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Power Sector Reform in China

An international perspective

César Alejandro Hernández Alva and Xiang Li

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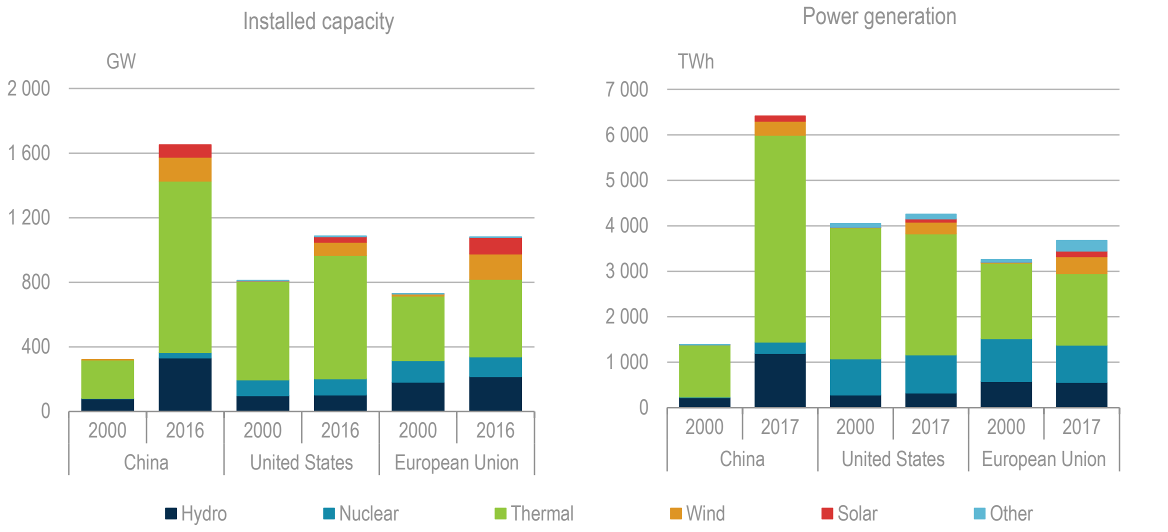
Executive summary

Background and context

The People's Republic of China has been remarkably successful in achieving very high levels of economic growth over the past decades. This economic growth has made China the world's second-largest economy, and it has lifted hundreds of millions on Chinese citizens out of poverty.

This has, in turn, propelled electricity demand, which has grown from 1 387 TWh in 2000 to 6 418 TWh in 2017, making the China the world's largest electricity consumer, surpassing the United States or the entire European Union (Fig ES.1).

Figure ES.1 • Installed capacity (left) and electricity generation (right) of selected regions, 2000/2017



Key point: China's power system grew to become the largest in the world in only two decades.

Sources: IEA (2018a), *World Energy Statistics*, www.iea.org/statistics/; NEA (2018a), *China 2017 Power Sector Data,*www.nea.gov.cn/2018-01/22/c_136914154.htm.

To meet the challenge of this unprecedented growth in electricity demand, the main emphasis of the Chinese institutional framework has been on sufficient investment rather than economic efficiency. A domestic resource, coal was the fuel of choice although diversification into other fuels such as hydro, nuclear, and, more recently, wind and solar power have reduced coal's share.

In recent years, Chinese policy making has come to focus more and more on the environmental and economic costs of this growth in the power sector. In terms of the environment, coal plants contribute substantially to local air pollution and carbon dioxide (CO_2) emissions. The Chinese power system is the country's largest source of CO_2 emissions, accounting for 40% of total emissions, and for 11.1% of the world's total. It also produces around 1.16 million tonnes (Mt) of sulfur dioxide (SO_2) and 1.11 Mt of nitrogen oxides (NOx) emissions. In terms of economics, slower demand growth has led to a substantial overcapacity and, hence, to low utilisation of some power plant assets.

To address these challenges, China's power system has embarked on a structural transformation. To improve environmental performance, China is putting emphasis on clean energy with the long-term objective of substantially reducing its reliance on coal. Indeed, coal has already reduced its share in the power mix from 81% in 2007 to 65.5% in 2017, a decrease that is attributable to the growth of hydro, nuclear, natural gas, wind and solar PV resources. Today, China has the largest installed capacity of land-based wind power and solar photovoltaics (PV) globally.

In order to improve economic efficiency, China has implemented several rounds of electricity sector reform. In 2015, the government put forward a reform agenda under "Document No. 9", with the aim of increasing reliance on market forces (see next section).

Achieving such a deep transformation is not an easy task. Achieving a cleaner, more efficient power system that can serve the needs of Chinese society in the 21st century requires overcoming a number of challenges. However, China is not alone in grappling with this issue. While each country has its unique context, understanding the situation in other countries can help accelerate progress. Against this background, *Power Sector Reform in China* has two objectives. First, it reviews reform efforts and challenges across selected aspects of the power system in China. The aim is to foster a broader international understanding of how the Chinese power system works in practice and to highlight the main challenges. Second, this report presents selected international experience that can inform further policies to achieve a power sector that is less costly, more efficient, and environmentally sustainable.

Power market reform in China

The history of China's power sector reform dates backs at least to the 1980s with attempts by the central government to cope with power shortages that hampered economic development. It was in those years that third parties were first allowed to invest in the power sector. This was also when rules – which have lasted until today – were established to provide certainty to investors, for example, the "fair dispatch" rule, which allocated the same number of full operation hours to every plant of the same technology.

Nonetheless, the first milestone in the Chinese power sector reform was in 2002, with a policy document known as the "Document No. 5" reform. Nowadays, the sector's structure is largely a result of this reform, which divested the vertically integrated utility's assets into five different generation companies – the "big five" – and two grid companies, in charge of transmission, distribution, system operation and retailing. Regulatory authorities were strengthened, and the first attempts to rely on market-based mechanisms to operate the system date from this time.

Despite the restructuring of the system, the main emphasis of the Chinese institutional framework has been on timely investment rather than economic efficiency. The central government defines the amount of investment and the technologies involved through the publication of a Five-Year Plan. This process has been gradually decentralised to the provinces, who are in charge of an important part of the administrative approval.

Plant operation is also determined administratively rather than through a market-based process. Each province defines the number of full power hours that each dispatchable plant will operate during the year through the application of a fair dispatch principle that allocates the same number of hours to plants of the same type, with little consideration as to their efficiency. In addition, each province relies primarily on their own resources, limiting inter-provincial and inter-regional trade.

Rates paid by customers, as well as the compensation to generators and network owners, are also determined administratively. With respect to generators, in each province, each technology receives a benchmark payment per megawatt-hour (MWh) for its output, with the amounts varying by technology. This payment is made for all production up to the production quota. End customers pay a regulated retail price for power, with prices relatively high for industrial customers compared to residential and farm customers. Network companies receive the difference between what is paid to generators and received from customers.

China has experimented before with measures to improve efficiency, like direct power purchasing, generation rights trading, interprovincial/interregional trading, and energy conservation dispatch. Nonetheless, these measures have not been scaled or even stopped because of the complexities involved with reforming the system.

Although many of these experiences were discontinued, they certainly influenced the second round of reform that came in 2015 with the publication of Document No. 9. Given its ambitious goals, this document can be considered as a second milestone in the transformation of China's power sector. The main policies implemented as result of this reform can be summarised as follows:

- Separate rates for transmission and distribution tariffs were established, following a revenue cap model based on authorised costs and a permitted revenue margin.
- Wholesale energy prices are decided by negotiation or auction between generators and large consumers in mid- to long-term electricity markets, and the retail price charged to the costumer is the sum of wholesale price, transmission and distribution tariff, and government charges. Energy trading institutions were established to facilitate trading and to serve as clearing houses for transactions.
- Retail companies are able to aggregate smaller customer and represent them in the wholesale market.

Although the implementation of Document No. 9 is an ongoing process, it has gone through many important steps: transmission and distribution rates are ready; large shares of the produced energy are being traded through energy trading institutions; final customer rates are being defined by the market for large customers; and the first pilots on the spot market are being implemented. Two interesting cases provide a sense of where the Chinese markets could be heading: the first case is the spot market in Guangdong, which is being tested as a nodal market, built from the beginning with the objective of co-ordinating all the resources in the China Southern Power Grid (CSG) footprint. The second is the ancillary service market in the Northeast region, also referred as the peak ancillary service market, which created an incentive for coal plants to change their generation at certain times in order to accommodate wind and solar PV power generation.

Relevant international experience

This report presents international experience from several countries and jurisdictions, with the objective of providing Chinese policy makers with insights that could help them to tackle the challenges related to reforming China's power sector. These experiences are presented along three main themes: system planning, electricity trading and system operation, and renewable and low-carbon energy development. Pricing is discussed in the context of electricity trading and system operation.

Long-term planning

China has already started on its path away from a fully centrally planned approach towards an approach that offers a stronger role for market co-ordination in the power system. The ongoing reform under Document No. 9 provides further impetus in this direction. It is, therefore, interesting to consider a case where a country has recently embarked on a similar transition, moving away from a centrally planned approach in the power system towards a more market-based system. Mexico provides a pertinent example of electricity market reform in this regard. **Mexico's Power System Development Program (PRODESEN)**[1] provides an indicative plan for a mix of the country's power technologies for the next 15 years, and it defines the associated transmission and distribution investments. PRODESEN considers traditional fossil fuel generation and renewable investments in a simultaneous optimisation exercise, which looks to minimise the long-run costs of the system.

With a growing role for market-based co-ordination, access to relevant data for all market participants becomes crucial. **Japan** has recently moved from a system of regional monopoly supply companies towards a more liberalised market system. One crucial step in its transition was the introduction of **improved data transparency** as well as an independent organisation to conduct system planning. Today, power exchange volumes between different grid areas, hourly demand, and hourly generation by fuel type are all publically available. In addition, a new independent organisation, Organization for Cross-Regional Co-ordination of Transmission (OCCTO), is in charge of co-ordination of cross-regional flows and long-term planning of the grid.

A stronger role for markets is not the only impetus for changes in planning processes. Indeed, the fundamental drivers of power system transformation are: (*i*) the rise of low-cost renewables and decarbonisation, (*ii*) the increased importance of distributed energy resources and electrification, and (*iii*) digitalisation). A power system that is undergoing a very rapid shift from being dominated by coal to a much stronger reliance on renewable energy is Australia. In 2018, the **Australian Energy Market Operator (AEMO)** published its inaugural **Integrated System Plan (ISP)**. The plan analyses different possible futures for the power system in Australia, based on various assumptions concerning the frequency with which more wind and solar power plants should be built, the possible future for natural gas in power generation, or the point at which coal power plants should retired. Based on these scenario assumptions, a highly sophisticated computer model calculated the least-cost mix of resources, taking into account an optimised transmission grid and generation mix as well as advanced options such as battery electricity storage.

Electricity trading and operations

International experience regarding the use of market forces to improve efficiency and attract investment to the power sector is very rich and holds many aspects of interest to Chinese policy makers. The experiences discussed in this report offer tools used in other markets to tackle the challenges specific to reforming power sector. One of the challenges that has been successfully solved is ***linking long- and short-term power contracts to optimise operational efficiency***, with the use of spot markets providing economic signals to market participants that enables them to co-ordinate their investments and operations. More ambitious wholesale markets use prices not only to bring operational efficiency and reduce short-term costs, but also to ***encourage the right levels of investment to their system.*** Another benefit that markets can bring is better co-ordination among jurisdictions in order to ***unlock trade across larger geographic areas***. Given

[1] PRODESEN stands for *Programa de Desarrollo del Sistema Eléctrico Nacional*.

the relevance of all the existing assets, instruments to help ***transition legacy assets into a new market environment*** are presented, since in many reforms this is one of the main obstacles to transitioning to more efficient operation paradigms.

Linking long- and short-term power contracts to optimise operational efficiency - spot markets

Successful markets all over the world have managed to make an efficient **link between long- and mid-term contracts with spot markets** designed to discover the economic value of energy during specific intervals of the operation day. The prices of these spot markets are used as reference for mid- and long-term contracts. One of the most successful **spot markets** is run by **PJM,** an organisation originally created in 1927 to help vertically integrated utilities to share their resources; in 2002 this became the first Regional Transmission Operator in the United States. PJM creates savings every year of more than USD 2.2 billion (United States dollars).

Encouraging the right levels of investment

A crucial objective for any power system is to provide a high enough level of investment to cover the peak demand. Although most markets rely mainly on energy revenues to pay for generation investments, the so-called **Energy-only markets** allow also for large price hikes in scarcity periods that provide an incentive to generators to be available during critical periods and, in the long run, provide incentives to invest. Other markets use complementary products, such as **capacity payments** to those generators available during certain number of hours, in order to guarantee that enough generation will be available during critical periods of the system. The markets of **France**, the **United Kingdom**, **Mexico**, **PJM** (United States) and **MISO** (United States) are examples of electricity markets where both mechanisms (increased energy revenues in shortage periods, and capacity products) are combined to guarantee the right level of investment.

Unlocking trade across larger geographic areas

Large geographical areas with diversity in their demand patterns and load resources can benefit from sharing resources that often are located in different jurisdictions and might not be under the same operational authority. The **U.S. Western Imbalance Market** in the United States is a good example of an organisation that enables different states, i.e. California and its neighbours, to share balancing resources on a regional basis. This results in a more efficient dispatch and reduces the need for new transmission investment. **The European Market experience** is relevant since it illustrates how a joint governance structure can be used to create rules that allow a more efficient use of the system though larger cross-border integration.

Transitioning of legacy assets into a new market environment

One of the most relevant aspects in the design and implementation of any reform are the mechanisms provided to existing assets in order to transition into the new regulatory environment. The risks of not foreseeing the need for such mechanisms include delayed implementation and having to compromise with intermediate and, often, inefficient rules. An example of a successful mechanism is the **Mexican Legacy contracts**, which were designed as a complement to the opening of the market to competition in 2016 and the unbundling of CFE, the state-owned enterprise. These contracts were designed to hedge the price risks in a new market environment, both for the retailer and for the generation companies, and to prevent market power on the generation side, where CFE generation companies still provided 90% of the energy.

The **U.S. stranded costs treatment** is also an interesting example of a transition mechanism towards competitive markets. The US Federal Energy Regulatory Commission (FERC) recognised the risks facing utilities that stemmed from the fact that the utilities had entered into agreements based on an expected demand and that exiting clients would reduce the revenue base that the utilities relied on to pay for these commitments. FERC needed to provide explicit mechanisms to facilitate the transition to competitive markets and discussed two mechanisms to tackle this issue: a “wires charges” that would be linked to transmission rates and mandatory for consumers; and exit fees, paid by consumers switching suppliers.

Renewable and low-carbon energy deployment

Efficient electricity spot markets are designed to achieve the lowest short-run cost for the system through an efficient dispatch of available resources. However, prices coming from these markets do not necessarily attract sufficient levels of investment in renewable and low-carbon technologies. This is the reason why many governments have implemented mechanisms to promote the deployment of renewable and other low-carbon power-generation technologies. Among the most common mechanisms used to support the deployment of these technologies are feed-in tariffs, auctions, and clean energy certificates.

The optimal design of these mechanisms involves assessing the competitiveness of these resources. To make a fair comparison of renewable and other low-carbon technologies’ competitiveness one must take into account the fact that they have different generation patterns, and that the correlation of their generation with periods of high value of the energy vary as well.

New mechanisms have been developed in order to take into account the economic value of energy in the renewable energy development policies. One interesting example of a renewable-energy support mechanism that takes into account not only the cost but also the value of the new investments for the system is the **German market premium.** This mechanism is designed to pay a fixed premium above the market price such that an average wind power plant will generate revenues that match the feed-in tariff level. This mechanism thus provides an incentive to develop plants that produce higher-value electricity compared to the average and a disincentive for plants whose output is valued by the market as less than average.

Another example is the **Mexican auction system**, which was developed to account for fact that Mexico has a large endowment of renewables such as wind, solar and geothermal resources, but these resources do not each produce the same value for the system. The solution was a technology-neutral auction with a system that incorporates premiums and penalties in the bids, so that different technologies can make comparable bids. These premiums and penalties are based on the expected value of energy within the next 15 years, and they consider the location and the time of the day. A capacity product can also be procured from dispatchable technologies. The auction compares all the bids, and a replicable algorithm chooses the bids that minimise the “adjusted” costs for the buyers – once it considers the value that the plants will generate. This allows “expensive” plants (on a cost basis) to be chosen if they produce more value.

In both the Mexican and the German cases, sufficient levels of investment in these technologies are secured through long-term contracts awarded in competitive processes, while the short-term efficiency of the system is ensured by including the generation coming from these plants in the spot markets.

Introduction

The People's Republic of China has experienced an exceptionally high level of economic growth over the past two decades. The country's power sector has provided a crucial basis for this success, meeting a dramatic increase in power demand. The Chinese government has confronted the double challenges of attracting sufficient investment in the power sector while also reforming the institutional framework to provide better incentives to sector participants. Much has been achieved already, but evolving priorities in China mean that finding the right balance for the power sector is work in progress. The latest power market reform – issued in 2015 by the State Council – marks an important step on the path towards a more-efficient power sector, where market forces have a stronger role in the allocation of resources.

China has the largest power system of any country in the world. In 2016, it accounted for 48.9% of the world's coal consumption, and its power plants contributed 24.9% to global power generation. Its transmission network of 687 786 kilometres connected 1 777 gigawatts (GW) of capacity, meeting a total demand of 6 418 terawatt hours (TWh). The electricity it provides has helped to lift hundreds of millions of citizens out of poverty and has propelled China towards becoming the second-largest economy globally. However, this success has also brought challenges. Some 11.1% of global carbon dioxide emissions originate in Chinese coal power plants, and 1.16 million tons of SO_2 and 1.11 of NOx emissions contribute to considerable local air quality and pollution issues.

These values indicate that the path of the Chinese power sector shapes the landscape of power generation globally. Successfully meeting the targets of the Paris Agreement depends on addressing the challenges in China's power sector. It is thus surprising how little information is available for an international audience that explains the recent history of the system, its current mode of operation and, most importantly, its possible future prospects in the framework of ongoing market reform.

This publication closes the gap in information and therefore contributes to an enhanced sharing of experience and best practices between China and the world. The structure of this report is as follows:

- This chapter gives readers an overview of China's power sector, its possible influential factors and its evolution through several rounds of reforms. It also outlines the challenges that the power system is currently facing.
- The next chapter gives a detailed description of China's power system, which could be helpful by giving unfamiliar audiences a view of how the power system works in China. China's power system is a deeply rooted planning system combined with relatively fresh elements of the market, and so this chapter explains the physical and institutional characteristics of the Chinese power sector. It focuses on key aspects in the Chinese power system that are different from other countries. These crucial factors include investment and planning, mid- and long-term power trading, spot markets, power dispatch, pricing systems and development of energy from renewable sources. Evolution, progress and challenges in the above-mentioned aspects are discussed.
- The following chapter provides some case studies from an international perspective. These are selected based on the challenges and the crucial aspects of China's power system described in the earlier chapters. This chapter aims to offer China possible policy options by providing international experience that could be beneficial for China's transition towards a more market-oriented, energy-efficient and cleaner power system.

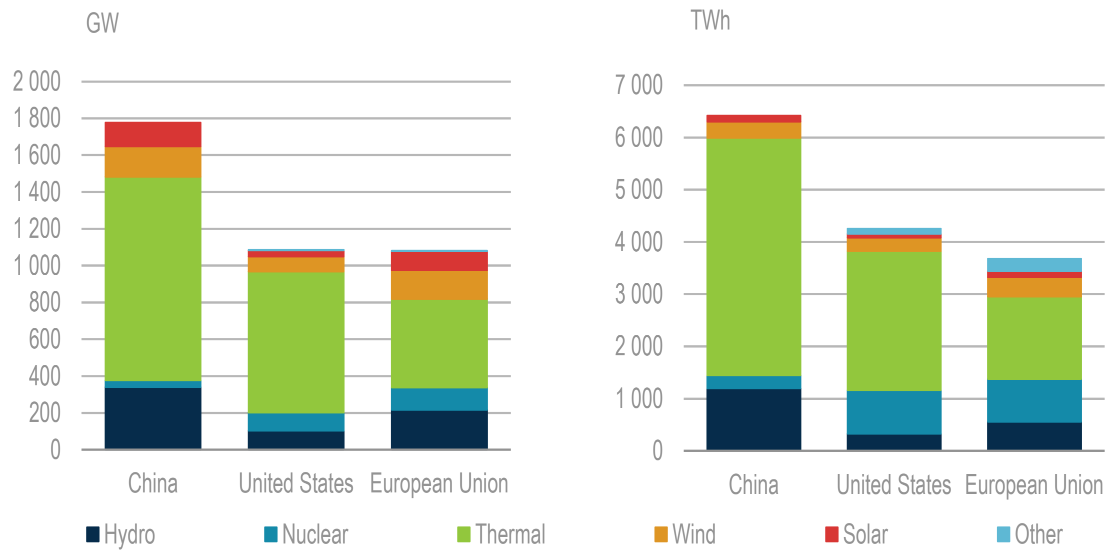
- Finally, the Conclusions section provides an overview of the main achievements of the ongoing power reform, and of the experiences from other markets that could be useful to be considered by Chinese officials.

China's power sector

General perspective

The Chinese power sector is the largest power system in the world. With 1 777 GW of capacity (end of 2017) (NEA, 2018a), it is more than 60% larger than the United States (US) or European Union (EU) fleets, the next two largest systems (see Figure 1).

Figure 1 • Chinese, US and EU capacity (left), 2016 and generation (right), 2017



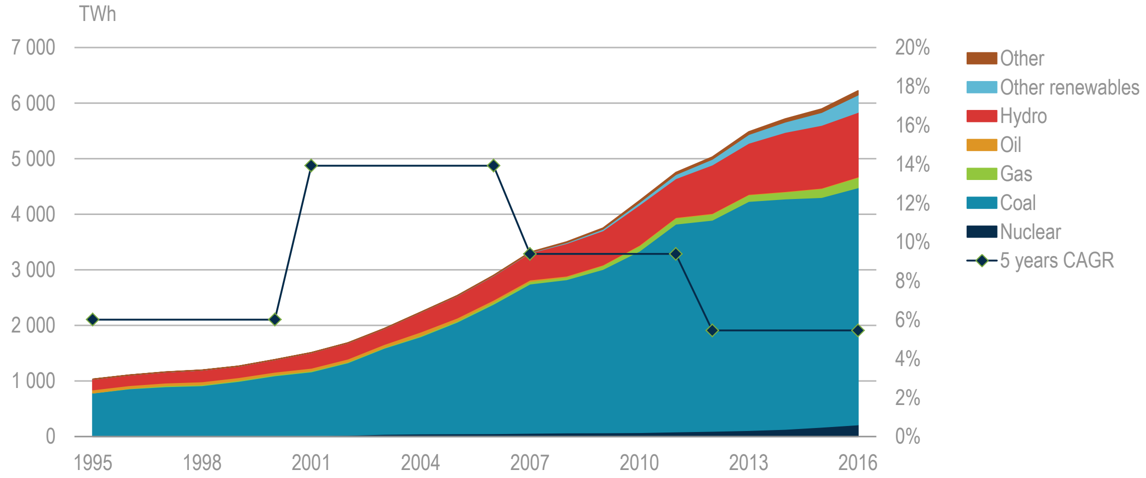
Sources: IEA (2018a), *World Energy Statistics*, www.iea.org/statistics/; NEA (2018a), *China 2017 Power Sector Data*, www.nea.gov.cn/2018-01/22/c_136914154.htm.

This was not the case two decades ago. Figure 2 shows the extraordinary dynamics that this power system has followed since the opening of the Chinese economy to the world, with the most-relevant milestone being the entry of China to the World Trade Organization in 2001.

During 2001-06, the annual average growth rate in electricity demand increased from an already high 6% to almost 14%. This rate represents a challenge to any power sector. It explains many characteristics of the framework ruling the power sector in China, which is focused on planning and deployment of investment.

Rates of demand growth have now gradually decreased again to closer to 6%, partially because of a shift towards an economy that is less energy intensive, focusing more on services and less on heavy manufacturing. A comprehensive landscape of the China's energy sector can be found in the *World Energy Outlook 2017* (IEA, 2017), as well as a detail analysis of these structural changes.

Figure 2 • Chinese power sector electricity demand growth (left) and generation mix (right)



Notes: CAGR = compound annual growth rate. *Other renewables* includes solar, wind, geothermal and tide/wave/ocean.
Source: IEA (2018a), *World Energy Statistics*, www.iea.org/statistics/.

Table 1 demonstrates another prevailing trend in the Chinese power sector: the coal share in the power sector reduced from its maximum of 81% in 2007 to 65.5% in 2017. This is the result of larger shares for other sources such as hydro (19.5%), wind (4%), nuclear (3.5%), natural gas (3.1%) and solar (1.1%).

Table 1 • China's power mix, 2016 and 2017

	Generation, 2016 (TWh)	Generation, 2017 (TWh)	Annual change (%)	Fuel share on generation, 2017 (%)
Hydro	1 174.8	1 194.5	1.7	19.5
Wind	242.0	305.7	26.3	4.0
Solar	67.4	118.2	75.4	1.1
Nuclear	213.2	248.3	16.5	3.5
Coal	3 945.7	4 136.5	4.8	65.5
Gas	188.3	202.6	7.6	3.1
Other thermal	193.4	212.2	9.7	3.2
Total	6 024.7	6 417.8	6.5	

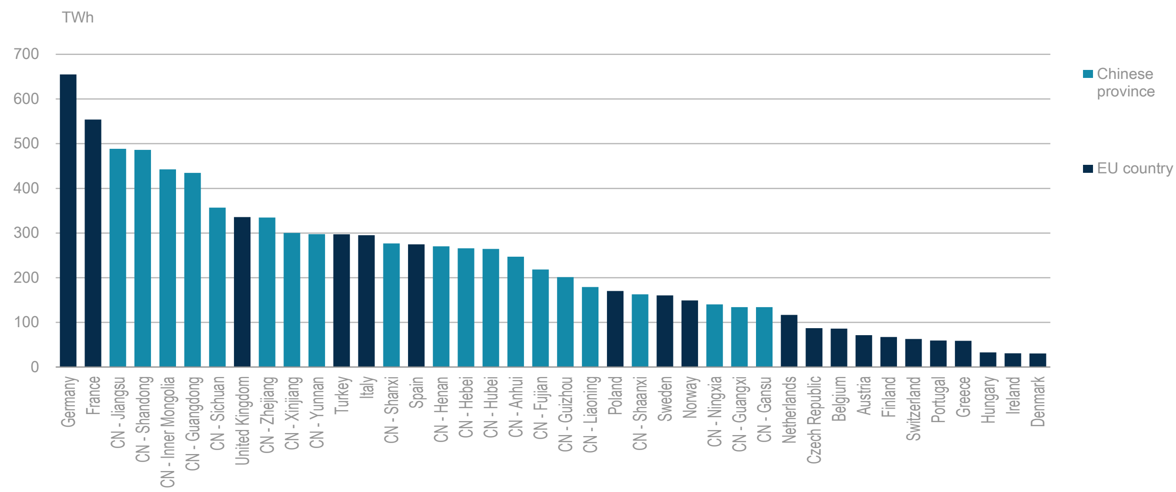
Source: NEA (2018a), *China 2017 Power Sector Data,* www.nea.gov.cn/2018-01/22/c_136914154.htm.

This shows an increasing diversification of the power energy mix, as the shares of wind, nuclear, gas and solar have each taken a small but growing portion of the supply. Despite this, in 2017, electricity generation from fossil fuels (gas and coal) grew more than that from zero-emissions sources in absolute terms.

Regional and provincial perspectives

Although often referred to as the "Chinese power sector", it is important to note that this sector comprises a heterogeneous set of provincial power systems that are different in size and power mix. Figure 3 shows the generation of the largest 40 jurisdictions within EU countries and Chinese provinces to provide a sense of dimension.

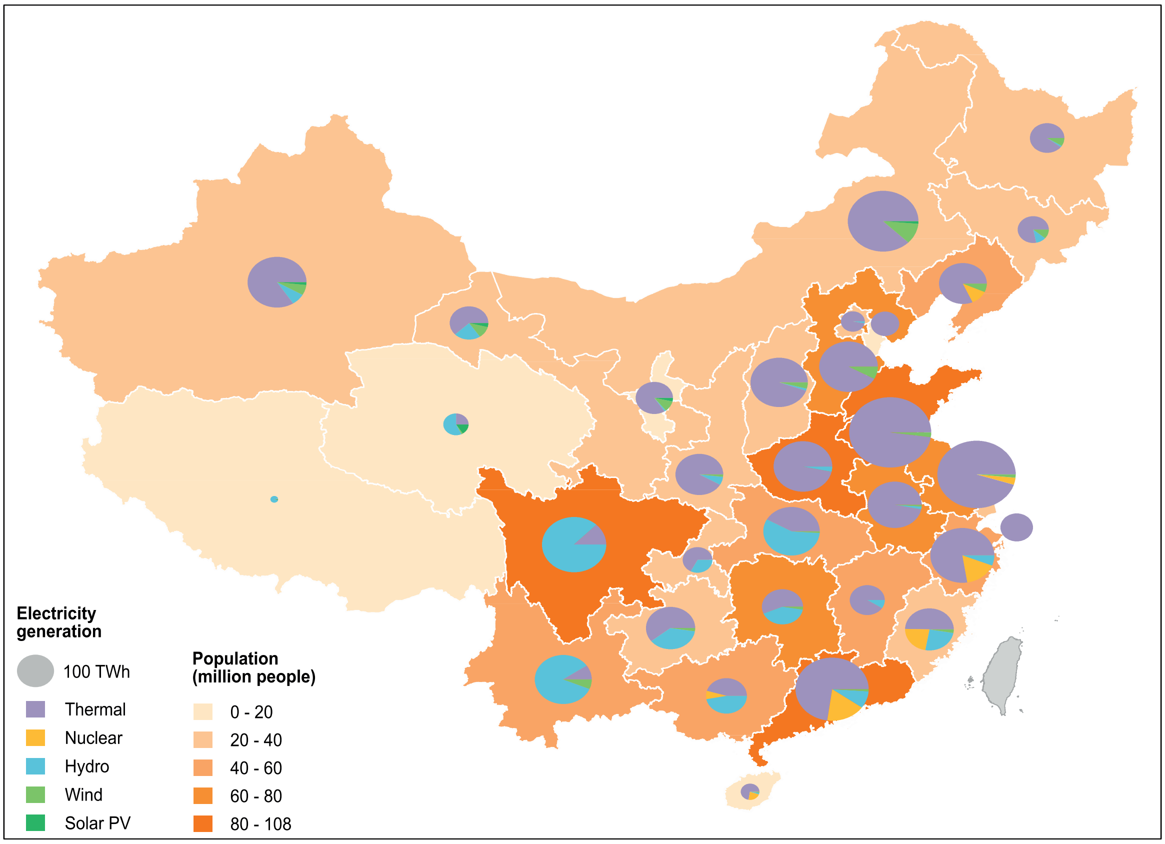
Figure 3 • Largest EU countries and Chinese province's generation (TWh)



Sources: IEA (2018a), *World Energy Statistics*, www.iea.org/statistics/; NEA (2018a), *China 2017 Power Sector Data*, www.nea.gov.cn/2018-01/22/c_136914154.htm.

The Northern, Central and Eastern regions of China are the largest generation zones. Most regions depend on coal, with the Northern, Eastern, Northeastern and Northwestern regions having shares of 70% or higher (Figure 4). However, the Southern and Central regions satisfy only about half of their electricity needs from this resource.

Figure 4 • Generation and energy mix of provinces, 2017

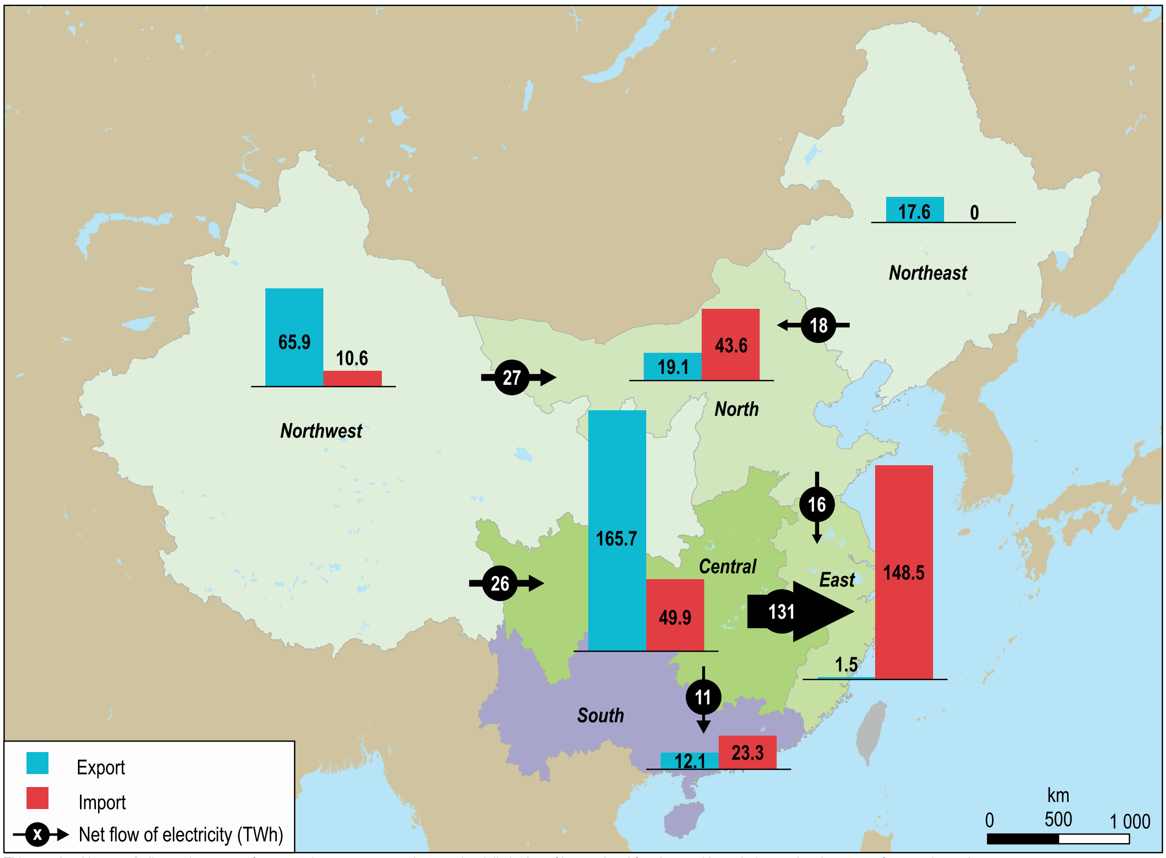


The map presents data of provinces in China.
This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries, and to the name of any territory, city or area.

Source: IEA (2017), *World Energy Outlook*, OECD/IEA, Paris, www.iea.org/weo2017.

Figure 5 shows net interregional exports, which tend to go from the Western and Northern to the Southern and Eastern regions of China. These regional flows represent a marginal amount of the total energy consumed, despite the size of the country and the variety of resources available. This is compatible with the common perception that provinces try to balance their demand with their own resources.

Figure 5 • Electricity flows among regions (TWh), 2015



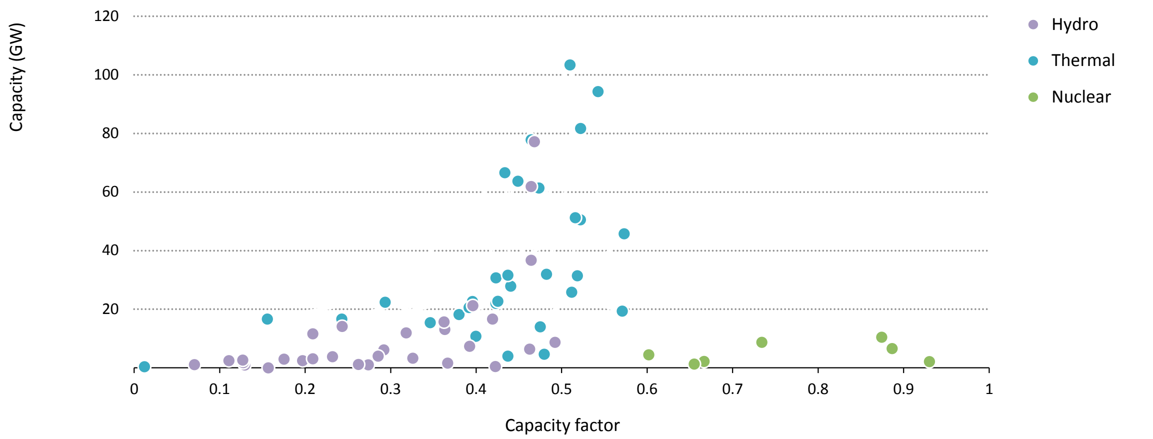
This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries, and to the name of any territory, city or area.

Source: CEC (2016), *China Power Industry Annual Development Report 2016*, www.cec.org.cn/guihuayutongji/gongzuodongtai/2016-08-24/157409.html.

Note: Regional quantities might not add to the total amount as only main flows are shown.

The energy mix and productivity of energy sources vary depending on the region. Figure 6 shows the capacity factors (percentage of hours in a year that a plant produces energy) of different technologies in various regions. Although thermal plants have capacity factors in the range 0.40-0.60, three provinces, all of them with "small" fleets (by Chinese standards) of around 20 GW, have capacity factors of less than 0.30. For nuclear, the picture is heterogeneous: three provinces operate close to international standards (<0.90), while another three have relatively low capacity factors of less than 0.7. Hydro fleets also have large variability in size and productivity, as expected from the diversity of these resources. In the case of the largest hydro fleets in China, eight provinces have capacity factors greater than 0.4.

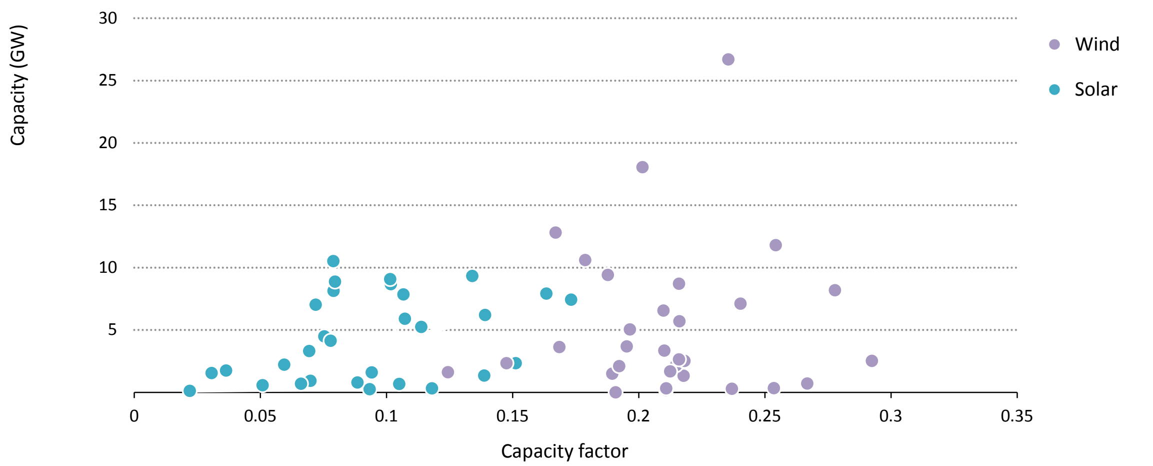
Figure 6 • Provincial capacity and capacity factor (dispatchable technologies), 2017



Source: NEA (2018a), *China 2017 Power Sector Data,* www.nea.gov.cn/2018-01/22/c_136914154.htm.

The landscape is similar for variable renewable energies (VREs) (Figure 7). Provinces display large heterogeneity in the size of their fleets and the productivity of their plants, measured as capacity factors. Curtailment of wind generation in China has decreased from 15% in 2015 to 12% in 2017, while solar PV curtailment reduced from 12.6% to 6% in the same period.

Figure 7 • Provincial capacity and capacity factor (non-dispatchable renewables), 2017



Source: NEA (2018a), *China 2017 Power Sector Data,* www.nea.gov.cn/2018-01/22/c_136914154.htm.

Factors affecting power sector development

Economic transition

China has experienced rapid growth in its economy over the last two decades. Even with the recent slowdown, it continues to expand at an impressive speed, with a 6.9% gross domestic product (GDP) growth rate in 2017. The Chinese government has promoted transition in the economy, aiming at adopting a more sustainable model driven by domestic consumption and tertiary sector of the economy. The government proposed a supply-side structural reform plan to fulfil its targets in economic transition. This stated that the reform would be anchored in market-driven allocation of resources and pricing of economic inputs.

Energy system transformation

China has made optimising the structure of energy supply a top priority since the early 2000s. The goals were to reduce the share of coal and increase the share of clean energy in the energy mix. The goals of reducing the coal share to 58% by 2020 and achieving 15% of power from sources other than fossil fuels in the total energy consumption are binding in the 13th Five Year Plan (NDRC, 2016a). China continues to set ambitious targets for renewable energy capacity and generation, which have consistently provided impressive acceleration in renewable deployment over the past decade. Targets are also in place to expand the share of gas to 10% by 2020 and further to 15% by 2030.

China now has the largest installed generation capacity in the world, nearly 60% of which is coal power. However, in the last few years, the large expansion in capacity has coincided with a period of slower power demand growth. The country has therefore experienced overcapacity in the power sector, particularly a reduction in the capacity factor for coal generators.

China's newly installed renewable capacity in the past decade has had a share of more than one fifth of the global electricity capacity. The country already leads the world in installed capacity of hydropower, wind and solar photovoltaic (PV) power. However, the rapid growth of renewables has created an issue of integration, leading to the curtailment of 17.2% of wind generation and 10.3% of PVs in 2016. In some regions, the curtailment rates exceeded 40%.

Environmental protection

China's energy consumption makes the country the largest emitter of CO_2 in the world. Air quality in many areas fails to meet the national health standard. China is going through a clean energy transition, in accordance with the pledges of the Paris Agreement and to also improve air quality.

CO_2 emissions

China issued its first carbon intensity target in the 12th Five Year Plan (NDRC, 2011a). This was followed 2 years later by the release of the *National Plan on Climate Change 2014-2020* (NDRC, 2014). Carbon intensity targets have been included in provincial target assessments since 2012, reflecting their high priority. An emissions trading system, based on efficiency standards for each type of technology, has been announced. It is in the form of subnational pilot projects and a national system, and is a key policy response with the primary purpose of reducing emissions in China.

Internationally, China submitted a Nationally Determined Contribution to the Paris Agreement, which includes the goal of peaking CO_2 emissions around 2030, to lower CO_2 intensity of GDP by 60-65% by 2030, and to increase the share of non-fossil fuels to 20%. China has implemented sub-national pilot Emissions Trading Systems (ETS) in five cities and two provinces since 2013. The Government has launched the national ETS in December 2017 that will be implemented through phases to 2020 covering CO_2 emissions from the power sector only at its initial stage. The ETS will strengthen emission data monitoring while creating a price on carbon. It is part of China's climate policy package to reduce CO_2 emissions and support China in achieving its NDC mitigation target

Air pollution

The Chinese government is aware of the importance of curbing air pollution. The State Council released the *Action Plan for Air Pollution Prevention and Control* in 2013 (State Council, 2013), acting as guidance at the provincial level to improve air quality over the period 2013-17. This nationwide document aimed to reduce pollution by fine particulate matter towards the national ambient air quality standard and also contained detailed measures to reduce other pollutants.

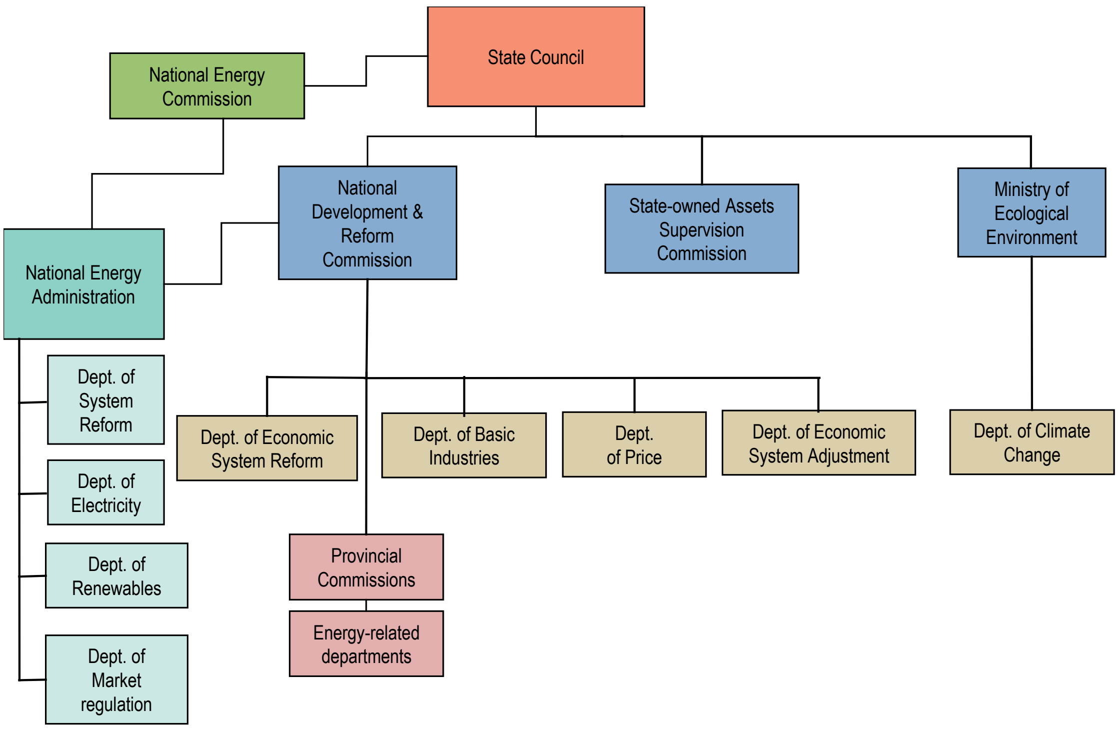
The State Council released the *Three Year Action Plan on Blue Sky War* in July 2018 (State Council, 2018). Key measures to implement this plan included: the development of local air pollution plans in key urban areas and for the energy industry:

- inclusion of air pollution reduction performance in provincial assessments
- strengthening of industrial restructuring measures
- management of end-of-pipe pollution
- conservation of energy
- control of inefficient coal-fired power generation
- switching from coal to gas for heating in industrial and residential buildings.

Governance structure

There are several ministries involved in power policies. The National Development and Reform Commission (NDRC) and the National Energy Administration (NEA) are responsible for issuing and implementing industrial plans, policies, pricing and energy sector regulation. There was a restructuring of ministries in March 2018 after the 19th National Congress of the Communist Party of China, but the eight departments within the NDRC and NEA responsible for the power sector reform remained the same.

Figure 8 • Authorities regulating China's power sector, 2018



The Economic System Reform Department in the NDRC leads power sector reform. Three other departments in the NDRC are also involved in the reform. The Pricing Department is in charge of the regulation of power prices, including benchmark prices of coal power, feed-in tariffs of renewables, and interregional and interprovincial transmission and distribution tariffs. The Economic System Adjustment Department is in charge of demand-side management and reform related to administrative generation planning. The Basic Industry Department is in charge of integrating the power industry plan within the macroeconomic development plan, ensuring the targets of power sector reform do not collide with the broader national economic targets.

Four departments in the NEA are also involved in the power sector reform. The Electricity Department focuses on fossil fuel power generation planning and grid planning, electric vehicle charging facilities and incremental distribution grid reform. The Renewable Energy Department is in charge of renewable energy development and integration. The Energy System Reform Department is in charge of institutional aspects of the reform. The Market Regulation Department is responsible for regulation of the power sector. Figure 8 provides an organisational chart of the authorities regulating the Chinese power sector.

Players in China's power sector

China's power sector is integrated by a large set of players that comprises multiple private and state-owned generators, grid companies (providing transmission and distribution) and retailers. It is important to note that in the case of grid companies, they also perform system operation and default retailing, i.e. they supply electricity to customers that have not switched supplier. The sections below provide brief descriptions of these players.

Grid companies

Figure 9 • Grid company footprints (2018)

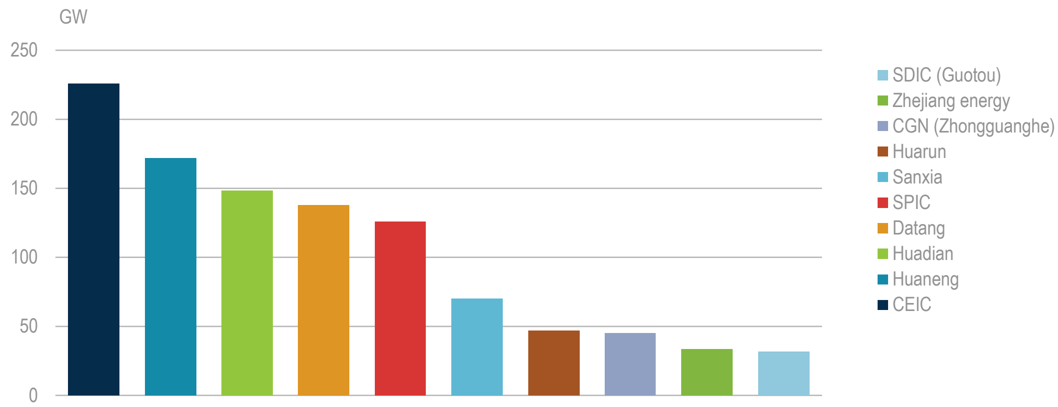
This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries, and to the name of any territory, city or area.

There are two major companies providing transmission and distribution services: the State Grid Corporation of China (SGCC), one of the largest corporations in the world by number of employees, and the China Power Southern Grid (CSG) company. A third player, though smaller, the Inner Mongolia Electric Power Company, provides these services in the west of that region. Figure 9 shows the footprint of these companies. Although they are referred to as "grid" companies, because they develop and operate the transmission and distribution networks, their activities also comprise scheduling, dispatching generation and default retailing.

Generation companies

There are several generation companies in China. The landscape is dominated by state-owned enterprises (SOEs), although participation of private stakeholders is permitted in most technologies. However, the largest five generators (usually referred to as the "big five") – Huaneng, Datang, Huadian, Guodian and China Power Investment (CPI) Corporation – have been undergoing rapid changes in recent years. The CPI merged with the State Nuclear Power Technology Company in 2015 to form the new State Power Investment Corporation. Guodian merged with Shenhua, the coal giant, in 2017 to form the new China Energy Investment Corporation. This replaced Huaneng as the largest power generator in terms of generating capacity in China (Figure 10). By 2017, the five largest generation companies in China (each with more than 100 GW of capacity) – had a larger fleet than countries such as the United Kingdom.

Figure 10 • Largest Chinese generation companies, by generation capacity, 2018



Note: CEIC =China Energy Investment Corporation; CGN = China General Nuclear; SDIC = State Development and Investment Corporation; SPIC = State Power Investment Corporation.

Retailers

Since the opening of the market in China, retail companies have begun operations. The number of registered power retail companies reached about 7 000 at the end of 2017, that for the time being aggregate consumption from industrial buyers. Even if many of those registered companied are not actively operating, they are already important participants in the market-based trading in some provinces, reaching 90% of the energy sold in the trading exchanges in Guangdong, Shandong and Anhui Provinces.

Ownership

The Chinese power sector has transited from one system in which all activities were performed by a single entity to one in which multiple participants are involved in different segments of the industry. Many participants are owned by provincial governments, private national companies and foreign investors (Table 2), although national-level SOEs still dominate the retail and generation sector. It is noteworthy that thermal and wind generation are owned mainly by state-owned companies, while solar facilities are owned mainly by private and foreign parties.

Table 2 • Ownership of undertakings in the Chinese power sector, 2015 (%)

	Power supply firms	Generation firms	Thermal	Hydro	Nuclear	Wind	Solar	Other
Total	100	100	100	100	100	100	100	100
State-owned holdings	94.74	58.44	66.03	49.89	100	77.53	41.49	32.46
Collective holdings	2.16	3.44	2.54	6.37		1.25	0.62	2.62
Private holdings	2.23	25.74	16.51	33.72		12.11	44.27	44.59
Foreign holdings	0.07	2.15	3.25	1.5		1.5	0.93	3.61
Other	0.81	10.23	11.67	8.52	0	7.62	12.7	16.72

Source: CEC (2016), *China Power Industry Annual Development Report 2016*, www.cec.org.cn/guihuayutongji/gongzuodongtai/2016-08-24/157409.html.

Power sector reform

Power sector evolution (1978-2001)

The nationwide "reform and opening up" campaign boosted China's economy in the 1980s. However, at the same time, China experienced power shortage, which largely influenced its economic growth. The Chinese government thus released policies aiming at incentivising power sector investment and boosting power supply capability.

Changes to the vertically integrated utility structure and ownership were made in the power sector in 1984, with the aim of incentivising power investment to keep pace with economic growth. The most influential change was the right for third parties outside the central government to invest in power plants. Provincial governments, local governments, SOEs, private sector investors and foreign companies were encouraged to invest in the power sector. Power plants built in this period were granted a power purchase agreement (PPA) with predetermined utilisation hours and power prices to guarantee the rate of return for investment. Moreover, a so-called "fair dispatch rule" was introduced in 1987 to ensure "transparency, equity and fairness" in dispatch (SERC, 2003b). The PPA contract together with the fair dispatch rule substantively incentivised power sector investment, and boosted the power supply capability. At this time, although power generation was opened to diversified investors, grid assets were still controlled by the central government.

The second major change took place in 1997, when most of the assets of the power sector were transferred from the Ministry of Electricity to the newly formed State Power Corporation (SPC). This marked the first step towards separation of government regulatory and market operation. The SPC owned approximately half of China's generation assets and almost all grid assets.

Power sector reform in 2002

After nearly two decades of rapid increase in generation capacity, power supply exceeded power demand for the first time in the late 1990s. This oversupply situation became severe in 1997, due to the inertia of investments in power generation and a reduction in power demand caused by the Asian financial crisis. A year later, a hydro curtailment incident happened in Sichuan Ertan hydro power station, worsening the situation. Ertan was then China's largest hydro project, financed by a loan from the World Bank. Ertan was forced to curtail a large portion of output to accommodate coal power generation, because of regional overcapacity, inflexible dispatching and interprovincial trading barriers. This incident drew the attention of the highest-level leaders and triggered the power sector reform in 2002 (IEA, 2006).

This round of power sector reform started with the release of an official document entitled *Power System Reform Scheme* (Document No. 5) in 2002 (State Council, 2002). Goals for the reform were to break the institutional monopoly and introduce competition, improve overall efficiency particularly through interprovincial transactions, protect the environment and adopt better regulations.

Reform under Document No. 5

Unbundling the SPC

The structural focal point of this round of reform was to eliminate the SPC monopoly and introduce competition. The reform therefore disaggregated the SPC generation assets and grid assets into five generation companies, two grid companies, and four power service companies.

The new "big five" generation companies were all SOEs. The initial purpose of unbundling on the generation side was to introduce competition. Therefore, each of the big five was given about one-fifth of the SPC generation capacity, ensuring each company had less than one-fifth of the market share in a certain geographic region. After the unbundling, each of the big five companies started to expand its generation capacity in different geographic regions. For example, after years of development, Huaneng was strong on the east coast region, Datang focused on the coal-rich region in northern China and Huadian dominated in Shandong Province.

The two grid companies after unbundling were the SGCC and the CSG. The SGCC was authorised to construct and operate an interregional power grid, with five subsidiary regional grid companies each responsible for interprovincial transmission in its own geographic region. Each of the five regional companies also had subsidiary provincial grid companies. On the other hand, the CSG was established as a regional grid company separated from the other five regions under the SGCC, with the intention of experimenting with more integrated regional dispatching.

There were different opinions on the organisation of the transmission and distribution business during the process of unbundling the SPC. On the one hand, the State Planning Commission (predecessor of the NDRC) wanted to establish six regional power grid companies with authorities to invest and operate interprovincial grids. On the other hand, the SPC did not want to disaggregate transmission and distribution, and proposed the idea of a national grid company with six regional branches. The final plan was seen as a compromise between the two options, with the new SGCC controlling five regions with five corresponding subsidiary regional companies, and the CSG controlling one region as an experiment in interprovincial trading. The regional subsidiary companies under the SGCC were expected to play an increasingly important role in breaking provincial trading barriers. However, as regional companies were wholly owned subsidiaries, they were transformed into branches through a restructuring campaign proposed by the SGCC.

Four power service companies were founded after the unbundling. These companies were distributed with key ancillary services that had been previously integrated into the SPC.

Attempts at improving system efficiency

Another focal point of this round of reform was to improve overall system efficiency. Several new initiatives to encourage market trading and more-efficient dispatching were practised after the release of Document No. 5. However, not all achievements matched expectations. Attempts to improve system efficiency included the following:

- Regional wholesale power markets were piloted in the Northeast China grid and east China grid, from 2002 to 2006. These two regions selected a small number of power generators to participate in the market competition with only a small portion of the total power demand. Owing to the surge in power demand and vested interests from different stakeholders, these pilots were not successfully established.
- Direct power purchasing was carried out in some provinces in 2004. This was between power generators and large industrial consumers selected by the government. Direct power purchasing was promoted as a breakthrough method in 2009, and has continued to be crucial in China's market trading since then.
- Interprovincial and interregional trading was also implemented. However, most of the trade deals were government plans such as the large hydro powers (e.g. the Three Gorges Dam) and trade deals made among provincial governments.
- Generation rights trading was introduced in 2007, along with the "shut down small power units" campaign. After 2007, generation rights trading was expanded to interregional/interprovincial trading.
- Energy conservation dispatch was piloted in 2007, as an alternative practice to the fair dispatch rule, which has been widely used in China. The promotion of energy conservation dispatch encountered obstacles, and its application was limited.

Introducing regulation

The State Electricity Regulatory Commission (SERC) was established in 2003, showing a clear sign of China's commitment to independent regulation in the power sector. Priority duties of the SERC were to establish rules to form competitive power markets, with authorisation for supervising interprovincial power transmission, policy making and implementation. In general, the SERC had a positive influence on China's power market transition progress, but some of its function overlapped with the NDRC. The SERC merged with the NEA in 2013.

Reasons why Document No. 5 did not fully achieve all its initial targets

The initial idea of transforming the power system to a more energy-efficient and interconnecting system was only partly realised under the Document No. 5 round of reform. The reasons why Document No. 5 lost its momentum and did not fully realise its initial goals are complicated – the three main ones are given below.

Underestimation of power demand growth

The reform originated from a power oversupply that started in 1997 and then worsened. To alleviate the situation, the central government suspended approval for construction of coal power plants from 1998 to 2000. After 2000, the national 10th Five Year Plan (2001-05) predicted the average annual growth rate of GDP to be 7% from 2001 to 2005, and the corresponding annual growth rate of power demand was predicted to be around 5%. However, this situation dramatically changed after the Asian financial crisis, resulting in China's average annual power demand exceeding 15%. The oversupply in 1997 quickly turned into a power shortage in 2003, less than a year after the release of Document No. 5. Therefore, the focus shifted from improving system efficiency to accelerating power construction, leaving the driving force of reform as a lower priority.

Resistance from provincial governments

One of the characteristics of this round of reform was that the central government was in charge and directed the reform. The resistance was mainly due to the critical role provincial governments have long been playing in the power sector. Provincial governments have had responsibility for power planning, authorising, administrating and even financing power projects since the 1980s. For provincial governments, power infrastructures raise local employment, tax revenues and manufacturing business. However, the power retail business was a large and stable revenue source, and retail price setting was considered an effective tool for the adjustment of local economic development. Power reliability has always been the joint responsibility of provincial governments and grid companies. Therefore, because of these institutional, economic and political considerations, provincial governments were reluctant to co-operate in the reform, which meant losing control of the power sector, giving up their own interests and possibly causing social instability.

Uniqueness of the role of grid companies

Grid companies acted as a single transmission and distribution system operator, plus a single buyer on the wholesale side and a single seller on the retail side. As regulation was not effective, sometimes each of the regional grid companies tended to favour their own portfolios, which discouraged interprovincial and interregional trading. In addition, there was no separate transmission and distribution tariff, which made it difficult to know accurate investment and operation costs.

Power sector reform in 2015

After several years of rapid development, China realised many achievements in its power sector. It has by far more generating capacity and more transmission lines than any other country. Nearly all of its 1.3 billion people have access to electricity. After unbundling the vertically integrated utility, a diversified power system structure has formed, in terms of multifaceted, multi-owned and multiregional power generation companies, and multiple grid companies including the SGCC and CSG.

The power pricing system has also been improved. Benchmark feed-in tariffs have been implemented on the generation side, and differentiated pricing and a residential ladder pricing mechanism have been implemented on the retail side. In addition, market mechanisms have been explored, including auctions in the wholesale market, direct power purchasing among large consumers and generators, generation rights trading, and interprovincial and interregional trading.

Though the achievements are remarkable, several remaining problems still need to be resolved to realise a more-efficient, environment-friendly, low-carbon and safe power system, including the following:

- Governmental co-ordination has not functioned well in the planning and investment process. There has sometimes been a large deviation between the plan and its implementation.
- Lack of a market trading mechanism leads to inefficient resource allocation. Effective competition on the retail side has not yet been established, and market-based trading between generators and end users is limited. High-efficiency low-emission power units cannot be fully utilised. Curtailment of water, wind and solar power occurs frequently, and the curtailment rate can be high in some regions.
- A market-based pricing mechanism has not yet been fully formed. Pricing management is dominated by the administrative methodology. Power price adjustments often lag behind cost changes. They are therefore insufficient in reflecting the power cost, the change in the balance of supply and demand and the scarcity of power in terms of time and location.

- Renewable energy development has encountered obstacles. There is a mismatch in the large manufacturing capacity of PVs and the construction and operation of new plants.

Reform under Document No. 9

The State Council released an official document entitled *Opinions on Further Deepening the Reform of Power System* (Document No. 9) in 2015 (State Council, 2015), symbolising the beginning of China's new round of power sector reform. The objectives were to: create market-based prices for the wholesale and retail sides to develop market mechanisms; establish a separate, transparent transmission and distribution tariff; expand interprovincial and interregional transmission; enhance government regulation; and improve power planning.

Among the issues stressed in Document No. 9, pricing reform is the most crucial and hence the need for elaboration. There are four key issues in the reform in the current pricing system as follows:

- A separate transmission and distribution tariff will be established, although the transmission and distribution system will still be operated mainly by the grid companies. This tariff will follow a design with a revenue cap model based on authorised cost and a permitted revenue margin. The transmission and distribution price was bundled in the retail price before Document No. 9. However, it is important to have a separate and transparent transmission and distribution tariff for market transactions, including intraprovincial, interprovincial and interregional trading. The investment and operation costs of the power grid will be clarified, and the results released to the public.
- Wholesale energy prices will be decided by negotiation or auction between generators and consumers in mid- to long-term electricity markets. Retail price will be the sum of the wholesale, negotiated price, transmission and distribution tariff, and government fees. However, only end users with high voltage levels, large capacity and large power consumption are allowed to participate in the mid- to long-term market at this point.
- Retail companies will appear for the first time, which means smaller customers will have the option to buy power from a retailer. By choosing a retail company to buy electricity from, consumers, including small and medium-sized enterprises (SMEs) and residential and agricultural users, are able to purchase power at the market price, rather than at the benchmark retail price issued by the central government.
- Cross-subsidies will be properly handled. Cross-subsidies in the power sector make the cost of electricity in some sectors much higher than the efficient levels. Some customers (e.g. industrial users) pay more for power, while others (notably households) pay less. Eliminating these cross-subsidies will be difficult.

Document No. 9 also mentions the importance of administrative planning, in terms of power generation planning and power construction planning:

- China has used administrative power generation planning ever since the country's foundation. Together with the so-called fair dispatch rule, annual power generation planning can recover the cost of investment and guarantees a certain rate of return for each power generator. However, in the future, all industrial and commercial power demand will be gradually transferred to mid- and long-term contracting. Furthermore, the amount and capacity of direct contracting will no longer be included in the administrative plan. Newly installed power generation will be encouraged to participate in the market trading.
- For power construction planning, permitting power construction remains the responsibility of provincial governments. Following a "streamlining administration" campaign proposed by the State Council, the authority for power construction transferred from the central

government to provincial governments in 2014. This induced excess investment in coal power capacity.

Improving renewable energy development is also important for China's power sector. Government-planned renewable energy will follow the "guaranteed purchase hour" policy (see the renewable energy development section below) and will have priority in the administrative power generation plan. Generation rights trading can be applied to the prioritised administrative power generation contract. Renewable energy is encouraged in the power market, particularly for interregional and interprovincial trading (Davidson, 2018).

Document No. 9 tried to redefine the role of grid companies. The major business of grid companies in the future will be investing in power grids, power transmission and distribution, grid system security, ensuring fairness and non-discrimination to all players and providing grid services. With the opening of the wholesale and retail markets, grid companies will no longer be the single buyer on the wholesale side or the single seller on the retail side. The separate and government-approved transmission and distribution tariff will be the major revenue of grid companies, instead of the previous mode of charging the difference between the on-grid price and retail price.

The 2015 round of reform was different from the previous round of reform in 2002. Provincial governments now implemented reform instead of the central government. In the previous reform, provincial governments were the ones being reformed and were forced to give up some of their jurisdictions (e.g. the SERC attempted to break the interprovincial/interregional trading barriers). This time, however, responsibilities for establishing a separate transmission and distribution tariff, promoting direct contracting, founding power exchange institutes and constructing power markets were all authorised to provincial governments. Pressure of increasing local GDP growth, reducing the cost of real economy and trading electricity with other regions for better economic efficiency will provide strong incentives to provincial governments to promote power sector reform.

Mid and long-term bilateral contracting will comprise most of the market, and the spot market will be seen as supplementary.

Progress made after implementation of Document No. 9

It is now over 3.5 years since the State Council issued Document No. 9 and launched this round of reform. The reform is an important part of the supply-side structural reform, and a breakthrough in the energy sector. Among others, polices derived from Document No. 9 has resulted in the following achievements:

- clarification of the transmission and distribution tariff for provincial grids and some of the interprovincial/interregional grids
- establishment of trading centres and regulatory committees
- establishment of mid- and long-term provincial/regional power markets
- three batches of incremental distribution grid pilots
- appearance of retail companies.

Progress on these is described in the next chapter of this report.

Challenges in the power sector

Power sectors in countries around the world are undergoing significant changes, pursuing a more sustainable, efficient and resilient power system. This general trend for power system transition processes requires the establishment of a planning system that incentivises investments and the use of efficient and environment-friendly technologies. It also needs policy, market and regulatory frameworks that are well designed and functioned to fit with the institutional reforms and new technology adaptions.

China's power sector is also going through major changes. The current power system has realised significant achievements by attracting investments to match the fast demand growth over the past 40 years. However, as the objective shifts towards a more market-oriented, low-carbon and cleaner system, the power sector in China is facing new challenges.

China has the largest installed power generation capacity in the world, and approximately 60% of it is coal fired. China's coal fleet is relatively new and has high efficiency, given that many large-scale ultra-supercritical and supercritical units have been commissioned in the past 10 years. However, the large capacity in coal power has collided with the modest power demand growth. As a result, the excess coal capacity results in substantive reduction of the capacity factor (IEA, 2017).

At the same time, China is also adjusting its direction in the energy and power sector by adopting more renewable energy, due to the transition in economic structure and increasing concerns for sustainable development and public health. After several years of rapid development, China now leads the world in wind and solar PV power installed capacity. However, the rapid growth of these VREs has led to a curtailment issue in some of the regions with the highest penetration levels. Although the central government has made tremendous efforts for VRE integration, it remains a critical challenge due to technical, economic and institutional reasons.

The ongoing power sector reform aims at introducing a fundamental transformation of electricity supply by creating a more flexible power system based on market principles. The reform sees the challenges as follows:

- system planning
- flexible operation of coal power generation
- introduction of market competition to reduce average power generation costs
- introduction of market competition at the retail end to offer multiple choices to consumers
- modernisation in the use of network infrastructure
- renewable energy development and integration.

Responding to these challenges requires innovative approaches and also learning from experiences and lessons from other countries to avoid possible pitfalls. This may include a need for the Chinese government to change policy and regulation, and may also require enhanced power system planning and operation.

Key aspects of China's power sector reform

China's power system was originally designed to support a planned economic structure dominated by heavy industries. Since coal has been the only self-sufficient natural resource in China, the baseload of the power system has long been dominated by coal power. Therefore, some key aspects of the power system in China have been substantially different from those of other countries. Given nationwide concerns regarding air pollution and the effects that emissions have on climate change as well as the need to improve system efficiency, China's power sector has gone through reforms and changes. It is now being shaped towards an advanced, market-oriented system (e.g. market transactions are becoming increasingly important after the release of Document No. 9). It is interesting to note that the current power system is a combination of the old planned system together with the new market-based system. China's power system shows its uniqueness in the following aspects:

- The planning and investment cycle in China follows a centrally planned system. The NDRC and NEA are responsible for developing a five-year national plan, consistent with the overall objectives in the energy sector. This plan should include strict investment and technology deployment objectives for generation, transmission and distribution by province. Provinces are responsible for achieving these targets and are in charge of permitting for many of the projects.
- Mid and long-term contracting contributed a relatively small portion (2-10%) of the total power transaction before Document No. 9. These contracts were usually the result of negotiation between government-selected generators and government-selected consumers, or imposed by the central government directly. However, mid- and long-term contracting was encouraged as the major form of market trading after Document No. 9. Multiple timescales (annually, quarterly, monthly, weekly and day ahead) and multiple forms (bilateral negotiation, listed auction, centralised auction, unbalanced energy trading, etc.) have been adopted, achieving a substantive share of traded energy as a share of total generation (26%) in 2017.
- An administrative dispatch system has been adopted and needs to be emphasised. At the end of each year, provincial governments forecast the total power demand for the next year, and then allocate power generation quotas to each generator within its province following a fair dispatch rule. This rule allows each generator in the same category (e.g. coal power) to be allocated with the same annual operating hours, only with minor differences considering capacity, emissions levels and operating efficiency.
- The spot market is seen as supplementary to the current market trading system. Remarkable progress has been made since Document No. 9: the ancillary services market has been successfully implemented in Northeast China and promoted to other regions, the interregional renewable energy spot market has been adopted for surplus renewable trading, a design plan for the spot market has been released and a provincial/regional spot market is on schedule.
- Power pricing in China has adopted a centrally determined benchmark pricing system, with a benchmarked on-grid price and a benchmarked retail price. As there was no separate transmission and distribution tariff, grid companies charged the difference between the retail price and on-grid price as their revenue. The benchmarked pricing reflects the cost of power construction and return expectations. Owing to the differences in the economic development levels, benchmark prices varied for different provinces. This pricing system, together with the annual allocated operating hours, guaranteed the rate of return for power

investment and so, for a certain period of time, successfully boosted power construction and tackled the power supply shortage.

- Renewable energy is considered crucial to the power system transformation, and integration challenges of wind and solar PV power must be addressed.

The following sections give further detailed descriptions of the above-mentioned issues. This allows readers to gain a better understanding of China's power sector by providing a comprehensive review of the key aspects, including their evolution, progress and challenges.

Planning and investment

The planning process for the power sector in China is an essential role. Most of the investments in grids and generation assets have to undergo a complex process that relies heavily on a centrally planned economy paradigm. Many of the steps have been gradually decentralised to the provinces (e.g. approvals). However, the central government remains in charge of drafting a Five-Year Plan consistent with national and provincial dynamics, which takes into account policy objectives for the rest of the energy sector (NEA, 2016d). This section explains the mechanics of the processes for attracting investment in one of the fastest-growing power sectors in the world.

Long-term planning and investment

Investment in generation, transmission and distribution in the Chinese power sector is decided in a complex planning process that engages multiple stakeholders, including provinces, grid companies, power industry representatives, governmental organisations and academies (NDRC, 2014; State Council, 2016). The culmination of the process is the Five Year Plan for Power Sector Development, an exercise with an outlook of 10-15 years, which defines generation capacity additions, technology and locations at a provincial level, as well as the transmission and distribution investments undertaken during the period. The latest of these exercises is the 13th Five Year Plan (NDRC, 2016a), which defines investments undertaken during 2016-20, and which is subject to mid-term revision 2 or 3 years after being issued.

The Five-Year Plan defines all the investments. Even if the market is expected to encourage more decisions in the power sector under Document No. 9 reform, investment in generation cannot take place unless it is considered in the Five Year Plan. Unauthorised projects may not enter the electricity market, nor can they have access to open-access grid tariffs or be beneficiaries of support policies or tax deductions.

Planning processes

Power sector planning takes inputs from higher-level planning instruments issued by the Chinese government, in particular the National Five-Year Plan and the Five-Year Energy Plan. These inputs are detailed in Table 3.

The NEA is responsible for national electricity planning, and co-ordinates provincial authority participation. Provincial governments are responsible for provincial power plans, taking as input the Five Year Plan. To gather the inputs and to guarantee consistency among the provincial plans, and the generation and the transmission investments, a process of revision and adjustment called "two up and two down" is followed:

- First "up": the provincial energy authorities prepare a draft provincial electricity plan and submit it to the NEA at the beginning of the planning process.

- First "down": the NEA organises and summarises the preliminary draft of the provincial plan, clarifies the initial national planning objectives, the overall framework and the provincial planning boundary conditions, and provides feedback to the provincial energy authorities.
- Second "up": the provincial energy authorities establish the provincial electricity plan (including an environmental planning impact assessment) in accordance with the feedback provided, and submit it to the NEA.
- Second "down": the NEA assesses the revised provincial electricity plan, and provides feedback to the provincial energy authorities. The provincial energy authorities improve the provincial electricity plan accordingly.

Table 3 • Inputs for the Five-Year Plan for Power Sector Development

Document	Planning inputs
Five Year Plan for Economic and Social Development	GDP forecast, efficiency, non-fossil fuel ratio and main projects
Five Year Energy Plan	Forecast production, demand growth and efficiency
Five Year Plan for Power Sector Development	Forecast capacity, generation, consumption, structure and project details

Sources: NDRC (2016a), *13th Five Year Plan for Economic and Social Development*, www.ndrc.gov.cn/gzdt/201603/P020160318576353824805.pdf; NDRC/NEA (2016b), *13th Five Year Plan for Energy Development*, www.ndrc.gov.cn/zcfb/zcfbghwb/201701/W020170117350627940556.pdf; NDRC/NEA (2016a), *13th Five Year Plan for Power Sector Development*,www.ndrc.gov.cn/zcfb/zcfbghwb/201612/P020161222570036010274.pdf.

Power sector planning is a binding exercise that has to consider the location and fuel availability of new investments. The planning management regulations therefore share many of the authorisations between the central government and provincial governments. Following a trend of decentralisation, planning responsibilities are now shared in the manner shown below.

National electricity planning focuses on:

- large-scale hydro generation, including pumped storage
- nuclear generation, including project construction arrangements
- defining shares of renewables generation and coal-fired generation
- cross-provincial and cross-regional grid project construction arrangements
- project construction arrangements of provincial 500 kilovolts (kV) and above electricity grids (including production and start).

On the other hand, provincial electricity planning focuses on:

- construction of large and medium-sized hydro plants (including pumped storage)
- coal, gas, nuclear and other project construction arrangements (including production and start)
- clarification of renewables generation scale and layout
- construction arrangements of 110 kV and above grids.

Over the last few years, the NEA has issued many guidelines that decentralise the approval process of many projects.

Investment approvals

China has decentralised many of the investment and authorisation processes in recent years. The Catalogue of Investment Projects Approved by the government has undergone three rounds of revision (in 2013, 2014 and 2016), since the first version was introduced by the central government in 2004. Table 4 shows the authorisation level, either central or provincial, for various types of projects in the power sector.

Table 4 • Decentralisation process: Government levels in charge of approvals in 2004 and 2016

Project	Approved by the central government in 2004*	Government in charge of approval in 2016**
Large hydro	Projects on major rivers and projects with a total installed capacity larger than 250 megawatts (MW)	Central government: Projects on major rivers and projects with a total installed capacity larger than 500 MW Provincial governments: Projects with a total installed capacity below 500 MW
Pumped storage station	Projects of every scale approved by the central government	Provincial governments
Thermal station	Projects of every scale	Provincial governments, if included in a national plan
Wind station	Projects larger than 50 MW	Provincial governments, if included in a national plan
Nuclear station	Projects of every scale approved by the central government	Central government
Grid	Projects of 330 kV and above	Central Government: Projects of 500 kv and above, and interregional lines

* www.gov.cn/zwgk/2005-08/12/content_21939.htm;

** www.gov.cn/zhengce/content/2016-12/20/content_5150587.htm.

Sources: NDRC (2004), *Notice of the State Council on Issuing the Catalogue of Investment Projects Approved by the Government*, www.gov.cn/zwgk/2005-08/12/content_21939.htm; NDRC (2016c), *Notice of the State Council on Issuing the Catalogue of Investment Projects Approved by the Government*, www.gov.cn/zhengce/content/2016-12/20/content_5150587.htm.

The comparison between the years 2004 and 2016 in Table 4 illustrates the trend to decentralise more technologies at larger scales to the provincial level, as well as the new measures to keep control of the total amount of investments through the Five-Year Plan in the 2016 Notice. Only projects foreseen in the national plans by the central government can receive approval by provinces.

Performance of planning processes

In a country that faced energy scarcity for many years, the capacity additions included in the Five Year Plans were considered as minimum targets. This explains why actual capacity addition and energy generation have been larger than the amounts issued in each of the last three Five Year Plans (Table 5).

Table 5 • Comparison of planned capacity versus actual capacity built

Five Year Plan		Planned value (adjusted)	Actual value	Actual value /planned value
10th (2001-05)	Generation (TWh)	1 750	2 497.5	1.43
	Increased capacity (GW)	70.68	197.86	2.77
11th (2006-10)	Generation (TWh)	3 200 (3 750)	4 080	1.28 (1.09)
	Increased capacity (GW)	132.82 (312.82)	432.82	3.23 (1.39)
12th (2011-15)	Generation (TWh)	5 763	5 694	0.99
	Increased capacity (GW)	1 490	1 521	1.02

Sources: State Economic and Trade Commission (2001), *10th Five Year Plan for Power Sector*, www.nea.gov.cn/2011-08/17/c_131054186.htm; NDRC (2007), *11th Five Year Plan for Energy Development*, zfxxgk.nea.gov.cn/auto79/201109/P020110921527315023013.pdf; NDRC (2013), *12th Five Year Plan for Energy Development*, www.gov.cn/zwgk/2013-01/23/content_2318554.htm; NDRC/NEA (2016a), *13th Five Year Plan For Power Sector Development*, www.ndrc.gov.cn/zcfb/zcfbghwb/201612/P020161222570036010274.

The new regulations on planning might change this trend, as no plant is allowed to trade energy if it is not considered in the Five Year Plan.

Mid- and long-term power trading

Mid and long-term power trading has been complementary to administrative allocation since 2002. Before the Document No. 9 round of reform, mid- and long-term contracting was referred to as direct power purchasing, which was allowed only between certain government-selected generators and government-selected consumers. In other countries, the mid- and long-term contracting price converges to the average spot market price because of risk-hedging behaviour. However, as China does not have a spot market but does have a benchmark pricing system with a regulated on-grid price and retail price, the mid- and long-term contracting price is always lower than the regulated price. Therefore, mid- and long-term contracting has become a method for provincial governments to lower costs for their local industries.

The central government promoted interprovincial and interregional trading for more-efficient system operation, but provincial governments were reluctant to participate in this trading. Interprovincial/regional trading was used to implement national-level energy strategies such as the Three Gorges Dam and west to east power transmission. The central government also piloted a regional wholesale market under the Document No. 5 round of reform to achieve more interprovincial/regional power transactions. However, this pilot ended quickly due to economic and institutional reasons.

Mid- and long-term contracting

Mid and long-term contracting makes up most of China's current power market trading (NDRC and NEA, 2016c). It became increasingly important after the central government launched Document No. 9, which marked the beginning of the new round of power sector reform. Power trading via mid- and long-term contracts (sum of intraprovincial, interprovincial and interregional trading) in 2017 reached 1 630 TWh (26% of the total power consumption, Table 6). This was 63% higher than that of 2016, which was 1 000 TWh (19% of the total power consumption).

The cost for transmitting the power must be clear to both parties ahead of the transaction so that buyers and sellers can successfully negotiate a price. However, this fundamental prerequisite was not in place in China before Document No. 9 reform, because the transmission and distribution fee used to be embedded in the power retail price, as the difference between the benchmark retail price and the benchmark on-grid price. Realising that this opaque transmission and distribution price acted as a barrier to the power market and required reform, the central government decided to make it more transparent. By December 2017, all provinces except Tibet had published an approved transmission and distribution fee.

Each province adopted a different market design for its mid- and long-term market trading (Table 7). In general, three types of market operate in China: bilateral negotiation, listed auction and centralised auction. Bilateral negotiation dates back to direct power purchasing (see Box 1). It is the most-common form applied by most provinces. Bilateral contracts can be monthly, quarterly or yearly. Contracts are discussed between generators and consumers through bilateral negotiation. These contracts are flexible in terms of price setting. They also result in a slightly lower price than centralised auction, mainly because the generator and the consumer develop a long-term relationship through the bilateral negotiation, which helps the price setting. Listed auction normally starts with the consumer side submitting power quantities and a predetermined price in a specified price level. The generation side can bid for these quantities. When there is a single buyer (usually the buyer would be a grid company) and a fixed price, multiple bids exceeding the amount of the auction are allocated according to capacity. Centralised auction allows generators and consumers to bid simultaneously. Under this framework, both sides submit quantities and prices to a centralised system, with a presettled algorithm to determine quantity and price for each participant. Single market clearing price, matched pairing and pay as bid are the three major ways for centralised auction.

The mid- and long-term trading currently adopted in China still has some problems. In particular, the time and location value of power cannot be included. Renewable energy trading still has only a small share of the total, but the mechanism does not provide special support for renewables.

Table 6 • Intra-provincial power trading

Province	Energy trading （TWh）	Intraprovincial trade / total traded energy （%）
Inner Mongolia	199.6	69
Yunnan	70.3	46
Guizhou	41.1	30
Anhui	55.0	29
Guangxi	38.2	26
Shanxi	50.5	25
Sichuan	52.5	24
Liaoning	50.4	24
Gansu	28.0	24
Qinghai	16.8	24
Jiangsu	126.5	22
Ningxia	21.3	22
Chongqing	20.2	20
Hubei	34.7	19
Guangdong	115.6	19
Shaanxi	28.5	19
Henan	54.6	17
Hebei	53.9	16
Fujian	31.2	15
Xinjiang	30.0	15
Shandong	75.4	14
Jiangxi	15.0	12
Jilin	8.3	12
Shanghai	14.1	9
Heilongjiang	8.7	9
Tianjin	5.2	6
Hunan	2.0	5
Zhejiang	1.3	3

Source: EPPEI (2017), 中国电力发展报告 [*Development Report of China Power Sector 2017*].

Table 7 • Mid- and long-term contracting

Province	Yearly contracting	Monthly contracting	Day-ahead contracting
Yunnan	Bilateral trading Guaranteed mutual contracting	Centralised bidding Bilateral trading	Unbalanced energy trading
Guangdong	Bilateral trading	Centralised bidding	
Shandong	Bilateral negotiation	Centralised bidding	
Shaanxi	Bilateral negotiation	Centralised bidding (quarterly)	
Hunan	Bilateral trading Listed transactions	Centralised bidding Bilateral trading	
Sichuan	Bilateral negotiation Retry bidding	Retry bidding	Unbalanced energy trading (weekly)
Chongqing	Bilateral trading	Unbalanced energy trading	
Jiangsu	Bilateral trading	Centralised bidding	
Guangxi	Bilateral trading	Centralised bidding	
Jiangxi	Bilateral trading		

Source: EPPEI (2017), 中国电力发展报告 [*Development Report of China Power Sector 2017*].

Box 1 • Direct power purchasing

Direct power purchasing was the initial form of mid- and long-term contracting. The SERC issued an official document, *Interim Measures for Direct Contracting between Power Producers and Consumers* (SERC and NDRC, 2004; SERC, 2009; SERC, 2010b), allowing large industrial consumers to directly negotiate and sign contracts with power generators. Before then, all power generation was distributed by administrative allocation. The application of direct power purchasing was the first market-based mechanism introduced in China's power sector.

At the beginning, provincial governments usually granted 2-10% of the total amount of the yearly generation plan to direct power purchasing. Direct power purchasing was organised by provincial governments, with participants chosen from power generation companies and large industrial consumers. The price agreed by the generator and the consumer was settled as the new on-grid price. The retail price would be the sum of this on-grid price and a predetermined transmission and distribution fee. Given that the transmission and distribution fee was not published as a separate price until recently, the grid company had some degree of freedom to fix it. After signature by both parties, a direct power purchase contract was sent to the grid company for a security check, and then to the central government (the NDRC) for official approval.

Direct power purchasing had some specific Chinese characteristics. First, consumers could always purchase power at a fixed benchmark retail price without signing a direct contract. They would therefore only agree to sign the contract if the price was lower than the benchmark retail price. Second, until 2009, it was not clear if the contracted portion of the capacity should be taken away in the year operation planning (i.e. if contracting via direct contracts would reduce by the same amount the energy sold through the traditional fair dispatch process), which remained a controversial topic for several years. Third, a limited number of players, chosen by the central government, could participate in direct power purchasing, which seemed unfair to other generators and consumers. Fourth, the total amount of energy traded was small, and there was no spot market as a companion tool; therefore, it had limited influence in system efficiency improvement. Fifth, possible fluctuations of coal price were usually not included in the direct power purchase contracts.

Direct power purchasing became a policy tool for provincial governments to reduce the power cost for local industrial and commercial consumers. By applying direct power purchasing, provincial governments were able to bypass the fixed on-grid and retail prices benchmarked by the central government. Power generators were therefore sometimes mandated by provincial governments to sign direct contracts with lower prices.

After the administration decentralisation campaign in 2013, provincial governments were authorised to approve direct contracts. Direct contracts therefore expanded in scale and scope.

Interprovincial/interregional trading

Interprovincial/interregional trading was first introduced in 2003 after the SERC released an official document, *Provisional Rules for Optimal Inter-provincial Power Dispatch* (SERC, 2003a). By the end of 2017, power exchange via interprovincial/interregional trading reached 290 TWh, 17.8% of the total amount of power exchanged via market. The transmission fees for the interprovincial power grids including those for Northern, Eastern, Central, Northeast and Northwest China have been published, and several ultra-high voltage (UHV) lines started the process of developing estimates for the transmission fee at the beginning of 2018.

Introducing interprovincial/interregional trading was intended to improve the overall efficiency of power systems and make provincial grids more resilient by sharing their energy and backup services. Direct power purchasing is more of a new market arrangement using the existing strong provincial physical structure and under the framework of the well-established institution of intraprovincial power balance. However, interprovincial/interregional trading requires grid co-ordination among different provinces. There are two challenges to encouraging trade: institutional and technical. The institutional challenge is that each province has its own system and no joint governance. This makes trading more difficult to co-ordinate for two provinces connected to one another. Trading among non-adjacent provinces is even more difficult to envisage. Interprovincial links are relatively small, limiting the technical ability of provinces to trade with one another.

The power flow of interprovincial/interregional trading includes: coal and wind power transmission from Northeast China to north China, hydro power transmission from Central China to Southern China and coal power transmission from east or Northwest China to Central or Northern China (Table 8). Most generation was still allocated through centrally planned annual planning, while market exchange held only a small share. Grid companies played a dominant role in interprovincial/interregional trading. Therefore, the power generators closely related to the SGCC got a better chance to participate in the trading process, while the local power generators and private generators were less likely to participate.

There are several problems and non-market behaviours in the trading process, given that the government and grid companies control interregional/interprovincial trading. There are also technical restrictions.

The first problem is that the planned portion of interregional/interprovincial trading could have a negative impact on power source optimisation. Since the SGCC took charge of the interregional/interprovincial trading plan, some power units directly dispatched by the SGCC from the exporting province could obtain generation hours allocated from the SGCC. This resulted in a higher capacity factor than power units in the importing province, which was perceived as being unfair to generators in the importing province. Also, though the yearly interregional/interprovincial trading plan should be a guideline proposed by the SGCC, provincial grid companies usually took it as a mandatory contract, resulting in inflexibility. An example was in June 2012, when Sichuan Province already had hydro curtailment because of the expectation of rainy weather, but it still had to import 350 gigawatt hours (GWh) of energy from north China, according to the interregional trading plan.

Table 8 • Interprovincial/interregional power exchange, by category

<table>
<tr><th colspan="2">Category</th><th>Examples</th><th>Volume (TWh)</th></tr>
<tr><td rowspan="3">Planned exchange</td><td>Mandated or approved by the central government</td><td>Three Gorges (18 200 MW hydro, Hubei-to-Eastern, Central, Southern Grid)
Ezhouba (2 715 MW hydro, Sichuan-to-Central, Eastern Grids)
Ertan (3 300 MW hydro, Sichuan-to-Chongqing)
Lijiaxia (2 000 MW hydro, Qinghai-to-Eastern regions)
Yangcheng (1 200 MW coal, Shanxi-to-Jiangsu)
Jinjie (3 600 MW coal, Shaanxi-to-North Grid)
Fugu (3 600 MW coal, Shaanxi-to-North Grid)
Western Inner Mongolia-to-East
Wandian-to-East (Anhui-to-Eastern Grid)
Yimu high-voltage direct current line (Eastern Inner Mongolia-to-Northeast Grid)
Power plants directly dispatched by specific regional dispatch centres (RDOs)</td><td>358.8</td></tr>
<tr><td>Facilitated by provincial governments</td><td>Power exchange within the CSG region</td><td>81.9</td></tr>
<tr><td>Planned by grid companies</td><td>High-voltage interregional exchange
Eastern Ningxia-to-Shandong
Power plants directly dispatched by specific RDOs
Power exchange between the SGCC and CSG</td><td>109.3</td></tr>
<tr><td colspan="2">Market exchange</td><td>Exports from the Northeast Grid
Transactions between Northwest and Central Grids
Transactions among the Eastern, Central and Northeastern Grids
Lijiaxia non-planned power exports
Non-planned Southern Grid transactions</td><td>74.1</td></tr>
<tr><td colspan="3">Total</td><td>621.3</td></tr>
</table>

Source: SERC (2010a), 年度全国电力交易与市场秩序情况监管报告 [*2009 Regulatory Report on National Electricity Trading and Market Order*], www.spic.com.cn/flgz/gfxwj/201301/P020130105510691871037.pdf.

Another problem is that investments in transmission lines have been lagging behind the rapid development of clean energy (wind, solar and hydropower). The great potential for using interregional/interprovincial transmission to reduce curtailment has remained underutilised, because of these transmission constraints.

Regional wholesale market

A consideration for the reform in 2002 was to increase interprovincial power flows, allowing power to flow from low-cost provinces to high-cost provinces and resulting in better system efficiency. From 2003 to 2006, the SERC promoted a pilot regional wholesale power market in Northeast China, including Liaoning, Jilin and Heilongjiang Provinces.

There were several convincing reasons for establishing a regional market in the Northeast region. First was it was the only region with an excessive power supply at that time. The maximum load was about 60% of the overall capacity. Second was the good infrastructure in terms of regional transmission lines. Third was that retail prices for these provinces were similar, and hence had the advantage of easier implementation.

A pilot market was designed to unify dispatching and a two-part tariff structure, with a selection group of 10-20% of the total generation in the Northeast region participating in the market. The two-part tariff included a capacity price and a power output price, aiming to facilitate a competitive power pool. The central government determined the capacity price, based on the average investment costs of generators.

This pilot design encountered several obstacles. It was ended by the SERC in 2006 for the following main reasons:

- The power shortage in several provinces and the California electricity crisis meant that stakeholders were reluctant to undertake potential risks for market competition.
- Many generators that participated in the market still had PPAs, and were therefore not willing to fully engage in the market.
- The regional wholesale market meant that importing provinces had lower prices but lower operation hours for their own generators, while exporting provinces had increased operation hours but higher prices. This made it difficult for provincial governments to balance their intraprovincial generators.
- The regional wholesale market price increased dramatically in 2005, due to the soaring coal price. However, the retail price was fixed, hence causing large deficits for grid companies. The grid companies wanted to increase retail prices, but this was firmly rejected by the provincial governments. This was because it would have a profound negative effect on provincial heavy industry, which has been the pillar of industry in Northeast provinces since the foundation of China.

After the end of the Northeast regional market, no further attempts were made to form a regional market until the announcement of a new round of reform under Document No. 9. The NDRC announced a plan in July 2016 to unify dispatch in the Beijing-Tianjin-Hebei region. The plan was to first unify the annual administrative generation plan and direct contracting, and then trial a regional spot market if circumstances allowed.

Establishing trading centres and regulatory committees

- As part of Document No. 9 implementation, and with the objective of facilitating mid- and long-term trading, 35 power trading centres had been founded nationwide by January 2018. These include a regional trading centre in Beijing to cover interprovincial transactions in SGCC and one in Guangzhou to cover interprovincial transactions in the CSG, and 33 provincial trading centres.
- Twenty-six regulatory committees were founded based on power trading centres. Members of the regulatory committee were from power generation companies, power grid companies, power sales companies, consumers and trading centres.

Generation rights trading

Generation rights trading has been introduced for improving energy efficiency and reducing pollution in the power sector (SERC, 2008a). The trading process allows power generation rights to be transferred from generators of fossil fuels (e.g. coal, oil and gas) to power generators that do not use fossil fuels (e.g. hydro, wind, PVs and nuclear), and from low-efficiency, high-emission coal power to high-efficiency, low-emission coal power. The generation hours that power generators get from administratively allocated generation quotas (base generation hours) and mid- and long-term bilateral contracts (direct contracting) are permitted to be traded within the generation rights trading system.

The idea of generation rights trading was proposed in 2007. Back then, coal power had a 70% share of the total power capacity mix. Though the installed capacity of large-scale advanced coal power has increased since 2000, the 30% coal power capacity was below 100 MW, with low efficiency, high emissions and a long operation period. The central government decided to shut these small coal power plants down, as their operation under fair dispatch influenced the overall efficiency of the power system. These small coal power plants continued to receive generation quotas for 3 years, as compensation, which they could sell to more-efficient plants to obtain revenue.

Generation rights trading was mainly intraprovincial and under the instruction of provincial governments before the release of Document No. 9. There were no trading centres such as those at Beijing and Guangzhou. Moreover, wind and PV trading was not included, as the shares of wind and PVs were small at that time.

The scale of generation rights trading in 2017 was 152.77 TWh, which increased by 25% on a year-on-year basis, and was 2.4% of the total power consumption. Guangzhou trading centre organised interprovincial generation rights trading in May 2017, among a group of 49 coal power plants in Guangdong and a group of 14 hydro power plants in Yunnan. Though both sides showed great interest, the final deal was just 24 GWh due to the maximum trading limit set by the trading centre.

The NEA further encouraged interregional generation rights trading of renewable energy in May 2018. An example is the eastern province of Jiangsu trading its coal power generation rights to wind power in the Northwestern provinces of Gansu and Xinjiang, which started at the end of May 2018. Specifically, trading between a Jiangsu coal power generator and a Gansu wind power generator, with a total generation energy of 30 GWh transferred to the wind generator, saw the on-grid power price set at CNY 0.391 (Chinese Yuan renminbi) per kilowatt hour (kWh). Through this trading deal, the coal power generator from Jiangsu earned CNY 0.04/kWh more compared to its benchmark on-grid price, not to mention its saving on fuel costs. In addition, the wind power generator from Gansu earned a total profit of CNY 0.33/kWh with the renewable energy subsidy also included, and managed to reduce its curtailment.

Power dispatch

System operators in many countries usually minimise costs based on a merit-order dispatching approach. However, power dispatch in China is different. Provincial governments are responsible for preparing an administrative dispatch plan every year. Following this plan, each generator in the province gets its annually allocated number of operating hours, following a fair dispatch rule that ensures the same operating hours for the same type of power generator.

The fair dispatch rule has successfully incentivised power investment and helped China tackle its power supply shortage. But as the economy has entered a new stage and the main issue has been transferred from power construction to system efficiency and adopting clean energy, the current fair dispatch system is no longer appropriate.

Some provinces in China have tried a new dispatch system called energy conservation dispatch. This prioritises renewables and nuclear energy, and continues with coal power generators based on their operating efficiency. However, this system has encountered some practical obstacles and its application is therefore limited in the current dispatch system.

Administrative generation plans

The current dispatching regulation in China follows two official documents issued by the State Council: *Regulations on Management of Power Grid Dispatching* (State Council, 1993) and *Implementation of Regulations of Power Grid Dispatching* (NEA, 1994), in which the key principle is unified dispatching and multilevel management.

Provincial-level governments play a decisive role in terms of administrative dispatch planning. Provincial economic and information commissions (sometimes industrial and information commissions, or provincial development and reform committees) generally take charge of making a yearly generation plan. The overall power demand and supply balance will be predicted, and generation hours will be granted to each power generator, taking into consideration interregional contracts, interprovincial contracts and intraprovincial contracts. The remainder will be administratively allocated (see the fair dispatch rule section below). The provincial dispatching organisation provides advice during preparation of the dispatching plan. Usually, the dispatching plan for the year ahead is finalised and published in late December of the previous year.

Dispatching organisations are responsible for execution of the generation plan once it has been agreed. Dispatching organisations belong to grid companies, and are usually at five levels: national, regional, provincial, prefectural and county. The national, regional and provincial levels play crucial roles in the current dispatch system. The national level is in charge of dispatching above 500 kV transmission (UHV lines); the regional level is in charge of dispatching regional transmission with voltage levels of 330-500 kV; and the provincial level is in charge of provincial transmission with a voltage level of 220 kV.

For every power generator, a yearly generation plan is an administrative instruction, rather than simply a guideline. The yearly generation plan will be dissolved into a monthly generation plan that considers the monthly hydro output prediction, fuel price and supply, heating supply and generator maintenance plans. The monthly generation plan will be further disaggregated into a daily generating curve.

Dispatch centres

Table 9 • Power dispatch hierarchy in China

Level	Host	Jurisdiction	Key functions
National dispatch centres	SGCC	Voltage level: >500 kV Generators: large thermal or hydropower interregional transmission	Interregional balancing Interregional dispatch
RDOs	Regional grid companies	Voltage level: 330-500 kV Generators: pumped hydro storage, regulation	Interprovincial balancing Interprovincial dispatch
Provincial dispatch centres	Provincial grid companies	Voltage level: 220 kV (330-500 kV terminal substations) Generators: large generators not controlled by RDOs or national dispatch centres	Intraprovincial balancing and dispatch Co-ordinating load management Scheduling
Prefecture dispatch centres	Prefecture power supply organisations	Voltage level: ≤220 kV Generators: smaller local generators	Prefecture load management
County dispatch centres	County power supply organisations	Voltage level: ≤110 kV Generators: any remaining generators	County load management

Source: RAP (2015), *Integrating Renewable Energy into Power Systems in China: A Technical Primer*. www.raponline.org/wp-content/uploads/2016/05/rap-e3-chinaelectricityplanning-2015-oct.pdf.

The rules and regulations governing power dispatch in China were stipulated by the State Council in 1993 and modified in 2011. The NEA has the authority to determine the responsibilities of dispatch organisations, which are power dispatch and communications centres within the SGCC/CSG and their provincial and regional grid companies.

The organisational hierarchy laid out in the regulations is based on a principle of "unified dispatch and multilevel management". This principle sought a compromise between the need for unified dispatch, following a diversification of generation ownership, and the prerogatives of local governments to manage local generation and loads. Multilevel management is based on a five-level hierarchy of dispatching organisations (see Table 9), each with a separate jurisdiction and function.

Fair dispatch rule

The fair dispatch rule is the dispatching rule in China. It administratively allocates generators within the same category (e.g. coal power, hydro, wind and solar PVs) roughly the same base generation hours. Provincial governments grant base generation hours to generators. These generation hours are therefore different from those that generators can obtain via direct contracting or generation rights trading.

When the fair dispatch rule was first implemented in 1987, all coal power plants were granted exactly the same base generation hours, with the purpose of guaranteeing equal opportunity for cost recovery (see Box 2). An adjustment to allow differentiated base generation hours took place years later when considering the influence of technologies in efficiency and pollutant emissions. For instance, in the 2016 yearly generation plan of Fujian Province, supercritical coal power units of 600 MW were granted 150 more hours than the 300 MW-units. Ultra-supercritical coal power units of 600 MW were granted 100 more hours than the 600 MW-supercritical coal power units (the average base generation for coal power plants was 3 881 hours). In addition, coal power units that had completed ultra-low-emission retrofitting were granted 200 more base generation hours in several provinces.

Box 2 • Reasons why the power sector in China uses fair dispatch

The fair dispatch rule dates from the 1980s, when the power sector was first opened to independent power producers to increase investment to meet rapidly rising demand. To assure independent power producer investors that their plants would be able to operate, China implemented a fair dispatch rule to incentivise investment in the power sector. For that purpose, the central government issued an official document, *Interim Provision on Providing Incentives for Power Generation Financing and Implementing Multiple Electricity Tariffs* (State Council, 1985). The principle was that all generators of the same type (e.g. coal) in a given province were granted equal numbers of generating hours, regardless of their capacity, efficiency, emissions or operation years.

Implementation of the fair dispatch rule encouraged greater independent power producer investment. However, it removed incentives for plants to be efficient. As a result, plants with low operation efficiency and high emissions level were guaranteed significant revenue. The rule created an ingrained belief among power generators that everyone should get an equal share of benefit no matter how inefficiently or environmentally unfriendly they performed.

Base generation hours vary for different provinces because their economic circumstances vary, and therefore the power demand is not the same. In some provinces rich in wind and solar resources, base generation hours for coal power plants have decreased significantly in recent years to accommodate the rapid growth of wind and PV installed capacity.

Fair dispatch is contradictory to renewable energy development. Though renewable energy has guaranteed purchasing hours, there is no mechanism to encourage more renewable generation in addition to the guaranteed portion. Instead, the fair dispatch rule allocates the remaining generation hours to fossil fuel power plants. One way to encourage development of renewable energy is the application of energy conservation dispatch, which was proposed by the central government in 2007 (see the next section below). However, only some provinces have adopted energy conservation dispatch, mainly in the region covered by the Southern grid. Most provinces still use fair dispatch in China.

Energy conservation dispatch

Energy conservation dispatch was implemented in 2007, (NDRC and NEA, 2007) aiming at energy conservation and environmental protection. Energy conservation dispatch tends to minimise fuel consumption and pollutant emissions, unlike the economic or merit-order dispatch that some countries adopted with minimum cost as a target. The merit order for generators would be: 1) renewables that cannot provide a grid service, including wind, PVs and some hydro; 2) renewables that can provide grid services, including some hydro, biomass and geothermal; 3) nuclear; 4) co-generation; 5) gas-fired; and 6) coal-fired plants. Coal power plants were to be prioritised in order of heat rates, and if two units had the same heat rate, they would be further prioritised by emissions levels.

The central government chose Guangdong, Guizhou, Jiangsu, Henan and Sichuan Provinces as the first pilot provinces in 2007. The Southern grid further enforced energy conservation dispatch in all five of its provinces (Yunnan, Guizhou, Guangdong, Guangxi and Hainan) at the end of 2010. In the Southern grid region, the provincial development and reform commission organised the yearly, quarterly and monthly dispatching plan. Intraprovincial plans were first made and then optimised to include interprovincial contracting. The dispatching order of coal power plants was decided by real-time coal-consumption rate measurement and pollutant emissions monitoring data provided by the provincial environment bureau. By the end of 2017, 17.66 million tonnes (Mt) of coal-equivalent savings, 46.98 Mt of CO_2 emissions reduction and 0.35 Mt of sulphur dioxide reduction were achieved in the Southern grid region.

If energy conservation dispatch had been fully implemented, it would ideally have significantly improved clean energy integration and reduced emissions. However, promoting energy conservation dispatch was extremely challenging. The main challenge was that it would result in lower generation hours for some coal plants than when applying fair dispatch. Not surprisingly, coal generators (many of whom were owned by provinces) were concerned by the potential loss of revenue given that there was no clear guidance on the financial compensation for these units.

Jiangsu and Henan Provinces used generation rights trading and differentiated base generation hours to achieve similar effects as energy conservation dispatch. This was due to lack of an economical compensation methodology and market mechanism, according to a monitoring report (SERC, 2010a). Sichuan Province returned to fair dispatch after 4 years of piloting energy conservation dispatch.

Establishing spot markets

Although Document No. 9 and the following six supporting guidelines (see the Annex below) on implementation of the reform provide an idea of how Chinese provincial markets will look, the details are still uncertain. This is because provincial governments are in charge of implementation, and they have much freedom in defining their market design.

It is likely that provinces will follow the initial successful examples and pilots. This section therefore describes some interesting cases that give the best indication of how the provincial power markets may look.

North-east ancillary services market

The Northeast region of China consists of Liaoning, Jilin and Heilongjiang Provinces and the east Inner Mongolia area. The Northeast grid piloted a market-based system in 2014. This was to improve renewable energy integration and was referred to as the Northeast peak ancillary services (deep-down regulation) market. The market operates on a day-ahead basis and creates an incentive for coal power plants to reduce their generation at certain times to allow for wind and PV power generation instead.

The Northeast region became industrialised early, because of its natural resources, particularly coal and oil deposits. Co-generation[2] units make up a large share of the total power mix because of this resource advantage, together with the region's cold winters and large population. The region's wind and PV capacities have developed rapidly in recent years, due to China's energy transition and government subsidies to incentivise renewable energy development. The combination of a high share of co-generation capacity, which presents a bundling between heating and power production, and a high share of wind capacity caused significant renewable energy curtailment in the winter heating season.

Heating demand dictates the operating levels of co-generation plants during the winter, with associated electricity production taking priority over other generation sources. The peak ancillary services market provides an opportunity for these plants to offer to reduce their electricity generation in exchange for an incentive payment. The exact levels of the payments depend on the type of generator and the extent of reduction.

As an example, the assumed minimum generation of a co-generation unit is 50% of its maximum. A co-generation unit operating at 36% of its maximum output can therefore bid energy reduction into this market at two levels. For the 10% reduction from 50% to 40%, the plant can receive a price of CNY 0-0.4/kWh, depending on the clearing price. For the 4% reduction from 40% to 36%, the plant can receive a price of CNY 0.4-1.0/kWh (Table 10). The costs of the ancillary services market payments are shared among all other generators operating above their minimum output, including all co-generation units operating above 50%, wind power operating above 0% and nuclear power operating above 77%.

Table 10 • Ancillary services market bidding output tiers and limits for coal plants

	Non-heating season outputs		Heating season outputs	
	Tier 1	Tier 2	Tier 1	Tier 2
Electricity-only plants	40-50%	≤40%	40-48%	≤40%
Co-generation plants	40-48%	≤40%	40-50%	≤40%
Price floor	≥0	≥CNY 0.4/kWh	≥0	≥CNY 0.4/kWh
Price ceiling	≤CNY 0.4/kWh	≤CNY 1.0/kWh	≤CNY 0.4/kWh	≤CNY 1.0/kWh

Source: NEA (2016f), 东北电力辅助服务市场运营规则(试行) [*Operation Rules for North-east Ancillary Services Market (Trial)*], www.raypwr.com/DownFile/?ContentId=216.

The NEA officially authorised the Northeast ancillary services market as a pilot project for China's power market reform in October 2016. The pilot project began operating at the beginning of 2017. Since its inception, 86 out of 88 large-scale, national-dispatch coal power plants have operated below 50%, and 73 of these have operated below 40%. The space created by this reduction in coal generation has reached 3 GW, which has significantly improved the integration

[2] *Co-generation* refers to the combined production of heat and power.

of renewable energy during the winter heating season. Nuclear power also gets a higher capacity factor compared to previous years by paying the ancillary services market fee.

The Northeast ancillary services market has therefore been successful. Based on the Northeast example, provinces such as Shandong, Shanxi, Gansu, Ningxia, Xinjiang and Fujian have introduced, or are planning to introduce, their own ancillary services markets (Table 11).

Table 11 • Ancillary services market

Province	Peaking adjustment (day ahead)	Frequency adjustment
Northeast	√	
Xinjiang	√	
Fujian	√	
Ningxia	√	
Shandong	√	
Shanxi	√	√ (weekly)
Gansu	√	
Guangdong		√ (day ahead)

Source: EPPEI (2017), 中国电力发展报告 [*Development Report of China Power Sector 2017*].

Interregional surplus renewable spot market

An interregional spot market of surplus renewable generation was established in August 2017 (National Dispatch Centre, 2017). This aimed to promote renewable integration, especially reducing the curtailment of wind, PV and hydro generation in Southwestern and Northern areas of China. Sellers participating in the spot trading are generation companies in the sending-end power grids, mainly in Gansu, Xinjiang, Ningxia, Qinghai and Sichuan Provinces, where limited demand within regions failed to match the abundant renewable resources. Buyers in the receiving-end grids can be either consumers, electricity sales companies or grid companies.

The spot market runs at a small scale due to reliability and stability considerations. The premise of entering the spot market is that in the sending-end power grid, after using up all methods to integrate local renewable generation and settling all the long-term contracts, renewable plants are still able to generate and a curtailment is predicted. Trading this amount of "surplus" generation is allowed on the spot market, utilising the remaining transmission capacity among regions. The pricing of the surplus generation tends to be low, which is favourable to the receiving-end provinces in the Central and Eastern parts of China.

China has made progress after foundation of the spot market. By the end of 2017, 6 billion kWh surplus renewable generation had been traded on the spot market throughout China. Gansu Province, with abundant wind and solar resources, was the largest provider in the renewable surplus spot market, selling 2.35 billion kWh in the first half of 2018.

Guangdong spot market

The first spot market pilot began operation on 31 August 2018, in the province of Guangdong. Although the first pilot project covered only Guangdong, the objective is to gradually include all the provinces in the Southern China Power Grid Company's footprint (Guangdong, Guangxi, Yunnan, Guizhou and Hainan).

If successful, this market design could be the basis for many spot markets in the other Chinese provinces. The design of the market considers many features that are state of the art, including:

- central optimisation of the commitment and dispatch of units by the system operator, taking generators bids and security constraints into account
- a gross pool model, where prices will be defined by the most expensive clearing bid
- the high granularity of prices, geographically (with different prices for every node in the system) and temporally (with trading intervals of 15 minutes)
- integration of operations of large geographical area, which will allow participating provinces to benefit from sharing their resources
- demand and supply will be allowed to bid, although only generators will be able to bid in the first stage of the pilot project
- optimisation of all ancillary services
- long and medium-term contracts will be settled through contracts for differences, taking as reference the price in the day-ahead market
- a centralised system of bonds that will be used to guarantee all the long, medium and short-term transactions, meaning that power exchange will work as well as a clearing house
- implementation of capacity markets, financial transmission rights and other derivatives left after 2020.

The market considers the existence of plants not participating in market transactions (type A plants) and that will continue with the existing on-grid feed-in price, and those participating in the market (type B plants). The description of the market acknowledges that old rules will coexist with the new market, but defines as an explicit objective the gradual phasing out of the amount of generation defined by administrative authorities in type B plants. It is unclear how generating hours will be defined for type A plants, given that it will be affected by the number of customers opting out of the regulated retailer.

This pilot project has many items that deserve acknowledgement, but it is generally a technically sound system that will improve efficiency and decrease system costs. It is not clear to what degree the generation of both types of plants (A and B) would be defined by administrative decisions, or if, for instance, contracts for difference could be used to separate the administrative defined price and quantity from the system operation. Separating the administrative defined price and quantity for the system operation would provide more freedom to the system and would reduce the overall costs of the system.

Pricing systems

Wholesale and retail electricity prices in China are regulated to ensure overall recovery of costs to build and operate power plants. The central government sets benchmark prices for each province, according to their costs and economic development level.

Feed-in tariffs

Feed-in tariffs for all power generation types are benchmarked in China, and are regulated by government. Provincial governments decide the feed-in tariffs, and report them to the central government for approval.

Feed-in tariffs can substantially differ in different provinces, due to the variation in natural resources and economic development. The type of generator also affects the feed-in tariff. Hydro power plants usually have the lowest price, followed by coal, nuclear, gas, wind and solar power plants, in ascending order.

The benchmark feed-in tariff was first implemented in 2004, aiming at sending a clear price signal to investors to encourage improvements in the efficiency of newly built generators. Under a system with the benchmark feed-in tariff and fair dispatch rule, capital costs and annual energy costs of each power plant are supposed to be recovered with the power price per kWh and the administratively allocated number of operation hours.

Before the benchmark feed-in tariff mechanism, the "new price for new power units" and "operating period power price" were used to determine the on-grid power price. Box 3 gives further details of these two mechanisms (State Council, 2003).

Box 3 • History of the Chinese pricing system

Before 1986, all power plants in China were constructed with investment from the central government. The on-grid price of power was set according to approved catalogues published by the central government, which took into account operating costs but not capital costs.

Faced with a rapid growth in economy and a severe power shortage in the 1980s, together with a budget shortage, the central government started to allow investment from multiple sources, including local governments, SOEs, private sector players and foreign investors. To further attract investment in power generation, newly built plants were allowed to charge higher power prices to recover costs and to provide a fixed return on profit. This so-called "new price for new power units" enabled the setting of a new price separately for each newly built power unit, considering its efficiency, fuel type, location and whether it was used for baseload or peak adjustment, and another new price after the debt repayment period. This policy led to substantial differentials in the power price. For example, the average price paid to coal power units constructed before 1985 was CNY 240 per megawatt hour (MWh), while the average price paid for new units built in 1997 was CNY 410/MWh.

The "new price for new power units" effectively boosted investment, but it was based on the separated cost of power units and provided no incentive for investors to reduce their costs. The central government introduced a new policy known as the "operating period power price" in 1998 to encourage efficiency improvement and cost reduction, considering a sufficient power supply using the existing fleet. This policy set the price on the expected lifetime of a plant, rather than on the debt repayment period. The cost of a new plant was measured by the average cost of similar types of plant, and the assumed return on equity was set at 2-3% above the long-term lending rate. The average on-grid price reduced by CNY 50/MWh after implementation of the "operating period power price" policy, successfully maintaining the competence of China's industries during the Asian financial crisis.

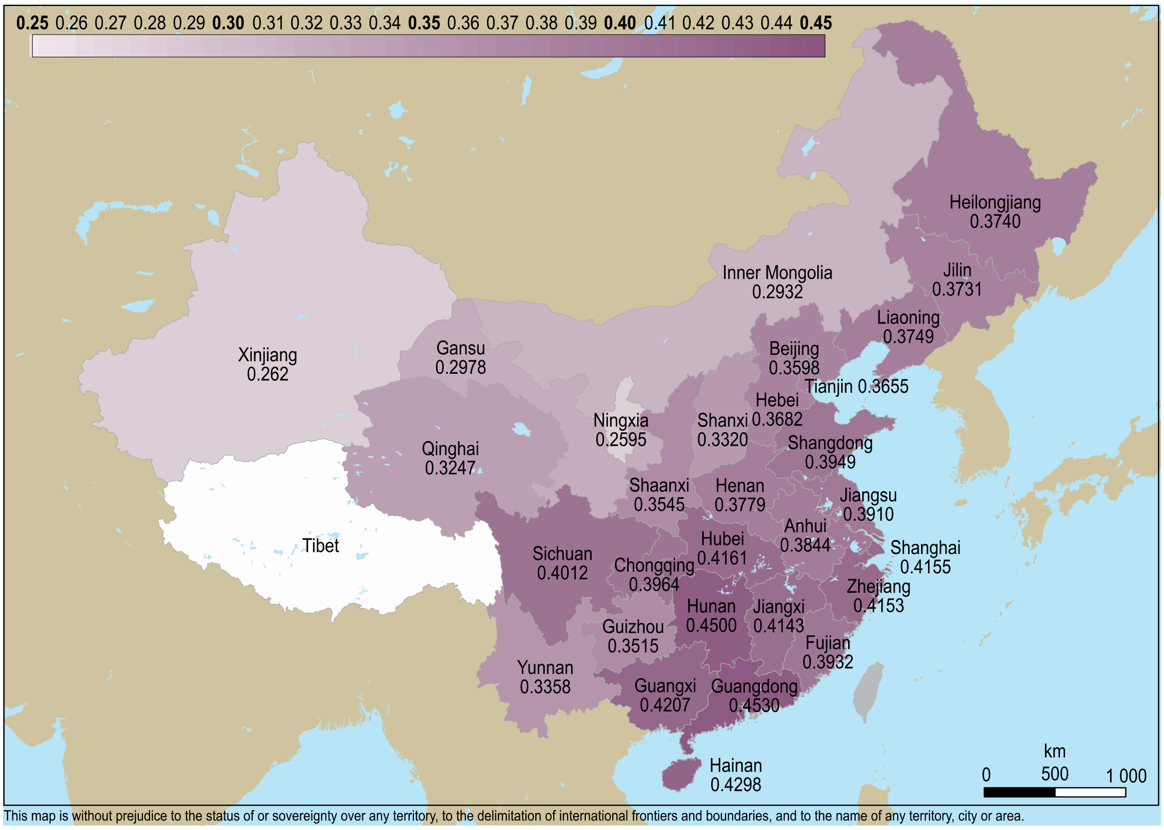
Coal power

Coal power has the largest share in China's power mix (65.5%). Therefore, the feed-in tariff of coal power is crucial to the power sector. As mentioned above, provincial governments propose the benchmark feed-in tariff of coal power, which varies among provinces. For example, in 2018, the feed-in tariff for coal power in the less-developed, coal-rich province of Gansu was benchmarked at CNY 297.8/MWh, while the feed-in tariff in the more-developed, coal-poor province of Guangdong was benchmarked at CNY 450.5/MWh.

There are additional tariffs for coal power. These tariffs are mainly for air quality improvement and emissions reduction. Additional charges for desulphurisation (since 2004), denitrification (2011) and dust removal (2013) are added to the benchmark price for units that have installed controls. The NDRC is responsible for issuing the benchmark on-grid price and the additional tariffs on environmental protection. The additional environmental tariff in 2013 for desulphurisation was CNY 15/MWh, for denitrification was CNY 10/MWh and for dust removal was CNY 2/MWh. To ensure the emissions control devices were operating, the local environmental protection bureau monitored the emissions data of every coal power plant on a daily basis. By the end of 2017, all coal power plants had installed desulphurisation devices, 92%

had installed denitrification devices and all had installed dust removal devices, incentivised by the additional environmental tariffs (NDRC, 2011b).

Figure 11 • Coal power feed-in tariff (CNY/KWh), 2018



Source: NDRC (2017d), 关于取消、降低部分政府性基金及附加合理调整电价结构的通知 [*Notice on Cancellation, Reduction of Some Government Funds and Additional Reasonable Adjustment of Electricity Price Structure*], www.sohu.com/a/202517251_99908549.

After implementation of the feed-in tariff for coal power, the benchmark price underwent several rounds of administrative adjustment. The main reason was the large change in the average cost of power generation, which could be due to changes in coal prices, construction costs, annual generation hours, fixed costs, long-term lending rates, depreciation rates or repayment periods.

The latest round of administrative adjustment was in July 2017. At that time, the soaring coal price caused nationwide complaints from coal generators about losing money. The central government issued a document on reducing the government funds bundled in the benchmark retail price. This was to alleviate the operational difficulties of coal generators while attempting not to increase the cost of electricity for end users. The reduction of government charges allowed provincial governments to increase the feed-in tariff of coal power plants. Figure 11 shows the prevailing feed-in tariffs.

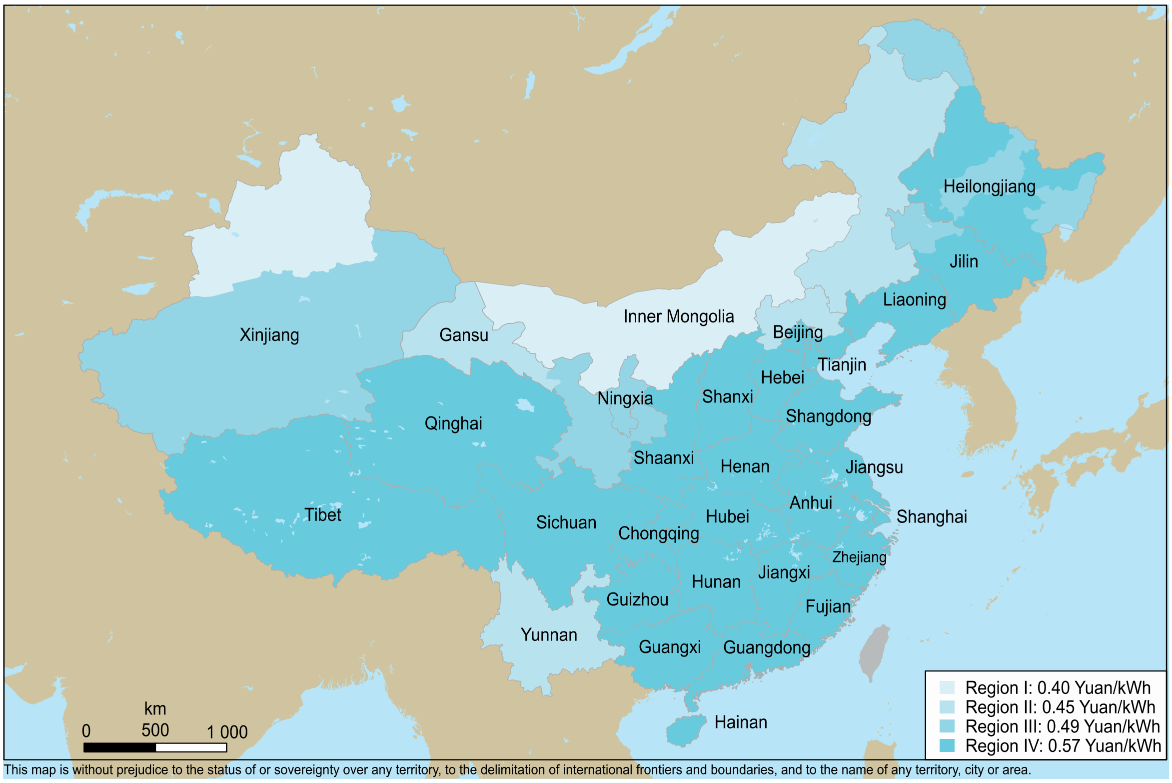
Feed-in tariffs are adjusted through a mechanism called "price linkage for coal and electricity", introduced by the NDRC in 2004. This mechanism is a formula that includes standard coal consumption and the heat value of coal to define this linkage. An average change in coal price of 5% or more will trigger an immediate adjustment of the coal power feed-in tariff, based on a review over six or more months. As wholesale and retail prices are regulated, high prices for coal do not translate automatically into higher power prices.

This price linkage mechanism revealed several problems. First, the mechanism was unable to adjust the power price in time and efficiently, because the adjustment was always made way after the coal price rose and power generators needed to absorb 30% of the coal price change. Second, by applying this mechanism, there is a possibility of creating a cyclical rise in the price of coal and the price of coal power. Third, a 2015 revised document on the coal and electricity linkage allowed adjusting the power price only at the beginning of the next year, which seemed inefficient compared to other possible administrative measures. Today, the coal price in China depends on the market. Prices change frequently, but the administrative mechanism only allows changes periodically. When coal prices rise, it may be difficult for generators to remain profitable.

Wind and solar power

The benchmark feed-in tariff for wind power was first introduced in 2009. Prior to this, wind power plants received tariffs determined on a project basis or through concessions determined by competitive auction. Under the feed-in tariff system, regions in China belong to four tiers, each of which has a with different tariff level, depending on factors such as wind resource quality and construction costs.

Figure 12 • Onshore wind feed-in tariff per region, 2018



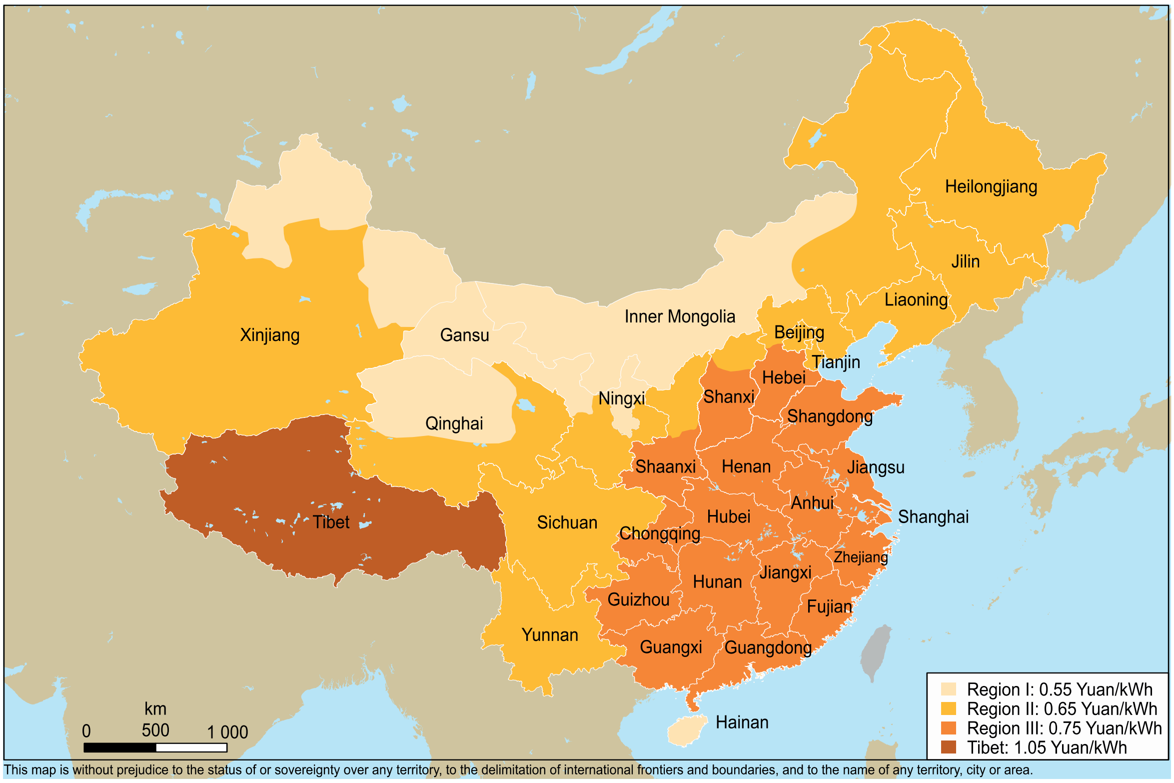
Note: Altay municipality is located in Region III.

Source: NDRC (2018a), 全国陆上风力发电标杆上网电价表 [*List of Benchmark Feed-in Tariffs for Nationwide Onshore Wind Power Generation*], www.ndrc.gov.cn/zwfwzx/zfdj/jggg/201612/W020161228343602191833.pdf.

According to the Renewable Energy Law published in 2006, the central government subsidises the difference between the feed-in tariff of wind power and the provincial benchmark feed-in tariff of coal power. Feed-in tariffs for plants beginning operation in the 2009-18 period are shown in Figure 12. The subsidy comes from the renewable energy development surcharge (see the section on benchmark retail price below) bundled in the retail price, which means all end users in China pay for renewable power through electricity purchasing. When wind farms participate in the power market, although the direct contracting price does not include the subsidy, they can still receive this subsidy granted by the central government. In addition, for goods produced using their own produced wind power, there is a 50% value-added tax refund.

The benchmark feed-in tariff for solar PV power is similar to that of wind power, except for the different regions included in the dividing tiers Figure 13.

Figure 13 • Feed-in tariffs for solar PVs, 2018



This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries, and to the name of any territory, city or area.

Source: NDRC (2018b), 全国光伏发电上网电价表[*List of Feed-in Tariffs for Nationwide Solar Power Generation*], www.ndrc.gov.cn/zwfwzx/zfdj/jggg/201712/W020171222354137560863.pdf.

Transmission and distribution tariff

Transmission and distribution price before Document No. 9

Before Document No. 9, transmission and distribution pricing was not based on transmission costs and losses. It was embedded in the retail price, according to official documents. Therefore, grid companies took the difference between the regulated retail price and the regulated on-grid price, instead of charging the transmission and distribution tariff as revenue.

Therefore, intraprovincial transmission, which accounts for most of the power transmitted, was not a separately priced service charged to generators. However, for interprovincial power transaction, there was a separate transmission price set by the NDRC considering capacity charges. In addition, for interregional power transaction, there was a separate transmission price set by the NDRC, considering capacity and energy charges.

Table 12 • Transmission and distribution tariffs of provincial grids

Province	Transmission and distribution electricity prices for large industrial consumers (CNY/kWh)					Time of release
	330 kV	220 kV	110 kV	35 kV	1-10 kV	
Beijing		0.1493	0.1508	0.1751	0.1956	January 2017
Shaanxi	0.1034	0.1034	0.1084	0.1284	0.1484	January 2017
Guangxi		0.0793	0.0993	0.1243	0.2702	January 2017
South Hebei		0.1371	0.1421	0.1571	0.1721	February 2017
North Hebei		0.0940	0.0990	0.1140	0.1290	February 2017
Tianjin		0.1723	0.1772	0.1774	0.2052	February 2017
Shanxi		0.0588	0.0688	0.0888	0.1188	February 2017
Hunan		0.11534	0.13934	0.16734	0.19634	February 2017
Jiangxi		0.1335	0.1435	0.1585	0.1735	June 2017
Chongqing		0.1309	0.1459	0.1632	0.1859	July 2017
Sichuan		0.1090	0.1350	0.1727	0.1998	July 2017
Henan		0.1757	0.1837	0.1987	0.2137	July 2017
Liaoning		0.0967	0.1067	0.1197	0.1327	July 2017
Jilin		0.1236	0.1386	0.1536	0.1686	July 2017
Xinjiang		0.1100	0.1300	0.1520	0.1740	July 2017
Zhejiang		0.1576	0.1626	0.1846	0.2146	August 2017
Fujian		0.0961	0.1161	0.1361	0.1561	August 2017
Shandong		0.1331	0.1481	0.1631	0.1781	August 2017
Hainan		0.1247	0.1345	0.1362	0.1897	August 2017
Jiangsu		0.168	0.183	0.198	0.213	September 2017
Gansu		0.1197	0.1287	0.1599	0.1699	September 2017
Qinghai		0.0823	0.0823	0.0923	0.1023	October 2017
Shanghai		0.3772	0.3772	0.3957	0.4214	October 2017
Heilongjiang		0.1092	0.1342	0.1468	0.1680	October 2017
Guangdong		0.0871	0.1121	0.1121	0.1371	November 2017

Source: EPPEI (2017), 中国电力发展报告 [*Development Report of China Power Sector 2017*].

Establishing a separate transmission and distribution tariff

Establishing a separate transmission and distribution tariff is a crucial issue for the ongoing round of power sector reform (NDRC and NEA, 2015; NDRC, 2016c; NDRC, 2017b; NDRC, 2017c). The transmission and distribution tariff should be "allowed cost plus reasonable profit", according to Document No. 9. In 2016, the NDRC issued the document *Methodology on Clarifying Provincial Level Transmission and Distribution Tariff (Pilot)* (NDRC, 2016e). Since then, work has been implemented at the provincial level to calculate the cost of construction and operation of transmission lines. By the end of 2017, all provinces except Tibet had finished accounting for the provincial grid transmission and distribution tariff, and the NDRC published approved intraprovincial transmission and distribution tariffs. The provincial transmission and distribution tariff reduced by CNY 10/MWh on average nationwide. Table 12 shows the intraprovincial transmission and distribution tariffs. According to the Methodology document, the work of establishing interprovincial and interregional transmission tariffs is expected to finish by the end of 2018.

However, considering that accurate construction and operating costs are difficult to obtain, achieving cost reflective tariffs will be a challenge for regulatory authorities.

Retail price

Benchmark retail price

The government regulates the retail price in China. Provincial governments formulate it, and the NDRC approves it. The retail price, which is benchmarked, consists of four parts: on-grid purchase cost, transmission and distribution loss, transmission and distribution price, and government charges.

The retail price has four pricing categories depending on the type of end users: large-scale industrial, commercial and industrial, agricultural and residential. Within each pricing category, retail price varies with voltage level and time of use. Prices due to different times of use are typically divided into peak, normal and valley prices. This mechanism was introduced as part of successful efforts to shift load to avoid supply shortages. Some provinces have implemented a demand-based pricing mechanism for the retail price of large industrial consumers and commercial consumers with high voltage levels. Some areas have implemented a differentiated residential price (referred to as the "ladder residential price") to encourage household energy saving. This works in a similar way to a higher power price per kWh charged once electricity consumption exceeds a certain amount.

The benchmark retail price also contains a range of government funds, which have changed over time. The main charges and fees for government funds are now:

- debt payment for network construction (about CNY 20/MWh)
- the Three Gorges Dam construction fund (from CNY 4/MWh to CNY 15/MWh for different consumers in different regions); consumers all over China need to pay for construction of the Three Gorges Dam whether they use the electricity generated by it or not
- the urban utility surcharge (from CNY 2/MWh to CNY 20/MWh for different consumers in different regions)
- the renewable energy development surcharge (CNY 19/MWh) to subsidise wind and PV power construction (NEA, 2011; NEA, 2012).

Cross-subsidies widely exist in the current retail pricing system. There are generally four types in the power price:

- Cross-subsidisation among different types of consumers: it is common in China that agricultural and residential retail prices are lower than those for industrial and commercial consumers, even though the costs are higher.
- Cross-subsidisation among different voltage levels: there are five voltage levels in China; higher-voltage-level consumers cross-subsidise lower-voltage-level consumers.
- Cross-subsidisation among consumers with different load factors: the load rates of different consumers are not considered in the retail price. This is equivalent to pricing all consumers with an average power load factor, and therefore consumers with higher load rates cross-subsidise consumers with lower load rates.
- Cross-subsidisation within regions: an example is that electricity in some rural areas is subsidised to a lower price, although the cost may be higher. This kind of cross-subsidy is due to the need for urban and rural equity, therefore strengthening social stability.

Cross-subsidisation in China contrasts with retail markets elsewhere, where retail prices are regulated to achieve better efficiency and promote cost-effectiveness. However, it has always been a challenge for the Chinese government to choose between efficiency and fairness. The influence of cross-subsidisation in power price becomes increasingly vital as the necessity for lowering cost to maintain the advantage of "made in China" keeps growing. Moreover, cross-subsidies have a negative influence on SMEs in the commercial sector, but SMEs are crucial to China's economic growth and modernisation.

Renewable energy development

The deployment of renewable energy has grown rapidly in China (NEA, 2015; NEA, 2016e; NEA, 2017). From 2012 to 2016, an average of 20.7 GW of hydropower was installed per year, together with 21.8 GW of wind power and 17.7 GW of solar PV power. The fast growth in the capacity of the VREs such as wind and solar PVs has increased beyond the expectations of the central government. The central government released a target in 2007 to build 5 GW of wind by 2010 and 30 GW by 2020. However, by 2010, wind capacity had achieved 30 GW and is now on track to meet its new and much higher target of 210 GW proposed in the 13th Five Year Plan (NEA, 2016b). Moreover, the capacity target of solar PVs in 2020 was set at 110 GW in the 13th Five Year Plan for solar power development (NEA, 2016c). The installed capacity reached 77.5 GW in 2016; in 2017, it reached 130 GW, already exceeding the 2020 target.

Challenges

The increasing use of the VREs raises the challenge of their integration under the current power system and market structure. The overall amount of wind curtailment in 2016 was 49.7 TWh, with an annual average curtailment rate of 17% nationwide. The curtailment rate of Gansu Province reached 43%, that for Xinjiang Province 38% and that for Jilin Province 30%. A high curtailment rate also occurred in solar PV power generation, with an annual average curtailment rate of 10.3% nationwide in 2016, and an annual average curtailment rate of 20% with 7 TWh power curtailed in Northwest China alone.

The central government has made tremendous efforts, and the curtailment rates of wind power and solar power decreased in 2017. While the installed capacity increased by 15 GW, overall wind power curtailment was reduced by 7.8 TWh, with a 5.2% decrease in the curtailment rate. The curtailment rate of Gansu decreased by more than 10%, while those of Xinjiang and Jilin decreased by more than 5%. The rate of solar PV curtailment was reduced to 6%, despite the record growth of solar PV power of 53 GW.

Although the curtailment in the VREs was alleviated in 2017 compared with the previous year, it remains a critical challenge to China's renewable energy development. The universal curtailment issue could be a challenge in technical, economic and institutional aspects. Technically, curtailment happens when there are security issues, such as transmission lines reaching their safe loading limits. In some power markets around the world, there are insufficient economic incentives for other generators to curtail their output during periods of high variable renewable production. In China, there are additional challenges, such as existing rules in power system operations that may limit economic use of variable renewable electricity. The section below on barriers to renewable energy development describes the institutional challenges.

Supporting policies

Integration of the VREs has been a crucial task for the Chinese government in recent years. Guaranteed renewable purchasing was included in the Renewable Energy Law in early 2006, requiring the grid company to integrate all possible renewable energy except in cases of grid security issues. Minimum capacity factor requirements for wind and solar were put in place at the provincial level in 2016 (NDRC, 2016b). The renewable power generation included in the minimum factor has been mandated to have a priority in making the provincial annual power generation plan.

The central government has always encouraged the development of renewable energy through pricing incentives. Before introduction of the wind and solar feed-in tariffs, wind farms received tariffs determined on a project basis or through concessions determined by competitive auction. The benchmark feed-in tariff was first implemented in 2009. Feed-in tariffs for wind and solar PVs were categorised into four tiers each, in terms of resource quality, construction costs and other considerations. After evaluating the development of technologies and reduction in costs, the central government gradually reduced the feed-in tariffs by releasing official documents on the new pricing for each tier.

The central government established the Renewable Energy Development Fund to subsidise wind and solar power plants. This fund covers the difference between the feed-in tariff of wind/solar PV power and the provincial benchmark feed-in tariff of coal power. This means the grid companies pay a coal feed-in tariff for on-grid wind and solar power, and the central government pays for the rest.

Although the gradually reduced feed-in tariffs for wind and solar power mean less subsidy from the Renewable Energy Development Fund, the boost in wind and solar capacity still creates a great deficit in available funds. It is estimated that by the end of 2017 the deficit reached CNY 100 billion, and generators claim they have not received this money since 2015. The NEA therefore designed and revised several times a mandatory quota allocation system (NEA, 2018b; NDRC and NEA, 2018), aiming to force either grid companies or other generators to purchase credits up to a certain percentage of the total consumption or generation. The quota allocation system proposal was first released to stakeholders for public consultation in April 2018, and a revised version was released for public consultation in September 2018.

Barriers

Administrative planning has long been the main method for power dispatching in China. The annual power generation plan predetermines the power generation for each generator. This plan is further broken down into monthly and daily plans for execution. Similarly, most transmissions inside provinces or interprovincial/interregional transmissions are also administratively planned. This planned system used to work well before the high penetration of the VREs.

The appearance of wind and solar generators in the power system is naturally contradictory to this predetermined planning system. The variability and unpredictability of wind and solar power interact with the inflexibilities of fossil fuel generators, power demand and transmission line constraints.

The integration of renewable energy has drawn resistance from coal power plants, due to economic and institutional considerations. Under the current system, the planned allocated operating hours and the benchmark on-grid pricing predetermine the annual revenue of a coal power plant. Coal power has experienced severe overcapacity in the last few years, due to the boost in construction after the administrative approval authority shifted from the central government to provincial governments. During this time, newly built coal power plants were in the debt-servicing period and therefore did not wish to see a substantial reduction in their operating hours. The rise in the coal price in recent years has increased the resistance of coal generators to renewables even further.

There is also resistance from grid companies. The current pricing mechanism mandates grid companies to charge wind and solar power the same on-grid price as the benchmark feed-in tariff for coal power (the governmental renewable energy development surcharge covers the difference between the feed-in tariff of coal power and wind/solar power).

Interprovincial or interregional renewable energy transmission seems like a feasible way to improve wind and solar integration and further achieve better overall system efficiency. However, this is not a good solution in reality, at least for imported-end local governments. The wind and solar on-grid price is fixed to a benchmark price, and this price plus the transmission tariff is now higher than the local coal power price. Therefore, local governments tend to use cheaper coal power in their own province. Furthermore, allowing local coal power plants to generate more electricity is perceived as being helpful for the local economy.

International experience relevant to China

The previous chapters have given an overview of the basic characteristics of the Chinese power system and highlighted directions of reform in the 21st century. This chapter provides selected international experience with regard to system planning, electricity trading and system operation, and development.

It is worth noting that several examples below have been selected from one country. Mexico is a relevant example because it is the first middle-income country that has implemented comprehensive electricity market reform that considered the need for a transformation of the power system from the start. It can thus provide insights into relevant areas.

Long-term planning

Long-term planning by central, usually public, entities plays different roles depending on market, policy and regulatory frameworks. In a centrally planned approach, the long-term plan directly translates into investment decisions. This is in sharp contrast with systems that have unbundled the electricity system and introduced fully competitive wholesale markets. In this case, the long-term plan does not translate directly into investments for the generation segment of the value chain. Nevertheless, it provides visibility for market participants to inform investment decisions, and the process of establishing the plan is an opportunity to reach consensus on the desired direction of the system. This can then provide the basis for introducing specific policies to ensure the market has appropriate framework conditions. It also gives certainty regarding the new investment decided for transmission grids.

As discussed earlier, China has already started on its path of moving from a fully centrally planned approach in the power system towards a stronger role for market co-ordination. The ongoing reform under Document No. 9 provides further impetus in this direction. Hence, it is interesting to consider a case where a country has recently embarked on a similar transition, moving from a centrally planned approach in the power system towards a more market-based system. The electricity market reform in Mexico provides an interesting example in this regard.

With a growing role for market-based co-ordination, access to relevant data for all market participants becomes crucial. Understanding where new power generation might be feasible requires access to transmission grid data as well as information on the supply-demand balance of electricity at a sufficient level of detail. Japan has recently moved from a system of regional monopoly supply companies towards a more-liberalised market system. A crucial step in its transition was the introduction of improved data transparency, as well as an independent organisation to conduct system planning.

A stronger role for markets is not the only reason for changes in planning processes. The fundamental drivers of power system transformation are: the rise of low-cost renewables and decarbonisation, the increased importance of distributed energy resources and electrification, and digitalisation. A power system that is undergoing a rapid shift from a coal-dominated power system to a much stronger reliance on renewable energy is that of Australia. The Australian Energy Market Operator (AEMO) published its inaugural Integrated System Plan (ISP) in 2018. This plan is part of Australia's answer to its energy transition and provides interesting insights for the Chinese context.

Mexico's development programme of the national power system

The Mexican power sector transited from a vertically integrated utility organisation to an open market paradigm for the generation and retail segments, with the opening of the market in January 2016. The planning process for the new investments was transferred from the state-owned monopoly CFE to the Energy Ministry, along with opening of the market and changing the way in which decisions were taken.

The new planning exercise was adapted to the following conditions:

- Entry to the market is open on the retail and on the generation side, so it is no longer promoted by a regulatory decision.
- The Mexican legal framework (Climate Change Law, Law for the Renewables Promotion and Financing of the Energy Transition, and Energy Transition Law) established an objective to reach a cap of 65% fossil fuels in the power energy mix.
- The SOE CFE will unbundle the transmission activities and compete on an equal basis with new entrants in the generation and retail segments of the industry.
- The Programa de Desarrollo del Sistema Eléctrico Nacional (PRODESEN) in Mexico has three deliverables:
    - the generation forecast (indicative)
    - the transmission expansion plan (binding programme of investments)
    - the distribution expansion plan (binding programme of investments).

The differentiation between indicative and binding elements follows a different approach for generation investment decisions under a competitive wholesale market. The following three aspects in the new planning exercise are particularly relevant in Mexico's energy transition.

Stakeholder engagement

In the new market context, PRODESEN requires much information from multiple parties, including the Ministry of Finance, existing generators, new generators, the independent system operator and other market participants. A streamlined process enables gathering of the best information available in a timely manner for this annual activity.

Renewable integration and generation forecast

The PRODESEN generation forecast and transmission expansion plan is the result of a cost minimisation problem. It takes into account the costs and benefits of fossil fuel and renewable generation simultaneously. The objective is to minimise the cost of the system, including the fixed and variable costs of every resource, with no preference for any technology. The only restriction is adding the amount of clean energy required in the energy mix. The transmission expansion proposed in PRODESEN supports this cost-minimising generation mix.

Demand forecast

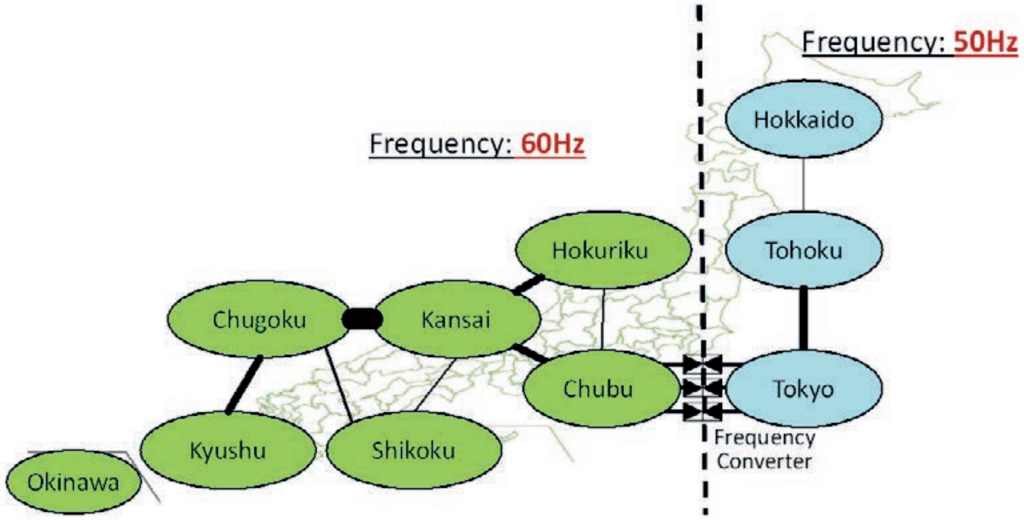
As in many regulated power systems, the Mexican system had a systematic overinvestment, partly due to an optimistic demand forecast. The PRODESEN demand forecast was therefore reformed to improve its accuracy. In addition, investment decisions were transferred to market participants, who pay market penalties if they do not have sufficient generation to fulfil customer needs.

Japan's improved data transparency

Electricity market reform in Japan

The power grid in Japan used to have ten vertically integrated regulated monopolies with different frequencies between the east and west (Figure 14). This historical dominance of the vertically integrated market model has led to lack of competition.

Figure 14 • Japanese regional power systems (2018)



Sources: METI (2013), *Electricity Market Reform*, www.meti.go.jp/policy/energy_environment/energy_policy/denjihou/pdf/20131206_003.pdf; OCCTO (2015a), *Electricity System Reform*, www.occto.or.jp/en/about_occto/about_occto.html.

Electricity market reform has been implemented in Japan since 2015 to: stabilise electricity supply and demand, make better allocation of electricity across different transmission system operator (TSO) areas (i.e. enable merit-order dispatch on a nationwide basis) and lower electricity tariffs via increased competition. The reform is comprehensive, gradually introducing unbundling of transmission and generation as well as introducing full retail competition. A full description of the reform is beyond the scope of this case study. Instead, the main elements related to improved data transparency and an improved institutional structure with regard to the establishment of the Organization for Cross-regional Co-ordination of Transmission Operators (OCCTO) are highlighted.

Establishment of OCCTO

OCCTO was established as an authorised organisation approved by the Japanese government in April 2015 to facilitate cross-regional commercial electricity exchange. It is neutral and does not own any assets such as transmission lines and generators. The functions of OCCTO include:

- developing a fair environment for power systems by formulating transmission/distribution rules and new market design
- securing mid- and long-term stable electricity supply by formulating a cross-regional network development plan
- strengthening the supply-demand control function on a nationwide basis by continuously monitoring supply and demand.

Data transparency

Data transparency refers to the timely availability of accurate data regarding the power system, including demand and supply information at sufficiently high temporal and spatial accuracy as well as information on available transmission capacity in the system. Data transparency is vital for generators to connect to the grid, enhance project predictability and contribute to efficient operation. Hence, the Japanese Ministry of Economy, Trade and Industry (METI) developed a guideline for data transparency in April 2012, taking into consideration publicly available information in the European Union and the United States. This guideline also outlines the division of roles between OCCTO and TSOs regarding publicly available information (Table 13). An ad hoc working group established by METI carries out data checks of publicly available information at regular intervals.

Table 13 • Examples of data transparency provided by the guideline in Japan

Transmission and distribution	Electricity demand and supply
Available transmission capacity, net transmission capacity and margins	Electricity demand and supply forecast on a daily basis
Planning of enhancement and periodic inspections	Electricity demand and generation by type for each hour
Expected and actual electric flows (e.g. electricity trade among TSO areas)	Time and area of VRE curtailment

Note: Data available at OCCTO's webpage http://occtonet.occto.or.jp/public/dfw/RP11/OCCTO/SD/LOGIN_login#.

Sources: METI (2016), *Guideline for Data Transparency*, www.enecho.meti.go.jp/category/electricity_and_gas/electric/summary/regulations/pdf/h27keito_kangaekata.pdf.

Electricity trade, supply and demand data

On its website, OCCTO provides information on electricity trade among Electric Power Companies (EPCOs) areas as well as the net transmission capacity for each hour. In addition to publishing this information, each TSO has to submit the expected and actual electricity trade among TSO areas to OCCTO so that OCCTO can secure a mid- and long-term stable electricity supply. Enhanced trade across the different EPCO areas is crucial for improving the competitiveness of the sector and optimising the operation of the system on a national level.

Each TSO must also make available on its website its actual and forecasted electricity demand (on a daily basis) as well as generation by type of fuel for every hour (published quarterly). An important driver for the obligation to publish daily electricity demand was the need to enforce strict demand-side measures in the aftermath of the 2011 Great Earthquake, including rolling blackouts. A driver for the obligation to supply hourly data is the rapid rise in renewable energy. Owing to generous feed-in tariffs since 2012, the amount of renewable energy in the system has grown rapidly, raising increasing concerns over VRE curtailment. It is therefore vital for generators to improve foreseeability of VRE curtailment; this requires availability of demand and supply information.

In addition, data are vital for new market entrants in an environment that is still dominated by legacy monopoly providers. It also provides a common basis for modelling studies.[3]

[3] The German Federal Ministry for Economy and Industry recently supported a European-wide effort to improve the availability of information to conduct modelling studies of the power system, details of which are available at https://open-power-system-data.org/.

Australia's Integrated System Plan (ISP)

Australia is undergoing a rapid, structural transformation of its electricity system. One key factor of this transformation is the rapid increase of wind and solar PV power, driven by a combination of policy support and increasing competitiveness of the technologies. These resources meet an established power system that has been built around coal and some hydropower. The wind and solar PV capacities increased from just 1 864 MW (wind) and 399 MW (solar PVs) in 2010 to 4 327 MW (wind) and 4 718 MW (solar PVs) in 2017. Australia is a federal state, and its states and territories play an important role for setting energy and electricity policies. Owing to a lack of policy guidance at the federal level and a lack of co-ordination among the states and territories, the deployment of wind and solar power occurred in a geographically concentrated way. Deployment flowed particularly strongly into South Australia, a sparsely populated area with a peak demand of merely 3.1 GW but ample wind and solar resources. On 28 September 2016 a large-scale blackout occurred in that state. While this was due mainly to a strong storm, it raised attention to the fundamental shift in the structure of the electricity system, moving from baseload coal plants towards the VREs.

Following the event, the government ordered an independent review into the future security of the National Electricity Market (NEM), led by Australia's Chief Scientist Dr Alan Finkel. The Finkel review provided 50 recommendations on how to ensure orderly transition of the Australian power system. One area of recommendation concerned improved system planning. Because of these recommendations, the Australian National Energy Market Operator prepared the first ISP and released it to the public on 17 July 2018.

This is a remarkable development for Australia. Traditionally, centralised planning has played only a marginal role, and market-based investments in the NEM were the main method by which the pathway of the system was determined. However, the Finkel review revealed that market forces alone could not guarantee an optimised, orderly transition. A mechanism was needed to provide guidance for policy making and certainty for market participants. The ISP plays an important role in this. While it does not directly lead to approved investments, it does provide a basis to prioritise grid investments and also gives an indication about the future trend of the system.

ISP

The ISP analyses different possible futures of the power system in Australia. It is based on various assumptions about the speed at which more wind and solar power plants are built, the possible future for natural gas in power generation, or the speed at which coal power plants are retired. Simulations include the achievement of relevant government targets. Based on these scenario assumptions, a highly sophisticated computer model calculates the least-cost mix of resources, taking into account an optimised transmission grid and generation mix as well as advanced options, such as battery electricity storage.

The plan results in recommendations on priority infrastructure, such as transmission lines, which benefit society and reduce the cost of electricity across all scenarios considered. The plan has found that, once coal plants reach the end of their technical lifetime (which, in Australia, will be in the 2030s and 2040s):

> [T]he lowest cost replacement (based on forecasted costs) for this retiring capacity and energy will be a portfolio of resources, including solar (28 GW), wind (10.5 GW), and storage (17 GW and 90 GWh), complemented by 500 MW of flexible gas" (AEMO, 2018).

However, unlocking this future pathway relies critically on a balanced mix of policy and market instruments to ensure an optimised evolution of the transmission grid and the establishment of advanced flexibility resources.

Relevant characteristics of the ISP

The plan marks an important milestone in optimising the planning process in Australia for its energy transition. The following elements are particularly noteworthy:

- AEMO is an independent system and market operator. It does not earn a profit from transmission, generation or storage investments. That is, the organisation making the plan does not have a financial interest in any specific technology. In addition, AEMO is sufficiently financially independent so it does not need to fear retaliation from a specific stakeholder in the sector.
- As the system operator, AEMO has a deep technical understanding of the Australian power system and thus has the ability to oversee such a detailed technical assessment. One of the objectives of the plan is to identify the required investments to provide reliable, low-cost power. Thus, only a technically competent body with robust information can carry out such a plan.
- AEMO organised a wide-ranging stakeholder consultation on the assumptions used in the model and incorporated input from different stakeholders regarding assumptions, settings and modelling.
- The plan looks at the entire, integrated system that spans different states and territories. It seeks to find the best solution for the entire country, rather than focusing on the benefits for individual regions in isolation. Such a holistic approach is crucial to finding an optimal pathway – in a next step, it may be seen how benefits can be shared among different regions.
- The model optimisation looks at one integrated optimisation of all power system resources: fossil fuel plants and renewables, grids and batteries. This allows identification of the best mix of options, rather than individual plans that prioritises a specific solution in a more isolated fashion.

The ISP is one step in the longer journey of transformation of the Australian power system. However, having an integrated, independent long-term system plan that looks at different scenarios is a valuable reference to inform policy discussions and market design.

Electricity trading and system operation

The design of appropriate policy, market and regulatory frameworks is a highly complex task. Demand and supply must be matched precisely in real time because of the specific characteristics of electricity. The investment decisions for system assets need to be taken several years, in some cases, decades, in advance. Consequently, policy, market and regulatory frameworks need to ensure that long-and short-term requirements are well harmonised. As the discussion in previous chapters showed, harmonising these different timescales is a central topic of electricity market reform processes. China is not alone with this challenge, and many other power systems are grappling with similar issues.

Providing a comprehensive account of international practices on this topic is far beyond the scope of this report. Indeed, providing such an account would amount to a review of past and current approaches to electricity sector governance globally. The International Energy Agency (IEA) has published a comprehensive account of electricity market design in the current context of power system transformation (IEA, 2016a), and interested readers will find a more comprehensive discussion there.

Instead, this section summarises experience in four areas that appear especially relevant in the Chinese context:

- **Linking long-and short-term power contracts to optimise operational efficiency**: market-based trading of electricity in China takes place via medium-term trading, typically for a year or several months ahead. The result of this trading is then taken into account in the annual dispatch plans and further disaggregated into monthly plans and so forth. However, this can lead to continued issues when operating the system during real-time dispatch. Hence, this section reviews experiences regarding the establishment of efficient short-term markets and looks at how these can be linked with long-term contracts.
- **Encouraging the right levels of investment**: the history of the Chinese power system is characterised by swings between capacity shortage and surplus. In the current surplus environment, there are concerns that a quick move to market-based pricing based on economic dispatch could put too much strain on the system and lead to capacity shortages in the future. China is not alone with these concerns, and some other countries have recently adopted measures to encourage the right levels of investments while avoiding overcapacity.
- **Unlocking trade over larger geographic areas**: electricity trade remains limited in China and is usually based on large-scale projects with predetermined electricity flows. However, as the system moves to higher shares of renewable energy, there can be a large benefit for the country to use the grid more dynamically, reducing the total cost of power generation. While this area is linked to complex political questions, there are some international examples of how such trade has been made possible.
- **Transitioning legacy assets into a new market environment**: China has a substantial amount of existing coal-fired capacity, some of which has been built recently. When deciding on the investment in these plants, companies assumed that the regulatory framework of regulated on-grid prices and guaranteed full load hours would be maintained. However, with the current overcapacity and the changing role of power generation away from baseload operation and towards flexibility, these arrangements may require reform. There are examples of transition mechanisms, which may be of interest in this context.

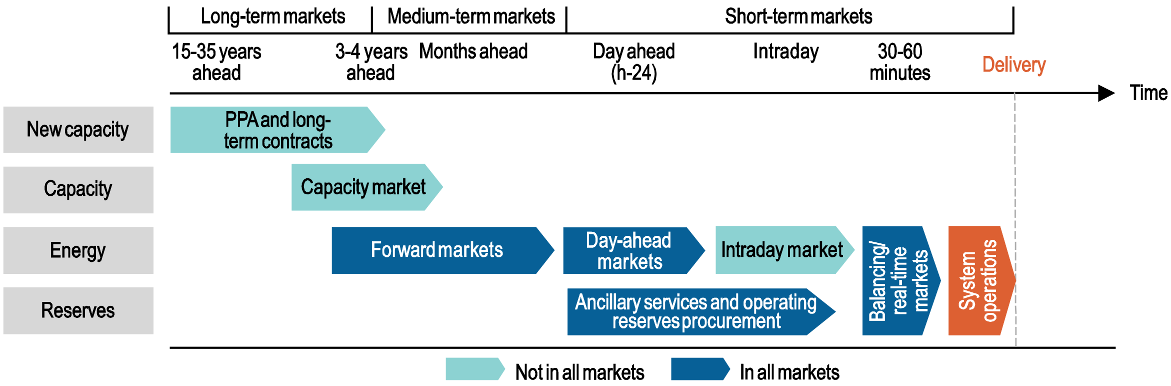
Linking long-and short-term power contracts to optimise operational efficiency

The current Chinese market reform emphasises medium-term bilateral trading between generators and large consumers with the objective of reducing the price for customers via enhanced competition. As explained previously, this form of trading builds on well-established practices and is thus a straightforward way to meet the objective of reduced costs. However, this approach does not directly address the issue of efficient system operation in real time. Currently, contracted electricity is added to the allocation of generators in the annual dispatch plan, but the dispatch system itself remains largely the same as it has been traditionally. Clearly, this can bring issues for efficient system operation, especially for wind and solar generation (see the discussion in the power dispatch section above).

The key to achieve the benefits of letting market forces to determine dispatch lies in the decoupling of the electricity supply contract between the generator and a customer from the requirement to physically generate the electricity with precisely the contracted power plant. The current practice of generation rights trading follows the same idea. However, different approaches internationally have been taken to achieve this decoupling, mostly through the establishment of a liquid short-term market for electricity.

Short-term markets are the foundation of all market-based electricity systems and have proven to be a valid approach to reduce the cost of electricity supply and to promote cost-effective integration of high shares of the VREs while avoiding curtailment. In most cases, they consist of two main markets: the day-ahead market and the real-time market (Figure 15).

Figure 15 • Overview of the building blocks of electricity markets



Source: Reprinted from IEA (2016a), *Re-powering Markets: Market Design and Regulation during the Transition to Low-Carbon Power Systems*, www.iea.org/publications/freepublications/publication/REPOWERINGMARKETS.pdf.

In the day-ahead market, participants bid for energy and the market clears and sets hourly prices for each hour of the next day. Generating units are committed accordingly. Then, during the day, adjustments have to be made to balance supply and demand, which are continuously updated. This is done either by system operators or by generators. In Europe, participants can also exchange electricity blocks on an intraday market platform before system operators set balancing energy prices that clear the balancing (or real-time) market. In North America, system operators calculate real-time prices in a five-minute market. System operators also procure ancillary services, including operating reserves, to restore frequency instantaneously.

A key advantage of a liquid short-term market is that it provides the basis to establish a reference price for medium and long-term electricity trade. In China, the on-grid feed-in tariff currently plays this role. This explains why trading is possible, even in the absence of a short-term price signal. China has recognised the importance of short-term markets, and a number of pilot projects are underway to implement these. International experience in North America and Europe confirm the vital importance of the short-term market for achieving an optimised power system and low cost for consumers.

Once a liquid spot market is available, it is possible to achieve decoupling of bilateral electricity contracts and system dispatch in real time. There are different ways of achieving this.

Under the so-called power pool design, generators bid their short-run operating costs on a market and the system operator selects those plants that can meet demand in the cheapest way possible (merit-order dispatch). This will then yield a price for every time step of system operation. If a plant has a long-term contract, but was not selected to generate, it must buy market from the power pool. However, this will still be more favourable for the plant, because its cost must have been above the market price at that moment. From the consumer side, the electricity will always cost as much as the agreed contracted price.

Under a power exchange arrangement, generating companies (and, in some cases, energy traders) simply declare how much electricity they wish to generate at a given moment at which price or how much they want to buy at what price. Depending on how the market is cleared, generators can then either choose to run their own power plant or buy the electricity from the spot market. The effect is similar to the power pool arrangement. The main factors that drive selection among models are considerations of market power and the existing industry structure. The largest restructured electricity market that runs a single real-time market is the PJM in the United States. Another interesting case is market coupling in Europe (see below).

PJM: Operational efficiency thanks to short-term markets

PJM Interconnection is a regional transmission organisation (RTO) that co-ordinates the movement of wholesale electricity in all or parts of Delaware, Illinois, Indiana, Kentucky, Maryland, Michigan, New Jersey, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia and the District of Columbia. Founded in 1927, PJM gradually made its transition into an independent, neutral organisation, opened its bid-based energy market and became the first fully functioning RTO in the United States in 2002. Its efficiencies in reliability, generation investment, energy production cost and grid services create as much as USD 2.2 billion (US dollars) in savings to the region each year. Its centralised merit-order dispatch produces significant efficiencies and annual savings of USD 340 million to USD 445 million.

Encouraging the right levels of investment

The ability of power systems to provide sufficient levels of investments to cover the most critical hours of a system is an important test of any market design. Power systems all over the world have dealt with this issue in many ways.

Vertically integrated utilities link the planning process to the investment, usually with regulatory approval, to check that the investment is prudent. The associated costs should be translated to the final user rates.

In contrast, power systems with wholesale markets decouple the planning from investments, and organise markets with the two objectives of reaching short-term efficiency (least-cost dispatch) and of providing the right signals to bring sufficient investment to the power system (adequacy). To achieve this, market organisation must guarantee that the market provides sufficient revenue to cover the operating and fixed costs for demand and generation resources. These resources are crucial for maintaining the system's ability to supply peak demand during critical hours, even if they are seldom used. Most power systems have been organised using one of the following adequacy mechanisms.

Energy-only markets

In energy-only markets, all the revenue comes from the energy prices. Market rules allow generators to bid higher prices than their variable cost, so they can recover the revenue needed to cover their fixed costs. This income comes mainly in hours of scarcity, where there are large differences between the revenues and the costs. Most European markets, and also those in Texas and New Zealand, are examples of this organisation. There is a lively debate around the ability for energy-only markets to provide sufficient revenues for investment. Most analysts agree that improved design of energy-only markets is a no-regret option and at the least it can reduce the need for further mechanisms (IEA, 2016a). However, in markets that are experiencing a combination of overcapacity and a rapid rise of renewable energy, it is generally advisable to introduce a mechanism to safeguard against a sudden wave of capacity retirements.

Capacity markets

Capacity mechanisms supplement energy market revenues with explicit, forward-looking capacity requirements. Auctions are held a few years (typically three or four) ahead of when the need for capacity is expected, with payments guaranteed for one year, or in some limited cases multiple years.[4] In each of these cases, the resource adequacy target – or demand for capacity – is administratively determined.

Such mechanisms aim to provide the incentive for investment in sufficient supply to safeguard resource adequacy. They are prevalent in organised wholesale markets in the United States (the Electric Reliability Council of Texas, is an exception), and are becoming more prevalent among competitive markets in Europe (EC, 2016). Forms of capacity mechanism have recently started operations in the United Kingdom (2015) and France (2017). Some EU countries, such as Spain, Ireland, and Italy, as well as Japan, are currently implementing or considering such instruments.

Capacity mechanisms have typically been designed based on the needs of traditional power systems. The question therefore arises as to whether they are well suited to "transformed" power systems. For example, the traditional metric for resource adequacy is the power system reserve margin (or amount of capacity in excess of expected peak load). However, for systems with high penetrations of the VREs, appropriate reserve margins may be difficult to calculate. This is because the amount of available capacity needed at any given time is dependent on more inherently stochastic processes.

The design of capacity mechanisms also increasingly enables the participation of demand response, which has proved to be a highly effective solution to kick-start the business of aggregators. These systems may also find that resource adequacy is less of a concern than overall system flexibility. Some have called for capacity mechanisms to be reformed to incentivise investment in more flexible generation (RAP, 2012). Others have expressed concerns that capacity mechanisms may incentivise continued operation of conventional fossil fuel generation and new investment in flexible polluting capacity (such as diesel engines or gas turbines), making it more difficult to decarbonise the power sector (ODI, 2016). This has led to the introduction of emission performance standards in some cases, which could undermine the objective of capacity mechanisms to prevent a shortage of capacity.

These criticisms are best addressed by ensuring that capacity mechanisms are designed in such a way as to be technology neutral and to minimise distortions to the wholesale market. To put capacity mechanisms into perspective, in PJM, the capacity component represented 21.9% of the total wholesale electricity price per MWh (Monitoring Analytics, 2017). In France, the first capacity price was EUR 10 (euros) per kilowatt (kW), and the regulator estimated that this would represent EUR 1.44/MWh for 2017 (CRE, 2017). It is also clear that, depending on the future progress of demand response and policy-maker tolerance for lower levels of reliability, properly designed energy-only markets can also provide the incentive for investment (IEA, 2016a).

Although markets are often categorised as energy-only markets or markets with capacity products, many systems have adopted both mechanisms. The markets of France, the United Kingdom, Mexico, PJM (United States) and the Midcontinent Independent System Operator (MISO) (United States) are examples of electricity markets where both mechanisms (increased energy revenues in shortage periods, and capacity products) are combined to guarantee the right level of investment.

[4] Some auctions, such as the capacity market organised by the New York Independent System Operator, operate on a shorter-term time horizon, with payments only guaranteed for the following month.

Unlocking trade over large geographical areas

Different regions within large geographical areas often have uneven endowments of generation resources and demand patterns[5]. Integration of the power systems of these regions can therefore achieve important benefits. Although the building of transmission lines among regions is a first step, regional integration goes far beyond the physical interconnection. Developing co-ordination mechanisms can increase the benefits from cross-border trading.

Strengthened integration of markets over large regional areas is important to unlock the benefit of smoothing out the variations and forecast errors associated with the VREs and dynamic loads. However, regional integration of power systems is not new. In fact, the development of electricity markets is inseparable from regional integration (IEA, 2014). For instance, the creation of large independent system operators/RTOs, such as PJM and MISO in the United States or the NEM in Australia, is aimed at integrating many small balancing areas into one large market. Similarly, in Europe, power markets have largely been designed with the objective of enabling cross-border trade of electricity. Two examples are presented below: the Energy Imbalance Market (EIM) in the western United States and the integration of electricity markets in Europe.

EIM in western United States

In the western part of the United States, the Western EIM enables California and its neighbours to share balancing resources on a regional basis, allowing for more-efficient dispatch and reducing the need for new transmission investment. This initiative is relatively advanced compared to other regions, where balancing decisions are generally made at a local level, even when regional interconnections are available.

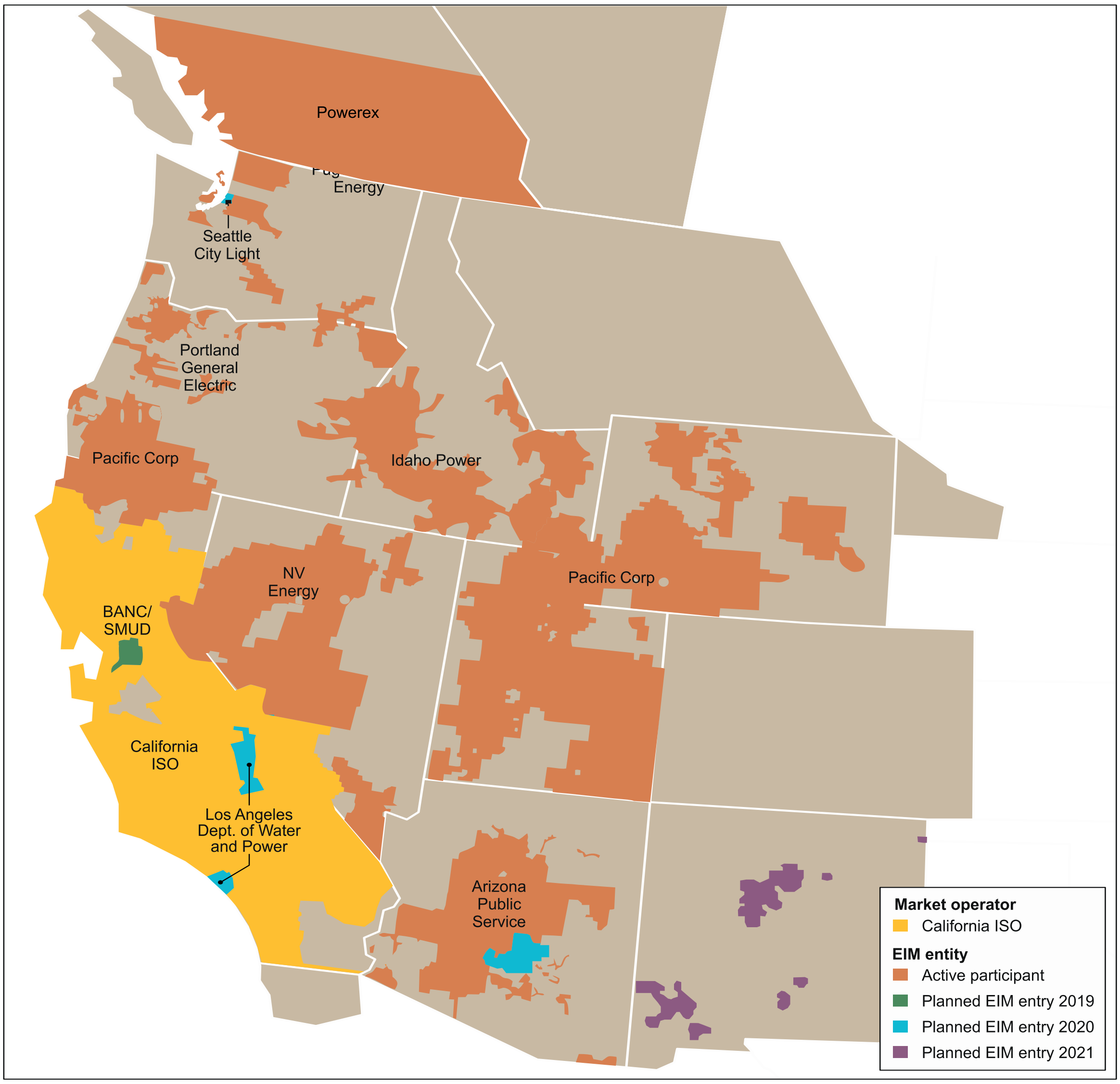
The Western Interconnect is a large synchronised area that includes 14 US states, two Canadian provinces (Alberta and British Columbia) and the northern portion of Baja California, Mexico. Regional reliability is co-ordinated by the Western Electricity Co-ordinating Council, but historically balancing responsibilities have remained at the state or local level. The California Independent System Operator (CAISO) is the region's only independent system operator. It operates entirely within the borders of California.

The Western EIM is the first effort to create a regional electricity market in the western portion of the United States. It is unique in two respects. First, unlike the regional wholesale markets in the Eastern Interconnect (PJM, MISO, etc.) the Western EIM is only a balancing market. Broader responsibility for transmission system operations remains the responsibility of each balancing area. Second, the service territory of the Western EIM is not contiguous (Figure 16). Participation in the EIM is voluntary, and utilities may exit at no cost with 180 days of notice. Besides CAISO, seven utilities currently participate, with five more expected to join over the next few years.

In the absence of a regional entity capable of taking on explicit responsibility for organising the Western EIM, CAISO acts as the market operator. This has led to a unique governance structure. Although operational responsibility is centralised in CAISO, the Western EIM has its own governing board that includes representatives from participating utilities and regulators from relevant states.

[5] This section follows Status of Power System Transformation 2017 (IEA, 2017)

Figure 16 • Utilities participating in the EIM, 2017



This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries, and to the name of any territory, city or area.

Source: CAISO (2018), *Western Energy Imbalance Market (EIM).*

While increased system reliability is often highlighted as a potential benefit of the Western EIM (NREL, 2013); since its implementation, the quantification of benefits has focused on economic and environmental effects. Three benefits are highlighted: more-efficient dispatch, reduced curtailment of renewable energy resources and reduced requirements for flexibility reserves. Estimated benefits for the fourth quarter of 2016 are summarised in Table 14.

Table 14 • Estimated benefits of the Western EIM, quarter 4, 2016

Benefit	Estimated savings
More-efficient interregional and intraregional dispatch	USD 28.27 million
Reduced curtailment of VREs	23 390 MWh
Estimated CO_2 savings from reduced curtailment	10 011 t
Reduced flexibility reserves	Upward: between 399 MW and 490 MW Downward: between 474 MW and 482 MW

Source: CAISO (2017), *Western EIM Benefits Report Fourth Quarter 2016,* www.caiso.com/Documents/ISO-EIMBenefitsReportQ4_2016.pdf.

European "market coupling"

Efforts to increase market integration and harmonisation in Europe have centred on the development of network codes. The EU 2009 legislative package (colloquially known as the "Third Package") mandated, among other things, the development of European network codes and guidelines. These network codes establish a common set of technical and commercial rules for a wide range of topics, including: network security; third-party access; data exchange and settlement; emergency operational procedures; and capacity allocation and congestion management (CACM) for real-time, day-ahead and long-term markets.

Development of the network codes has been managed through an iterative, multi-stakeholder process. The Agency for the Co-operation of Energy Regulators (ACER) is responsible for developing general framework guidelines for each network code, which the European Network for Transmission System Operators for Electricity (ENTSO-E) then turns into fully developed documents. ACER reviews the network codes, but only the European Commission can approve the final text. Responsibility for implementing the network codes rests with member states.

This iterative process has been slow and complex, and implementation of some network codes has lagged behind others. However, their development has been driven by a set of common concerns, including the need to integrate more efficiently the increasing penetrations of the VREs while maintaining system reliability. Implementation of the CACM was seen as critical, as it increases the utilisation of interconnectors and improves overall system flexibility (Hesseling and Hernández, 2015).

Recent proposals by the European Commission have been to increase regional integration focus on the development of so-called regional operating centres (ROCs). These are an evolution of the existing regional security co-operation initiatives (RSCIs), which are voluntary regional collaborative bodies established by the TSOs. The RSCIs do not work in real time, but instead develop system forecasts for their regions based on TSO data. These are the components of a directive proposed as a part of a broader "Clean Energy for all Europeans" package of legislative proposals, presented in November 2016 and currently being discussed at the EU level.

The evolution towards ROCs is being driven by a requirement of the Third Package for increased regional co-operation. The meaning of this in practice is still under debate. At a minimum, ROCs would perform five services: common grid modelling; analysis of system security; co-ordination of outage planning; short-and medium-term resource adequacy forecasts; and co-ordinated calculation of transmission capacity (ENTSO-E, 2017). The preferred approach by ENTSO-E, which represents national TSOs, has been a gradual, "evolutionary" approach. Regional co-operation would be enhanced, but decisions on what additional responsibilities should be borne by the ROCs would be delayed for at least another decade (ENTSO-E, 2016).

Transitioning legacy assets into a new market environment

Most transitions from a centrally planned power system to one relying on market mechanisms require consideration of how the old system will be phased out and the new one implemented. A smooth transition requires special instruments and mechanisms. Although there are no two examples with the same transition instruments (because they respond to each country's power sector circumstances), two examples that provide interesting insights are given below.

Mexico's "legacy contracts for the regulated supplier"

The wholesale Mexican market was opened to competition in 2016. Approximately 90% of the generation belonged to or was controlled by the SOE CFE. Retail competition was opened for large customers, with a minimum threshold of 1 MW, which could aggregate a load of 25 kW.

Although investment from new entrants has begun to flow, transition to a system where the SOE is not dominant in the market will take a long time.

The SOE was divided into different legal entities, with six generation companies, one transmission company, one distribution company and one regulated retailer, which retained the customers. The regulated retailer could have bought in the spot market from the beginning, but this would have created a shock in prices. Large investments have been made in generation, and exposing the generating companies to the spot market would create additional risks to them.

The mechanism to deal with these risks was the creation of a legal obligation for the generators to provide long-term contracts to the regulated retailer, where prices were based on the costs of the plants. The Energy Ministry defined the prices and quantities allocated in these contracts, following an evaluation of the expected profitability of the plants in the long term. Plants expected to be profitable in the long term would have longer contracts. This provides a portfolio of contracts to the regulated retailer that will decrease in time and that will be complemented by an increasing number of contracts from auctions and spot market transactions with the new entrants.

One of the uncertainties in many market openings is how fast the regulated or default retailer will lose clients. In the case of Mexican legacy contracts, the regulated retailer can drop the excess capacity in the contracts, if it presents a surplus.

This process protects regulated retailer customers from price hikes, for cost recovery to the existing generators, while creating opportunities for new entrants to enter the market.

Treatment of "stranded costs" in the United States

The United States is another example of a country that has had to consider a transitional mechanism in the process of opening the market. The US Federal Energy Regulatory Commission (FERC) issued Order 888 that explicitly tackled the principles to be followed in the open-access system and recognised that there could be transition costs. These costs were labelled "stranded costs", and were used to identify "capital investments that are unrecoverable because of the transition to competition".

In the US case, the risks faced by utilities in jurisdictions being opened to competition came from previous commitments made to satisfy expected demand. Utilities in the United States had entered into agreements based on expected demand, and exiting clients would reduce the revenue base that the utilities relied on to pay for these commitments.

Order 888 treated the opening to competition and the transition as issues to be considered simultaneously. In the final rule, it was decided that utilities could come to the FERC to recover the "legitimate, prudent and verifiable stranded costs".

Two mechanisms were discussed for recovering these costs:

- an exit fee, paid once, when customers leave the utility
- a wires charge, a fee linked to the transmission service that would be unavoidable for every customer.

Although Order 888 supported the first mechanism as an ideal one, the use of a wires charge has many advantages that could make it the right tool for policy makers. This is because it makes transition to a competitive market faster as it reduces the costs of switching retailer for exiting customers.

Renewable and low-carbon energy development

International experience on renewable and low-carbon energy policy has increased dramatically over the past two decades[6]. It is beyond the scope of this report to provide a comprehensive review of these trends. A recent joint report of the IEA, the International Renewable Energy Agency and the Renewable Energy Policy Network for the 21st Century entitled *Renewable Energy Policies in a Time of Transition* (IEA/IRENA/REN21, 2018) provides such an overview.

For the current context of China, two central concepts have been selected for an in-depth discussion: system value (SV) and system-friendly deployment. This section introduces these concepts and provides examples in Germany and Mexico.

SV as a key concept for renewable and low-carbon energy development

The generation cost of various technology options is most commonly expressed in energy terms and labelled the levelised cost of energy (LCOE), which is a measure of cost for a particular generating technology at the level of a power plant. It is calculated by summing all plant-level costs (investment, fuel, emissions, operation and maintenance, etc.) and dividing them by the amount of electricity the plant will produce. Costs that are incurred at different points in time (e.g. construction costs or operational costs) are made comparable by "levelising" them over the economic lifetime of the plant – hence the name.

The LCOEs of wind and solar power have significantly reduced over the past two decades (IEA, 2015a, 2015b). In a growing number of cases, the LCOEs of wind and solar power are close to, or even below, those of fossil fuel or nuclear options. For example, the lowest currently reported contract prices for projects to come online 2019-2023 for onshore wind are under USD 30/MWh (Mexico/Brazil) and below USD 23/MWh for utility Scale solar PVs (Mexico, India and Saudi Arabia.

However, the LCOE as a measure is blind to the when, where and how of power generation. "When" refers to the temporal profile of power generation that can be achieved, "where" refers to the location of the power plant and "how" refers to the system implications that the type of generation technology may have. Whenever technologies differ in the when, where and how of their generation, a comparison based on the LCOE is no longer sufficient and can be misleading. A comparison based only on the LCOE implicitly assumes that the electricity generated from different sources has the same value.

The value of electricity depends on when and where it is generated, particularly in a power system with a high share of the VREs. During certain times, an abundance of generation can coincide with relatively low demand – in such cases, the value of electricity will be low. Conversely, when little generation is available and demand is high, the value of electricity will be high. Considering the value of electricity for the overall system opens a new perspective on the challenge of VRE integration and power system transformation.

The SV is defined as the net benefit arising from the addition of a given power generation technology. While the conceptual framework applies to all power generation technologies, the focus here is on wind and solar power plants. The SV is determined by the interplay of positive and negative effects arising from the addition. To specifically calculate the SV of a technology, which factors need to be taken into account first need to be specified. For example, a calculation

[6] This section follows Next Generation Wind and Solar Power (IEA, 2016b).

may or may not include positive externalities of technologies that do not rely on fuel that sees significant price fluctuations and associated risks.

On the positive side are all those factors included in the assessment that lead to cost reductions; these include reduced fuel costs, reduced CO_2 and other pollutant emission costs, reduced need for other generation capacity, and possibly reduced need for grid usage and associated losses. On the negative side are increases in certain costs, such as higher costs of cycling conventional power plant and for additional grid infrastructure.

The SV complements the information provided by classical metrics of generation costs, such as the LCOE. It captures the effects that additional generation has on the remaining power system. Simply put, the LCOE provides shows the cost of a certain technology, while the SV of that technology captures the net effects on the system (Figure 17).

Figure 17 • Illustration of the LCOE and SV

LCOE	SV
▪ Installation costs ▪ Operation and maintenance costs (fuel, emissions if applicable) ▪ Financing costs ▪ ...	*Positive* ▪ Reduced fuel and emission costs ▪ Reduced costs/need for other generation capacity ▪ Possibly reduced grid costs and losses *Negative* ▪ Increased wear and tear for other power plants ▪ Additional costs for grid infrastructure ▪ Curtailment

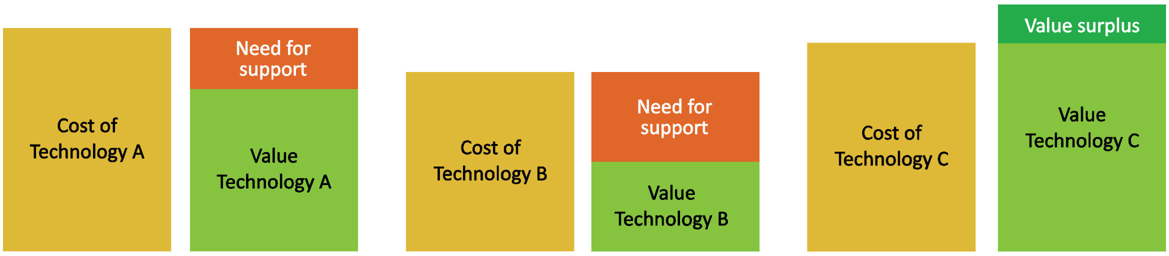
Comparing the SV values of different technologies – and not just their LCOE values – provides a complete picture and a sound basis for policy design (Figure 18). In the example in the figure, Technology B has the lowest cost, but also has a low value – hence it would require the most support to trigger deployment. By comparison, Technology C has an intermediate cost but a high SV – its deployment would not require any support because an appropriate market design was in place.

Calculating the SV of a technology requires making assumptions, regarding, for example, fuel prices or CO_2 prices. It may also require modelling tools that can compare costs among different scenarios. Furthermore, it is possible to estimate certain components of the SV by analysing actual market data, which is easy to obtain, but this requires careful interpretation of results. Only in the theoretical case that markets accurately price all relevant externalities, remunerate all benefits and charge all costs, do market prices fully reflect the SV. The degree to which this is met in practice depends on many factors. For example, assessing the SV based on spot market revenues may not capture all relevant effects on grid infrastructure if the same price is formed over large geographic regions. However, even partial information on the SV may provide critical insights for policy and market design.

A high SV indicates a good match between what a technology provides and what the power system needs. For example, when a new VRE power plant generates during times of high electricity prices, this favourable situation will be reflected in a high SV of this power plant. In well-designed power markets, a generator will receive an above-average price for the produced electricity on the market during these times.

The SV perspective provides crucial information above and beyond generation costs. Indeed, a comparison between the LCOE and the SV yields critical information for policy makers and other power system stakeholders. Where the SV of the VRE is higher than its generation cost, additional VRE capacity will help to reduce the total cost of the power system.

Figure 18 • Links among the VRE cost, the SV and competitiveness



System-friendly VRE deployment

Wind power and solar power can facilitate their own integration by means of system-friendly deployment strategies. That the VRE is often not seen as a tool for its own system integration has historic reasons. Policy priorities during the early days of VRE deployment were simply not focused on system integration. Instead, past priorities could be summarised as maximising deployment as quickly as possible and reducing the LCOE as rapidly as possible. However, this approach is not sufficient for higher shares of the VRE. Innovative approaches are needed to trigger advanced deployment and unlock the contribution of VRE technology to facilitating its own integration.

Reflecting the SV in policy frameworks requires striking a delicate balance. On the one hand, policy makers should seek to guide investment towards the technology with the highest SV compared to its generation costs. On the other hand, calculating the precise SV can be challenging; most importantly, the current and future SVs will differ.

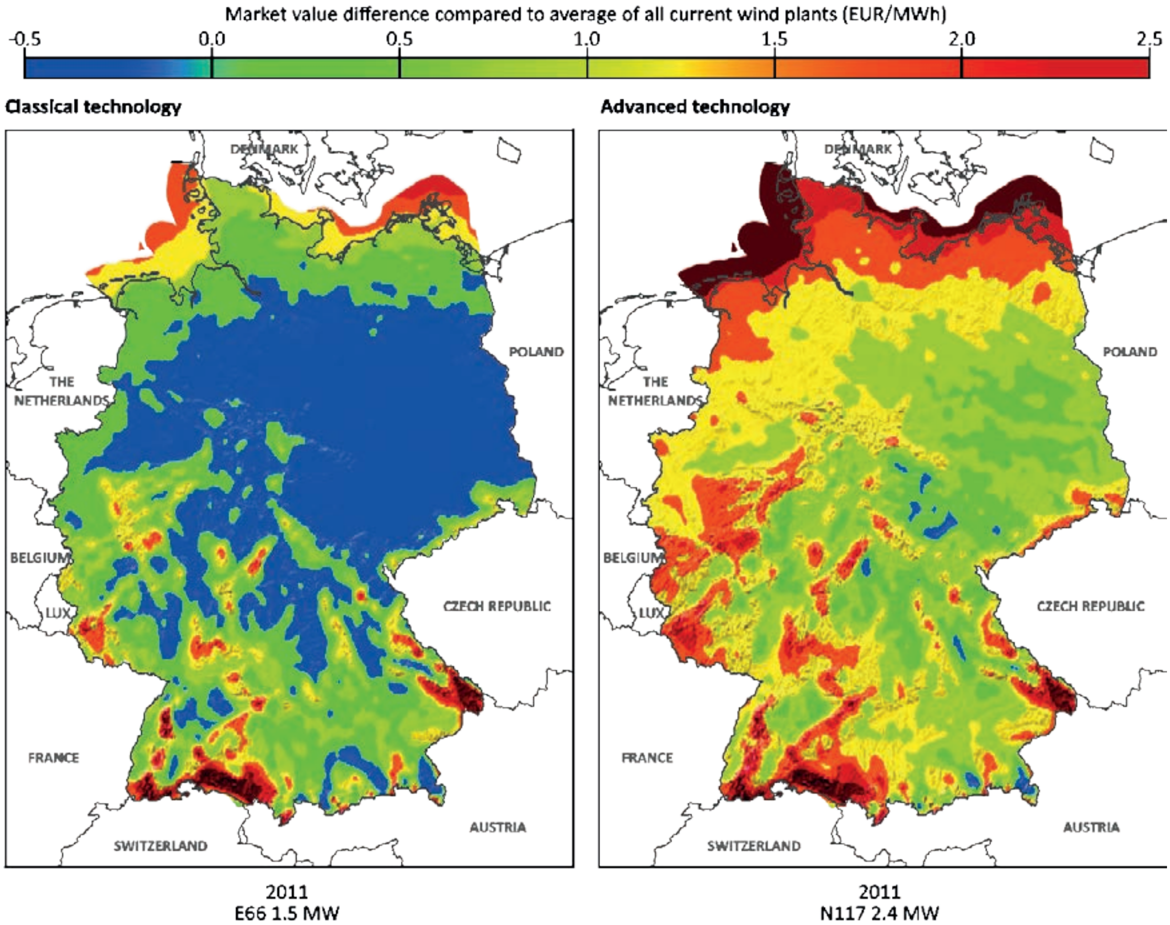
In practice, exposure to short-term market prices can be an effective way to signal the SV of different technologies to investors. This is why the introduction of a functioning spot market in China should be an important priority. However, the current SV of a technology can be a poor reflection of its long-term value. This is due to transitional effects that can be observed in some countries where the VRE has reached high shares. For example, in European electricity markets, the combined effect of renewable energy deployment, low CO_2 prices, low coal prices and negative/sluggish demand growth (slow economic growth or energy efficiency improvements) led to low wholesale market prices in recent years. These low prices mean that any new type of generation will only bring limited cost savings and will thus have a low short-term SV. Even where electricity demand is growing more rapidly, investments based purely on expected short-term wholesale power prices face multiple challenges. As wind power and solar power are capital intensive, such challenges will directly drive up the cost of their deployment, possibly widening the gap between the SV and generation costs. In addition, current market price signals may be a poor indicator of the SV in the longer term. A similar effect would occur in China in the current context, if economic dispatch and spot markets were introduced.

Mechanisms are therefore needed to provide sufficient long-term revenue certainty to investors for clean energy generation capacity. At the same time, such mechanisms need to be designed in a way that accounts for the difference in the SV among generation technologies. Some strategies have emerged to achieve this. Two examples are market premium systems, which reward VRE generators that generate higher-than-average value electricity, and advanced auction systems, such as the model recently introduced in Mexico, which selects projects based on their value to the system rather than simply on generation costs.

German market premium system

The German market premium system provides incentives for investors to choose more system-friendly deployment options. The mechanism is designed such that an average wind power plant will generate revenues that match the feed-in tariff level. The mechanism to encourage a more system-friendly deployment is this: if a power plant has a higher-than-average market value, the generator can make an additional profit. Investors are now increasingly aware of the difference in value depending on when wind turbines generate. Specialised consultancies provide data on locations where the wind blows during times when the value of electricity is particularly high (Figure 19).

Figure 19 • Market value of wind power projects depending on location, Germany (2011)



This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area

Note: Blue areas indicate below-average market value; red areas show above-average market value.

Source: Adapted from enervis/anemos (2016), *Market Value Atlas*, www.marketvalueatlas.com.

Mexican clean energy and capacity auctions

Mexico has developed an auction system that seeks to minimise the cost of support for low-carbon technologies by focusing on the SV of technologies competing in the auction. In this system, low-carbon technologies subject to support (in addition to renewables) are nuclear energy, the additional energy created by highly efficient co-generation in industrial process, and carbon capture and storage. All these sources get a Clean Energy Certificate per MWh, which is provided afterwards by the retailer, to the regulator, as proof that the minimum amount of clean energy in the portfolio required by the Energy Ministry has been fulfilled.

The Mexican auction system was developed to account for the high-cost uncertainty of renewable energy. It also considered that Mexico has a large renewable endowment of wind, solar and geothermal resources, but these resources do not each produce the same value for the system. For instance, geothermal and hydro are dispatchable technologies, while wind and solar PVs are not. Solar PVs, which were more expensive at the time when the first auction was conducted, could produce energy during moments of high demand, avoiding the use of expensive "peaker" plants in the system and providing some capacity value for a few years.

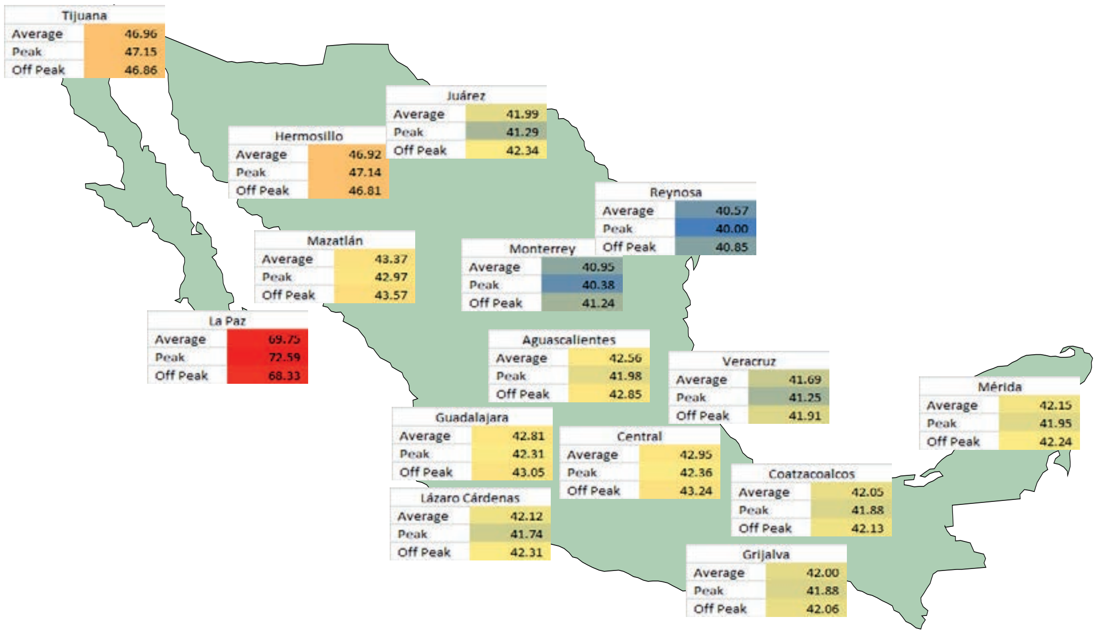
Furthermore, all these costs and value considerations will change with time, in an uncertain way. Some technologies can reduce their costs faster than others. Also, the value provided to the system can change if too much of one technology is deployed in a single region.

The solution was a technology-neutral auction with a system that incorporates premiums and penalties in the bids, so that different technologies can make comparable bids.

These premiums and penalties are based on the expected value of energy in the next 15 years (Figure 20) and are of two kinds:

- location – the country is divided into 51 power regions, and a penalty or bonus is calculated as the average difference between the values of the energy in that region and the rest of the country
- time of day – a penalty or bonus is included for energy at different times of the day.

Figure 20 • Expected average values of energy in Mexico (USD/MWh) (2016)



Source: SENER (2016), *Programa de Desarrollo del Sistema Eléctrico Nacional, PRODESEN [National Power System Development Programme]*, www.gob.mx/sener/acciones-y-programas/programa-de-desarrollo-del-sistema-electrico-nacional-33462.

The following features were incorporated to make the auction as flexible as possible:

- Three different products sold: Energy, Clean Energy Certificates and Dispatchable Capacity. Generators are not obliged to sell all three, and they can choose to sell only one.
- The auction is done 3 years in advance of the expected delivery date, although developers can engage different deliverable dates within certain limits.
- Developers can make bids conditional on other bids taken, which allows for development of large projects.

- Projects do not have priority on the grid access just because they win the auction. However, in a congested area, those who have done the interconnection procedures are given priority in the auction.

The auction compares all the bids and a replicable algorithm chooses the bids that minimise the "adjusted" costs for the buyers – once it considers the value that the plants will generate. This allows "expensive" plants (on a cost basis) to be chosen if they produce more value (i.e. they are located in a region with expensive energy, or produce energy at an expensive time of day).

Conclusions

The Chinese power system is in the process of a structural transformation that reflects new priorities and objectives as China evolves. According to the principal direction of the reform under Document No. 9, the power sector will rely largely on market forces to define the everyday operations of the power sector and prices for final consumers. However, determining the exact pathway is not an easy task and requires careful implementation. The existing rules have been very successful in attracting investments in the face of rapid growth because of the certainty they provide regarding investments. Thus, steps towards greater efficiency in the system must inspire confidence that they will address not only the current overcapacity but also future investment needs.

Moreover, this reform is not implemented in a vacuum, nor in a static power sector. The Chinese energy system is on a clear path to becoming more ecological and contributing to a cleaner environment. China has already successfully taken steps in this direction, and implementation of the power market reform can continue to bring important benefits in this regard.

Market forces can be powerful allies when properly harnessed. Document No. 9 and the six supporting guidelines provide a set of rules that provide guidance on an institutional framework, steering those forces to serve Chinese society. There are important benefits to be achieved from this endeavour:

- Even if gradual, phasing out of the "fair dispatch rule" by market-driven operations could reduce the costs of the system and improve overall efficiency. This would allow more-efficient plants to run a longer number of hours, resulting in reduced costs and emissions. Although the exact type of spot market rules needed are not yet clear from the existing pilots, the possible benefits of any system that would allow for merit-order dispatch are substantial. Indeed, part of the savings could also be used to pay for fixed costs of less-efficient plants, ensuring an orderly transition of the system.
- The explicit establishment of transmission and distribution prices will provide certainty on transactions, delivering a clear separation between grid investments and operations on the one hand, and retailing activity, on the other. The way the transmission fee has been designed in China could result in important advantages since it will explicitly include a fee for public charges. These could be also used to cover costs associated with transition while keeping part of the revenues to sustain subsidised rates.
- The large number of retailers offers good reasons to believe that competition can push final customer prices towards more cost-reflective pricing levels. This will improve economic signals on the use of electricity. However, this also requires continued progress in understanding the true cost of grid infrastructure and the attendant updates of tariffs.
- On regional integration, Guangdong Province's pilot from its conception has been designed taking into account the possibility of becoming a regional market and integrating all the provinces in the CSG footprint. Regions in China would benefit from such approach since the large geographical size of the country and the variety of resources and demand patterns would create opportunities for trade.

This document provides examples of international experience that are relevant for the Chinese case, both for the implementation of Document No. 9, and for the long-term objectives of increased efficiency and environmental sustainability (Table 16).

- **Long-term planning and data transparency –** integrating all the resources in the system, including demand-side management and response could reduce the costs of the system and enable planners to foresee the flexibility needs in the future. Such integrated planning exercises, along with data transparency, can provide guidance to market participants on the future of the system and help them to take the best decisions in line with overall system needs.

- **Electricity trading and operations** – this document presents four areas where accumulated international experience is relevant for Chinese policy makers:
  - The use of spot markets to link long- and mid-term contracts to efficient operation of the system.
  - The inclusion of adequacy mechanisms in market rules – China has seen periods of shortage and overinvestment in the power sector. The inclusion of explicit, well-designed adequacy mechanisms, such as scarcity pricing or capacity markets, can sent the right signals to attract an efficient level of investment to the sector.
  - Co-ordination of large geographical areas can bring increased benefits by enabling resources to be shared and taking advantage of different demand patterns.
  - The inclusion of transition mechanisms – Every change to the rules might bring losers, and a lack of mechanisms to address this risk can cause implementation to slow down and may reduce ambitions or result in finishing with inefficient compromises. Transitional mechanisms like vesting contracts or "wires" charges can provide the right incentives and address legitimate concerns.
- **Renewable and low-carbon energy deployment –** There is increasing international experience on how renewable and low carbon energy deployment can be guided in a way that reduces the overall cost of the power system rather than just costs of generation alone.

Table 15 • International experience relevant for China

Area	International experience
Long-term planning and data transparency	Mexico, Japan, Australia
Electricity Trading and Operation: *Link between long- and mid-term contracts with spot markets*	PJM
Electricity Trading and Operation: *Encouraging the right levels of investment*	France, United Kingdom, Mexico, PJM,MISO
Electricity Trading and Operation: *Unlocking trade across larger geographic areas*	US Western Imbalance Market Europe
Electricity Trading and Operation: *Transitioning of legacy assets into a new market environment*	United States, Mexico
Renewable and low-carbon energy deployment	Germany, Mexico

- The Chinese power system has made an impressive evolution over the past decades. Today, it is once again undergoing a deep transformation to make sure it can best serve Chinese society in line with new priorities and needs. Past reform efforts as well as the current reforms under Document No. 9 provide clear direction and a basis for making further progress. Translating this guidance into concrete steps will be an ongoing process over the coming years. We hope that the international experience presented in this document will be useful as the next steps along this path are taken.

Annex

Summary of six supporting documents (guidelines) detailing power sector reform in China

Guidelines on promoting reform of the transmission and distribution tariff

The first supportive document provides principles to be followed by provincial authorities to fix transmission and distribution rates, under supervision of the NDRC. These principles are summarised as follows:

- rates for transmission and distribution will be determined under an "allowable costs plus a reasonable income" principle, where revenues should be enough to cover the authorised costs of the grids, including capital costs
- rates are to be established by considering the reduction of inefficiencies (cost reduction)
- gradual phasing out of existing cross-subsidies, which tend to favour agricultural and domestic customers at the expense of industrial customers, should be undertaken
- grid companies should be able to recover the revenue authorised by the central government, and will not be in charge of covering any difference between feed-in tariffs and sales prices.

Guidelines on promoting construction of the electricity market

This document establishes a long-term vision for the structure of the market. It envisions opening the plan of generation and consumption so that it is the result of a competitive energy market.

Energy exchanges will be a fundamental piece of this architecture. The guidelines establish provincial obligations to set up energy exchanges that are operatively independent from grid companies. They will be in charge of running the following markets:

- energy
- ancillary services
- interprovince energy trading.

The guidelines establish the possibility for developing other products (once the run and medium-run trading mechanisms are mature) such as:

- capacity markets
- forward markets
- derivative markets.

Furthermore, the guidelines allow the annual electricity generation and consumption plan to gradually increase the share of energy allocated through competitive processes.

Once deployed, the market characteristics of the market, according to these guidelines, will include:

- stable medium and long-term trading mechanisms
- sound interregional and cross-border power trading mechanisms
- effective competition in the spot trading mechanism
- an ancillary services trading mechanism

- market mechanisms to promote deployment of renewable energy
- prevention and foresight of market manipulation.

The guidelines divide markets into:

- decentralised markets, where parties determine in advance the daily electricity consumption curve, and the deviation power is adjusted by real-time and balance transactions
- centralised markets, where market participants manage market risk with mid- to long-term and long-term contracts, and adopt spot trading through a centralised platform.

The guidelines also describe how dispatch of various resources should be given priority: wind, solar, biomass and other renewable energy have priority of dispatch; peak generation is a priority, so that the peak load can be met; and priority is given to co-generation units. A second priority is to reduce the consumption of coal and pollutants, hydropower, nuclear power, waste heat and residual pressure generation. Ultra-low-emission coal-fired units also have second priority in the dispatch.

Implementation guidelines on the establishment and standardised operation of power trading institutions

These guidelines define the institutional organisation that trading institutions (power exchanges) should follow:

- there are to be regulated not-for-profit organisations
- power exchanges will be the result of an organisational split of the trading branch from the original grid companies
- a supervisory committee formed by power grid enterprises, generators, retailers, final users and other stakeholder representatives can be established, to study and discuss the power exchange organisation charter and trading and operating rules, and to encourage proper co-ordination of matters related to the electricity market.

Two trading institutions have been formed from two grid enterprises:

- Beijing Electric Power Trading Center (relying on the State Grid Corporation)
- Guangzhou Electric Power Trading Center (relying on the Southern Power Grid Corporation).

Implementation guidelines on orderly development and utilisation of electricity

These guidelines establish the principle that, in the long term, the market must be the main mechanism to allocate resources in the power sector and allow for this to take place in an orderly manner. Therefore, the guidelines establish the co-existence of regulated services, where customers are served by generators who have not arranged a market-based contract, and a free market, where large customers and generators set energy prices freely.

On the regulated load side, the guidelines define customers as those without negotiation capacity, such as agricultural users, public utilities, and household and public services that have regulated rates, and large customers that have the bargaining power to negotiate their own rates. Industrial customers above 110 kV, commercial users above 66 kV and businesses above 35 kV are allowed to negotiate their rates. In addition, retailers, local power grids, wholesale counties,[7] industrial parks, and economic and technological development zones will be allowed to participate in direct trading.

The guidelines establish an opt-out system, where all customers can remain under the regulated service, thus paying regulated rates.

If generators have not freely fixed an energy transaction, a merit order can be established giving priority to the following technologies:

- first level: wind, solar, renewables and co-generation biomass
- second level: hydropower, nuclear power, waste heat and residual pressure generation, ultra-low-emission coal-fired generation and cross-provincial generation according to national plans and local agreement.

Coexistence of market-based generation and generation decided by previous rules

Dispatch centres are in charge of keeping the balance of the system in real time, and of providing a schedule for generators that is consistent with market transactions.

Market transactions should be considered in the annual allocation of generation (to balance the system):

- dispatch centres must annually forecast load and generation, including for renewables and exchanges with other regions
- generation sources must be set in the merit order provided in the guidelines
- market transactions should be scheduled according to load and generation profiles
- security analysis must be conducted to check if transactions are compatible with secure system operation
- the capacity available to serve the regulated entities should be determined by deducing the capacity of the generation participating in the free market
- the annual plan should be adjusted to correct for forecast deviations.

Provinces are encouraged to make agreements to consider interprovincial exchange of energy. All involved parties should negotiate other forms of interprovincial transactions.

Guidelines on promoting the reform of electricity selling side

These guidelines provide a framework for entities to sell electricity to final customers. Three kinds of entities can make retail sales:

- independent sales companies, without ownership of assets in the distribution segment
- power grid companies selling electricity
- companies owning "incremental distribution networks", i.e. those with the right to install new distribution grids in previously interconnected areas.

The guidelines provide the basis for regulations on various issues in the retail segment, such as access and exit requirements to the retail segment, the credit system, guarantees and related risk prevention.

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[7] *Wholesale counties* is a form of unique sales determined by China's existing power system. Apart from the state-owned large-scale power grids, some local power grids (mainly at the county level) are still local assets, i.e. county-level power supply companies. Most of these county-level power supply companies have a lower power supply in their power supply areas and cannot meet the demand for electricity. They bought electricity from the state grid, and then sold to users in the region.

Guidelines on strengthening and standardising the supervision and management of captive coal power plants

The sixth supportive document provides guidelines for regulation of self-supply generation.[8] In particular, it stresses the following regulatory principles:

- self-supply plants should be integrated into national planning, and expansion of new coal power plants should be consistent with national energy policy
- public and self-supply generators should have equal opportunities to be allocated new generation
- no further expansion will be allowed in the regions of Beijing, Tianjin, Hebei, the Yangtze River Delta or the Pearl River Delta, given the existing overcapacity
- construction of new power plants should follow the principles of the reasonable choice models and installed capacity
- self-supply plants should have open and not discriminatory access to grids.

The guidelines clarify that self-suppliers are not exempt from the regulations that other market participants are subject to. In particular, self-suppliers should:

- participate in the provision of auxiliary services, follow dispatch instructions and schedule maintenance
- provide, according to their technology, auxiliary services and receive compensation according to the provisions
- contribute to the various shared costs of the system, including funds and fees for cross-subsidies, according to the methodology set by the NDRC and applied by provincial authorities
- follow energy efficiency regulations to reduce coal consumption (as a means to promote efficient use of waste heat and residual pressure, without sharing the quota permission of local coal-fired plants)
- be subject to upgrading and eliminate inefficient units
- participate in market transactions
- promote modernisation of fleets
- invest in devices to meet environmental standards (thermal plants)
- follow public policy on energy and water efficiency (thermal plants)
- promote upgrading of plants and retirement of plants unable to meet efficiency and environmental standards.

[8] *Self-supply generation* comprises undertakings that generate electricity or heat, wholly or partly for their own use as an activity that supports their primary activity.

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Acronyms, abbreviations and units of measure

Acronyms and abbreviations

ACER	Agency for the Co-operation of Energy Regulators
AEMO	Australian Energy Market Operator
CACM	capacity allocation and congestion management
CAISO	California Independent System Operator
CPI	China Power Investment
CSG	China Southern Grid
EIM	Energy Imbalance Market
ENTSO-E	European Network for Transmission System Operators for Electricity
EPCO	Electric Power Company
EU	European Union
FERC	Federal Energy Regulatory Commission
GDP	gross domestic product
IEA	International Energy Agency
ISP	Integrated System Plan
LCOE	levelised cost of energy
METI	Ministry of Economy, Trade and Industry
MISO	Midcontinent Independent System Operator
NDRC	National Development and Reform Commission
NEA	National Energy Administration
NEM	National Electricity Market
OCCTO	Organization for Cross-regional Co-ordination of Transmission Operators
PPA	Power Purchase Agreement
PRODESEN	Programa de Desarrollo del Sistema Eléctrico Nacional
PV	photovoltaic
RDC	regional dispatch centre
ROC	regional operating centre
RSCI	regional security co-operation initiative
RTO	regional transmission operator
SERC	State Electricity Regulatory Commission
SGCC	State Grid Corporation of China
SME	small and medium-sized enterprise
SOE	state-owned enterprise
SPC	State Power Corporation
SV	system value
TSO	transmission system operator
UHV	ultra-high voltage
VRE	variable renewable energy

Currency codes

CNY	Chinese Yuan renminbi
EUR	Euro
USD	United states dollar

Units of measure

GW	gigawatt
GWh	gigawatt hour
kV	kilovolt
kW	kilowatt
kWh	kilowatt hour
Mt	million tonnes
MW	megawatt
MWh	megawatt hour
t	tonne
TWh	terawatt hour

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