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Sino-German Energy Transition Project

Energy Transition in China and Germany

Achieving climate targets and expanding renewable energy in Germany and China

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German Energy Agency

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Imprint

The report "Energy Transition in China and Germany" is a project research analysis paper. It provides a general overview of the energy transitions in Germany and China and the recent developments in both countries. The report is published by GIZ in the framework 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 mutual benefit policy research and modeling. The project is supported by the German Federal Ministry for Economic Affairs and Climate Action (BMWK) in the framework of the Sino-German Energy Partnership, the central platform for energy policy dialogue between Germany and China on 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.

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Executive summary

China and Germany are both committed to tackling climate change under the terms of the Paris Agreement. Each country has formulated short- and long-term goals to reach climate neutrality. Germany is aiming to achieve an 80% RES (renewable energy sources) proportion of gross electricity consumption by 2030. It is also aiming to phase out coal by 2038 (ideally by 2030) and to reach climate neutrality by 2045. China, on the other hand, is committed to peaking CO_2 emissions before 2030 and achieving carbon neutrality by 2060.

Transitioning towards clean energy is the main pillar of both countries' quest to become climate neutral. Although Germany is known as a forerunner when it comes to energy transition, China has caught up at incredible speed and is now the country with the world's largest installed capacity of renewable energy (RE). Only last year, China added nearly as much newly installed capacity as Germany's total renewable capacity.

As their energy transitions are underway, both countries face similar challenges with regard to successfully integrating rapidly increasing amounts of RE into their power systems. As weather conditions determine the availability of variable generation, power systems need to be adapted and higher levels of flexibility introduced to ensure a constant supply.

There are manifold solutions to integrating higher proportions of RE, including demand-side management (DSM), energy storage systems, green hydrogen, accurate power system planning and forecasting, and the further development of ancillary services. As Germany's and China's energy transition realities and potentials are unique, so are their government's goals for developing these solutions. Consequently, both countries find themselves at different stages of deployment.

In Germany at present, storage solutions are particularly attractive to prosumers, including households, for increasing self-consumption. In 2022, Germany had approximately 500,000 PV storage systems installed and the market for different electricity storage technologies has grown significantly in recent years. In China, the pairing of rooftop PV with energy storage offers the biggest potential for China's commercial and industrial consumers, rather than for households. Nevertheless, the deployment of energy storage by these consumers has so far been strongly impeded for various reasons, including economic concerns. With China's newly set goals for the energy storage industry, such as decreasing the per-unit cost of energy systems by 30% by 2025, greater deployment can be expected in the near future.

Both countries face challenges, in part due to their dependency on fossil fuels. Ensuring security of supply in the short term has been Germany's main priority since the beginning of 2022, as cuts in Russian natural gas have forced the country to rely more on coal and oil. Faced with a significant energy crisis, Germany is rethinking the role of natural gas for the energy transition and looking to speed up the development of alternative solutions. In China, energy security concerns have also influenced policy decisions. As a result of the severe energy shortages that the country has experienced in the past two years, domestic coal production and consumption have been ramped up.

These short-term energy security measures threaten China's and Germany's climate action and energy transition goals. Yet both countries remain committed: At the recently held 20th National Congress of the Chinese Communist Party and at the United Nations (UN) Climate Change Conference COP27, China reiterated its commitment to its carbon goals. Days before the climate conference, German Chancellor Olaf Scholz also confirmed that Germany would not stray away from its path of becoming carbon neutral by 2045. In order to move away from fossil fuels as quickly as possible, both countries need to remove all barriers to the further expansion and integration of RE.

1 Climate goals in Germany and China

Tackling the climate crisis and transitioning to clean energy are top priorities in Germany and China. Although their geographical, demographic and economic situations are distinctly unique, both governments have committed to an ambitious climate agenda. Germany has set out to reach climate neutrality by 2045, while China is aiming to get there by 2060 and peak its emissions by 2030.

1.1. Germany's climate goals

The German energy transition ("Energiewende") aims to establish a carbon-neutral and nuclear-free energy system by meeting climate neutrality goals. These have been adjusted and tightened several times, as shown in Table 1. The most recent goal foresees climate neutrality by 2045.

In 2010, the government adopted the German Energy Concept,[1] which outlines the overall target architecture of the German energy policy and is still valid today.

The initial target of the Energy Concept was a reduction of greenhouse gas (GHG) emissions by 40% by 2020 and 80% by 2050 compared to 1990. Expansion of RE was one of the key measures for achieving these goals. The Energy Concept therefore set the RE proportion of gross final energy consumption at 18% by 2020, 30% by 2030 and 60% by 2050, and of gross electricity consumption at 35% by 2020, 50% by 2030, and 80% by 2050. Moreover, primary energy consumption was to decrease by 20% by 2020 compared to 2008.

The Paris Agreement, which came into force in 2016, imposed targets that were more ambitious. The German government adopted the Climate Action Plan 2050 in November 2016, making Germany one of the first countries to submit a long-term low greenhouse gas emission development strategy to the UN as required under the Paris Agreement. The Climate Action Plan 2050 described a pathway to a largely climate-neutral economy by 2050,[2] and defined in more detail the government's ambitious climate targets. The medium-term target was to cut greenhouse gas emissions in Germany by at least 55% by 2030 compared to 1990 levels. The plan also laid down 2030 targets for individual sectors, described the necessary development pathways, listed initial measures for implementation and established a process for monitoring and updating policies and measures. With this plan, Germany was doing its part to achieve the international target set out in the Paris Agreement to limit global warming to well below 2 degrees Celsius, preferably to 1.5 degrees Celsius.

Nuclear phase-out

The nuclear catastrophe in Chernobyl in April 1986 caused widespread fear of nuclear power and strengthened the anti-nuclear sentiment. The majority of Germans were concerned about the risks of the technology, and most politicians began to stress that nuclear was a bridging technology but not the future. No new commercial nuclear power stations were built after 1989.

In the Energy Concept 2010, nuclear energy was still considered a bridging technology: The German government concluded that the limited extension of operating lives of existing nuclear power plants makes a key contribution to achieving the three energy policy goals of climate protection, economic efficiency and supply security in Germany within a transitional period.

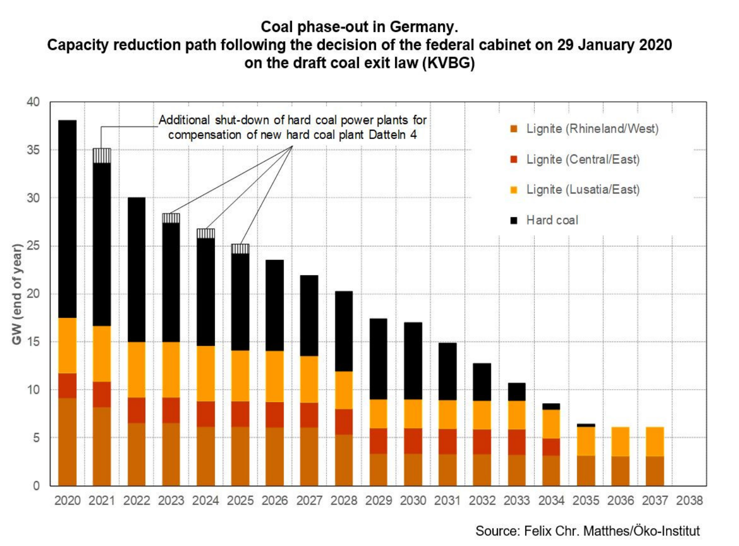
In light of the nuclear catastrophe in Fukushima, Japan, on 11 March 2011, the same government decided to phase out nuclear power by 2022 and to shut down Germany's seven oldest reactors within a few months. Due to the current energy crisis, the phase-out date has been moved to 2023.

Nine years after the German Energy Concept, emissions had not decreased significantly. As a result, the German government set a binding path towards climate neutrality through the Climate Protection Act 2019. It foresaw a GHG emissions reduction of 55% by 2030 compared to 1990 and climate neutrality by 2050. In the course of the expansion of RE, the emissions in the energy sector have decreased significantly since 1990, as shown in Figure 1. As the COVID-19 pandemic led to the sudden reduction of economic activity and mobility, Germany reached its GHG-reduction goal to cut emissions by 40% in 2020. Shortly after, however, emissions quickly increased to pre-Covid levels: In 2021, emissions only decreased by 38.7% compared to 1990. In 2021, total emissions were about 762 million tonnes of GHG, 4.5% more than in 2020.[3]

Even though previous climate targets were not met, the goal was tightened in 2021. Following a remarkable decision by Germany's highest court in 2021, deeming the German climate policy insufficient, the Climate Protection Act was revised in 2021 to mandate climate neutrality by 2045.

The newly elected German government (greens, social democrats, liberals) subsequently outlined a comprehensive plan to transform the energy system in their Coalition Agreement, for both the generation and the consumption sectors. The Coalition Agreement made reaching the climate goals a priority. The measures included new targets for 2030, such as an RE proportion of 80% of gross electricity consumption or 2% of the national territory for onshore wind.

Coal phase-out

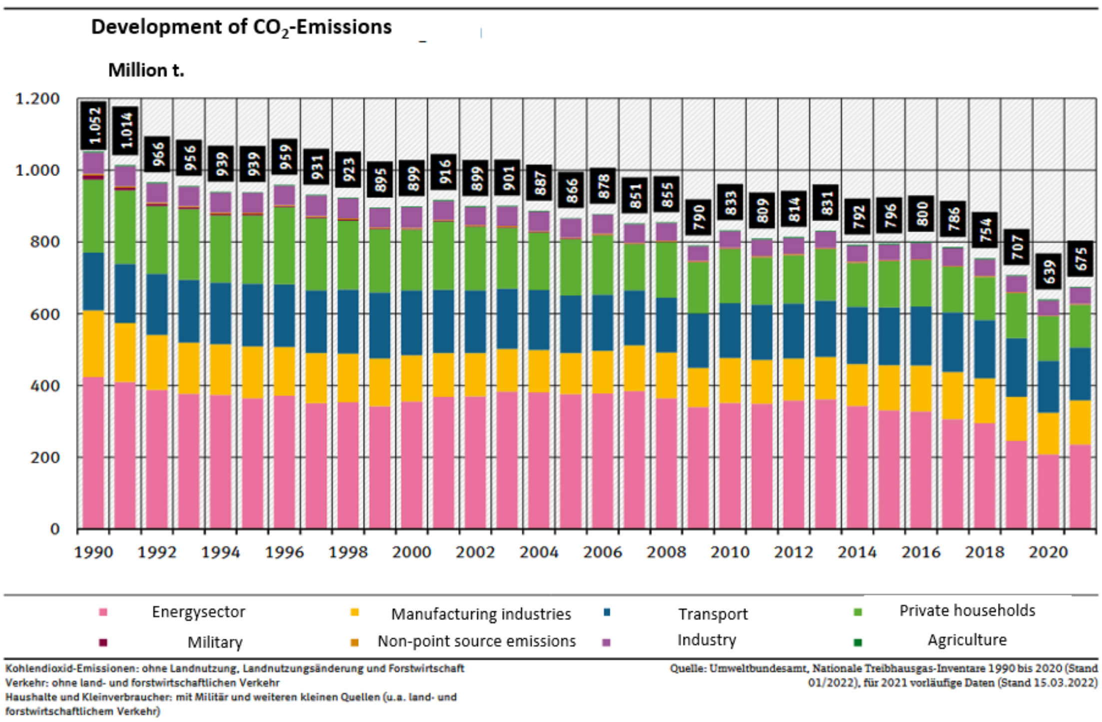


In 2020, the German government agreed on the coal phase-out by 2038. The Act to Reduce and End Coal-Powered Energy and Amend Other Laws (Coal Phase-Out Act) mandates that the power generated from both anthracite (hard coal) and lignite (brown coal) must each be reduced to around 15 gigawatts (GW) by 2022. By 2030, the output is further reduced to 8 GW for hard coal and to 9 GW for lignite. Finally, by 2038 at the latest, the use of coal-fired plants must cease completely. The act also mandates reviews of the phase-out schedule in 2026, 2029 and 2032, respectively, to decide whether a complete exit may be achieved by 2035. However, in its coalition agreement, the current government included the target to phase out coal by 2030.

Table 1: Overview of Germany's carbon emissions and renewable energy targets

Carbon emissions				
	2020	2030	2045	2050
Energy Concept (2010)	Reduction by 40%			Reduction by 80-95%
Climate Action Plan (2016)	Reduction by 40%	Reduction by 55%		Reduction by 80-95%
Climate Protection Law (2019)		Reduction by 55%		Reduction by 100% (net)
Amendment of Climate Protection Law (2021)		Reduction by 65%	Reduction by 100% (net)	
Renewable energy in electricity generation				
	2020	2030	2035	2050
Energy Concept (2010)	35%	50%		80%
Easter Package (2022)	80%		100%	

Figure 1: Development of CO_2 emissions in Germany[4]



1.2. China's climate goals

Over the past three decades, China's energy demand has dramatically increased, mostly due to the country's energy-intensive industrialisation and urbanisation. In combination with the country's heavy reliance on coal, this sharp rise led China to become the world's largest GHG producer in 2006. Against this background, President Xi Jinping in 2014 called for a domestic "energy revolution" (*nengyuan gemin* 能源革命) in four key areas: energy consumption, energy production, energy technology and energy system.[5] Decreasing energy consumption, capping primary energy growth and increasing energy efficiency became a central part of this energy transition plan. Diversifying China's energy mix to reduce the country's dependence on fossil fuels and expanding RE made up the second pillar of the strategy.[6]

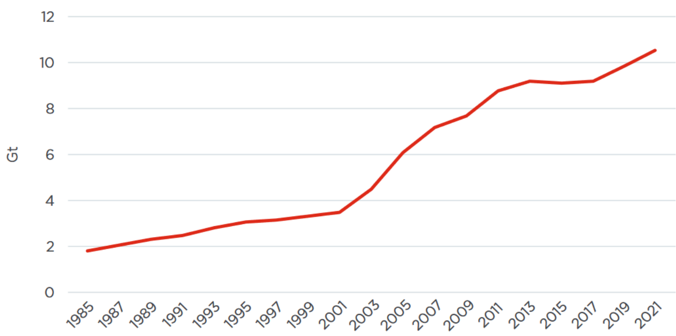
The commitment to start an "energy revolution" has been reiterated in China's 13th Five-Year Plan (FYP; 2016–2020) and underpinned by the release of the Energy Production and Consumption Revolution Strategy (short: Energy Revolution Strategy) by the National Development and Reform Commission (NDRC) and the National Energy Administration (NEA) (2016–2030) in 2017. The latter includes the main overall targets and strategies for reaching a low-carbon, clean, efficient and secure energy system in China by 2030.

With the submission of the first Nationally Determined Contribution (NDC) in 2016 as part of the country's commitment under the 2015 Paris Agreement, the Chinese government had already committed to ambitious climate and energy targets.[7] The country had pledged to peak its CO_2 emissions around 2030, lower its CO_2 emissions per unit of GDP by 40–45% before 2020 and by 60–65% before 2030 compared to 2005 levels, and to increase the proportion of non-fossil fuels in primary energy consumption to around 20%. The mentioned Energy Revolution Strategy built upon these goals and added several new targets for 2030, including the commitment to limit primary energy consumption to 6 billion tce. At the end of 2017, China had already reached its 2020 carbon intensity target set at the COP15 in Copenhagen by cutting the 2005 carbon intensity level by 46% three years ahead of time.[8] Viewed historically, overachieving climate goals is not unusual for China. For example, the country's RE development goals set in the 11th, 12th and 13th FYP have all been overachieved.[9]

A major milestone in China's climate efforts followed in 2020. In September that year, the Chinese government expanded on the existing targets by announcing that it aims to peak its CO_2 emissions before 2030 (rather than "around 2030", as previously promised in its first *NDC*) and achieve carbon neutrality by 2060.

These two new goals – also known as "30–60" goals or "Shuangtan" (双碳) – marked a significant shift in Chinese climate policy. GHG reductions were no longer just a "by-product" of other measures and goals, but the core goals themselves. These two major targets were later confirmed in the updated, most recent version of China's NDC, submitted on 28 October 2021, shortly before COP26 in Glasgow.[10] The carbon neutrality goal implies a dramatic transformation of China's energy system, which is still overwhelmingly dependent on fossil fuels, as can be seen in Figure 2. In 2021, roughly 10.5 gigatonnes (Gt) of the total 11.3 Gt of CO_2 emissions in China came from the combustion of fossil fuels (coal, oil and gas).[11]

Figure 2: China's CO_2 emissions from fossil fuels (Gt) (1985–2021)[12]



In comparison with China's initial NDC, the revised targets have become clearer and more ambitious. For example, while in the original NDC China aimed to reduce its CO_2 intensity by around 60–65% by 2030 compared to 2005 levels, in the updated NDC the target was raised to over 65%. Similarly, the target for non-fossil fuels in primary energy consumption in 2030 was raised from around 20% to around 25%. A look at the current situation indicates that these goals are achievable: As of 2021, China's CO_2 emissions per unit of GDP were 50.8% lower than in 2005 and the proportion of non-fossil fuels in primary energy consumption amounted to roughly 16.6%.[13]

The updated NDC also included a new target for solar and wind capacity: 1,200 GW by 2030. With that goal, China committed to more than doubling its installed capacity – already the world's largest – during the 2020s. Considering the record speed at which China is currently increasing its installed capacity of wind and solar energy, this goal is expected to be significantly overachieved.[14]

Along with the revised NDC, China submitted its Mid-Century Long-term Low Greenhouse Gas Emission Development Strategy to the UN on 28 October 2021.[15] In the document, several quantitative targets for 2025 and 2030 in key areas such as buildings and transport were added. For instance, according to the plan, 100% of new buildings in cities and towns are to implement green building standards by 2025, and 50% of new public buildings and new factory buildings should be covered with rooftop PV. As for clean mobility targets for 2030, the proportion of new energy vehicles[1] should reach about 40% of all the vehicles sold in that year.

In March 2021, the Chinese government also released its current 14th Five-Year Plan (2021–2025), which set new goals for 2025, including the goal to reduce China's CO_2 intensity by 18% from 2020 levels and its energy intensity by 13.5% by 2025. Compared to the levels set in the previous FYP, the goal for reducing energy intensity decreased by 1.5% in the current plan, while the carbon intensity goal remained at the same level. In the plan, the country also pledged to increase the proportion of non-fossil energy sources in its energy mix to around 20% by 2025 – a more ambitious target than the one in China's original NDC (i.e. 20% by 2030).

As part of its 14th FYP, China also released another two important policy documents prior to COP26 in November 2021. These two documents, titled the Working Guidance for Carbon Dioxide Peaking and Carbon Neutrality in Full and Faithful Implementation of the New Development Philosophy (short: Working Guidance; also referred to as the Climate Plan) and the Action Plan for Reaching Carbon Dioxide Peak Before 2030 (in short: Action Plan) form the foundation of China's climate policy framework for reaching its carbon reduction targets: the 1+N policy framework.

The so-called Climate Plan (the "1" part of the policy) unifies the Chinese government's official goals and strategies for achieving the CO_2 peak before 2030 and carbon neutrality by 2060. However, it also includes some additional goals, such as the quantitative target of reaching a non-fossil fuel proportion of 80% of total energy consumption by 2060. Sector-specific goals and measures are defined in the "N" plans. The Action Plan is the first released "N" document and it outlines the specific pathway towards CO_2 emission peaking before 2030. Both documents emphasise reducing energy consumption and accelerating RE development.

In addition to the main FYP, China also releases sectoral and sub-sectoral plans with more specific targets and plans of action. The 14th FYP on Modern Energy System (in short: Energy Plan), released on 22 March 2022, and its sub-sector plan on RE, the 14th FYP for Renewable Energy Development, released on 1 June 2022, may be the two most crucial documents for China's decarbonisation released so far. Especially the 14th Energy Plan breaks new ground, as it is the first issue of the plan to incorporate the words "modern energy system" in its name. Previous documents were simply called "energy development plans". According to a spokesperson from NEA, by changing the name, the government is signalling that it has recognised the urgent need to change the system and accelerate the development of a "low carbon, intelligent, diversified and multi-polarised" energy system. [16] An overview of China's current and most important climate goals can be seen below in Table 2.

Table 2: Overview of China's current climate goals

Carbon Emissions			
	2025	2030	2060
Co2 Emission Peak		Before 2030	
Carbon Neutrality			Before 2060
Co2 Intensity	Reduction by 18% from 2020-levels		
Co2 Emission Reduction (per unit GDP)		Reduction by <65% compared to 2005-levels	
Energy Efficiency			
Energy Intensity	Reduction by 13.5% from 2020-levels		
Renewable Energy			
Share of non-fossil fuel in energy generation	39%		
Share of non-fossil fuels of total energy consumption	≈ 20%	≈ 25%	80%
Renewable Energy Output	1,000 Mtce	Wind and solar capacity <1,200GW	

[1] In China, New Energy Vehicles (NEV) refer to battery electric vehicles, plug-in hybrid electric vehicles and fuel cell electric vehicles.

2 Expansion of renewable energy

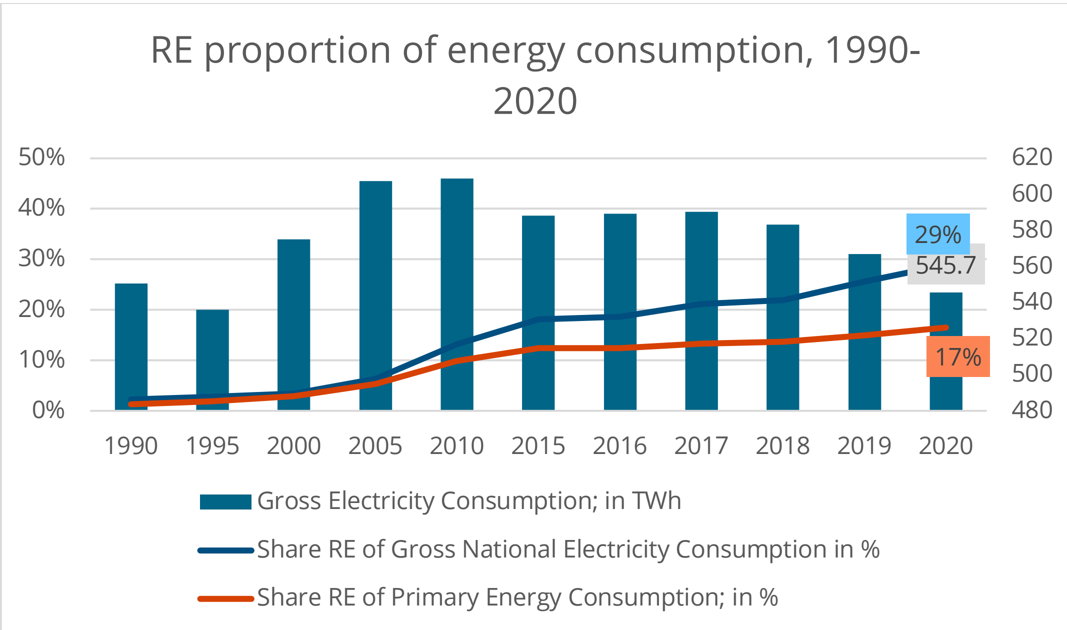
The expansion of RE sources is the basis for the energy transition in all sectors. Although Germany and China find themselves at different stages of the energy transition and are facing different challenges on their paths, they are both making great strides in this respect. However, successfully integrating rapidly increasing amounts of variable RES into the power system and maintaining system stability is a major challenge for both countries. Increasing flexibility, be it through the deployment of technical solutions, hydrogen or adaptations in the power planning processes, can reduce the pressure on the power grid and ensure security of supply.

2.1. Germany: current situation

The RE proportion of electricity consumption has increased significantly in the past two decades. In 2020, it was about 29% of gross electricity consumption, as shown in Figure 3. In the national electricity generation mix of 2020, RES even had a proportion of 44%.[2] In contrast, renewables play a minor role in the consumption sectors. In the mobility sector, RES has a proportion of only 6.8%.[17] Fossil fuels account for a large proportion of energy use in the industry and the heating sector, where renewables make up only 16.5%.

Today, electricity consumption in Germany amounts to approximately 500 terawatt-hours (TWh) annually. It is expected to rise to 750 TWh by 2030. For RE to cover a large proportion of this consumption, a massive expansion of installed capacities is required. In 2021, the overall RE capacity for electricity consumption was 138 GW, consisting mainly of wind onshore and offshore (64 GW) and PV (59 GW), both variable RES. The rest is provided by controllable RES such as hydropower or biomass.

Figure 3: RES proportion of electricity consumption and primary energy consumption[18]



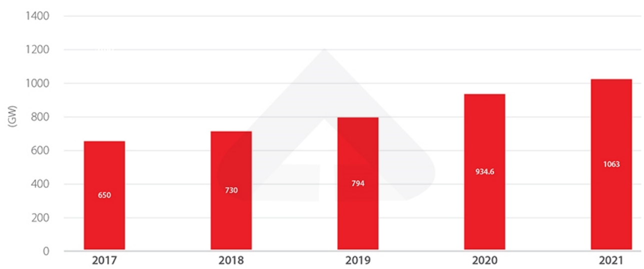
In terms of size, distributed generation (mostly PV) already makes up for a large proportion of total RE capacity in Germany. The 59 GW of PV translate into roughly 2 million small-scale systems, of which 60% were below 10 kilowatt (kW).[19] In 2019, the total capacity of installed small-scale PV below 10 kW was about 7,100 megawatt (MW), almost 15% of the total installed PV capacity. The capacity of small-scale PV between 10 and 20 kW was about 4,700 MW in total, or almost 10% of the total installed PV capacity. Open field PV contributes only small amounts to the installed capacity of small-scale PV.[20]

[2] Electricity generation includes electricity produced in electricity-only plants and in combined heat and power plants in Germany, whereas electricity consumption also includes electricity imports and exports. The RES proportion therefore differs, depending on imports.

2.2. China: current situation

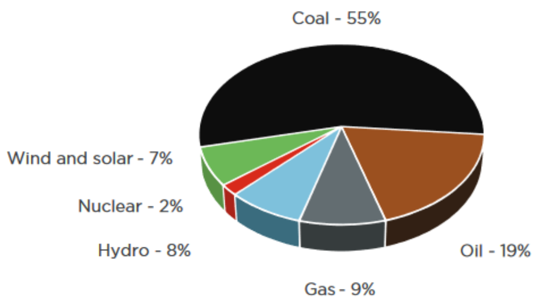
In 2021, China had a total electricity consumption of around 8,310 TWh. [21] According to various projections, China's total energy consumption is anticipated to rise in the short term and only begin declining after 2040.[22] With fossil energy currently accounting for more than 80% of total energy consumption, replacing it with non-fossil energy sources is the main way for China to curb the growth of carbon emissions.

Figure 4: Growth in total installed RE capacity (GW)[23]



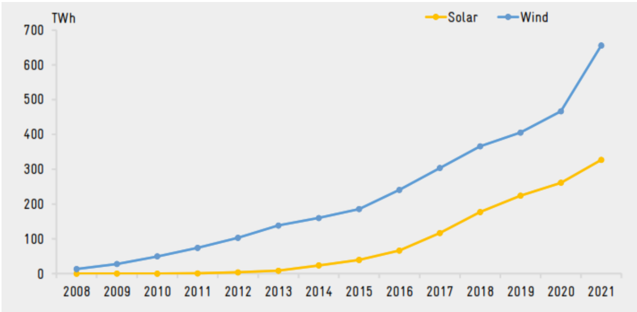
At the end of 2021, China had 1,063 GW installed RE capacity, making it the country with the largest installed capacity of RE in the world. That year, RE accounted for almost 45% of the country's total power generation capacity, while its proportion of actual power generation was around 30% (16.1% hydroelectric; 7.9% wind energy; 3.9% solar energy, and 2% biomass). As can be seen in Figure 5, as of 2021, the non-fossil fuels (wind and solar, nuclear, hydro) proportion of primary energy consumption amounted to around 17%.[24]

Figure 5: China's primary energy structure by fuel (2021)[25]



Out of all RES, solar and wind energy are currently experiencing the highest buildout. The surge in power generation from wind and solar can be seen in Figure 6. As of early 2022, the total installed capacity of wind (342 GW) and solar power (336 GW) amounted to 678 GW.[26]

Figure 6: Yearly wind and solar generation (TWh) from 2005 to 2021 in China[27]



Prior to 2019, China's rapid RE expansion was accompanied by high curtailment rates in order to preserve system stability. 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, renewable curtailment has meanwhile fallen to low levels in most provinces.

China's RE expansion relies mainly on centralised, utility-scale plants. However, over the past five years, distributed energy has also been gradually expanding in China.[3] Like in Germany, the most important distributed technology is solar PV, although it should be noted that, unlike in Germany, many solar PV facilities classified as distributed solar are typically multi-MW ground-mounted facilities located near industrial areas. Even though rooftop solar currently still accounts for a relatively small proportion of China's overall solar capacity, the number of installed rooftop systems has been increasing rapidly since 2017.[28]

It should also be noted that China is now not only the leading manufacturer of solar PV equipment, but has also evolved into an impressive innovator in the field of clean energy. It holds the largest number of green patents in solar PV solutions, wind energy and energy storge.[4]

2.3. Integration of renewable energy sources

In order for Germany and China to reach their climate neutrality goals by 2045 and 2060, wind and solar power will have to be the main source of electricity generation in the future. As RE depends on weather conditions and is thus variable in nature, power systems need to be adapted

[3] For more information on distributed energy and flexibility in China, refer to our previous paper "Decentralized Flexibility and Integration of Renewable Energy" (2022): https://www.energypartnership.cn/fileadmin/user_upload/china/media_elements/publications/2022/Decentralized_Flexibility_and_Integration_of_Renewable_Energy_EN.pdf.

[4] For more information on the innovation in the distributed generation and storage field in China, refer to our recent report "Innovative distributed generation and storage", which will be published soon on the Sino-German Energy Partnership website: https://www.energypartnership.cn/media-elements/.

and flexibility measures introduced in order to maintain a constant and stable supply and satisfy demand.

Ensuring security of supply depends on many factors, such as accurate power system planning and forecasting, both of which will become more difficult as variable renewables like wind and solar are scaled up. Being able to accurately assess capacity adequacy – meaning that there is sufficient capacity available in the power system to meet demand at all times – will play a crucial role in maintaining power system reliability.

System stability can also be provided by technical options such as energy storage technologies and DSM. By storing surplus energy and feeding it into the grid when demand is high, the energy storage sector can balance out variable renewable power generation. Making use of these options will help China and Germany integrate more RE into their systems and facilitate the countries' move towards carbon-neutral economies.

The system's operation and market design can also be adapted to accommodate higher proportions of variable renewable electricity through the further development of ancillary services, for instance.

Hydrogen, or more specifically green hydrogen – produced emission-free with renewable electricity – will also play an important role in the global energy transition. Green hydrogen enables transitions based on RES in different sectors, such as the chemical industry, or for applications that cannot be electrified with the current state of the art, such as maritime shipping and aviation. In the electricity sector, hydrogen can make renewable electricity storable over longer periods of time (seasonal storage) and transportable over longer distances, as well as increasing system resilience by coupling the electricity sector with other parts of the energy system.

2.3.1. Germany

Electricity storage

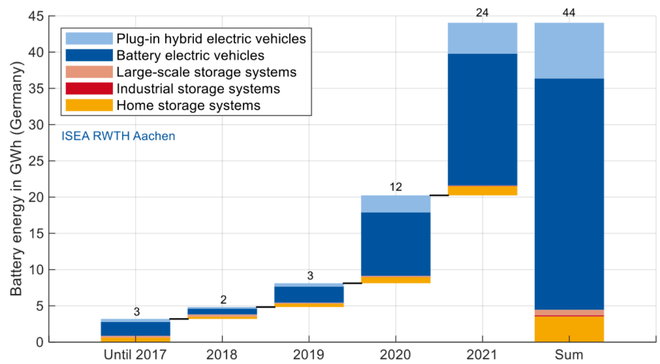
Depending on its type, electricity storage can provide a range of services to increase grid stability and the integration of RES.

Different types of conventional and innovative technologies are available to serve as electricity storage. At distribution grid level, batteries are the most relevant technology. Batteries can perform load shifting and provide a broad range of grid services, including balancing power, spinning reserves and black start capacity when aggregated. Behind the meter, batteries can contribute to increasing self-consumption and improving power quality for the customer.

The number of storage systems in Germany has increased significantly in the past two years. As of 2021, about 4.5 gigawatt-hours (GWh) of battery storage were installed in Germany, 3.5 GWh of which were home storage. In 2021, about 1.4 GWh of storage were added, the vast majority of which home storage. In 2022, Germany had approximately 500,000 PV storage systems installed. These 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 significant potential for integrating high volumes of distributed energy. In 2021, new EV registrations totalled 680,000, which corresponds to an overall battery capacity of approximately 22 GWh and a theoretical maximum output of 31 GW if simultaneously charged. The German government has set a target of 15 million EVs by 2030, so their use as a flexibility option is expected to rise in the future. [29] Bi-directional charging, which is currently available for only a few vehicle models, would allow EVs to serve as an electricity storage device. Private EVs are parked for around 23 hours per day on average, which makes them suitable for providing either grid services or storage of distributed renewable output. The market for different types of electricity storage has grown significantly in recent years, as shown in Figure 7.

Figure 7: Estimated stationary and mobile battery storage market in Germany[30]



DSM

Typical technologies providing DSM at 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 make use of DSM to optimise their procurement strategy, while distribution grid operators engage in load control contracts with providers of decentralised DSM to manage grid congestion.

In Germany, DSM is mainly used at industrial level. Residential DSM does not play a major role yet. Although Germany has established several marketing options for industrial DSM, market access and regulatory barriers still render significant DSM potentials unharnessed. To further facilitate industrial DSM potential utilisation, the German regulator can remove remaining market barriers and create a stable regulatory framework that gives stakeholders predictability and planning security.[5]

As for residential demand-side flexibility, it will play a more important role with the gradual introduction of intelligent measuring systems (smart meters) and other digital technologies.

Hydrogen

While hydrogen production is currently based on fossil fuels, the long-term goal is for it to be based solely on RES. Green hydrogen can contribute to the energy transition of several sectors, especially the ones that cannot be electrified easily, such as the chemical industry and heavy-duty transport. Green hydrogen can also serve as a flexibility option in the electricity system. Green hydrogen in Germany refers to electrolytic hydrogen produced from verifiably renewable electricity and not electrolytically produced hydrogen from grid electricity only. German ambitions and targets, as well as most support programmes, are very specific to green hydrogen.

The 2020 German Hydrogen Strategy set the goals of 5 GW domestic electrolyser capacity by 2030 and 10 GW by 2040. The 2021 Coalition Agreement of the German government doubled the target for 2030 to 10 GW. Only about 15% is set to be covered by domestic capacities in 2030. Imports from European but also other countries will be necessary. While some energy scenarios result in a high demand for hydrogen itself, others see a much higher demand for its derivates, the so-called power-to-X products (short: PtX).

The German hydrogen strategy does not explicitly restrict the use of hydrogen. Rather, it focuses on an application in the chemical, steel, logistics and aviation industries in a first phase, through the development of decarbonisation strategies. However, the German government is also promoting the installation of fuel cell heating appliances in buildings. [6]

Capacity adequacy

To achieve a stable electricity supply in the future, Germany also needs adequate capacity planning. The impending coal phase-out will exacerbate capacity adequacy concerns in Germany: Legislation initiating the decommissioning of all coal power plants by the end of 2038 was passed in 2020 and brought forward to 2030 by the government elected in late 2021.

For at least a decade, power sector officials have debated the general implications of the coming reduction in Germany's conventional generation capacity. This debate has even stimulated discussion about pan-European capacity adequacy. European capacity adequacy is especially relevant as several countries in Europe plan to retire coal capacity.

In an interconnected European system with increasing market integration, it is no longer possible to approach and perceive generation adequacy at the level of a single country. ENTSO-E and its predecessor UCTE (Union for the Coordination of the Transmission of Electricity) have therefore assessed capacity adequacy Europe-wide. ENTSO-E explicitly mentions the reduction in European coal and nuclear capacities as one of the drivers behind building on its Mid-Term Adequacy Forecast (MAF) to develop the European Resource Adequacy Assessment (ERAA) methodology, which should be applied now and in all future assessments.[31]

The ERAA methodology is a leap forward from the MAF, taking into account additional parameters that impact capacity adequacy, such as the European flow-based market coupling mechanism.[7] It also takes into account technologies such as batteries and PtX to a greater degree. In this regard, the ERAA is exemplary for the changes required in capacity adequacy assessment methodologies in Germany and elsewhere in the future.

- In Germany's case, the factors that need to be taken into account in addition to the nuclear and coal phase-out are **generation location and grid capacity:** A country or a control area may have an adequate supply in theory, but if the grid is incapable of transporting power to the load centres, it may be incapable of covering all demand. As the best places to locate RE generation are typically far from load centres, the retirement of former baseload generation units located close to load centres increases the importance of the grid in capacity adequacy assessments.
- **Interconnections, electricity trading and resource sharing:** A country or a control area that cannot cover its load with domestic resources may still have adequate supply if the power can be reliably imported/exchanged. Moreover, the capacity contribution of renewables increases with

[5] Additional information is available in the report "A comparative Analysis and Simulation of DSM and Energy Efficiency in Chinese and German Industry": https://www.energypartnership.cn/fileadmin/user_upload/china/media_elements/publications/2022/Analysis_DSM_and_Energy_Efficiency_in_Chinese_and_German_Industry_EN.pdf

[6] Additional information is available in the report "The Role of Synthetic Energy Carriers in Sector Coupling", which is available soon here: https://www.energypartnership.cn/fileadmin/user_upload/china/media_elements/publications/2023/202301_Hydrogen_policy_report_En.pdf

[7] Flow-based market coupling is used to maximise the usable transfer capacities between bidding zones. It differs from the previously used net transfer capacity (NTC) approach mainly by the fact that transfer capacities are continuously adjusted based on load flow calculations and the status of the grid. NTCs were also based on load flows, but bilaterally agreed between TSOs on a yearly or half yearly basis with fairy large security margins.

interconnection and resource sharing. Correct assessment of these characteristics requires a coordinated pan-European approach, as the effects may be under- or overestimated by national planners. For example, in 2018, the German Association of Energy and Water Industries published a study showing that the transmission system operators (TSOs) and federal grid agency (BNetzA) overestimated the available capacity in neighbouring countries.[32]

- **Flexibility measures**, such as DSM, energy storage and ptX.

Concerning the coal phase-out, both the methodology of capacity adequacy assessment and the measures to be taken in the event that capacity is not adequate are relevant.

The capability of the German system to cover the load at all times is linked to grid capacity and grid congestion. Adequate dispatchable generation capacity and/or import capacities are obviously necessary, but not sufficient for security of supply. This was already clear in 2013, when the grid reserve was starting to be discussed (it was introduced in 2016). Unlike the capacity and security reserves, the grid reserve is frequently used to alleviate grid congestion between the north and south of Germany. While there is enough generation capacity available at all times, the shift towards wind generation in northern Germany and the decommissioning of conventional generation close to load centres in southern Germany have increased the magnitude and importance of north-south power transmission. To address this issue, the German government introduced the “Netzentwicklungsplan” (NEP) (grid development plan), first published in 2013. Grid expansion has progressed much more slowly than anticipated, not least due to cost considerations and public acceptance issues. McKinsey stated in its annual energy transition review in 2019 that if grid expansion were not significantly accelerated, the targets for 2020 set out in the first NEP would not be reached until 2037.[33] Grid adequacy is currently as challenging for the security of supply as capacity adequacy – although the latter is only relevant due to the coal phase-out decided in 2020. Grid adequacy will become even more important due to the coal phase-out, since RE will replace most of coal’s contribution to electricity generation. [8]

2.3.2. China

Energy storage

In order to succeed with its green transition, China needs an advanced, efficient and cost-effective energy storage system. The rapid pace of RE expansion in China not only poses a major technical challenge to the country’s power grid, it is also outpacing the actual usage capacity of RES, resulting in an increasing amount of clean energy being wasted. For instance, certain northwest provinces with abundant wind and solar resources, like Qinghai or Inner Mongolia, typically record an excess of electricity that cannot be assimilated by the grid.[34] Energy storage is crucial to alleviating these problems and helping to balance out the variability of renewable power sources. However, so far, low profitability, safety concerns and lagging regulations have curbed the large-scale deployment of energy storage systems in China.

The pairing of rooftop PV with energy storage could be especially beneficial for China’s commercial and industrial consumers. However, according to interviews with Chinese industrial park consumers from a recent GIZ study, a combination of economic concerns and the absence of a government obligation led to an overall low motivation to combine PV with energy storage.[35] However, considering the unprecedented emphasis on energy storage development in China’s latest 14th FYP, this is likely to change in the near future.

In March 2022, NDRC and NEA released the Implementation scheme for the development of new-type energy storage during the 14th Five-Year Plan (short: The 14th FYP for Energy Storage). This document serves as a blueprint for the energy storage sector. China aims to advance its energy storage capacity from the initial stage of commercialisation to “large-scale development” by 2025. The plan also calls for technological advances and outlines the development of various new-type energy storage technologies, such as compressed air, hydrogen, battery and thermal energy, but excluding pumped hydro.

One of the main goals of the plan is to make energy storage more competitive by decreasing the per-unit cost by 30% before 2025. When these goals are achieved, the price of an energy storage system is likely to be between RMB 0.8 to 1.0 (EUR 0.11–0.14) per watt-hour, making it commercially feasible without subsidies.[36]

Generation-side and grid-side storage are clearly prioritised in the 14th FYP. The language used to describe customer-site storage included in the plan was very cautious, which suggests that user-side storage is not likely to experience a significant deployment in the near future. This is largely due to safety concerns and a lack of clear standards. Safety concerns were intensified by an incident that occurred in April 2021, when a large lithium-iron-phosphate battery caught fire at a shopping mall in Beijing.[37]

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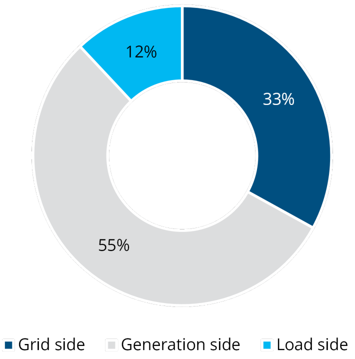
[8] Additional information is available in the report “Assessing power system adequacy in Germany and Europe, and lessons for China”: https://www.energypartnership.cn/fileadmin/user_upload/china/media_elements/publications/EnTrans/Assessing_power_system_adequacy_in_Germany_and_Europe_and_lessons_for_China.pdf

Figure 8: New energy storage by location in China[38]



By the end of 2021, the cumulative installed capacity of China's energy storage projects will have reached 46.1GW, accounting for 22% of the total global market size, a year-on-year increase of 30%. As can be seen in Figure 8, the majority of energy storage is located at the generation side. With regard to battery energy storage, China had over 4 GW installed at the end of 2021. 1.2 GW of this is on the grid side, while most of the remainder is located at power plants. The country continues to invest heavily in battery storage and is aiming to reach a storage capacity of 100 GW by 2030.[39] This expansion will have to be accompanied by the introduction of more safety standards and regulations. As of 2021, there were only 31 standards in effect or under development for the energy storage industry, compared to over 100 industry standards in place for EVs.

As of June 2022, 19 provinces have also issued additional policies for renewables energy and storage pairing (see Figure 9). Typical requirements call for storage with a capacity of 2 hours and 10% of peak production.[40]

Figure 9: Chinese provinces with storage requirement for renewables[41]

DSM

In China, DSM was first introduced as an energy-saving strategy in the 1990s. To ensure the daily power consumption of residential users, the government would deploy so-called "administrative DSM measures", such as compulsory load shifting and power rationing. In the case of a power shortage, a list of selected users would receive priority in energy supply, including the public sector, hospitals, utility providers and other systemically relevant users, while other users' power consumption would be restricted.[42]

After 2010, the Chinese government also introduced plans and measures to support market-based DSM directed at commercial users. DSM began to be supported by loans, and the government provided tax breaks for energy service companies as well as subsidies for pilot projects. In 2012, China also launched a DSM Pilot City programme in the cities of Beijing, Jiangsu, Foshan and Tangshan, in which it tested voluntary and incentive-based DSM. The cities formulated power conservation and load shifting targets, while the central government provided financial incentives.[43] Since 2014, the Chinese Ministry of Industry and Information Technology has released six batches of DSM demonstration enterprises and industry parks, with over one hundred participating enterprises. In this way, enterprises are encouraged to actively participate in DSM and explore the best technologies and management models through pilot projects.

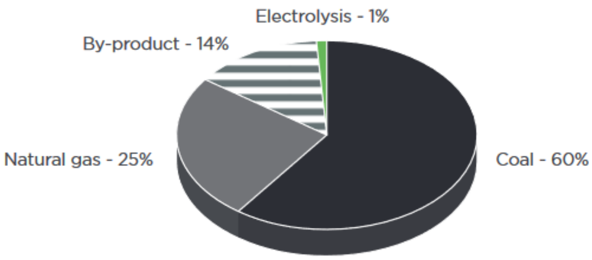
Currently, the available marketing options in China are still limited because of the lack of a market- or rule-based institutionalised process for procuring load flexibility. Orderly power consumption and administratively defined peak-valley pricing still restrict the marketing of DSM.

The need to improve China's DSM capabilities was emphasised in the 13th and 14th FYP. In the 14th FYP, the Chinese government set a target of DSM providing 3–5% of the maximum load in 2025. However, no public data on the percentage of peak load subject to DSM is currently available, and it is unclear how government officials will monitor this target or how frequently results will be available. Nonetheless, looking forward, market-based DSM is expected to become a central point on the government's agenda for offering flexibility. In recent years, the market has already been playing an increasingly important role in allocating demand-side management resources. By 2021, nine provinces within the State Grid region have issued supporting policies for DSM. Among these provinces, Shandong, Zhejiang and Gansu planned to allow DSM to participate in the spot market, while northern Hebei allows it to participate in the ancillary service market. Market participants are also growing more diversified, with policies encouraging households, retailers, aggregators, storage providers, and EV charging providers to participate, though this is still mostly a vision for the future.[44]

Hydrogen

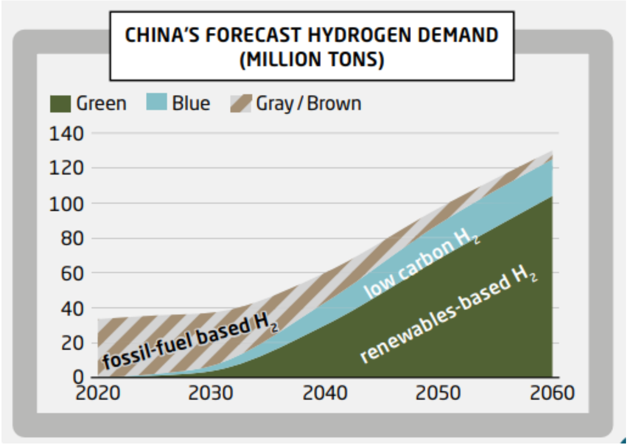
China is currently the world's largest consumer of hydrogen. With an annual output at 33 megatonnes (Mt), it is also its largest producer. In the recent 14th FYP, hydrogen is treated as frontier technology. However, the contribution of hydrogen to China's energy transition depends on the production method of the hydrogen that is used. Today, the country produces hydrogen mostly from coal (brown hydrogen; accounts for 60% of production) or from natural gas (grey hydrogen; accounts for 20% of production), releasing CO_2 into the atmosphere in the process. In order to contribute to the country's decarbonisation, renewables-based hydrogen ("green"), which now makes up about 1% of production, will need to replace brown and grey hydrogen as soon as possible.[45] However, it should be noted that China does not yet officially use the classifications of green, blue and grey/brown hydrogen, making attempts at direct comparison difficult.[46]

Figure 10: Energy sources for hydrogen production in China[47]



So far, national policy has mainly been focused on developing the general hydrogen industry and technology, rather than on green hydrogen specifically. This is reflected in China's first official long-term hydrogen strategy: The Medium and Long-Term Plan for Hydrogen Energy Industry Development (2021 to 2035), released in March 2022 by NDRC. A target for green hydrogen development by 2025 is nonetheless included in the national hydrogen plan. By that time, China aims to produce 100,000 to 200,000 tonnes per year of green hydrogen, which is considered easily achievable. From 2030 onwards, green hydrogen is expected to become more important, as can be seen in Figure 11. Even though the near-term hydrogen applications are mainly focused around industry and transportation, China is striving for a comprehensive ecosystem of green hydrogen applications, including energy storage and power generation, by 2035.

Figure 11: China's hydrogen demand forecast[48]



The fact that hydrogen from RE appeared for the first time in China's 14th Five-Year Plan for Renewable Energy this year also represents a significant step forward. According to forecasts by the China Hydrogen Alliance, hydrogen production from RE in China could reach 100 Mt by 2060, with total hydrogen use reaching 130 Mt and accounting for 20% of China's final energy consumption.[49]

Despite no strong prioritisation of renewables-based hydrogen at the national level for the time being, public funding for hydrogen research projects is already shifting towards "green" hydrogen technologies. The central government's R&D support has led to a boom in academic publications and patent registrations on hydrogen produced from RE, making China the leading innovator in renewables-based hydrogen technology.

Driven by provincial governments, research institutes and industries, a domestic industry for so-called "green" hydrogen is gradually taking shape around China's strategic policy impulses. Many local governments have recently released their own hydrogen strategies with ambitious provincial targets specifically for renewables-based hydrogen. This is true especially for those provinces rich in RE, such as Hebei, Inner Mongolia and Sichuan. For example, the province of Inner Mongolia, with vast solar and wind resources, aims to produce 500,000 tonnes of renewables-based hydrogen a year by 2025, which is more than double the target in the national strategy.[50]

Capacity adequacy

As China makes great strides with regard to RE expansion, policymakers, grid operators and the general public have concerns about the system remaining reliable and secure throughout this transition. In order to allay these concerns and support the smooth transition into utilising new energy, capacity planning has to account for the variability of wind and solar. By adopting the power system to this structural change, an unnecessary capacity expansion, especially that of fossil-fuel based power plants, can be avoided while still providing system adequacy.

In general, there is relatively little transparency in China surrounding capacity adequacy planning. The country's power planning schedule is generally divided into short-term plans (5 years), medium-term plans (10–15 years) and long-term plans (15 years or more). The short-term and long-term plans are revised every five years, while the medium-term planning is revised every three years. The planning system distinguishes between two types: national (led by NEA and approved by NDRC), and provincial (led by the provincial energy authorities in accordance with the national plan).

The first step in power planning is load forecasting. For that, China employs a bottom-up approach, from the province level to the regional level to the national level, focusing on long-term electricity demand, peak load, load distribution and load structure. The load forecast only includes three scenarios: high (strong economic growth and high temperature), medium (stable economy and slow temperature rise) and low growth (slowed economic growth and comparatively low temperatures). Ultimately, only one load scenario will be recommended as the basis for subsequent power generation planning and grid planning.

As for generation capacity planning, it determines the amount and location of each power source. The process will evaluate multiple power source construction plans to determine the new capacity requirements and investment needs. Based on the policy goals of non-fossil energy proportion and provincial RE quotas, power generation planning will first develop scenarios for non-fossil power sources. In each scenario, according to the regional power balance and local renewable power consumption capability, the plan proposes the amount of each region's fossil power capacity and peaking capacity. Finally, the regional total installed capacity and power structure will be determined according to an economic and technical analysis. The scenarios will consider different resource conditions and policies as well as regional characteristics, using annual, monthly or typical weekly and daily load curves. [51]

2.4. Recent developments

2.4.1. Germany

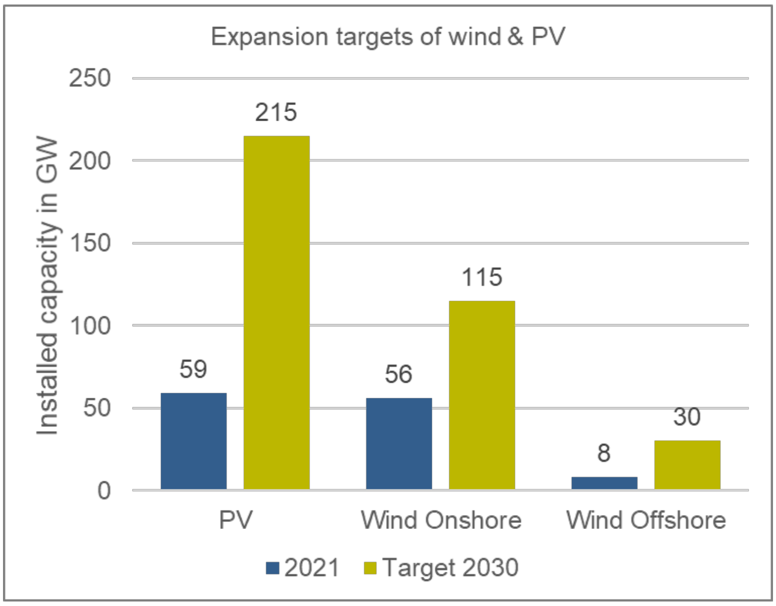
The Russian invasion of Ukraine raises questions of energy security and has therefore changed the focus and dynamics of German energy policy. While previously the focus was on the expansion of renewables, ensuring supply security at all costs is now the priority, which increases pressure on affordability and sustainability. RE now accounts not only for sustainability, but also independence. To increase RES expansion, the government has approved the so-called Easter Package. It includes amendments to the Renewable Energy Sources Act, the Offshore Wind Energy Act, the Onshore Wind Energy Act and the Energy Industry Act, and introduces:

- a new target for the electricity sector of 80% RE by 2030 and adjusted expansion goals;
- a new definition of RES in the public interest and to serve public security;
- the rapid implementation of planning and approval procedures for network expansion;
- the acceleration of planning and approval procedures for wind onshore;
- an increase of the efficiency default for new buildings (EH55).

Additionally, amendments to the Energy Security of Supply Act, the Energy Industry Act and the LNG Acceleration Act have introduced the following measures to increase energy security:

- A minimum filling level for gas storage;
- a legal basis for the government to intervene in the market;
- the acceleration of construction of LNG terminals and LNG floating transfer terminals;
- an emergency gas plan with measures in case of gas shortages.

Figure 12: Expansion targets of wind & PV in Germany[52]



Due to the current crisis, the nuclear and coal phase-outs have been adjusted. The phasing out of nuclear power plants has been postponed to 2023, and reserve coal power plants are allowed to participate in the market until 2024.

The energy crisis raised questions regarding the reliability and adequacy of the power market in a system with declining proportions of coal and gas and high proportions of RE. This issue is a decisive one and has been subject to lively public, academic and sector-wide debate. Reforms of the market design have accompanied the energy transition for about ten years, so far ensuring high levels of quality of supply and, in particular, very low levels of interruptions. To meet the challenges arising from the ambitious target of an 80% RE proportion by 2030, the new federal government has tasked a commission with making proposals for further changes in the market design by mid-2023.

According to the dena lead study, it is very likely that the proposals are going to include a mix of several measures[53]:

1. Some form of support for investments into hydrogen-ready gas-fired power plants that will provide back-up capacity in times of low RE generation, and ancillary services in a future climate-neutral electricity system.
2. Improvement of regulatory conditions for electricity storage, most notably batteries, as well as demand-side management.
3. New regulation for distributed generation, aimed at better network integration.
4. A reform of the market zones, potentially splitting Germany into several zones to improve the regional match of demand and supply.

2.4.2. China

In 2021 and 2022, China experienced several waves of severe energy shortages. They were caused by a combination of factors, including decreased motivation to operate coal-fired power plants due to restricted generation times and low prices, coal shortages, constrained energy generation from hydropower due to extreme drought, and specific policies. Ever since, maintaining the country's energy security has been the top priority for Beijing. Facing blackouts, China has had to reverse its stated course to strictly limit coal consumption.[54]

The Chinese leadership repeatedly stated that it will continue to advance the energy transition, but not at the expense of supply security. During the recently held 20th Chinese Communist Party Congress, China's existing climate targets were reiterated, but with a strong emphasis on *gradual* decarbonisation. This means that, in the near term, coal will continue to play a significant role in the name of energy security. This altered dynamic is also reflected in changes to the 14th Five-Year Plan for Energy, in which limits on total coal consumption and coal's percentage of primary energy consumption – both featured in earlier FYPs – were removed. The plan also stressed the role of coal as the backbone of the energy supply. Instead, the country now focuses on the "clean and efficient" use of coal – which includes using coal plants with ultra-low air pollutant emissions or equipped with carbon capture, utilisation and storage (CCUS) technology – as well as on reducing the operating hours of coal power plants while accommodating more RE.[55]

To understand Chinese policymakers' approach to coal, it is necessary to consider the bigger picture. First of all, China has abundant coal reserves at its disposal. It produces 90% of the coal it consumes, while for oil and gas, it relies heavily on imports. China's power grid has been originally built to solely accommodate coal power. This poses significant challenges for a swift coal exit and a smooth transition to RE. Nonetheless, many experts believe that the additional coal push should not hinder China in meeting its timeline and achieving the 30–60 targets, although the decarbonisation process may be slower and more costly.[56]

Even as China has ramped up consumption of fossil fuels, it continues to make great strides in the expansion of RE. In 2021 alone, China added 134 GW of RE capacity. That is only slightly less than Germany's total RE capacity, which amounted to 138.9 GW in 2021.[57] According to the State Grid Corporation of China, in the near future the role of conventional power sources will mainly consist of voltage support and power regulation, while installed capacity and power production should be increasingly covered by RES.[58]

Furthermore, in the second quarter of 2022, China recorded a historical decline in CO_2 emissions by 8%. Even though the emissions decline has to be seen in the context of weak growth in energy demand and an economic slowdown as a consequence of Covid-19 lockdowns, the 230 million tonne ($MtCO_2$) reduction is still the largest in at least a decade.[59]

3 Conclusion

China and Germany play leading roles in the global effort to tackle climate change and transition towards clean energy. While Germany is known as the pioneer of the “Energiewende”, China’s own “Energy Revolution” has made it the country with the highest installed RE capacities by far. Although each country’s climate targets and characteristics of the energy transition differ significantly, they share many similar challenges on their green transition path.

While a consequence of different factors, the challenge of maintaining energy security is currently the highest priority for both countries, negatively impacting both their climate agendas. Germany’s energy security worries are primarily caused by the country’s efforts to decrease its dependency on Russian gas supply in light of the Russian invasion of Ukraine. China’s recent energy security concerns are mostly the result of severe energy shortages in 2021 and 2022, brought about, among other things, by coal shortages and extreme weather periods.

The events of the year 2022 have also led to questions regarding the near- and mid-term future of fossil fuels. Coal power, for example, has been a contentious issue in both countries. Russia’s invasion of Ukraine has accelerated the ramp-up of Chinese coal production for power generation in order to decrease dependency on energy imports. In contrast to Germany, which aims to phase out coal by 2038 at the latest, China does not yet have a coal phase-out target and sees coal as the backbone of its energy system. In Germany, the gas supply crisis has resulted in an accelerated scale-up of renewables on the one hand, and in the decision to reactivate Germany’s coal plant reserve capacity and delay the nuclear plant phase-out on the other – a diversion from Germany’s set energy transition path.

Both countries now face the ultimate challenge – to find a balance between ensuring energy security and limiting carbon emissions.

The path to reach China’s carbon neutrality goal is long. A look at the figures makes this clear: China is currently responsible for about one third of total global emissions (tonnes). Its overall energy output and consumption is also expanding every year. On the other hand, China continues to record impressive figures for the expansion of RE. It is also making progress in adjusting and expanding its grid operations to accommodate more renewables, investing large amounts into innovation in the energy sector, and focusing on the large-scale development of new types of energy storage and hydrogen technology. In addition, considerable literature is now available on China’s prospects for meeting the 2030 peaking goal several years earlier.[60]

In Germany, the amendment of the Climate Protection Act had already introduced a new dynamic to the energy transition. The act now contains measures to ensure all sectors are on track to achieve climate neutrality by 2045. The current energy crisis has also highlighted the importance of an energy system based on RES, not only in terms of sustainability, but also energy security. The further expansion of RES, flexibility measures in the electricity system, adequate capacity planning and new hydrogen partnerships are just some of the measures that will accelerate the transition and, with it, energy independence.

List of abbreviations

BNetzA Bundesnetzagentur (Federal Grid Agency)

CCUS Carbon capture use and storage

DSM Demand-side management

ERAA European Resource Adequacy Assessment

EV Electric vehicle

FYP Five-Year Plan

GHG Greenhouse gas emissions

Gt Gigatonne

GW Gigawatt

GWh Gigawatt-hour

kW Kilowatt

MAF Mid-Term Adequacy Forecast

Mt Megatonne

MW Megawatt

NEA National Energy Administration

NDC Nationally determined contribution

NDRC National Development and Reform Commission

PtG Power to gas

PtL Power to liquid

PtX Power to X

RE Renewable energy

RES Renewable energy sources

TSOs Transmission system operators

TWh Terawatt-hour

UN United Nations

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