibility

- Regulated retail prices shall be phased out
- Roll-out of smart meters and right to a dynamic electricity price contract
- Introducing independent aggregators
- Requirement for DSOs to procure flexibility services where efficient

Market-first approach

- Storage such as batteries and EV charging stations shall not be owned by DSO or TSO
- Ancillary services shall be procured based on market principles
- Where DSO and TSO procure services they shall do so in a transparent and market-based way and not discriminate against certain market participants, e. g. prosumers

Figure 7 Summary of key elements of the EU winter package

The revised Electricity Directive paves the way for consumers to become active participants in the energy transition. Consumers now will have the right to produce their own electricity without discrimination, own storage assets and offer their flexibility to the market. To enable demand flexibility, consumers are given the right to a smart meter and dynamic price contract from the energy supplier. Consumers can also engage jointly as energy communities and for instance share electricity generated within the community. The directive also defines the role of independent aggregators, who can bundle small assets and consumers to portfolios that they bid into the power market or balancing power market, thereby offering flexible consumers an easy access to the electricity market.

Retail market competition is strengthened while ensuring increased customer protection: Regulated prices are, with some exceptions, to be phased out, regulation on energy poverty and minimum information provided to customers in contract and bills is introduced, as well as regulation on comparison tools, dispute settlement and single point of contact.

The Electricity Directive also specifies the tasks and responsibilities of both transmission system operators (TSOs) and distribution system operators (DSOs) and sets out modes of cooperation among Member States, regulatory authorities and TSOs towards the creation of a fully interconnected internal electricity market.

The role of monopolies in energy storage, EV charging infrastructure, and ancillary service provision are clearly defined: TSO and DSO shall not, in principle, engage in the provision of any. All these services shall, in principle, be provided by competitive markets. Some exceptions apply, for instance if the regulatory authority has decided that a market-based procurement of ancillary services would not be economically efficient. This might be the case if there is very little competition, for instance if markets are restricted to very small geographical areas.

Further, the Directive clearly introduces the idea that flexibility provided by local assets, such as storage, and demand side flexibility can replace, or at least, delay, the need for reinforcements in the distribution grid. For that reason, DSOs should be enabled and provided with incentives, to use flexibility services from distributed energy resources based on market procedures, in order to efficiently operate their networks and to avoid costly network expansions.

The role of TSO and DSO is then to provide transparent information about their needs and procure the needed services in a market-based, transparent, and non-discriminatory manner. For instance, DSOs will be required to publish network development plans with a 5-10-year outlook, which have to be sent to the regulatory authority after a consultation process with system users. This process is intended to provide to system users better information regarding the anticipated expansions or upgrades of the network, e. g. providing an indication for where the DSO might demand flexibility services in the future. DSOs also have to describe how new generation, such as distributed RE, and new loads, such as electric vehicles, will be integrated in their system, and how they will make use of alternatives to network expansion such as energy efficiency and the procurement of storage and demand side flexibility services. This might give the regulatory authority a better position in their regulatory oversight with third party access.

Distribution and transmission tariffs are regulated only at a very high level in the European regulation, demanding the regulatory authorities to ensure that tariffs are non-discriminatory and reflective of the costs that the user of the network induces. Nevertheless, some changes have been introduced in the new legislation, notably that tariffs shall be designed in such a way that they do not present a barrier to demand response and storage service providers or energy efficiency measures. It also strongly suggests that time of use tariffs, where the tariff reflects the system stress at different points in time (typically hours of the day), shall be considered. Another important change is that net metering for consumers with their own electricity generation has to be phased out, meaning that prosumers will have to pay tariffs separately for the electricity they consume and feed into the grid, as this better reflects the actual costs of using the grid.

2.3.1 Impact of the EU winter package on the further integration of distributed RE in distribution grids

The new European legislation described above provides a common framework for the future energy system with new perspectives for European customers and distribution grids. In the future power system, distribution grids have a very different role than in the traditional power system, with a much more active role for DSOs. This requires that DSOs are legally enabled to play this role by e. g. procuring local flexibility services for their congestion management. DSOs will also need to be more transparent in their network planning, and regulatory authorities have to ensure that the tariff models are not presenting barriers to new business models, because they build on the idea of the traditional power system.

The future distribution system which the “Clean Energy for all Europeans” package prepares for will see more active customers that respond to changing electricity prices, either directly, or through a contract with an aggregator, who can remotely operate customers’ flexible loads such as home EV-charging. Consumers who also generate their own electricity (so-called prosumers, e. g. with a rooftop solar PV) are encouraged, and might increasingly join forces with others, investing in collectively owned distributed RE. This consumer empowerment is especially important as consumers are also taxpayers who partly finance the energy transition, citizens who can oppose new onshore wind development or transmission lines, and voters, who can protest if they do not agree with the governments energy policy. The energy transition requires a collective effort, the more consumers invest in, and feel ownership of, the transition, the stronger it will be.

3 Suggestions to reduce obstacles for the integration of RE in China’s distribution grids

In order to make full use of the natural potential for RE and to allow for a cost-efficient energy transition, the development of distributed RE and their integration into the distribution grid is crucial. Since the start of the *energy transition*, Germany has relied on rather small-scale and distributed RE plants such as rooftop PV or scattered wind turbines. In China, in addition to the large RE plants in the Western and Northern regions, a new focus is now put on the potential of distributed RE particularly in the more densely populated Eastern regions.

Existing technical solutions can be transferred

Technical concerns regarding the integration of distributed RE into distribution grids are raised claiming that there is only limited potential to integrate RE on the distribution grid level. But experiences from Germany show that distribution grids can cope with quite large amounts of RE, provided that regulatory requirements and technical standards get updated and streamlined. Especially in the windy Northern part of Germany, the share of RE in some areas regularly exceeds 100 percent by far.(see chapter 2.1). Technical challenges such as reverse power flow or the lack of frequency support capability of distributed RE can be successfully managed with the help of a mix of rather simple and advanced technical measures (for more details, please see chapter 1.2.3 and 2.2.2):

- Laying of **parallel cables** in the low-voltage grid,
- **Replacing local distribution transformers** with more flexible transformer designs in order to accommodate maximum reverse power flow,
- Installing **new voltage regulated distribution transformers** to adjust the voltage ratio automatically without interrupting the power supply,
- Installing **PV inverters capable of providing reactive power**,
- Introducing **smart management and control systems** and other intelligent equipment,
- Installing **phase-shifting transformers** in areas with high levels of grid congestion,
- Performing the so-called **“Dynamic Line Rating”** to optimize the line utilization,
- Introducing **real-time monitoring of the capacity utilization**,
- Reacting to situations of congestion with so-called **“Sensitivity Analyses”** that identify critically influential transformers.

These technical experiences from Germany are to a large extent directly transferable to China. Given the corresponding regulations that require and incentivize DSOs to make use of these solutions, they clearly highlight that there are no technical reasons that prevent the integration of distributed RE into distribution grids.

The regulatory framework must be designed to foster distributed RE

More importantly, there is currently a lack of comprehensive and targeted rules for the integration of RE on distribution grid level. For developers of distributed RE projects it is crucial to know the exact technical standards to comply with and the regulatory process to follow in order to have their RE plants connected to the grid. However, in practice it is very difficult to know which standard applies to a specific RE project in China.

Germany has seen very positive results of the introduction of regulations for a **compulsory grid connection** and **priority dispatch of RE**, which both can be seen as the regulatory starting point of the German *energy transition*. Together with **transparent and continuously updated grid codes**, both regulations help to provide RE project developers with the necessary planning security and grid operators with updated knowledge and measures on Best Practices of RE integration. It is therefore recommended for China to consider the introduction of similar regulations. With the recently published "Supervisory Measure for Grid Enterprises to Fully Guarantee Purchase of Renewable Energy" drafted by the NDRC, an important step into this direction has been made.

With more distributed RE, the role of DSOs and consumers with RE capacities (so-called prosumers) is developing from a rather passive to a more active role. The following German regulations are key to enable and incentivize both, DSOs and prosumers, to adjust their behaviour and interaction (for more details, see chapter 2.2.1). They may serve as an inspirational basis for similar regulations in China.

- DSOs are required to perform a technical assessment **(grid compatibility check)** when connecting new RE systems to the grid and, if necessary, to implement the necessary measures to secure grid security.
- Addressing the issue of grid operation as a natural monopoly, the so-called **"Incentive Regulation Ordinance"** requires transparent calculation of grid fees as well as fair and equal access to the grid for all consumers. To get a hold on cost efficiency, the budget approach and the principle of an efficiency-benchmark with other DSOs are used.
- The **"Directive on System Stability"** gives grid operators greater leeway to control the cut-off of generating capacities in case of urgency while also imposing the obligation to, for example, perform required retrofits of RE plants to guarantee their effective integration.
- A reduced EEG-levy aims to incentivize **self-consumption of prosumers** (e. g. households or businesses with rooftop PV).

A market-based integration of distributed RE guarantees cost-efficiency

In order to guarantee overall cost-efficiency, it is highly recommended to establish and roll-out suitable **market structures** in China that support and strengthen the approaches on priority of RE and cost-efficiency amongst grid operators (for more details, see chapter 2.2.3):

- The **merit-order principle** ensures the integration of RE as well as a decrease of the wholesale electricity prices.
- The **power market** efficiently covers most of the flexibility demand for time frames of 15 minutes or more. The **balancing markets** ensure the real-time balancing of power and supply. In order to secure grid stability with a steadily growing share of distributed RE, more focus will in the mid-term need to be put on **demand side flexibility**.

4 Appendix

Distributed wind power
National Energy Administration: Notice of development of distributed wind power integration (National Energy Administration [2011] No.226) It is the first time to clarify the main ideas and boundary conditions of distributed wind power development in China, and actively explores the development mode of distributed integration of wind power according to local conditions. The document specifies the management department, management content and approval process, as well as the conditions for distributed wind power integration projects. Besides, it requires to simplify the approval process and supporting documents, supporting the bundling of projects for approval of construction, the capacity of each bundled project is limited to 50,000 kW.
National Energy Administration: Notice of guides on the development and construction of distributed wind power integration projects (National Energy Administration [2011] No.374) The definition, voltage level and project scale of distributed wind power integration project are clarified, and strict regulations are made on project construction, grid-integration and operation management.
National Energy Administration: Notice on the requirements for accelerating the construction of distributed wind power integration projects (National Energy Administration [2018] No.3) Project construction should be in order, grid integration management should be strengthened, plan construction standards should be settled, and management of planning should be reinforced. The capacity of distributed grid integration wind power integration projects should not be limited to annual guidance scale.
National Energy Administration: Interim management rules for the development and construction of distributed wind power projects（National Energy Administration〔2018〕No.30） The voltage level and grid-integration mode of distributed wind power are settled and not subject to the index management. Compared to centralized wind power projects, the approval process of distributed wind power projects is required to be simplified, multiple projects are encouraged to be bundled and carry out pre-stage work in a unified way, the trial of project pre-approval commitment mode and post-approval supervision mode is encouraged. The time from project declaration to approval should be reduced to 2-3 months, while the period for grid-integration approval should be shortened to 1 month.
National Energy Administration: Notice on the requirements of wind power construction management in 2018 (National Energy Administration〔2018〕No.47) For the provinces (autonomous regions and municipalities) that have not issued their own annual wind power construction plan for 2018, all new centralized onshore wind power projects and offshore wind power projects without identified investment should be configured and determined through competition. Distributed wind power projects may not participate in competitive configuration, and will be gradually included in the marketed transaction scope of distributed power generation.
Distributed PV power
State Council: Opinions on promoting the healthy development of the PV power industry（State Council〔2013〕No.24）

It is required to develop distributed PV power market vigorously, specify the main scene of development, construct 100 distributed large-scale PV application demonstration areas, 1000 PV power application demonstration towns and villages, carry out the corresponding demonstration pilot work, explore the corresponding power management system and operational mechanism, strengthen the construction of supporting power grids, improve policies on electricity prices and subsidies, form a new system for the construction, operation and consumption of distributed PV power generation.
National Energy Administration: Notice on further implementation of policies on distributed PV power generation （National Energy Administration〔2014〕No.406） In view of many factors that restrict the development of a distributed generation market, comprehensive policy adjustment has been made. The application planning and annual plan of distributed PV power generation are required; the development of various forms of application is encouraged; local governments are encouraged to formulate supporting fiscal subsidy policies on the basis of state subsidies; no limitation should be set on the scale of distributed self-use PV power generation projects; the regional enterprises should be guided to establish standard PV power energy management service modes based on power generation contract; the standards and quality management of distributed PV power generation projects should be improved; two main development modes of distributed power generation are clearly pointed out: "generate electricity primarily for own use, excessive part can be integrated into the grid " and " all generation feed into the grid "; the grid integration and integration services for distributed PV power generation should be improved. The above policies lay a foundation for the large-scale development of distributed PV power generation.
National Energy Administration: Management measures for distributed PV power generation projects (National Energy Administration〔2017〕Draft for comment） The term of distributed PV power is clearly defined, including three types of grid integration modes, subsidy scope and subsidy allocation sequence.
National Development and Reform Commission: Notice on PV power generation in 2018 (National Development and Reform Commission〔2018〕No.823) It requires a reasonable grasp of the development pace and optimization of the scale of new construction, firstly sets distributed PV power index constraints and reduces the subsidy intensity of distributed PV power.
National Development and Reform Commission: Notice on improving the on-grid tariff mechanism for PV power generation (National Development and Reform Commission〔2019〕No.761) For the first time, the subsidy intensity of distributed PV power electricity price under the mode of "generate electricity primarily for own use, excessive part can be integrated into grid" was lowered and included in nationwide bidding.

Table 5 Relevant regulations policies for distributed wind and PV power plants in China

Province	Planning scale and relevant content
Inner Mongolia	The "Notice about the Construction Plan for the 13th Five-Year Decentralized Wind Power Project in Inner Mongolia" was published at the end of 2017, with the specific intervention voltage level of 35 kV and below, the single building capacity of less than 10,000 kW, and the planned construction scale of 150,000 kW.
Shanxi	The Shanxi Energy administration issued the "Notice on Further Improving the 13th Five-Year Development Plan for Distributed Wind Power of Shanxi Province" in June 2018, which planned to develop 30 projects with a total construction scale of 426,000 kW.
Guizhou	The "Notice on Printing and Implementing the 2016 Wind Power Development and Construction Plan for Guizhou Province" was issued in 2016 and clearly stipulated that the scale of decentralized integration with wind power projects would be 72,000 kW. In addition, "the List of Major Projects in Guizhou Province in 2018" was released in February 2018 with 17 wind power projects.
Jilin	The "13th Five-Year Development Plan for New Energy and Renewable Energy in Jilin Province" issued in 2017 ensured that the development scale of decentralized wind power in Jilin would be 250,000 kW by 2020.
Shanxi	In March 2018, the Shanxi Development and Reform Commission formulated the "13th Five-Year Decentralized Wind Power Project Construction Plan of Shanxi Province", and determined that the development scale of the 13th Five-Year Plan distributed wind power project in Shanxi is supposed to be 987 MW.
Hebei	In February 2018, the "Decentralized Wind Power Development Plan of Hebei Province from 2018 to 2020" was released. It was pointed out that from 2018 to 2020, the province planned to develop distributed integration of wind power of 43 MW.
Henan	At the end of 2017, the "Notice on the Decentralized Wind Power Development Plan for the 13th Five-Year Plan of Henan Province" was issued together with the "Summary Table of the 13th Five-Year Distributed Wind Power Development Project of Henan Province", which listed out 124 decentralized wind power projects with a scale of 2107 MW. The cities were asked to adjust and supplement the decentralized wind power development plan in 2019. At present, 15 cities have publicized the adjustment plan, to totalling 4,537 MW.
Guangdong	The "First Batch of Development Plans for Onshore Wind Power in 2018" was issued in April 2018,with 7 projects and a total installed capacity of 450 MW.
Guangxi	The Guangxi Energy administration issued the "Development and Construction Plan on Wind Power of Guangxi in 2018" in February 2018, which clarified that there were 45 wind power development candidates in Guangxi in 2018, with a total of 26.94 MW.
Tianjin	In October 2018, the "Announcement for Soliciting Opinions on Development Plans of Tianjin Decentralized Wind Power (2018-2025)" was issued. The new installed capacity will strive to reach 200,000 kW by 2020; while the new installed capacity will strive to reach 370 MW from 2020 to 2025,, with a total installed capacity of 570 MW.

Heilongjiang	The "Publication of Heilongjiang Province Decentralized Wind Power Development and Construction Plan (2019-2020)" was issued in May 2019, in which 98 projects were planned to be installed with a total capacity of 627 MW.
Ningxia	The "Development and Construction Plan on Decentralized Wind Power Project of Ningxia in 2019" was released in June 2019, including 14 decentralized wind power projects with a total installed capacity of 453 MW.
Hubei	The "Notice on the Construction of Decentralized Wind Power Demonstration Projects in 2019" was issued in March 2019, requiring innovative development models, exploring multi-energy complementarity, and piloting in 10 counties and cities across the province. The total development capacity of each county or city is no less than 20 MW.
Jiangxi	The Jiangxi Provincial Energy Bureau issued the "Notice on the Doing Well Relevant Work on the development of Decentralized Wind Power in Jiangxi Province" in September 2019, clarifying 73 recent options, with a total project scale of 18.5 MW.
Yangzhou, Jiangsu	The "13th Five-Year Wind Power Development Plan in Yangzhou" clarifies that the city will develop 7 decentralized projects in industrial parks and other scenarios, with 35 kV grid-connected by 2025.
Chuzhou, Anhui	The "Notice on Announcement of Projects for Decentralized Wind Power Implementation Projects" clearly defines 18 projects with a total scale of 153 MW. The implementation plan will be rolled in due course and projects that are not included in the scheme in principle should not be approved.

Table 6 Overview of distributed power generation in China (2018)

Figures

Tables

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Abbreviations

ARegV	Incentive Regulation Ordinance (Anreizregulierungsverordnung)
DSO	Distribution System Operator
EEG	Renewable Energy Sources Act (Erneuerbare-Energien-Gesetz)
EnWG	German Energy Act (Energiewirtschaftsgesetz)
EU	European Union
EV	Electric Vehicle
NDRC	National Development and Reform Commission
NEA	National Energy Administration
PV	Photovoltaic
RE	Renewable Energy
SCADA	Supervisory Control and Data Acquisition
SGCC	State Grid Corporation of China
SINTEG	Showcase Intelligent Energy Transition
SysStabV	Directive on System Stability (Systemstabilitätsverordnung)
TSO	Transmission System Operator
UNFCCC	United Nations Framework Convention on Climate Change

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