Building a Unified National Power Market System in China

Pathways for spot power markets

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Abstract

Power markets are an instrument used globally to ensure electricity security while maintaining affordability and incentivising decarbonisation. The People's Republic of China (hereafter, "China") has been making big steps towards implementing markets, and the goals announced in 2020 of carbon dioxide emissions peaking before 2030 and carbon neutrality before 2060 have added momentum to expand their footprint. Provinces have taken a leading role in designing and implementing markets. To improve sharing of resources, the guidance to implement a unified national market system pushes for more co-ordination between provinces.

The main audience of this report is policy makers in China and all experts intending to contribute to power sector reforms. Other readers will also find information on the how the power sector and, in particular, power markets operate today in China and may evolve in the next decade.

This report examines the role of power markets in China and the pathways to develop a national market. The analysis focuses on short-term markets because they have the potential to unlock flexibility the system needs in light of renewables growth and changing weather patterns. The report provides recommendations to improve markets' co-ordination across the country as well as within the provinces.

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Executive summary

China's latest power sector reforms place electricity markets on the centre stage

Markets are taking a growing role in the power system of the People's Republic of China (hereafter, "China"). Although administrative mechanisms have been the main driver for China's power sector to achieve China's energy and climate policy objectives, benchmarking and competition among coal-fired plants have improved the efficiency and environmental attributes of electricity. The last major round of reforms started in 2015 gave a decisive nudge to markets to incentivise flexibility as the power system transforms. Increased participation in markets on both the supply and demand sides can be expected to continue as the 14th Five-Year plan (2021-2025) aims to give a leading role to markets.

Power sector reforms seek a balance between optimisation of resources across the country and protection of local industries, between stable, affordable electricity prices and active new capacity investment, and between energy transition and secure electricity supply. Over the last three decades, several rounds of reforms took place. They initially aimed at easing investment in new generation capacity to sustain China's economic growth, before addressing the efficiency of the power supply system and environmental aspects. After the power shortages of 2021 and 2022, the security narrative has taken a growing role in the national government guidance.

The mid-to-long-term (MLT) markets are the most developed form of markets in China. Launched under the 2015 reform, MLT contracts have gradually replaced the administrative allocation of hours to generators. Today, MLT contracts cover half of the electricity consumed and about four-fifths of the traded volume. Although the most common contracts have a duration of one year to one month, shorter and longer duration contracts are appearing, and these can now be traded directly between consumers and generators or on power exchanges.

Short-term markets have not achieved their full potential despite the possibilities they bring to unlock flexibility. The 2015 reform included the deployment of spot power markets (day-ahead and intraday) to implement economic dispatch and unlock flexibility from supply and demand resources. In market-based systems, these short-term markets play a central role in price formation and support electricity security, for example during the European winter 2022-2023 amid falling gas supply. In China, the first provincial spot market pilots were launched in 2019, with some of them operating continuously now. Spot markets are expanding across the country, but their share in trade

remains small and the connection with other established markets (MLT, ancillary services) is in practice still being completed.

Better sharing of resources across the country requires national co-ordination of local markets. The uneven geographical distribution of resources and demand in China has led to national projects to transfer power across the country. These interprovincial flows are supported by firm, unidirectional MLT contracts. The 2015 reform gave autonomy to provinces to define markets at the provincial level. The resulting market designs, which may diverge significantly, in combination with local economic incentives favour intra-provincial trade. Cost-effective sharing of resources will require more flexible arrangements and integration of the different products with varying geographical and time granularity. Pilots of interprovincial and regional spot markets are now being deployed and can be the foundation of a more unified system.

China aims to build a unified national power market by 2030

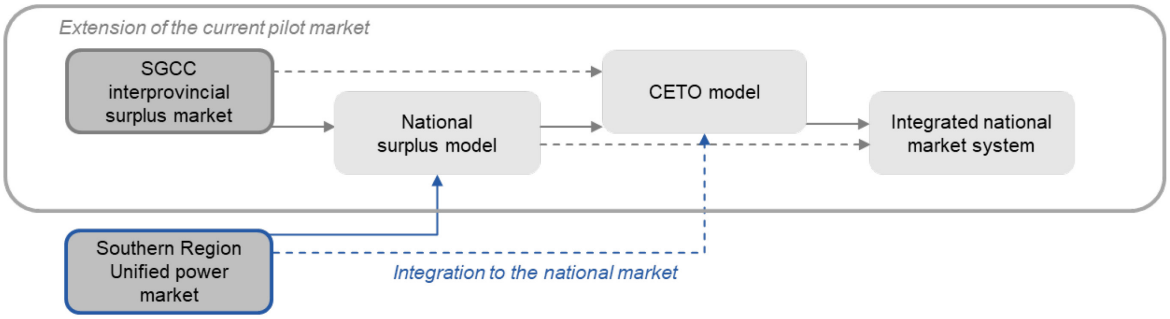
China targets a co-ordinated system of markets at the national level. While preserving the role of provinces in designing their local markets, the guidance released in 2022 by the National Development and Reform Commission (NRDC) and the National Energy Administration (NEA) – Document No. 118 – requires the creation of a multilayer market architecture with a national component. This system, to be initially established by 2025 and completed by 2030, aims to co-ordinate existing markets before enabling their integration in the future.

Existing markets can be the foundation of a national market system in China. A national spot market can be built by adapting and expanding the already established provincial and regional markets. Initiated in 2017 to enable exchange and increased use of renewable power “otherwise to be curtailed”, the pilot interprovincial spot power market in the State Grid area can be extended to become a national spot market according to a so-called secondary model, where a national market exists in parallel with the existing local markets. This market would enable better sharing of resources while preserving local autonomy in market designs and dispatch decisions. This is well-suited for China as local markets have adopted different models and are at uneven levels of maturity. This secondary market structure can operate in parallel with the existing provincial markets as well as the planned southern regional market – which aims to expand the Guangdong provincial market to integrate all provinces under the China Southern Grid area.

Several pathways can be taken to establish a national spot power market. Two models of secondary markets are considered to enable better sharing of resources across the country. In a surplus market (similar to the current interprovincial spot

market), only surpluses are exchanged between the local markets. A higher level of co-ordination can be achieved with "volume coupling" of local markets such as the model introduced by the China Energy Transformation Outlook (CETO). Both models can be intermediary steps before a higher integration in the future.

Several pathways can be taken to implement a national spot power market



Notes: SGCC = State Grid Corporation of China. The recommended pathway is indicated by the plain arrows. More direct upgrades as represented by the dashed arrows are possible.

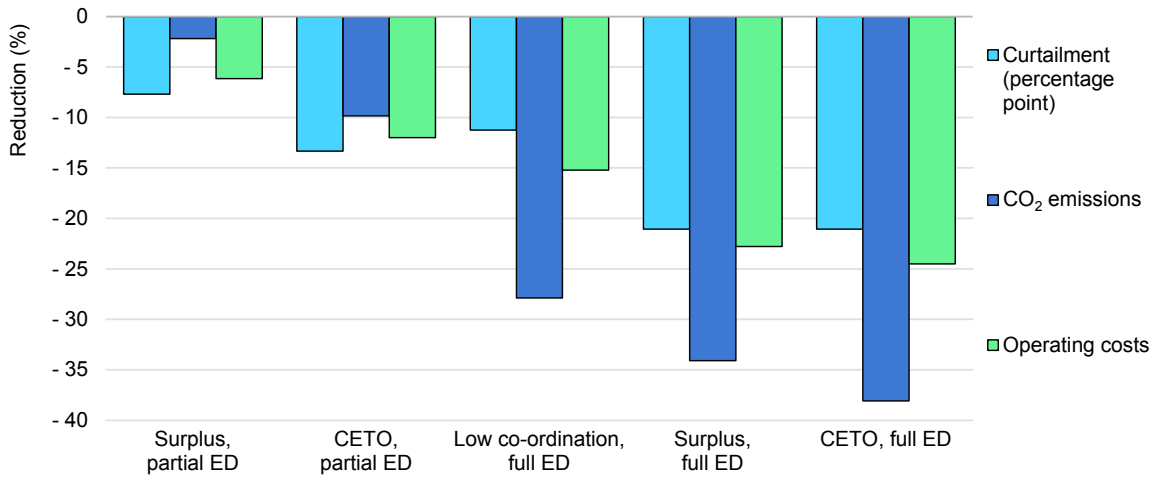
A national surplus market is a no-regret move on the path to more integration in the future. The implementation challenges may be the decisive factor to decide the path forward. Implementing a national surplus market has the advantage of quickly capturing the benefits of regional co-ordination while enabling to move later to more integrated forms of markets since all developments made to establish a surplus market can be reused and upgraded.

Regional trade co-ordination through a national market can deliver substantial efficiency benefits and increased resilience. Regional trade improves resources sharing across larger areas. This brings many benefits in terms of resilience and can contribute to reducing needed investments in generation assets for reserve. There are also operational efficiency gains. In the Announced Pledges Scenario (APS) in 2035, reductions in operating costs range from 6-12% and decreases in CO_2 emissions range from 2-10% compared with a situation where regional co-ordination is not improved (assuming the market orientation of dispatch is kept at the current levels).

Advancing economic dispatch in local markets delivers even higher benefits than regional co-ordination. Spot market development and financial MLT contracts have made dispatch more market-based, which already shows benefits. An advantage of secondary market models is the ability to deploy the national market with limited need for harmonisation of practices, so steps towards economic dispatch can be taken by provinces in parallel with the increased co-ordination. Achieving full economic dispatch in the modelled regions (with no improvement in regional co-ordination) leads to reductions in operating costs by around 15% and in CO_2 emissions by 28%. Rolling out economic dispatch

alongside market reform provides further benefits, amounting to more than double the benefit of the regional co-ordination alone.

Reductions in operating costs, CO_2 emissions and curtailment under different levels of co-ordination and economic dispatch in China in the Announced Pledges Scenario, 2035



Notes: ED = economic dispatch; CETO = China Energy Transition Outlook model based on volume coupling for regional co-ordination. Reductions are calculated relative to a low-co-ordination baseline scenario with interregional exchanges based on historical levels and dispatch reflecting current progress towards markets with economic dispatch in some regions and full load hour allocations taking place in the remainder.

National institutions can play a bigger role in co-ordination. The leading role in the move towards markets under the 2015 reform was largely assigned to provincial authorities and grid companies. Integrating the existing markets towards a unified national system will require a higher level of co-ordination and the leadership of strong and independent national institutions. Guidance for market design and market supervision by a national authority can enable future harmonisation of practices and efficient functioning of markets.

Power markets can accelerate the decarbonisation of the Chinese power sector. Electricity generated in China is twice the combined amounts of the United States and the European Union, and accounts for 14% of global carbon emissions. Therefore, reducing carbon intensity of China's electricity is crucial for achieving the dual carbon goals of China (peaking carbon dioxide emissions before 2030 and carbon neutrality before 2060) and the global climate goals. Global experience shows that well-functioning power markets, in combination with carbon pricing, can accelerate decarbonisation. A national emission trading system was launched in China in 2021. Further deployment of power markets can create the framework in which a carbon pricing mechanism can take effect and achieve the dual carbon goals smoothly.

Key policy recommendations to advance power markets that support China's policy objectives

- Establish a national spot market under a secondary market model that extends the existing interprovincial spot market and enables, for the time being, existing local markets to maintain autonomy in market design and dispatch decisions. This enables quickly capturing the benefits of enhanced regional co-ordination.
- Reinforce the role of national institutions to supervise market implementation and to support co-ordination between national and local markets, as well as co-ordination among national plans, markets and operational protocols.
- Lift barriers to interprovincial trade to enable smoothing variability over larger areas. Trading arrangements may be made more flexible, allowing adjustments closer to real time, and transmission tariffs can be adapted.
- Continue to incentivise the implementation of economic dispatch in local markets, through deployment of spot markets and by ensuring long-term and ancillary services markets allow for contractual flexibility. The shift from physical to financial contracts on the MLT market is particularly important to this end.

Background and motivation

The power system of the People's Republic of China (hereafter, "China") is the largest in the world, with an electricity production of 8 849 terawatt-hours (TWh) in 2022, exceeding the combined annual generation of the United States (4 524 TWh), the European Union (2 842 TWh) and Japan (1 017 TWh). Dominated by coal, it accounts alone for 14% of global energy sector CO_2 emissions, and over 40% of China's energy-related CO_2 emissions. Therefore, any change can have significant outcomes. Power sector transformation is one of the foundations of the clean energy transition needed to achieve China's goal for carbon dioxide emissions peaking before 2030 and carbon neutrality before 2060 ("dual carbon goals"). As the main global supplier of clean energy technologies, China's efforts to decarbonise its power sector will also be key to ensure clean supply chains worldwide. A symbolic milestone was achieved in 2022 when for the first time in China the total installed capacity of renewables exceeded that of coal-fired power plants. More than 30% of the power generation mix now comes from renewables, and 14% from wind and solar. Electrification of energy end uses is also quickly changing and expanding the demand side. Power sector reforms will continue to accommodate this transformation while ensuring electricity security and cost-efficiency.

The International Energy Agency (IEA) has been engaged for many years in China's power sector transformation, providing analysis and recommendations to implement the market-based mechanisms outlined in the third round of reforms of 2015. The 2019 IEA report China Power System Transformation already identified the establishment of spot markets (from day-ahead to real time) and trade between provinces as two of the main elements to improve system operation efficiency in China. The analysis included a state-of-the-art modelling exercise to quantify the benefits for the Chinese power system in 2035 of introducing economic dispatch, increasing interregional trade and deploying advanced flexibility options. The implementation of a national spot market was assessed using an economic dispatch protocol performed on an hourly basis, against a baseline scenario for 2018 with administrative allocation of running hours to generators. Variations around the use of interconnections and expansion of transmission capacities were applied to simulate different levels of interregional trading. The modelling also separately quantified the effects of advanced flexibility measures such as applying demand response, smart charging of electric vehicles and storage in a power system with optimised economic dispatch, interregional trading and additional transmission investments.

This previous work showed that significant benefits can be obtained in terms of reductions of operational costs, carbon emissions and renewables curtailment by moving away from an operation model based on administrative allocation and limited trade across regions. Moreover, advanced flexibility measures were found to be crucial for a modern Chinese power system with a high share of variable renewables (VRE). An updated analysis was then provided in the 2021 IEA report An Energy Sector Roadmap to Carbon Neutrality in China, to align with the dual carbon goals.

While previous reports demonstrated that achieving these benefits entails giving a larger role to short-term electricity trading across the country – and thus establishing stable and reliable wholesale spot markets – they contain some limitations. First, previous analyses considered only a situation where economic dispatch is performed at the national scale, which fails to translate the complexity of the Chinese power system, given its size and its constraints at multiple layers. Second, the administrative allocation of running hours to generators as used as a reference case has been evolving in China, as policies encouraged participation of generators and large consumers to MLT markets. Lately, the introduction of pilot spot power markets has further scaled back the minimum allocated hours of generators. Third, our previous work did not discuss what model of multilateral trading would be best suited for Chinese provinces and regions, nor the pathways towards integration of these diverse markets, some already well established and in operation, some nascent and some yet to be designed.

In January 2022, the National Development and Reform Commission (NDRC) and the National Energy Administration (NEA) issued the Guiding Opinions to Accelerate Unified National Power Market System, also known as Document No. 118. This document points out the need to improve the current system of markets and to improve co-ordination across the country and calls for the establishment of a "unified national electricity market system" by 2030. Although Document No. 118 does not explicitly require unification of spot markets, this report gives particular attention to these markets in light of the central role they play in other market-based systems around the globe.

Structure of the report

This report aims to illustrate pathways for implementing Document No. 118 and integrate power markets. This work does not provide detailed design options but highlights the main requirements to ensure market integration in an efficient and secure way.

The structure of the report is as follows. The first section takes stock of the role of markets in the Chinese power sector, with a general overview first before looking at spot markets in particular. Readers familiar with the Chinese power sector may

skip this first section. The second section looks at a few possible models for a national spot power market in China. These models are inspired by international experience and their application to the Chinese case is described. The third section makes a selection among the target models described in the second section and lays a pathway from the current situation to the selected target model. Finally, recommendations are provided for spot markets at both the national and provincial levels.

Power markets in China's power sector transformation

Developed markets, where all participants are made responsible for all costs and benefits arising from their actions, can support policy objectives which can be locally defined according to social preferences, and in particular guide the electricity system towards secure, affordable and decarbonised electricity. Outside of China, over 50% of the global electricity is generated in power systems relying on liberalised markets, delivering a wealth of experience in designing and deploying markets.

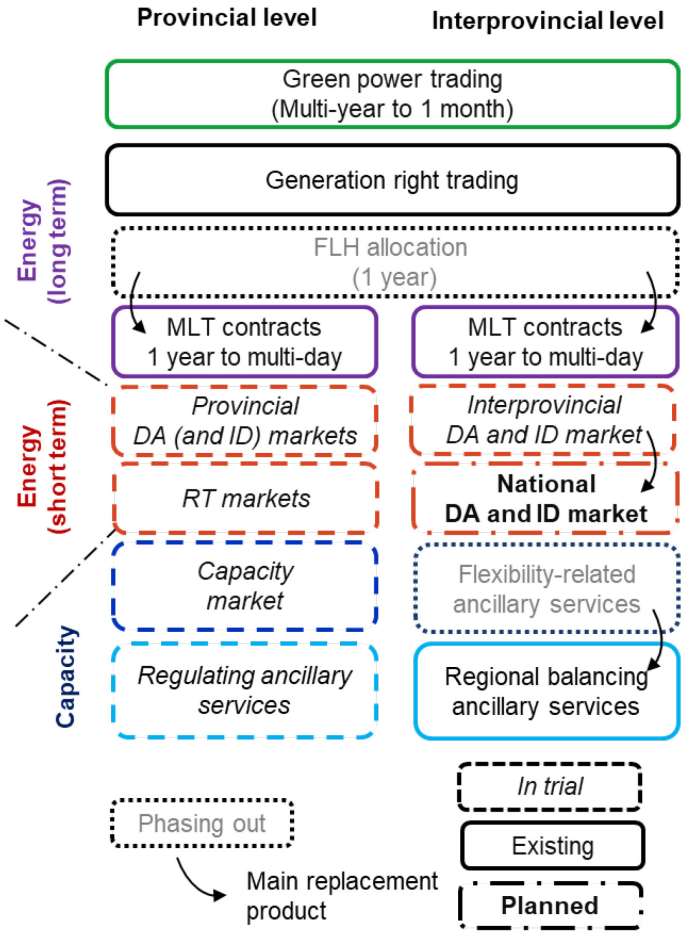
Until 2015 in China, the share of generation from every plant and the prices were administratively decided in order to keep prices stable and share benefits fairly. Initiating the current major round of reforms, the release of Document No. 9 promoted power markets to further improve cost-effectiveness of generation and adapt to the transformation of the power system. These markets mainly developed at the provincial level. Power trade expanded quickly in recent years: in 2022, 61% of the electricity generation was traded in markets, representing an increase of 39% from 2021. China's wholesale power market is dominated by bilateral MLT contracts, which represent 79% of total traded volume. Spot markets are at nascent stages and have limited scope. Since pilots were initiated in 2017, seven provinces representing 41% of China's power demand run continuously operational spot markets today.

To capture the numerous benefits of resources co-ordination across provinces, interprovincial and regional markets have also been initiated. Wider market and operating areas improve flexibility and allow optimising the volume and cost of required reserves, thereby reducing the need for dispatchable thermal units, a benefit that grows as the share of VRE increases. However, in 2022, 97% of the MLT trades took place within provincial borders, leaving a limited role for markets across provinces to optimise resource sharing. A new impulse was given in 2022 with the release of Document No. 118 requiring the establishment of a unified national market system.

This section describes the history and state of play of wholesale power markets in China. It is divided into two parts. The first part looks at the development of wholesale markets in general while the second part focuses on spot markets.

The push for power markets in China

System services and products in China's power system



Notes: FLH = full load hours; MLT = mid to long term; DA = day-ahead; ID = intraday; RT = real-time. Not all products and services are traded on a competitive market. Capacity and short-term markets exist only in part of the provinces and the intraday market is not required by the NEA. *Flexibility-related ancillary services* include services such as "peak adjustment" or "deep ramping", which become unnecessary once short-term markets are in operation.

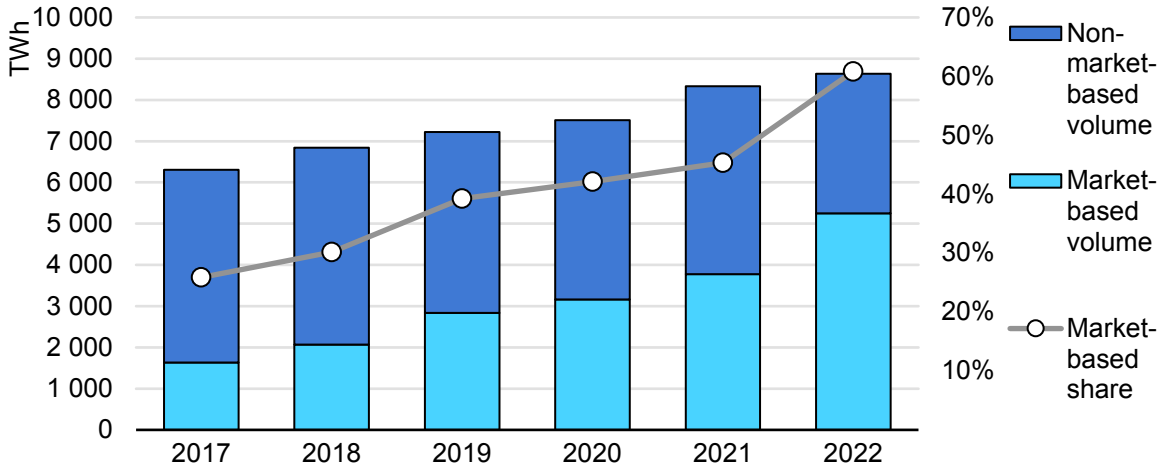
Electricity security and generation efficiency drive power sector reforms

The power sector in China started its transition from planned model in 1987. In 1997 and 2002, the country launched major power sector reforms, first to separate the sector from direct administration control, and then to unbundle the vertically integrated power company into generation and grid activities. As the generation business opened to private investors in order to address supply shortages, "fair dispatch", an administrative process ensuring that all plants would be allocated similar amount of FLHs over the year, was adopted.

In 2015, the State Council issued Document No. 9, marking a new round of reforms with a main target of liberalisation of the demand and supply sides, while giving a prominent role to efficiency, security, and reducing emissions of greenhouse gases and other pollutants. The reforms supported the establishment of MLT, spot and ancillary markets, and delegated to provinces the power to decide their own approaches and carry out pilots based on their different electricity structures.

Numerous pilots across different provinces and different reform orientations brought about rapid growth in market size. According to the China Electricity Council, the total volume of transactions in China's power market, mainly based on MLT contracts, has reached 5 254 TWh, representing 61% of China's total consumption, more than tripling from 2017.

Evolution of market-based electricity volume and share, 2017-2022



Source: IEA analysis from China Electricity Council data.

Transition requires linking legacy practices with markets

Markets in China face barriers due to the heritage of the planned economy. China seeks a balance between optimisation of resources across the country and protection of local industries, between stable electricity prices and active new capacity investment, and between energy transition and secure electricity supply.

To encourage investments in new capacity and prevent power shortages, China adopted "fair dispatch" in the early 2000s to ensure non-discriminatory FLHs execution for all power plants. Since then, administrative allocation has progressively moved towards MLT contracts between generators and consumers with a duration from one year to one month. Regulated electricity prices, however, challenged the profitability of generators as the coal price reached a historic high

in 2021, and an unprecedented heat wave shaved hydro capacity in 2022 while air conditioning pushed summertime demand upwards.

Future reforms will have to balance local and national interests

Provincial autonomy in the power sector also constitutes a barrier to markets. China has put provinces at the heart of power market reforms, allowing local governments to make rules for their respective power markets.

Due to the unbalanced geographical distribution of natural resources and demand, China has sought to optimise power transmission at the national level to reduce the curtailment rates of solar PV and wind in northwest China, and the threats of power shortages in other regions, as materialised in the summers of 2021 and 2022. China deployed a (ultra-)high-voltage grid with a transmission capacity over 200 gigawatts, which transmitted 1 770 TWh across provincial borders in 2022, representing a fifth of the total national consumption. The bulk of this energy transfer is associated to national projects such as the West-to-East transfer and large hydro plants such as the Three Gorges Dam in central China.

Unbalanced resource distribution is a motivation for central institutions to reinforce co-ordination, but provincial governments remain less proactive to promote an interprovincial market that may challenge the local power sector. The national strategy of transmitting electricity from the resource-rich west to the demand-intensive east is mainly carried out through administrative orders and bilateral contracts signed across provinces[1], which serve as firm inputs to provincial markets. Initial moves have been made to establish interprovincial contracts, but these are mostly unidirectional and for the long term, and under regulated price. Transmission tariffs, which cumulate along the flow paths ("tariff pancaking"), also limit the attractiveness of cross-provincial transactions.

Energy transition may accelerate power market reforms

In line with its ambitious dual carbon goals, China is transforming the power sector by massively deploying renewables. Renewables deployment outpaced any other source in 2022, with year-on-year capacity growth exceeding 28% for solar and 11% for wind. Ongoing and upcoming reforms must address the limited incentives for flexibility of resources and investment in new dispatchable capacities in parallel with the rapid growth of renewables.

[1] These bilateral contracts can be between provincial grid companies (grid-to-grid) or between a generator and a grid company (point-to-grid).

China is increasingly making use of markets to support the energy transition, such as the Emission Trading Scheme (ETS) that has been in place for nearly two years and the green electricity market that focuses on power purchase agreements (PPAs). These long-term bilateral contracts between renewable generators and large consumers help secure funding for renewable projects and hedge prices for the consumers.

To unlock more flexibility sources in a transforming power sector, China is paying a growing attention to capacity remuneration mechanism (CRMs) and virtual power plants (VPPs). According to NDRC's announcement during the National People's Congress in March 2023, CRMs will be able to support profitability of existing plants and investment in additional capacities, mostly targeting coal plants, the current major source of flexibility. Encouraged in several policy documents, including the NEA's spot market rules published in November 2022, VPPs aggregate distributed energy resources to provide short-term flexibility as road transport, heating and other sectors electrify.

Document No. 118 calls for a unified national market by 2030

The diversity of market initiatives and their lack of co-ordination are increasing the barriers to market operation. On 21 January 2022, the NDRC and NEA issued the Guiding Opinions to Accelerate Unified National Power Market System, also known as Document No. 118. This document points out the need to improve co-ordination of the existing markets and calls for the establishment of a "unified national electricity market system" by 2030. The foundations of this national market are the existing interprovincial markets, namely a centralised marketplace for bilateral MLT contracts and a pilot interprovincial spot market in the State Grid Corporation of China (SGCC) area. The detailed goals set out by the document are summarised in the table below. It is noted that Document No. 118 does not explicitly require unifying spot markets.

The construction of a unified national power market system is now raised at the level of national strategy, being referred to as a "key reform task" in the 14th Five-Year Plan for a Modern Energy System (2021-2025). It is also listed in first position in the NEA's key priorities for 2023 regarding energy regulation, with emphasis on preparing a development plan, standardising rules and pushing forward the construction of regional markets.

Goals set for national markets in Document No. 118

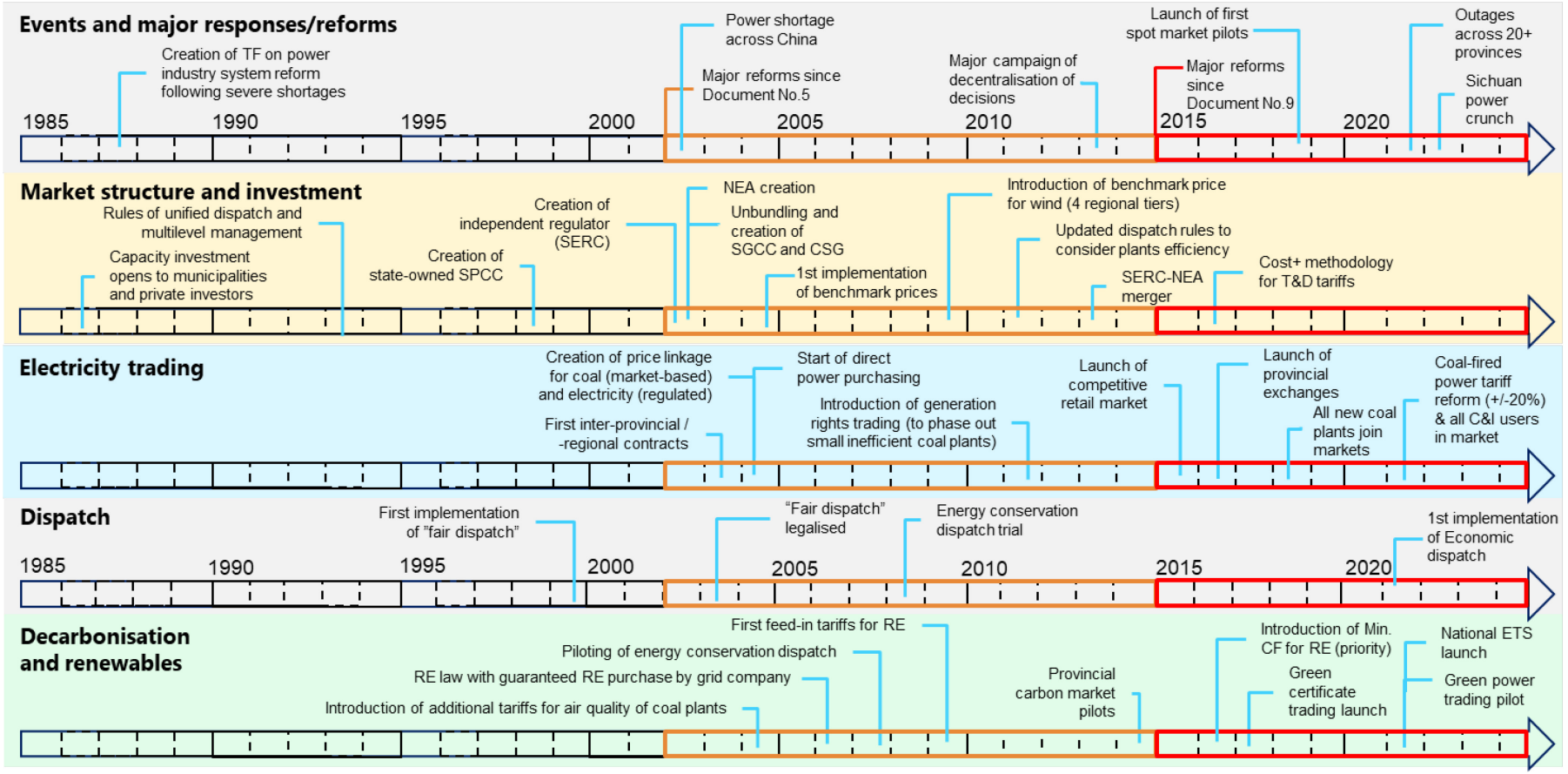
Items	2025 goals	2030 goals
Implementation of unified national electricity market	Establish preliminary structure of the market	Fundamentally establish a unified national electricity market
Role of provincial and regional markets	Co-ordinated operation with national market	Integrated operation with national market
Connection among MLT/spot/ancillary services markets	Design an integrated system and pursue linked operation	--
Interprovincial and regional trade/green power trade	Significantly expand trade volume	--
Renewable energy	Establish a preliminary foundation for market and price mechanisms that enables the development of renewables and energy storage	Full integration of renewables into the market

Global practices show the need to continuously improve market design

Since 2021, power markets globally have been stressed by the tightness on gas markets. In Europe, historic high prices hit customers hard and resulted in demand destruction in industry. This was echoed in China with an increasing focus on energy security in the 14th Five-Year Plan and 20th Party Congress after the record high coal prices in summer 2021.

As intense stakeholders' consultations take place in Europe, a major lesson learned is that market designs are not static and should be continuously adapted to exogenous changes and to support policy objectives. China is attentively monitoring to take onboard lessons for its own market designs to balance electricity security with effective price signals, price stability and affordability.

China's power sector reform milestones, 1985-2022



Note: TF = Task Force; SPCC = State Power Corporation of China; SERC = State Electricity Regulatory Commission; CSG = China Southern Power Grid; T&D = transmission and distribution; C&I = commercial and industrial; min. CF = minimum capacity factor; RE = renewable energy.

Source: IEA based on template by Fatras et al (2022), A systematic review of electricity market liberalisation and its alignment with industrial consumer participation: A comparison between the Nordics and China.

Spot power markets at the provincial and cross-provincial level

Reforms are making cautious steps towards a market-driven dispatch of resources.

Short-term markets have been a component of all power sector reforms in China. In 1998 and 2002, China launched two rounds of pilots of regional spot markets that were both stopped due to the issue of "imbalance funds" that can appear with the "dual track" system, in which in- and out-of-the-market resources co-exist.

Today, the most mature market is the MLT market where the dominant product is annual contracts relying on a benchmark on-grid tariff set administratively. China introduced generation rights trading in 2011 to compensate inefficient plants set to be decommissioned. As physical contracts are a barrier to flexibility, this mechanism can also be used to decouple real-time dispatch from long-term contracts. To further unlock flexibility and cost-effectiveness, Document No. 2752, the action plan of Document No. 9 (2015), aimed to complement the MLT markets with liquid short-term markets, which may also provide a reference price for MLT contracts.

On the other hand, authorities are deploying rules to mitigate the potential volatility of spot markets by, for example, limiting their size and imposing prices caps. In its annual instructions on MLT electricity contracts of December 2022, the NDRC clearly indicates that all in-the-market consumers shall sign MLT contracts in 2023 for volumes of no less than 90% of 2022 consumption.

Effectively connecting MLT and spot markets remains a heated topic of debate. As China continues to consider MLT as the foundation of power markets, policy makers have pushed for diversification of MLT products in terms of trade frequency, time frame and curve setting, and softened the requirement for physical execution.

Dispatch approach in provinces with a spot market pilot

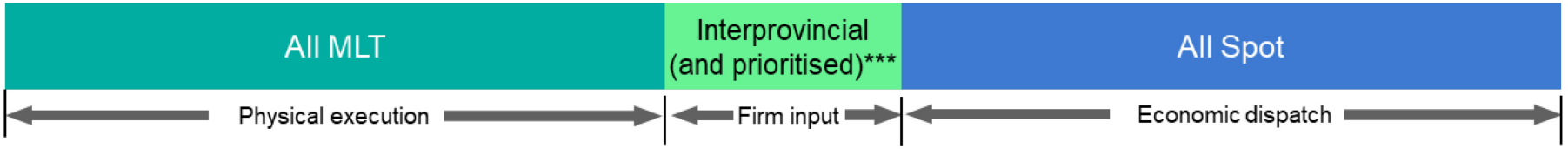
In provinces applying a gross pool model: MLT contracts are financial (CfD)

Prioritised generation (renewables, nuclear and, in some provinces, gas) serves as firm input in the clearing process.

*** Hydropower projects base their generation on the needs of reservoirs. Apart from allocated FLHs, they provide ancillary services and can participate in the spot market.**

**** Local VRE/nuclear/gas may decide to put a certain amount of generation in the market to be economically dispatched (and to be paid by market price), depending on whether it is allowed by the local authority.**

In Fujian, applying a net pool model: MLT contracts are physical



Prioritised generation in Fujian refers to VRE, hydro, nuclear and gas.

Trading parties agree on curves of MLT contracts to be physically executed. Interprovincial also serves as firm input to clearing.

***** Fujian rule is unclear on connection between prioritised generation and clearing.**

Notes: CfD = contract for difference. In a net pool, "All" refers to all non-prioritised generation within the province. Dispatch described is according to the common rules issued by the NEA (for consultation) as well as provincial spot market rules, and may be altered by administrative allocation of hours to generators. Lengths of the bars are not proportional to dispatched volumes.

Ancillary services markets were a first attempt to steer power generators' flexibility

In China, "peak adjustment" (or "deep ramping") refers to dedicated measures to incentivise power plant flexibility and reduce renewables curtailment, and they are classified as ancillary services. These services are meant to pay for forgone energy and energy arbitrage, and are distinct from the globally used services for frequency regulation, reactive power control and system restoration. Markets for peak adjustment were initiated in 2014 and designed to operate in the absence of spot markets by providing economic incentives to generators to operate below their contractual output level. The northeast region first implemented a peak adjustment market in the day-ahead requiring thermal plants without heat obligations to lower their output to reduce the curtailment of wind during the heating season, when co-generation units have priority. Having extended to all six regions in China by July 2022, these markets often operate at the regional level in support of the system balancing performed by regional dispatch centres.

Recently, developments in ancillary markets also happen at provincial level, with most provinces having launched provincial peak adjustment markets. Most first-batch spot pilot provinces including Zhejiang and Guangdong, and some second-batch provinces such as Jiangsu, have transformed previous peak adjustment markets to cover reserve and regulation services, as markets for lowering thermal output are no longer necessary once the spot market steers dispatch.

The first batch of provincial spot market pilots tested various designs

In 2017, the NDRC issued the Notice on Carrying Out Electricity Spot Market Pilot Projects, known as Document No. 1453, in order to "accelerate the construction of effectively competitive market structure and system", which was described as the "core target" in Document No. 9. By selecting eight provinces and regions as the first batch of pilot spot markets, the commission aimed at "changing the measures of planned dispatch, discover the commercial price of electricity, form an in-the-market mechanism for electric power balancing and let the market play a decisive role in electric power resource allocation".

Different market designs were adopted in pilot provinces, each trying to develop a market best suited to the structure of their local power sector (see box Provincial spot market design). Progress of spot market pilots lagged the timeline set in Document No.1453. This could be due to lack of momentum at the provincial level to push the reform forward and the diverging expectations of stakeholders. Local governments might have expected spot markets to lower the electricity price, which only partially reflects the central government's intent to

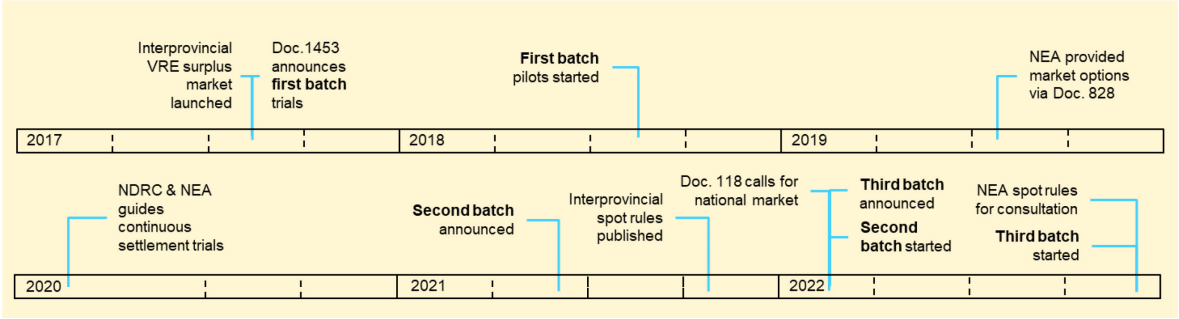
establish a true price signal of electricity, as is stated in Document No. 1453. Grid companies worrying about changing the status quo could be another reason.

Despite all challenges, by June 2022, all first-batch pilot markets except for Zhejiang had entered into the continuous operational test phase. Zhejiang planned to carry out its continuous operational test in 2023.

Document No. 9 intends to give spot markets the role to reveal the real value of electricity with a sufficient locational and time granularity. However, out of concerns of volatility in wholesale prices, upper and lower caps were set on prices in the existing pilots. These caps limit the price range well below the range allowed in spot markets around the world and remain an obstacle to an effective price signal.

An initial step was made by Guangdong in summer 2022 to temporarily remove the upper cap in the spot market amid skyrocketing coal and gas prices. The market then saw the record high price of CNY 1 366.95 (Yuan renminbi) per megawatt-hour (MWh), exceeding its original cap by over 30%, which incentivised generators to produce at full capacity to meet the southern province's summer consumption peak. In Shandong, negative day-ahead prices are officially recognised to reflect the gap between huge distributed solar capacity and lagging energy storage deployment, and to incentivise investment of the latter.

Timeline of spot market Introduction (2017-2022)



Source: IEA based on template by Fatras et al (2022), A systematic review of electricity market liberalisation and its alignment with industrial consumer participation: A comparison between the Nordics and China.

Provincial spot market design

The first batch of pilot markets were selected to explore different market designs under a large diversity of electricity supply and demand backgrounds:

- Gross pool versus net pool: In a gross pool (the American model), all generation is dispatched by a central market operator. Contracts made between generators and users are only financial, and do not require physical execution. In a net pool (closer to the European model), generating companies can schedule their own generation based on physical MLT contracts, while surplus/deficit is traded through a voluntary pool. As it is generally implemented with a high locational resolution, the gross pool model better suits the provinces with high network congestion and high renewables share.
- MLT financial versus physical contracts: According to the NDRC, financial contracts may be settled in both pool models, and physical contracts shall be settled only in net pool markets.
- Price clearing: Provinces may choose to clear the market on marginal prices of nodes, bidding zones, or the entire province (system) based on expected local congestion level.
- Price limits: All pilot markets apply both lower and upper limits on price. The limits are established based on the maximum generation cost and, in contrast to emerging practices in spot markets, do not take the approach of valuing scarcity (value of lost load).
- Type of generation allowed to participate: Most Chinese provinces follow the policy of guaranteed purchase of VRE, but some pilot provinces have started to introduce VRE into the market. In Shanxi, VRE may choose to act as price taker in the spot market. In three other provinces, VRE generation can be considered as an equal participant to thermal plants. More provinces are planning to introduce VRE into the spot market. In Sichuan, the spot market is open to hydro plants only in "wet" seasons and to thermal plants only in "dry" seasons, so different price limits apply.

Main characteristics of the first batch of provincial spot market pilots

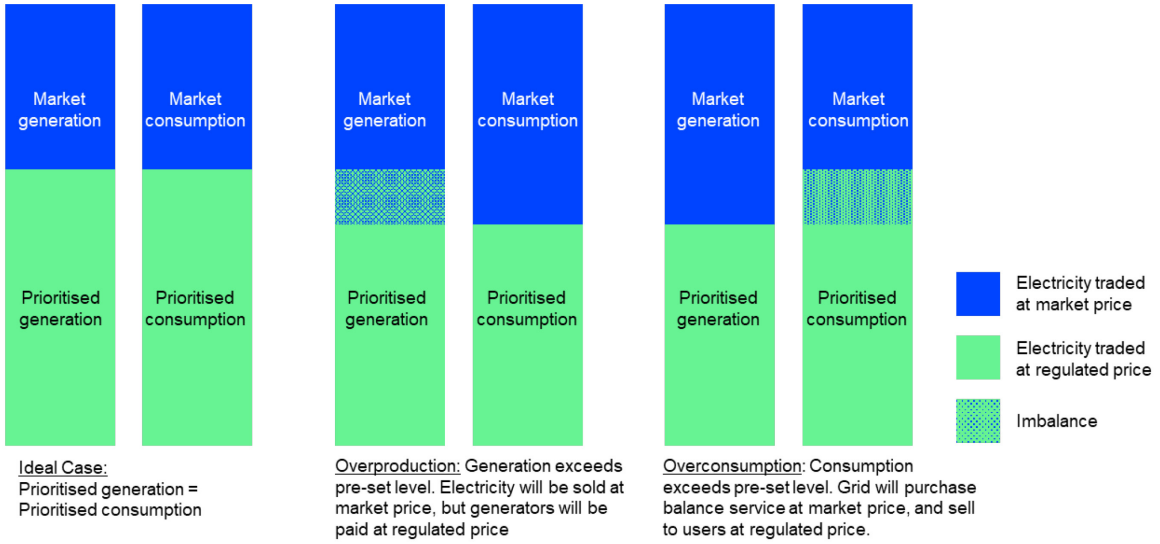
	Guangdong	Zhejiang	Shanxi	Shandong	Sichuan	Gansu	Fujian	Mengxi
Annual supply-demand gap (2021, TWh)	-175	-149	112	-157	105	23	-29	199 (incl. East)
Generation mix	Thermal: 60.11% VRE: 16.58% Nuclear: 9.43%	Thermal: 61.55% VRE: 18.30% Hydro: 11.34%	Thermal: 66.44% VRE: 31.58% Hydro: 1.98%	Thermal: 62.51% VRE: 34.95% Nuclear: 1.33%	Hydro: 66.36% Thermal: 22.11% VRE: 11.52%	VRE: 46.71% Thermal: 37.56% Hydro: 15.73%	Thermal: 51.52% Hydro: 19.85% VRE: 14.50%	Thermal: 57.77% VRE: 34.95% Hydro: 5.61%
Pool	Gross	Gross	Gross	Gross	Gross	Gross	Net	Gross*
MLT contract	CfD	CfD	CfD	CfD	CfD	CfD	Physical	CfD
Clearing	Nodal	Nodal	Nodal	Nodal	System	Zonal	System	System
Price limits (CNY/MWh)	0-1 000	<1 200 (gas)	0-1 500	-80-1 300	75-254 (hydro) 341-441 (thermal)	40-650	118-511	0-1 500
VRE participation	Volume +price		Volume	Volume +price		Volume +price		Volume +price
Ancillary – regulation	●	●	●	●	●	●	●	
Ancillary – reserve	●	●			●	●	●	
Capacity mechanism	●			●			In plan	

* Mengxi (West Inner Mongolia) transitioned from a net pool to a gross pool model in June 2022.
Sources: Power exchanges of Shandong, Shanxi, Sichuan, Gansu, Fujian, Mengxi; Provincial DRC of Zhejiang; NEA.

Spot market pilots shed light on issues related to out-of-the-market resources

The first-batch pilots experienced some challenges with imbalances due to the "dual track". Adopting a gradual approach and aiming at protecting certain participants, the spot pilots did not include all generation sources nor end users at the onset. On the supply side, besides in-the-market generation sources, there is also prioritised (out-of-the-market) generation whose production must be entirely purchased by the grid company at a regulated price. Each province has the right to announce its prioritised generation every year. In an effort to incentivise low carbon sources and flexible units, a document issued by the NDRC in 2019 requires including in prioritised generation all low-emission sources (VRE, hydro, nuclear), frequency adjustment units, and government-mandated interprovincial transmission. Co-generation plants are also included in some northern provinces. On the demand side, commercial and industrial (C&I) users did not fully enter the market until the release of Documents No. 1439 and No. 809 in 2021, while agricultural and residential users are still under the regulated price scheme. There are hence two tracks (in- and out-of-the-market) in the dispatch sequences of pilot provinces.

Imbalance fund in the "dual track" system



Notes: This figure shows two common scenarios under which imbalance funds emerge. Lengths of bars are not proportional to actual volume of generation/consumption.

The co-existence of in-the-market and out-of-the-market participants in these pilot markets created sometimes significant imbalance funds. When gaps emerge between pre-set level and actual volume of generation or consumption, grid companies as the middle party have to fill these gaps with in-the-market electricity.

The imbalance electricity will be bought/sold at regulated prices for out-of-the-market participants, and at market price for in-the-market participants, thus generating imbalance fund, usually held by grid companies.

In Shandong, CNY 95.08 million (USD 14.02 million) of imbalance fund was recorded in a four-day simulation test with settlement in May 2020, mainly triggered by VRE that generated beyond the forecast curve. As out-of-the-market demand remained relatively stable, Shandong faced challenges to balance the variation of its large PV generation and renewable electricity imports, both of which are not subject to market prices.

Based on the experience of Singapore, government-mandated contracts ("vesting contracts") have been considered as a widely applicable option to eliminate imbalance funds. Grid companies, under the mandate of provincial governments, are required to sign CfDs with out-of-the-market generation to cover the out-of-the-market consumption. The concept is comparable to two-way CfDs proposed by the European Commission for the revision of the internal electricity market, with a similar intention to lock in revenues for certain generation. Recently, in the MLT contract plan of 2023 (Document No.1861), the NDRC recognised vesting contracts as the solution to phase out provincial out-of-the-market generation to support Document No. 118 implementation.

Connecting spot markets to other markets and mechanisms appears as a necessity as variability grows

Connecting provincial and interprovincial MLT markets with spot markets has been another key challenge for many pilot regions. MLT contracts typically cover time frames from one year to one month and include an hourly demand/supply curve but tend to be firm commitments (not adjusted after signature).

Spot markets face difficulties connecting with intra-provincial MLT markets due to the slow transition from a full MLT market. In Shanxi, before the short-term operational test phase, MLT contracts were signed prior to spot pilots started. After the introduction of the spot market, hourly curves were negotiated between generators and users two days ahead of real time (D-2). As the province has abundant generation capacity, negotiations usually turned in favour of consumers, causing financial deficits to generators.

Connecting interprovincial MLT and intra-provincial spot is another challenge, particularly for importing provinces. In Zhejiang, the lack of connection between the provincial market and the interprovincial MLT trade lagged the province's pilot progress, illustrating another issue with the dual track. While the province followed Document No. 1439 to allow all C&I users to participate in the power market, interprovincial electricity is yet to be released into market. As a result, the grid

company held a great amount of imported electricity (37% of its total consumption in 2020) but was allowed to sell it only to protected end users, while the spot market saw a sudden rise of demand that had no matching supply.

Consequently, provincial and central governments have deployed measures to improve existing rules between pilots. Shanxi led the way by setting up a task force dedicated to spot power market discussions in April 2019, which has worked out 12 successive versions of provincial spot market rules to reflect the common expectations of market participants. Most pilot regions including Shandong and Gansu also adopted the idea of a task force to engage stakeholders and iterate on spot market rules during the pilot period. At the national level, besides organising a high-level task force, the NDRC and NEA also organised weekly meetings on spot market pilots since May 2019 and published internally several Spot Market Pilot Work Guidances. First-batch markets were invited by the NEA to share lessons learned with second-batch markets to accelerate the progress. Regular training sessions are organised by provincial dispatch centres to familiarise new market players with the spot power market.

NEA releases spot market rules for provinces while pilots expand and aim to integrate renewables

To accelerate spot power market pilots, the NDRC issued Document No. 339 named Opinions on Further Promoting Spot Power Market Construction Pilots in May 2021. Compared with Document No. 1453, this document puts increasing renewables consumption among its goals and aims to expand the scale of spot market pilots. Six provinces were selected for a second batch of pilots. In May 2022, the NDRC issued Document No. 129, setting goals for first-batch markets to enter into long-term continuous operational tests (see box Spot market pilots: From tests to permanent operation), second-batch markets to start tests by June 2022, and the rest of the provinces (third batch) to start pilot preparation by the end of 2022. By January 2023, 21 provinces/regions had started spot market pilots, covering 80% of China's total electricity consumption.

In December 2022, the NEA published the Basic Rules for Spot Power Market and Regulation Methods of Spot Power Market for consultation. A result from first-batch lessons and a guidance for expansion of the second and third batches, the documents provide a framework for provincial spot markets, explicitly suggesting adopting a gross pool model, while maintaining room for provinces to define detailed designs. In particular, some minimum requirements are provided for provincial rules, such as defining market caps, establishing CRMs, improving market regulations regarding market power, and maintaining ancillary services as a component of price formation mechanism.

These documents also include the promotion of renewable participation in power markets among the main tasks for spot market construction. At early stages of spot market pilots, the NDRC instructed non-hydro renewables to participate in the spot market as price takers before releasing a guidance in 2019 with reduction of VRE curtailment as a goal for spot market pilots.

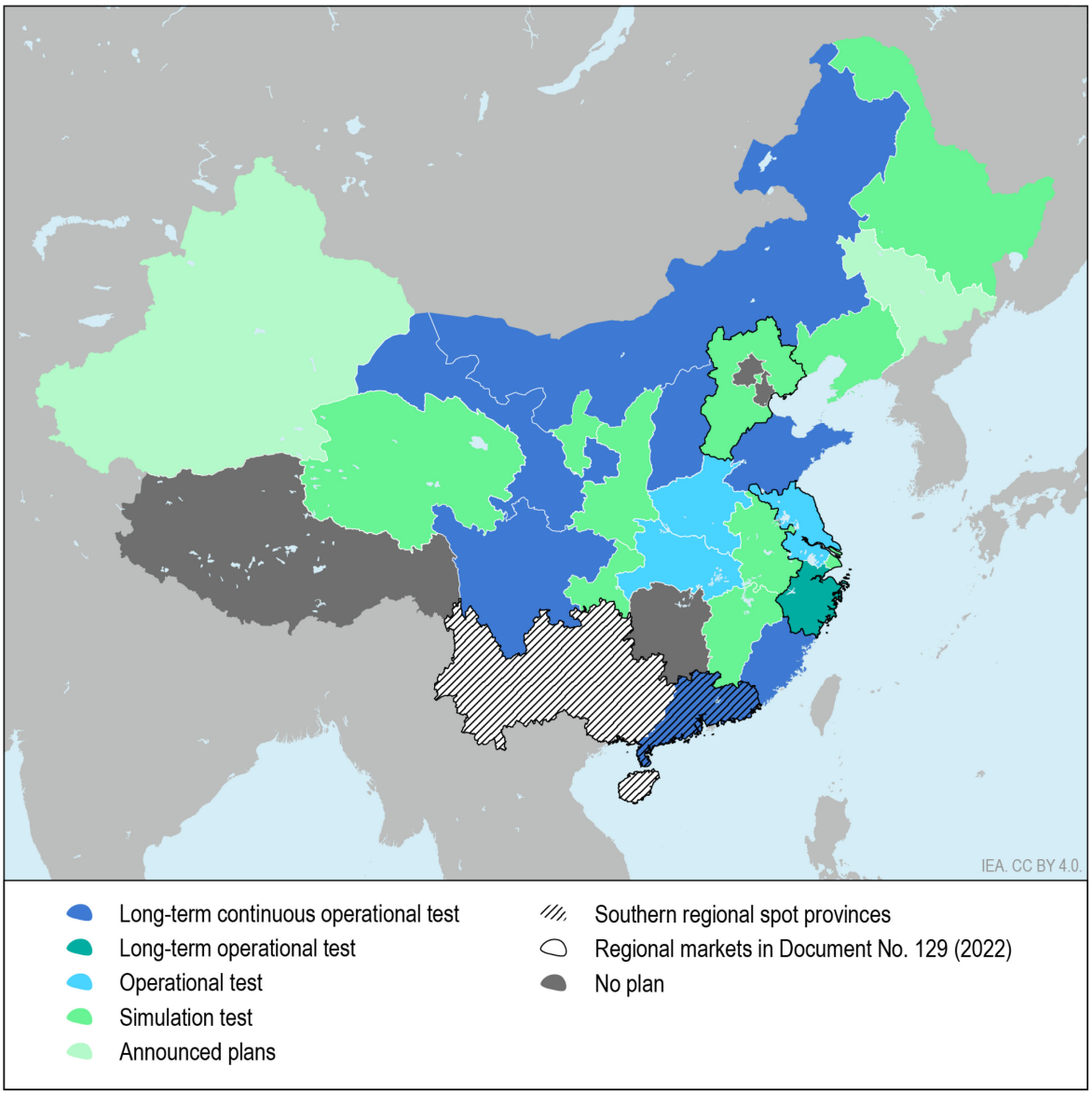
Spot market pilots: From tests to permanent operation

China often uses provincial or regional pilot projects to test out the feasibility and effectiveness of a policy before national roll-out. In spot markets, pilots generally follow the three-step procedure below as described in the Basic Rules issued by the NEA in December 2022.

Pilot phase	Steps	Description
1. Simulation test	Simulation test without dispatch	A "shadow market" phase when market entities submit simulation bids to observe the normal function of market operation system.
	Simulation test with dispatch	"In due course", production and dispatch need to be carried out according to simulation results,
	Operational test plans	Working plans and rules for operational tests with settlement need to be authorised or published before Step 2.
2. Operational test with settlement	Operational test (Short term)	A "semi-functional" phase when market entities submit actual bids in a market operating under working plans or provisional rules over a fixed period of time (weekly, monthly, quarterly).
	Long-term / Long-term continuous operational test	Market operation needs to continuously settle and form dispatch plan according to provisional rules for a year (long-term) or without an explicit end date (long-term continuous).
	Publication of spot market rules	Releasing spot market rules is the pre-requisite for a pilot market to enter into permanent operation.
3. Permanent operation		

Source: NEA (2022), Basic Rules for Spot Power Market (for consultation).

Status of China's spot power market pilots



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: National Energy Administration and its provincial branches.

Spot markets beyond provincial borders aim to smooth variability over larger areas but remain constrained by inflexible MLT arrangements

As the out-of-the-market role of interprovincial electricity in provincial markets became one of the barriers to spot pilots, an interprovincial spot market was needed to push forward the reform. The attempt to form an interprovincial spot market began in August 2017, when the SGCC, in response to a 2016 NDRC document, established an interprovincial surplus renewable power spot market covering multiple regions under the SGCC grid area. This market operated in

day-ahead and intraday and was restricted to surplus ("otherwise curtailed") renewable electricity that exceeded administratively allocated generation plans. By the end of 2021, over 27 TWh of electricity had been traded in this market.

In November 2021, the SGCC published the Provisional Rules for Interprovincial Spot Trade, marking the expansion of the interprovincial market to cover all generation sources, including thermal and nuclear, while also including the Mengxi grid under a separate operator. Similar to its predecessor, this market does not include the China Southern Power Grid (CSG)[2] and is a surplus market organised by the National Power Dispatch and Control Centre (under the SGCC) that only trades the surpluses that exceeded MLT market curves in day-ahead and intraday markets. In essence, the MLT contracts define the initial dispatch decisions but the remaining margin on available units can be sold on the interprovincial market. Moreover, generators are not allowed to sell electricity if their province is expected to be in power deficit at the trading time.

The interprovincial market pilot commenced after the publication of its provisional rules: the market went from a one-day operational test in January 2022 to a six-month operational test during the second half of 2022. The market saw 27.2 TWh trade volume in 2022, almost equivalent to the entire volume of its four-year-long predecessor. Starting in January 2023, this market has entered year-long continuous operational test and is expected to commence permanent operation "in due course".

Interprovincial power trade

Almost all (97%) of interprovincial power trade in China takes the form of MLT contracts. While senders of interprovincial MLT contracts can be power plants or grid operators, only grid companies can serve as counterparty in the receiving end, a feature that also applies to the interprovincial spot market. A document issued by the NEA in 2019 decided that signing parties of these contracts must confirm negotiated day-ahead curves for the traded electricity, on top of annual framework agreements signed between provincial governments, to serve as firm inputs to provincial spot markets.

Attempts to reform interprovincial MLT trade took place with little success. In 2016, the NDRC authorised consumers in Shandong to bid for interprovincial electricity from northwest China, transmitted by the Yin-Dong (Yinchuan-Dongying) high-voltage direct current (HVDC) line, although with a volume capped at 10 TWh.

[2] The two wide area synchronous grids in China, operated by the CSG and SGCC, are historically relatively isolated from each other, currently with two high-voltage direct current interconnections between them.

The lack of granularity of Yin-Dong MLT contracts soon appeared to be a barrier to meet the variable local demand, which was influenced by VRE and spot market prices. This was especially visible in 2021 and 2022 amid high coal prices. In the meantime, dispatch centres at the sending end reserved some of the generation for local supply security, further causing losses in the receiving end. As a result, monthly trade volume dropped from over 300 gigawatt-hours (GWh) in 2016 to 98 GWh in January 2022.

Connecting interprovincial MLT markets to spot markets is another challenge. All market rules forbid grid companies in importing provinces to act as the seller in provincial spot markets. However, as grid companies are the only buyers in interprovincial trade, they may possess electricity in excess of the demand of prioritised consumption. As a result, in some provinces, C&I users do not have access to imported electricity even though the price soars in the local spot market.

The needs for interprovincial power trade tends to differ across seasons. Allowing more point-to-point MLT and spot trades will increase flexibility but alters the business model and operations of grid companies. Some spot pilot provinces have started to introduce more point-to-point trades. In Zhejiang, the latest rules allow consumers to purchase interprovincial coal-fired electricity under a governmental framework agreement. Only when market-traded interprovincial electricity falls below the required volume for secure supply will grid companies be allowed to purchase from interprovincial market. Document No. 129, Notice on Accelerating the Promotion of Spot Power Market Construction, demands that electricity traded on the interprovincial markets be included in provincial spot markets at both sending and receiving ends to avoid imbalance in provincial markets.

A potential challenge for interprovincial trading is transmission tariffs. Currently, cross-regional transmission is priced by summing up all transmission charges generated along the contract path, a "tariff pancaking" approach that can discourage transactions. In addition, tariffs for interregional interconnectors are based on energy only and not linked to capacity nor time of use. As the interprovincial market expands, current transmission tariffs may have to evolve to promote commercial transactions and ensure a sound cost allocation between stakeholders.

Southern Grid leads the efforts for regional market pilots

Apart from the interprovincial market, regional markets also form an important component in China's power system, as regional grid companies are responsible for supply-demand balancing and operate most regulating resources such as pumped hydro storage stations. Logically, regions developed ancillary services markets to support this task. As for regional spot markets, three of them (Jing-Jin-

Ji, Yangtse Delta, Greater Bay Area) were proposed in Document No. 828 of 2019, an action plan following Document No. 1453. The three markets relate to regions of strategic importance in China: Jing-Jin-Ji covers the capital Beijing and surrounding provinces of Tianjin and Hebei; Yangtse Delta covers eastern coastal provinces of Jiangsu, Zhejiang, and Shanghai; Greater Bay Area covers Guangdong, Hong Kong and Macau in southern China.

Based upon the Greater Bay Area idea, the southern regional spot power market has progressed the most so far. Not included in the SGCC interprovincial market, the CSG is pushing forward a regional market that covers all five provinces under its grid, namely Guangdong, Guangxi, Guizhou, Yunnan and Hainan. With the Guangdong spot pilot named "Southern (starting from Guangdong)" spot power market from the beginning, the CSG's intent is to integrate the other four provinces into the Guangdong market to form a regional spot market. The Guangdong power exchange would operate this market, adding to the existing parallel regional market covering MLT contracts and ancillary services overseen by the Guangzhou power exchange. The regional spot market began its first simulation test on 23 July 2022. After the publication of its first spot market rules in August 2022, the market's first two-day simulation test with dispatch was executed in December 2022.

China's central government has acknowledged the expansion towards a southern regional spot power market and accordingly replaced the mention of the "Greater Bay Area market" in Document No. 129, which also noticed the less-progressing markets of Jing-Jin-Ji and Yangtse Delta, giving out the goals of drafting market construction plans, albeit without a clear timeline yet. These two regions are proceeding at a different pace. None of the three grid areas (Beijing, Tianjin, Northern Hebei) covered under the Jing-Jin-Ji market have published any plans on spot market pilots. On the other hand, all grid areas in Yangtse Delta (Jiangsu, Zhejiang, Shanghai) have started spot market pilots already. These two regional markets, if constructed, will deliver learnings from two different approaches to regional markets, i.e. constructing a new integrated market or integrating existing markets, which may serve as references for the pathway towards a national market.

Designing a national spot power market supporting China's policy objectives

For decades, neighbouring systems have entered into trading agreements to share resources and reserves. As countries transition, the benefits become even more apparent as systems with high shares of wind and solar PV benefit further from the smoothing effect of larger areas.

This section looks at market models to enable a higher share of trade between the entities that have established spot markets in China (mainly provinces, but also regions). A particular focus is given to secondary markets at the national level, where a national market exists in parallel with the existing local markets, since this matches the objectives of Document No. 118. Local autonomy can be preserved in defining market design and operating protocols. A secondary market can later be adapted into a primary market, where all local markets are fully coupled, making the national market the dominating market. Therefore, these secondary markets can be seen as either a target or a transition towards further integration.

This section is divided in two parts. The first part presents different models for multilateral trading among provinces and regions. The focus is on two types of secondary markets with different approaches to coupling provinces, a surplus market and a market based on volume coupling (the CETO model, named after the CETO where it was first introduced). An integrated (primary) market model is also presented as it can be a target for China, in this round of reforms or later. The second part is based on a regional model of the power system of China by 2035 and looks at the expected benefits of deploying markets and measures to promote VRE. It contains estimates of the gains in terms of operating costs, emissions and curtailment rates for a number of configurations useful for the presented models.

Models for market integration

International experience illustrates several pathways to building a unified national power market system

International experience has delivered a number of models for multilateral power trade, some of which are appropriate for replication in the Chinese context. These models differ by the level of integration between the different layers of the power

market system. Usually, a higher level of integration leads to higher welfare as it implies more electricity trade between jurisdictions[3] and a better allocation of resources (generation units, transmission grids).

Models of power system integration and trading arrangements

Nascent	Bilateral, unidirectional power trade	• Sichuan exports to eastern coastal regions
Nascent	Bilateral, bidirectional power trade	• Seasonal exchanges between Sichuan↔Shaanxi, Qinghai ↔Tibet, China↔Lao
Secondary	Multilateral, unidirectional power trade with intermediary	• Lao People's Democratic Republic-Thailand-Malaysia-Singapore (LTMS) Power Integration Project
Secondary	Multilateral, multidirectional trade among differentiated markets	• Southern African Power Pool (SAPP) • Central American Electrical Interconnection System (SIEPAC)
Primary	Unified market structure, differentiated operations	• EU Internal Electricity Market
Primary	Unified market and operations	• PJM (Northeastern United States)

Source: Adapted from IEA (2019), Multilateral power trade in ASEAN.

Power system integration models can be ranked from nascent trading arrangements where bilateral exchanges tend to be scheduled in advance (e.g. large hydropower stations in Sichuan exporting to eastern provinces) to primary models where transactions are determined across several jurisdictions by a uniform market protocol and the multilateral market is the main and default platform of trade (e.g. the European Union internal electricity market and PJM in the United States). Secondary models sit in between and are characterised by multilateral trading between jurisdictions taking place separately and on top of domestic market or system operation arrangement (e.g. SIEPAC in central America and SAPP in southern Africa). There is not a single path towards market integration and choices of models depend on local conditions, each coming with their own choices and challenges.

In the case of China, bilateral trading is already well established, although not harmonised across the country. Harmonising bilateral trading between provinces or regions can already enable more efficient system operations. This requires the development of standardised bilateral MLT contracts, wheeling methodologies and a common trading platform. However, this model of trading falls short of the ambition highlighted in Document No. 118, which supports at least the

[3] Jurisdiction boundaries can be international or intranational. In the current context, jurisdiction boundaries are within China (between provinces/regions). Power trade between jurisdictions is referred to as "multilateral".

establishment of multilateral, multidirectional trade between provinces and regions. Thus, models under secondary and primary trading arrangements would suit China's current reform.

For multilateral, multidirectional trade to take place, further co-ordination is required for data sharing and central institutions become necessary, such as a central market operator and settlement entity. These central institutions will take over some of the responsibilities previously assigned to interconnected entities. These central institutions can support increased trading volumes and establishing pool-wide reserves to encourage trading electricity between provinces and avoid overbuilding of power plants locally. Eventually, increasing the flexibility of dispatch protocols will allow capturing the full benefits of the interconnections.

Both secondary and primary trading arrangements have in common the introduction of a national spot market (day-ahead and intraday). In this report, the focus is on the national day-ahead market (NDAM) as it is the main market that defines system operation. In market-based systems, the day-ahead price also delivers the reference price signals for the other markets. Closer to real time markets[4] (such as an intraday market) are also necessary to maximise the use of variable renewable generation and incentivise flexibility, but can be developed later, once the day-ahead market is well-functioning.

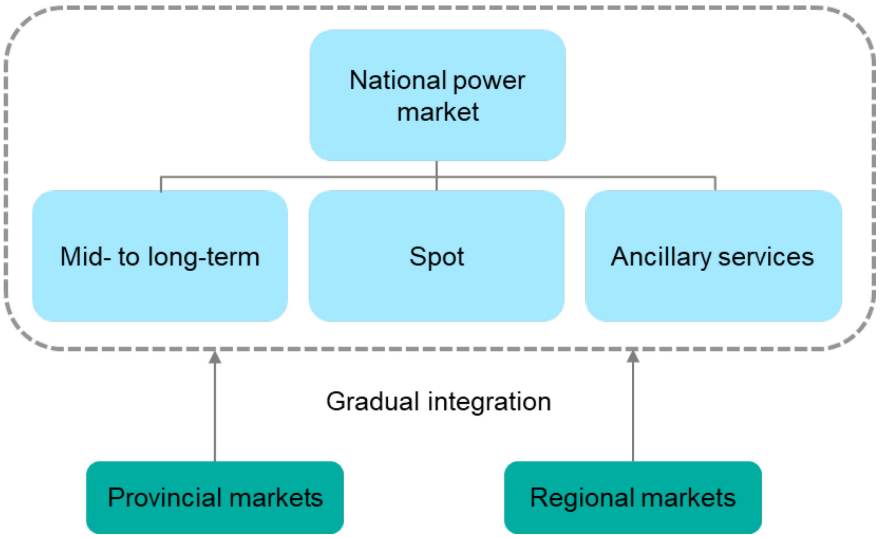
Secondary market arrangements comply with the goals of Document No. 118 and match the current multilayer organisation of markets

Document No. 118 suggests the implementation of a multilayer power market framework where a national market operates jointly with provincial/regional markets. Two models belonging to the category of "secondary" market arrangements suit the vision of a national market that co-exists with local (provincial/regional) markets: a surplus market or volume coupling of local markets.

These secondary models allow for better sharing of resources on a wider scale, while preserving differentiated local market designs and operations. At the local level, each jurisdiction adapts its own rules to enable its market agents to participate in the national market.

[4] The design space for short-term markets is large. The United States, Europe and Australia use different combinations and timelines for their markets. As Chinese spot markets rely on a day-ahead market, the Australian model (classified as a real-time, energy-only gross pool market) is not elaborated in this work.

Multilayer power market system as envisioned in Document No. 118



Source: Yan Qin (2022), China's national ETS and the power market: how the ETS can achieve significant emission reductions.

A national surplus market can build on the existing interprovincial spot market

In a surplus market model, local markets with different designs co-exist while the whole interconnection is supported by a national market where excess generation is traded on a voluntary basis. Since only surplus is traded, local markets remain relatively autonomous for deploying capacities but their usage can be made more efficient. This model has been successfully applied among 6 central American countries interconnected with the SIEPAC transmission line and in SAPP which covers 12 countries (see boxes The Central American Electrical Interconnection System and The Southern African Power Pool). In these two cases, the "regional" aspect of trading arrangements refers to macro-regions composed of several countries.

The surplus NDAM operates once pre-dispatching in the local day-ahead markets has been established. Local pre-dispatch results in power injection opportunities and supply gaps transmitted to the national surplus market, which performs an optimisation at the national scale. Outputs of the national market are then returned to the local dispatch centres for agreement or re-optimisation. This sequence of operations allows local markets to first cover local demand with their own least expensive resources and to substitute high-cost generation by surplus production from lower cost markets. Prices on the receiving end can thus reduce costs without an increase in prices at the sending end. This avoids the common concern of "undesired price formation" (that is, when prices increase in regions having traditionally low energy generation costs) when integrating markets. The latter is a real concern in China and has led to a reluctance of provinces with low electricity

prices to trade with neighbouring provinces. The same reason led to choosing this type of surplus model for the Western Energy Imbalance Market in the United States, an energy-only real-time market optimising resource sharing across 6 American states.

The Central American Electrical Interconnection System

The Central American Electrical Interconnection System (SIEPAC) is an example of a secondary market, which has been designed as a "seventh market" operating on top of national markets of the six countries covered (Costa Rica, El Salvador, Guatemala*, Honduras, Nicaragua and Panama). Those countries signed a Regional Market Treaty in 1996 and have been fully interconnected by a 230-kilovolt transmission line of 1 800 kilometres since 2014. Regional institutions were created and located in different member countries: a governing board representing the national governments; a regulator; a regional market operator; and a grid owner.

The objectives behind this initiative were notably to ensure the security of supply and to optimise the allocation of resources in a region highly dependent on hydropower. After the commissioning of the SIEPAC line and the harmonisation of rules at the national and regional levels, the volume of cross-border trade has significantly increased. Since the beginning of the project, multiple benefits were reported for the region, in terms of economic efficiency, electricity security and regional cooperation in generation and transmission planning.

Electricity in the SIEPAC market is mainly traded on a short time horizon, either on the "Opportunity" or spot market (day-ahead and real-time), or on the Regional Contracts Market. The Opportunity market uses nodal hourly marginal prices. The nodal approach was indeed considered easier to implement in the regional context of scarcely meshed networks. Locational marginal prices resulting from the Opportunity market are applied to each national pre-dispatch as a whole and to regional transactions. Operating in parallel, the Regional Contracts Market is for medium-term bilateral contracts (less than one year, most of the time from weeks to months). In 2021, more than two-thirds of the transactions took place on the Regional Contracts Market, and the rest on the Opportunity market. In total, injections into these two markets accounted for 5.8% of regional electricity consumption and primarily came from Costa Rica, Guatemala and Panama, all important hydropower producers.

* Guatemala announced in 2021 its intention to pull out from the SIEPAC market, a decision that could take years to materialise. One of the reasons advanced was the lack of enforcement rights from the regional regulator.

In the Chinese case, the surplus market approach would consist of local spot markets performing pre-dispatch before trading excesses or deficits of generation on a national spot market. The entities exchanging surplus could be both provinces and regions depending on existing local markets.

The surplus concept has already existed in China since 2017 for the sale across provinces/regions of otherwise curtailed renewable generation. This laid the foundation of the pilot interprovincial spot market in the provinces covered by SGCC, which started trial operation in 2022. Thus, establishing a national spot surplus market would be an adapted extension of these pilot experiments and could build on existing institutions, such as the National Dispatch Centre, which operates the interprovincial pilot market.

The Southern African Power Pool

The Southern Africa Power Pool (SAPP) is another example of a regional power market with secondary trading and is currently the most advanced regional power pool in Africa. Created in 1995 with the vision of establishing a fully integrated and competitive energy market within the Southern African Development Community (SADC), it covers 12 countries participating through their national power utilities. Independent power producers can also participate in the market. Nine of the 12 countries are interconnected through a regional synchronised grid. A regional competitive market was introduced in 2004, progressively including a day-ahead, an intraday, and a physical forward (monthly and weekly) market, with most of the trade taking place on the day-ahead market. The latest step of the integration process was the implementation of a regional balancing market in April 2022.

The SAPP region is divided into several price nodes (generally one node per country or more for those with a constrained transmission network). In the day-ahead market, a co-ordination centre matches total bids and offers received to determine the market-clearing price (MCP), which is the price used to settle all transactions. This MCP does not take into consideration transmission constraints, thus leading to divergence in prices between nodes when those constraints are binding and restrict the physical trade of power.

A large majority of the electricity traded in the SAPP region is still exchanged outside the competitive market under bilateral contracts (representing more than 81% in the year 2020/2021), with utilities mainly using PPAs to fulfil the bulk of their demand requirements, while the day-ahead market covers surpluses. Although bottlenecks exist to enhance the scale of trading in the SAPP (limited transmission and generation capacity, lack of a regional regulatory authority), its more than 25 years of experience in promoting and co-ordinating power trade between neighbouring countries provides an interesting example of regional integration.

While many SADC countries have recently faced recurring demand shedding, enhancing the role of SAPP has been identified as a key task to alleviate the electricity crisis in the region.

Higher use of interconnections can be achieved with volume coupling of local markets

An alternative secondary market model is the approach based on volume coupling described in the China Energy Transformation Outlook 2022. This model is therefore called the "CETO model" throughout this report. The objective of this approach is to capture as quickly as possible the benefits of national co-ordination through improved utilisation of interconnection, while keeping local autonomy in price formation and dispatch. In terms of efficiency of resource sharing across the interconnection, this secondary model is therefore more advanced than the surplus.

Similarly to the surplus model, an NDAM is deployed and co-exists with local markets, which keep their market structure and control over their market operation. For provinces where there is no local day-ahead market, market participants can directly participate in the NDAM. Provinces are represented in the national market as bidding zones. In China these can naturally be defined in correspondence with provinces, and, depending on local congestion issues, some provinces could be split into multiple zones. Several Chinese policy documents recommend choosing zonal or locational marginal pricing for provincial spot markets depending on grid structure and congestion. This choice for the local market is not incompatible with a national market with a zonal model, but solutions to calculate a reference price for each bidding zone would need to be elaborated.

In contrast with the surplus market, clearing of the national market is orchestrated prior to local markets and delivers as main outputs the scheduled flows of interconnectors between bidding zones. The available interconnector capacity is allocated based on the implicit needs of the volumes that cleared in the NDAM ("implicit auction" or "implicit capacity allocation"). The resulting interconnector flows are then taken as firm inputs by local market operators for their own clearing process, equivalent to firm demand or generation. Dispatch is performed locally and takes into account the matched orders from both national and local spot markets, long-term contracts, and (where applicable) administrative allocation of hours to priority generators.

In contrast to integrated (primary) markets, volume coupling allows circumventing the significant challenges of implementing price coupling between provinces/regions with differences in their power market designs. Volume coupling was implemented at the early stages of the European power market integration and is a solution considered for connecting the United Kingdom after its exit from the internal electricity market. Although the optimisation resulting from volume coupling is not as efficient as price coupling in terms of allocation of transmission capacities and price convergence between bidding zones, it represents a pragmatic option to ramp up resource sharing across China and has the potential for faster and simpler implementation.

An integrated national market can be an objective for the next phase of market reforms

In a primary market model, the interconnected systems are fully integrated and multilateral trading is the default option. All market participants across the geographical scope are exposed to the same rules and participate directly in a multilateral market. The participating jurisdictions need to agree politically and co-ordinate further with a stronger role for central institutions. In addition, jurisdictions need to harmonise their operational and trading frameworks and may have to restructure markets to ensure full competition. Spot markets (day-ahead and intraday) are a key segment of a primary trading model, as more integrated power systems allow trading larger volumes close to real time based on system conditions.

Main characteristics of three possible models for a national power market in China

	Secondary models		Primary model
	Surplus	CETO	
Rationale in a nutshell	Increase renewable energy resource utilisation while maintaining differentiated local markets	Improve interconnection use while allowing local autonomy for price formation and dispatch	Interconnection-wide competition and integration
Power markets sequence	• Local pre-dispatch • Surplus/gaps of generation offers submitted to NDAM • Clearing of NDAM, which provides updated power flows to local market	• Pre-clearing of NDAM • Resulting interconnectors flows taken as firm input by local markets • Clearing of local markets	• NDAM receives bids from all market participants • Clearing of NDAM
Market operator (MO)	Local + national MOs	Local + national MOs	National MO or cooperation of local MOs
Use of interconnector capacities	Limited, based on surplus power traded	Implicit allocation* by NDAM	Implicit allocation* by NDAM
Coupling between bidding zones	No coupling	Volume coupling**	Price coupling**

* During an implicit auction, transmission capacities are integrated into the clearing of the NDAM (as opposed to an explicit auction, where transmission capacities are allocated separately from traded energy). Implicit auctions are often referred to as "market coupling".

** Price coupling refers to a situation where a coupling algorithm centrally calculates both prices and interconnectors flows, whereas under a volume coupling approach, only flows are calculated based on bids received.

Applying a primary mode of trade in the Chinese case entails the establishment of a single day-ahead market where all generation and demand are cleared. However, unlike the secondary models presented above, there is only one clearing procedure happening in the day-ahead so the existing provincial spot markets are no longer relevant. The most advanced form of primary trading for China would be to implement such a model at the national level, but other less integrated options exist that are more realistic under the timeline of Document No. 118. For instance, it is possible to imagine a primary mode of trade within some regional markets (the current approach taken in the southern regional market) which would trade with one another under secondary arrangements.

Moving towards a primary market requires some design choices. Two well-known examples of primary trading arrangements are the EU internal electricity market and the PJM market spanning 13 states in the United States. Interconnections between European countries started decades ago to increase power system stability and sharing of reserves between regions with diverse profiles of electricity production and consumption. The EU market construction was meant to increase competition and to remove barriers to cross-border trading. This was done thanks to a gradual – and still ongoing – integration of markets through market coupling (text box). Similarly, the construction of PJM was initially driven by the objective to realise economies of scale between neighbouring states, by optimising the costs and use of production and transmission assets.

Market architectures may vary among primary trading models. In the case of the EU internal market, although efforts were made to harmonise national market designs, the integration approach has left freedom for differentiated operations between countries. On the contrary, PJM fully integrated markets with unified operations.

In Europe, countries participating in the price coupling process have adopted a decentralised model with self-scheduling of market entities, which are responsible for balancing supply and demand (thereby referred to as "balance responsible parties"). This differs from the centralised model of PJM where a central system operator executes the central unit commitment in the day-ahead market: in that case, scheduling of generators ignores bilateral physical contracts which are settled financially, typically with CfDs (in a gross pool). On the contrary, the EU model for electricity markets historically relied on net pool arrangements, i.e. physical scheduling of generators was based on bilateral contracts, and the difference between scheduled and actual demand was traded on spot markets. Recently, the trend in Europe has been towards a higher share of trade on spot markets while using financial contracts for price hedging, thus significantly reducing the share of physical contracts.

Another key difference between these two markets is the price formation mechanism adopted: zonal for the European Union and nodal for PJM (and in all the organised wholesale power markets in the United States). The zonal pricing system results in a uniform price within a "bidding zone", while the nodal approach is more reflective of the physical constraints of the grid by providing prices that may diverge between nodes in case of grid congestion. In a zonal market, constraints within a bidding zone are assumed not to affect trade. Therefore, bidding zones should be defined based on structural constraints of the grid. It is, however, common that jurisdictional borders define bidding zones, leading to inefficiencies and less accurate locational signals.

Although it is an appealing prospect, implementing a unified national market framework in China with a similar level of integration as the EU or PJM market would require years of efforts. Thus, it could be seen as a long-term objective beyond the 2030 horizon set in Document No. 118. It is, however, important that China makes a design choice early for the national power market system that keeps the door open for future further integration.

A long-lasting discussion has been whether China power markets should follow an integration pathway similar to PJM or the European Union, with much attention given to the design of their respective spot and contract markets. So far, China took the PJM model as a reference in the design of most provincial pilot spot markets. Moreover, the ongoing construction of the southern regional market follows a centralised approach with one single operator of the regional market. However, for the design of a national market, several characteristics of the EU target model make it more compatible with the envisaged integration process in China:

- It works better with diversity of local power markets' operations and designs. Although efforts to create a single European market led to a standardisation of national market features, there are no rules in the European Union prescribing a common market design, and significant differences remain across countries.
- Decentralised dispatching operated by multiple operators seems more realistic for China considering the current multilayer dispatch protocol, mainly orchestrated by provincial grid companies.
- An NDAM market coupling like the one in the European Union, which is mainly based on capacity constraints of interconnections, is easier to expand to a growing number of participating regions, compared with a centralised dispatching model.
- Bidding zones with uniform pricing as in the European Union seem more socially acceptable in China than locational marginal pricing, which entails prices variation between neighbouring nodes of the network. However, bidding zones should be designed in a way to ensure both economic and congestion management efficiency. Inspiration can be drawn from the ongoing bidding zone review in Europe.

- The nodal model adopted in PJM is particularly relevant for regions showing transmission congestion locally (e.g. Guangdong province). However, from a country-wide perspective, Chinese provinces are relatively well interconnected with one another through (ultra-)high-voltage grids (such as the west-to-east corridors) and have the potential to become even more so in the coming years with massive planned expansion of transmission capacities. In this regard, lessons can be drawn from the European Union, which has achieved a very high level of interconnection among countries, at a scale proportional to that of China, although the EU system appears to be more meshed compared with the Chinese system where HVDC connections represent the bulk of the transmission capacity. In particular, the European Union has set an interconnection target of at least 15% for each country by 2030, which could be replicated in Chinese provinces.

The construction of the European internal electricity market

Market organisation in Europe offers a good example of how decentralisation can support increased regional integration. Allowing different countries (or, more generally, jurisdictions) to retain functional control over their power systems, while at the same time encouraging market, system and regulatory harmonisation at the interregional level, has enabled a flexible yet scalable approach to cross-border power system integration.

The EU internal electricity market is now the largest wholesale power market in the world and an example of a primary trading model. Its highly integrated design was achieved progressively after years of gradual integration of national and sub-regional markets. Four energy policy packages (1996, 2004, 2009, 2019) constituted the main milestones of the market construction, setting up a target model for electricity markets and a set of common rules and grid codes to achieve it.

Efficient cross-border trade enables taking advantage of the uneven distribution of renewable energy resources within the European Union and has delivered significant social welfare. The European Agency for the Cooperation of Energy Regulators (ACER) estimated savings of EUR 34 billion in 2021, compared with a situation with isolated markets.

One of the main successes in the process towards market integration in Europe was the implementation of a day-ahead market coupling through a uniform price algorithm. It was made mandatory in 2015 and now covers 27 countries. As several power markets were already well established with their own power exchange when the EU target model was adopted, coupling between existing markets was achieved through the algorithm known as EUPHEMIA (standing for Pan-European Hybrid Electricity Market Integration Algorithm) which links all power exchanges. National transmission system operators share their available transmission

capacities and power exchanges share their order books, which serve as input parameters for the common day-ahead auction. Power exchanges among the Nominated Electricity Market Operators (NEMOs) take turns to run the algorithm, after which prices, volumes and cross-border flows are calculated ensuring a least-cost dispatch and an optimised use of interconnectors. Later in 2017, the intraday markets were also coupled.

The EU internal market demonstrated its ability to support resilience of power systems during the global energy crisis. As France was facing historical low nuclear outputs during the winter of 2022/23, the country relied on imports from its neighbours to avoid power outages, becoming a net importer for the first time in decades.

Assessing and selecting a model for China's national spot market

To examine how different market models could impact the future Chinese power system, we have carried out techno-economic analysis using the IEA's Regional Power System model for the Announced Pledges Scenario (APS) for a one-year "snapshot" in 2035. The national values for supply and demand come from the IEA's World Energy Outlook (WEO) model and are disaggregated into six regions[5] with regional transmission interconnection between them (see Annex for detailed modelling methodology).

Different settings are studied to explore the impact of varying levels of co-ordination and trade among the regions, including a "low co-ordination" option based on historical flows between regions and three different models for national markets: surplus, north-south surplus and CETO. Note that due to the six-region representation of the Chinese grid, co-ordination within regions is effectively assumed and thus the results give only a conservative estimate of the full benefit of progressing from province-level markets to a nationally integrated approach. A north-south surplus may be relevant in case of full coupling of provincial markets in the SGCC area while trade between SGCC and CSG remains limited.

[5] Note that China can also be considered to have seven grid regions with a southwestern region consisting of Sichuan, Chongqing and Tibet.

Settings summary for different levels of co-ordination among provinces/regions

Co-ordination setting	Description
Low co-ordination	Limited flows among regions based on historical levels.
Surplus market	Unit commitment determined within each of the six modelling regions separately, dispatch then allowed to adjust within the stable operating range of all generators to take advantage of trading among regions.
North-south surplus	Unit commitment set within the (SGCC) northern and (CSG) southern grids, dispatch then allowed to adjust within the stable operating range of all generators to take advantage of trading between the north and south.
CETO	Nationally integrated dispatch with flows optimised across the entire system.

Dispatch incorporating different levels of administrative allocation of FLHs and economic dispatch is also explored to highlight the interplay between China's move towards more economic dispatch and the role of a national market. Historical allocations of FLHs are used as a reference point for past practices to understand the benefits of progress towards economic dispatch that are already expected based on the rules of existing spot market pilots. A partial economic dispatch case represents the level of economic dispatch consistent with these trials, and a full economic dispatch case represents a progression towards full merit order dispatch in all provinces.

Settings summary for different levels of penetration of economic dispatch

Dispatch setting	Description
Historical FLH allocations	FLHs constrained on thermal generation in keeping with historical dispatch levels for all regions.
Partial economic dispatch	FLH constraints on thermal generation in the northwest, northern, north-eastern and eastern regions only. Central and southern regions have fully optimised economic dispatch.
Full economic dispatch	All dispatch determined on a least-cost basis without constraints on the operating hours for any generation.

Note: FLHs = full load hours, also commonly referred to as capacity factor, refers to the operating levels of a plant over some period of time (typically, one year) relative to its maximum output.

These settings are then applied in different combinations to explore the impact of different market arrangements within different contexts for regional dispatch.

Institutional efforts may be a decisive factor for preferring a model over another

The quantitative analysis performed evaluates and compares the different models in terms of their economic efficiency, their ability to integrate renewables and their contribution to reducing CO_2 emissions. Use of transmission capacities and impacts on imports and exports of electricity for each region are also assessed.

Although these criteria already provide good indicators of the social welfare potential associated with implementing these models, they should be complemented with other decision factors to choose a market design over another. Chinese policy makers may wish to assess impacts on price stability and security of supply. With growing concerns associated with the effects of climate change on power systems, criteria of climate resilience are to be considered when evaluating the robustness of a model. The ability to provide price signals incentivising flexibility and new investments could also be considered, as well as other social aspects such as impacts on employment.

Beyond techno-economic criteria, institutional factors and ease of implementation may be more decisive in the Chinese case to select a model over another. Especially with secondary market arrangements, many of the benefits of a national market will depend on actions taken locally, so it is important to anticipate barriers to the transition at this level. In this context, policy makers may favour a move towards a market design compatible with existing set-ups (notably limiting the need for new institutions) and allowing no-regret decisions (see next section: Transitioning towards a national spot market in China).

China's market reforms to date can already deliver benefits

While past policy settings in China stipulating administrative allocations of FLHs for generators had an important role in providing the revenue certainty to enable thermal generation capacity build-out, this mechanism also resulted in inefficiencies in power system dispatch. The move towards MLT contracts has the potential to support more efficient dispatch, but this depends strongly on the contract structure: in particular whether physical or financial contracts are used.

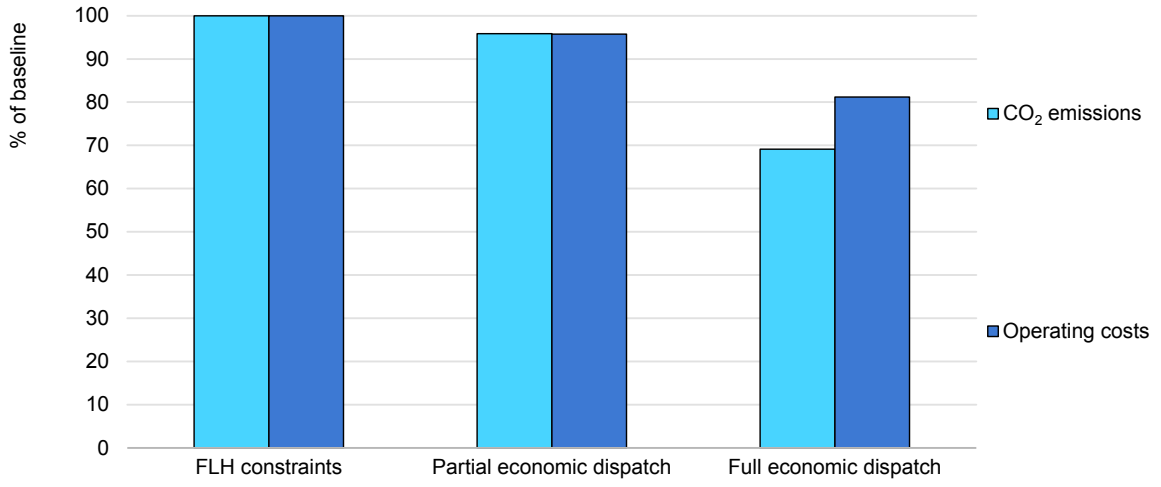
In this respect, multiple spot market pilots in China today have rules that dictate a move to financial CfDs for thermal generators, which are then to follow economic dispatch: Guangdong, Zhejiang, Shanxi, Shandong, Sichuan, Gansu and Inner Mongolia. While these provinces still take the output from some generators as a

"firm input" to the dispatch, provided economic dispatch is applied to the entire coal fleet the impact should still be quite close to merit order dispatch, since the firm generators are either technologies with low variable costs that fall early in the merit order (solar, wind, hydropower, nuclear) or are present in small shares (gas).

In order to assess the benefit for the Chinese power system of a shift to economic dispatch in these provinces, we compare operating costs,[6] CO_2 emissions and solar and wind curtailment with our "partial economic dispatch" setting to the historical baseline with FLH allocations in all regions. Note that these provinces are distributed across the modelling regions, so to capture the impact of the partial move to economic dispatch two regions are selected which are relatively advanced in their market trials and cover a similar share of coal generation in the future APS system (27%) to the share covered by these provinces in 2021 (31%).

The introduction of partial economic dispatch already provides a reduction in operating costs around 4% in the APS in China in 2035. A further case with economic dispatch across the entire system illustrates that this could increase to an 18% reduction in operating costs even without any increase in co-ordination and trade among the regions. Curtailment is also reduced from around 25% with FLH constraints to around 24% with partial economic dispatch and 12% with full economic dispatch.

Operating costs and CO_2 emissions relative to a baseline with full load hour constraints in China in the Announced Pledges Scenario, 2035



Note: Interregional exchanges are all constrained based on historical flows so that only improvements in the dispatch are taken into account.

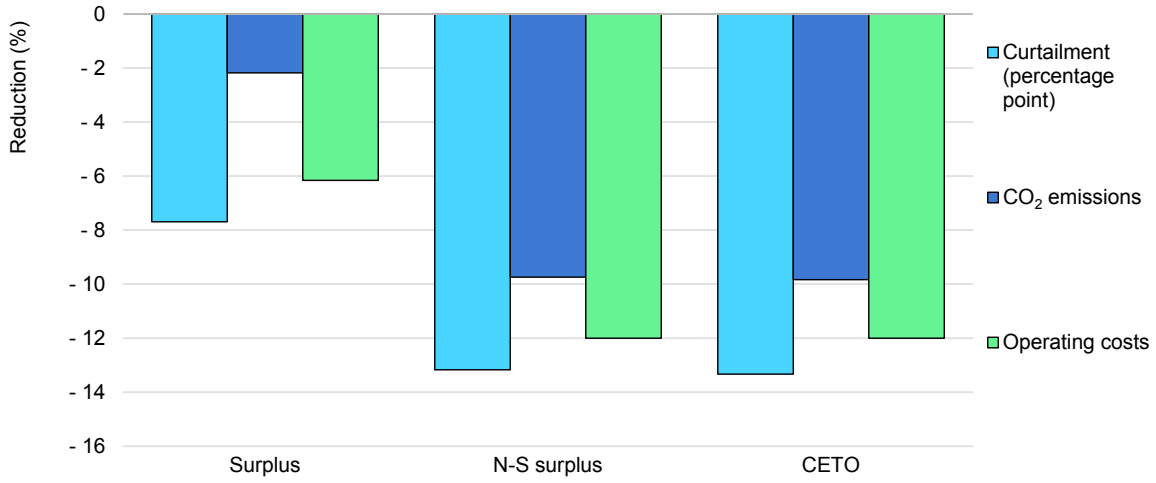
[6] In the figures, the operating costs do not include emission costs.

Increased regional co-ordination can improve system operations under current dispatching rules

While current spot market pilots open the door to more efficient dispatch, limited regional co-ordination today restricts the use of transmission infrastructure which also leads to inefficiencies. In order to understand the benefits that increased regional co-ordination and trade could bring in the context of China's current dispatching rules, we now compare the three different market models – surplus, north-south (N-S) surplus and CETO – against a baseline with historical levels of regional trade. All cases use the "partial economic dispatch" setting to reflect the level of economic dispatch consistent with the rules of existing spot market pilots.

At the lowest level of co-ordination, the surplus market assumes that unit commitment decisions (which generators will be switched on and off) are made at the regional level, and then the market allows trading within the stable operating range of all generators. Note that this assumption is still a significant advance from the surplus market operating in China today, as it has full participation from all technologies and allows for bi-directional flows between regions, with all committed plants participating in the market within their stable range. Increased trade between regions under this model allows for a 6% reduction in overall operating costs in the APS in 2035, as well as a modest reduction in emissions (2%).

Reductions in operating costs, CO_2 emissions and curtailment under different models for regional co-ordination under current dispatching rules in China in the Announced Pledges Scenario, 2035



Note: Reductions are calculated relative to a baseline scenario with interregional exchanges based on historical levels and dispatch reflecting current progress towards markets with economic dispatch in some regions and FLH allocations taking place in the remainder ("partial economic dispatch" setting).

Both the north-south surplus model and CETO model represent a very high level of co-ordination between regions, with the north-south surplus optimising within the northern and southern grids and only retaining surplus trading between them. The CETO model, by pursuing a volume coupling approach, allows the flows to be optimised between all regions. In both these cases, we see an operating cost saving of more than 12% due to increased regional trade. Benefits of the north-south surplus model are very similar to the CETO model with full regional optimisation, since co-ordination within the regions already provides substantial benefit and transmission capacity between north and south is limited.

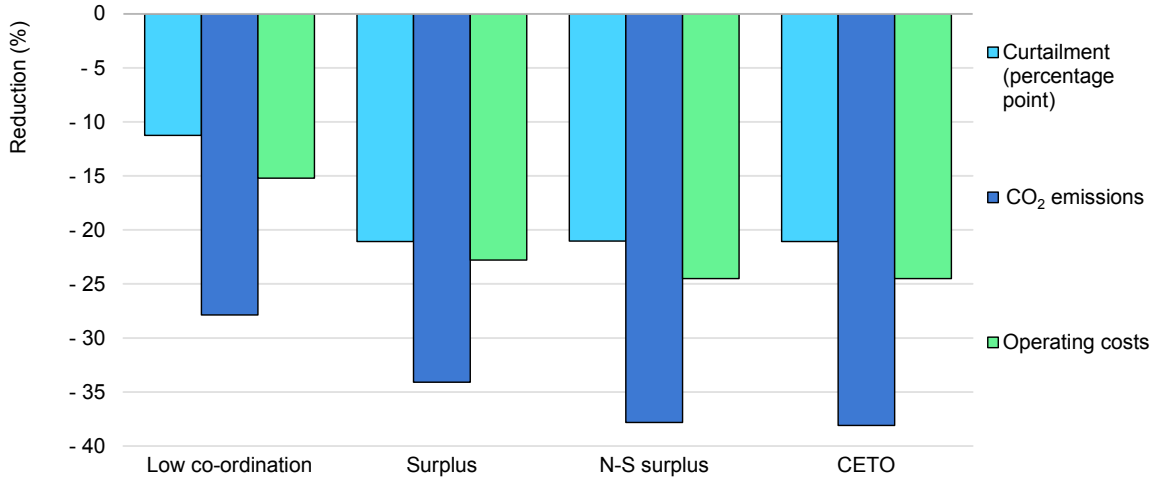
In these comparisons it is important to bear in mind that the model represents the benefit of regional co-ordination only and co-ordination among provinces inside the regions is effectively assumed. Beside the indicators considered here, increased co-ordination across provinces will bring other benefits, notably reducing reserve requirements which will become increasingly important for renewable integration.

Extending the application of economic dispatch will deliver enhanced benefits under all co-ordination models

Even in the case that regional co-ordination is increased under one of the market models discussed in this report, realising the full benefit of these approaches will depend on enabling more efficient dispatch, for example by transitioning from existing physical MLT contracts to financial products. In order to illustrate the benefit of enabling economic dispatch across the entire Chinese power system in combination with increasing regional co-ordination and trade, we now look at cost and emissions impacts from a shift to both full economic dispatch and each of the different co-ordination settings from the baseline with partial economic dispatch and low co-ordination.

This analysis shows that the shift to full economic dispatch alone without improving trade can save around 15% of operating costs in China in the APS in 2035. Adding the benefits of a surplus market brings this saving to nearly 23%, which is further improved to 24-25% under the north-south surplus and CETO models. All cases also bring very large reductions in solar and wind curtailment, which falls to less than 3% under all three market models compared with around 24% in the low co-ordination, partial economic dispatch baseline.

Reductions in operating costs, CO_2 emissions and curtailment using economic dispatch under different models for regional co-ordination in China in the Announced Pledges Scenario, 2035



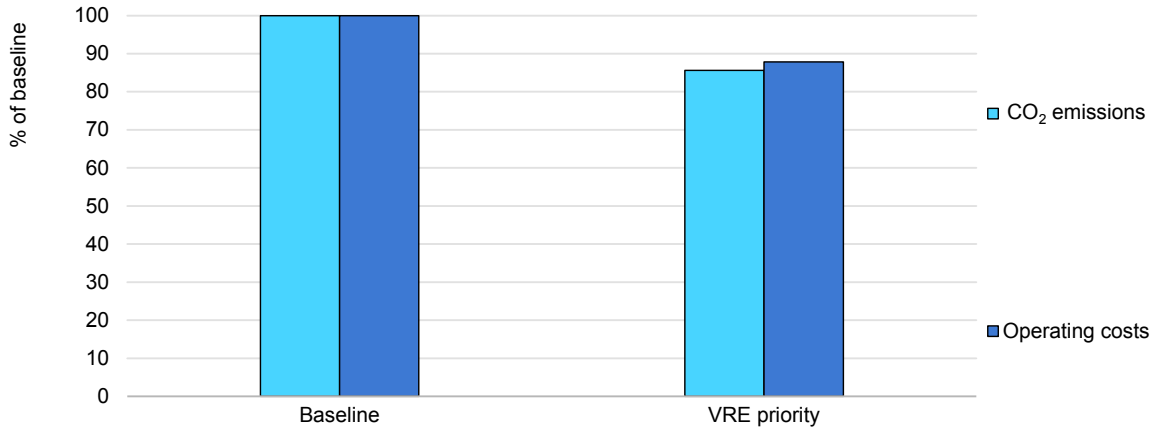
Note: Reductions are calculated relative to a baseline scenario with interregional exchanges based on historical levels and dispatch reflecting current progress towards markets with economic dispatch in some regions and FLH allocations taking place in the remainder ("partial economic dispatch" setting).

This highlights that while regional co-ordination has important benefits in its own right, maintaining the conditions for economic dispatch and extending these to all provinces remains critical to achieve a more efficient power sector.

Preventing renewables curtailment through prioritisation brings significant benefits on its own

Under dispatch based on FLH allocations or physical contracts, renewables output may be curtailed to make room for committed generation with higher operating costs and emissions. To illustrate the impact of prioritising renewables even without a full transition to economic dispatch or explicitly increasing co-ordination, we look at a case with part of the system being governed by FLH allocations combined with priority dispatch of renewables. Introduction of priority dispatch for renewables results in around 12% savings in operating costs and around a 14% reduction in emissions.

Reductions in operating costs, CO_2 emissions and curtailment with priority dispatch for renewables in China in the Announced Pledges Scenario, 2035



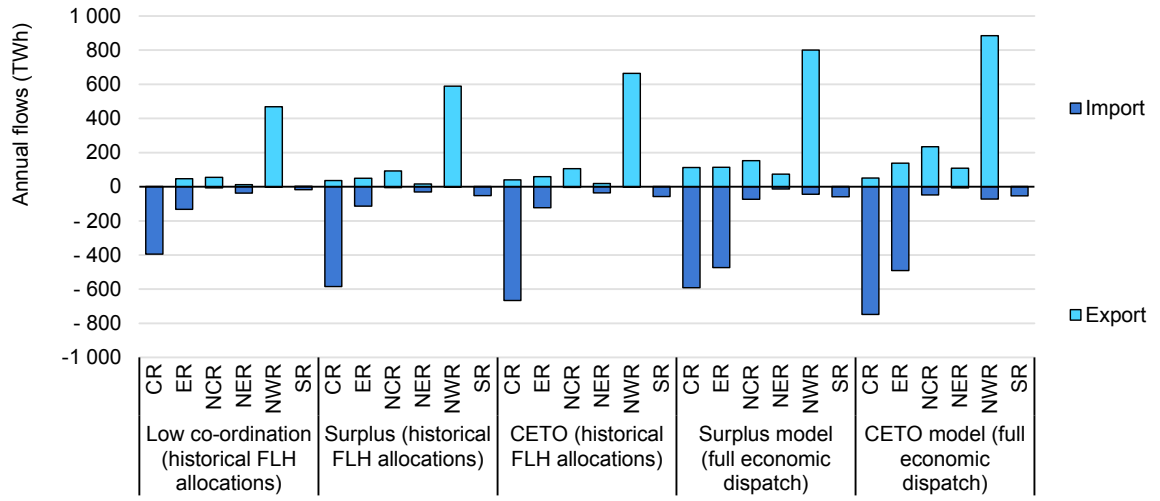
Note: Both cases incorporate interregional exchanges based on historical levels and dispatch reflecting current progress towards markets with economic dispatch in some regions and FLH allocations taking place in the remainder ("partial economic dispatch" setting).

These results illustrate that early steps to minimise renewables curtailment even ahead of broader reforms to dispatch and regional co-ordination can already provide significant benefits.

Regional export patterns will shift with increased co-ordination and implementation of market-based dispatch

Both limited regional co-ordination and administrative FLH allocations lead to a restricted usage of transmission infrastructure since co-ordination is required to facilitate advantageous trades between regions and FLH allocations limit the opportunity for imports. As a result, both increasing economic dispatch and increased co-ordination in the development of the Chinese power sector are expected to increase interregional flows. This includes both an overall increase in net imports or exports but also a bi-directional increase in both imports and exports for most regions.

Annual imports and exports by region under different dispatching practices and market arrangements



Notes: CR = Central region; ER = Eastern region; NCR = Northern-central region; NER = Northeast region; NWR = Northwest region; SR = Southern region. Low market co-ordination is represented by interregional exchange limits based on historical levels.

Such increases in bi-directional flows reflect an additional benefit leveraged from existing transmission infrastructure particularly under increasing renewables penetration, allowing regions to export during periods of abundant renewables supply and import the lowest-cost available generation during periods of low renewables output and/or high demand. The current arrangements with unidirectional contracts between provinces/regions represent a significant opportunity cost.

Transitioning towards a national spot market in China

China could achieve the goal of the current round of reforms through the implementation of various spot market models in complement to further developments with other markets (MLT, ancillary services and real-time markets). As institutional efforts may be a key factor in selecting a model, it is proposed to implement a secondary model with a national market that interfaces with the existing local markets. It is acknowledged that the CSG is making progress to integrate all provinces in its grid area under a single market, based on Guangdong's provincial market model. Therefore, the co-ordination efforts required by the secondary market will take place between this southern regional market and the provincial markets in the SGCC grid area. This section will thus consider indistinctively the southern regional market and the provincial markets as local entities. This secondary market could be a surplus market, through an extension of the SGCC interprovincial spot market, or a more advanced volume coupling model (the CETO), as both leave open the possibility to further integrate markets and establish a primary market.

This section presents pathways to first deploy a national surplus market before later implementing a CETO model, and possibly a primary market. As the national spot market will require strong co-ordination between the local entities and the national level, special attention is given to the role of national institutions.

Implementing a secondary market model

A secondary market model enables integrating existing and future markets while giving time to address barriers to markets

Implementing an integrated national market in China may face many obstacles and take a long time. For example, full competition among generators may require restructuring of the market. On the other hand, a national market based on a secondary model can deliver quick benefits.

A secondary market model meets the requirements of Document No. 118 and allows the gradual transition from the current state of play inside provinces and regions. By following a multilayer market approach, it also embraces the five-level dispatch protocol in place in China. The interface between local and national

markets under a secondary model has the flexibility to enable provinces to achieve at their own pace the required changes to efficiently integrate with the national level, such as phasing out administrative allocation of hours, creating or expanding application of local spot markets, and adopting flexible interprovincial agreements. In the meantime, provinces can gradually become familiar with short-term trading of electricity with one another. As they become more comfortable with trading, local entities can gradually increase their participation in the market and take advantage of the benefits it provides.

A secondary market (surplus or CETO) requires some co-ordination and harmonisation between the connected entities. These need to harmonise their approach to operational security as well as transmission capacity allocation and congestion management. The calculated available transmission capacities (ATC) at the borders between one another must be shared, and bi-directional interconnector flows must be allowed. Existing bilateral contracts between provinces should be harmonised. A common, transparent methodology to calculate wheeling charges to compensate transmission owners of transit areas is also needed.

SGCC's interprovincial spot market

The interprovincial spot market covers the SGCC grid area. In November 2021, SGCC issued the Provisional Rules for Interprovincial Spot Trade. Before this regulation, spot trading between individual provinces was allowed only for surplus of renewable power as part of the SGCC pilot market launched in 2017 (provided that the trading provinces belonged to different regions). The new rules expand the geographical scope of the market, and allow all types of power sources (including nuclear and thermal) to be traded on the interprovincial spot market.

Market feature	Description
Simplified zonal grid model	Each province corresponds to one "trading node" in principle, with the option of internal splits in case of local congestion. Sichuan, Jiangsu and Gansu have two nodes each.
Market participation	Opened to generators, power grids companies, retailers and power users. The latter can participate directly into the market or through the intermediary of grid companies in an initial stage. Participation to the market is restricted in nodes showing tight supply and demand balance (no power can be sold) and in nodes with surplus of VRE (no power can be bought).
Market trading frequency	Day-ahead trading takes place with a 15-minute resolution for the execution day. Intraday trading transactions occur 12-times a day for the next two hours.
Transmission capacity	Determined based on remaining capacity after MLT contracts and direct dispatch.
Transaction declaration	Market entities declare curve orders with a 15-minutes resolution. Quotation range must be between CNY 0 per kilowatt-hour (kWh) and CNY 10 000/kWh.
Market clearing	The clearing procedure follows a centralised bidding with a conversion of purchase bids according to transmission costs and a "principle of decreasing price difference". Provinces with a pilot spot market perform a pre-clearing (and those without perform pre-planning) before the National Dispatch Centre clears the interprovincial market. Interprovincial market clearing results are treated as boundary conditions by provincial spot markets.
Transmission pricing	Calculated by adding transmission charges of interprovincial alternating current (AC) and direct current (DC) corridors and provincial ones. Transactions fees are charged according to the actual traded volume.

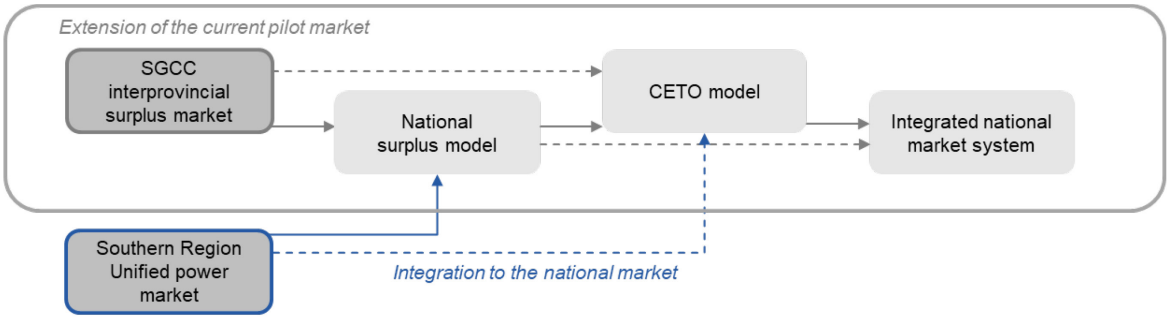
Source: IEA summary from SGCC rules and information shared by Norwegian Embassy in Beijing.

Extending the interprovincial surplus market towards a national surplus market is a no-regret move for the future

A secondary market can build on existing structures and enables resource sharing between local entities without compromising the ability to move later to more integrated market models such as a primary market. Meeting the requirements to deploy a surplus market also helps create the foundation needed for establishing more advanced target models such as the CETO or an integrated market.

Another benefit of a secondary market is that it can be implemented quickly at a small scale and expanded over time. Once a secondary market is established and stakeholders are familiar with its functioning, there is room for adding more participants and improving performance gradually. More co-ordination in how to manage interfaces (such as calculation of ATC and plans for transmission infrastructure expansion) will benefit the system but are not required at first.

Transition pathways towards a national spot market



Note: The recommended pathway is indicated by the plain arrows. More direct upgrades as represented by the dashed arrows are possible.

The minimum requirements are the following. The national (secondary) market will have to be established, as an expansion of the current surplus market, with transparent rules, a methodology for wheeling (transit) charges, and a mechanism for settlement and dispute resolution. Ensuring transparent and non-discriminatory use of interconnections needs special attention. Pre-requisites are permitting bi-directional interconnector flows, sharing of ATC, and allocation of ATC to MLT contracts, as well as allowing third-party access.

The trading platforms and associated information technology (IT) infrastructure will need to be deployed and be supported by a common and secure method to share data and information. At the provincial level, harmonisation of policies and regulations is required, in particular those that relate to operational security and use of interconnections. Harmonisation of bilateral interprovincial contracts also facilitates cooperation and further technical co-ordination.

A market operator (MO) – preferably independent – will need to be designated. This can be a national MO or a cooperation among local MOs, similar to the situation in Europe where mandated power exchanges (the "NEMOs") take turns running the day-ahead and intraday markets. The MO receives orders from markets participants, oversees the matching and allocation of orders according to the NDAM results, publishes prices, and acts as a central clearing party for clearing and settlement.

A regulatory authority will be needed to monitor the market and participants behaviours. Both the MO and regulator ensure that the market operates in a transparent and secure manner.

Strengthening of interconnection between the SGCC and CSG domains will also be needed. Only two transmission lines exist today (Hubei-Guangdong and Fujian-Guangdong), which is keeping the two grids relatively isolated from each other. Further investments into transmission infrastructure will contribute to the integration of the Southern Region Unified Market into the national surplus market.

After a surplus market is deployed, transition towards the CETO model requires moderate adaptations. To achieve the CETO model, implementing implicit auction and pre-clearing of the NDAM is necessary. The technical functioning of the national market is not drastically different from the surplus market, except for the sequence between the national and local markets and the need for implicit allocation of transmission capacity. On the other hand, there is a stronger role of the regulator to ensure that local markets comply with the outcome of the national market to maximise the use of interconnectors.

Minimum requirements for establishing a national surplus market and main changes for transition to CETO and primary market models

	Secondary models		Primary model
	Surplus	CETO	
Role of national institutions	Establish or designate a national MO (which takes on the central clearing party function) and a market regulator	Reinforce role of regulator to supervise compliance of provinces to NDAM's clearing outcomes	Reinforce role of regulator to monitor market participants competition
Design of a national market and clearing algorithm	Extend or design surplus algorithm	Upgrade clearing algorithm to solve combined flow optimisation problem	Upgrade clearing algorithm to full market coupling
National market rules	Transparent market rules, methodology for wheeling (transit) charges, and mechanism for settlement and dispute resolution	Establish regulations of volume coupling	Establish national transmission pricing congestion rent
Trading platform and IT infrastructure	Establish a common, secure method for data sharing and corresponding infrastructure	Enable higher volumes of data transfers	Enable significantly higher volumes of data transfers
Local markets clearing	Harmonise timing of local market clearing to precede NDAM	Switch sequence to clearing after NDAM. NDAM clearing result as firm input for local market clearing	Can exist but not necessary
Participation and bidding in national market	Local market participants send estimated excess volumes to the NDAM	Provinces with spot market submit their net positions to NDAM. Market participants from provinces without spot market can bid directly in NDAM	Establish a process where all market participants can bid to the NDAM
Calculation of ATC and use of interconnectors	Permit bi-directional interconnector flows, allow third-party access, increase harmonisation and co-ordination of ATC calculations	Implement implicit auction for optimisation of the allocation of ATC	Harmonise ATC calculation methodology
Economic dispatch within provinces	Voluntary	Voluntary but provinces without ED may experience sub-optimal gains	ED assumed
Grid codes and standards within provinces	Harmonise grid codes (operational security and use of interconnectors) and cross-provincial contracts	Produce an updated national grid code	Further harmonise rules to create a level-playing field

Notes: ED = economic dispatch. For the national surplus market, the minimum requirements are listed. For the CETO and primary markets, the marginal upgrades are listed.

Reinforcing national institutions for a national market

Although the deployment of a national spot market will benefit China, some stakeholders may have concerns. Thus, strong central directives will need to be complemented by engagement of stakeholders. At times, top-down decisions will be necessary to balance the interests and roles of the various stakeholders involved.

Benefits of a national market depend on the capacity of the national regulator

Central institutions play a key role in power sector reforms in China. The NDRC and NEA are leading the reforms through delivery of framework policies. The design of markets is largely under the responsibility of the NEA, although it can be developed in cooperation with or delegated to grid companies and research institutes. However, the design choices are to be approved (or denied) by and eventually owned by the NEA.

Moving forward will require giving a large role and capacity to the regulator. The current trading landscape in China, with weakly or non-connected markets and administrative mechanisms, makes market oversight complicated and puts generators in a strong position to keep wholesale market prices high. To address this issue, the implementation of a regulation similar to the European Union's Regulation on Wholesale Energy Market Integrity and Transparency (REMIT) may be considered. REMIT was introduced in 2011 to improve the monitoring and regulatory oversight of transactions with wholesale energy products. The regulation is based on four principles: transparency, integrity, monitoring and co-operation, with the aim of increasing transparency, market integrity and consumer protection. ACER is responsible for monitoring energy trading operations to detect and prevent trading based on inside information and market manipulation, and the cost of ACER's market monitoring and surveillance activities are financed through a fee imposed on market participants. Similar to Europe where the regulators of the interconnected entities (the national regulators of the member states) keep a role in market monitoring, the provincial regulators can also play a role in monitoring the local markets.

Organisations leading power market reforms in China

The National Development and Reform Commission (NDRC) serves as the main reform body, issuing guiding documents and setting the direction for the reforms. Various departments such as the Department of Price, the Bureau of Economic Operations Adjustment, and the Department of Economic System Reform have specific responsibilities to keep power prices fair and stable, ensure reliable and affordable power, monitor industry impacts, and provide active guidance during pilots. The General Office of the NDRC provides cross-department co-ordination, while provincial development and reform commissions have local pricing regulation and energy divisions.

The National Energy Administration (NEA) is responsible for drafting and implementing reform policies and legislations. NEA departments – Renewable Energy department; Electricity department; Reform and Legislation department; and Markets and Regulation department – each have their respective mandate to create renewable energy policies, monitor the economic health of thermal fleet and grid companies, turn reforms into law and enforce them, design markets and regulation, release market rules, and oversee market operations. The NEA also has regional and provincial branch offices.

The State-owned Assets Supervision and Administration Commission of the State Council (SASAC) does not have a direct role in policy making but can influence reforms if they affect the economic health of state-owned enterprises (SOEs). The Ministry of Industry and Information Technology also does not have a direct role in power reforms but can influence them if they threaten industrial development goals. At the provincial and regional levels, the development and reform commissions, responsible for local GDP growth and planning and permitting for new assets, often play a significant role in implementing provincial pilots due to their possible impacts on GDP and jobs.

The two grid companies, State Grid Corporation of China (SGCC) and China Southern Power Grid (CSG), also play a significant role. They have research institutes that support market reforms and designs in cooperation with think tanks and universities. Their local subsidiaries also have specific roles. Exchanges centres were given responsibility for MLT trade. Provincial and regional dispatch centres directly influence spot market rules, given their responsibility to match generation dispatch with contracts and administrative allocation.

Source: Yiyan Cao, Ruosdia Lin, Bingqi Liu, Zihe Meng, and Daniel Wetzel (2019). Tracking China's Provincial Spot Market Designs.

Addressing stakeholder concerns through transparent consultations

Although widely beneficial to China, the move towards spot markets raises concerns among many stakeholders. The more granular and volatile price signal of a fully functioning spot market will affect the supply-demand balance and decision-making of generating companies and investors.

The creation of a national market will also change the roles of stakeholders. In particular, provinces will need to operate within a framework of national guidelines and grid companies will need to follow the direction of market operators and regulators.

Another factor that will affect the effectiveness of markets is the link between power markets and system planning. In a market-based power system, planning can be considered as an essential information channel between policy makers and market participants, delivering information on the system needs to meet the policy objectives as a guide for competitive stakeholders to make the right decisions. The current process for transmission grid planning in China is strongly linked with the approval for new plants and the expected utilisation rate. In a market-based environment with a high share of VRE, the flows will vary more and the planning process can be adapted to capture faster the benefits of markets over large areas. The feature of such an adapted process may be to be made system-wide and based on a probabilistic assessment.

Going ahead with the reforms will require a central entity to take the lead of the process while making sure conflicts of interest are minimised. Global experience shows that integration is often hampered by the absence of strong, enabling institutions. Given its mandate and independence, the NEA is best positioned to play this role and provide regulatory certainty. Open consultations with all stakeholders will allow gathering the necessary expertise while also considering all concerns, and eventually increase the buy-in of the outcome. This process can be initiated to support the new design(s) but can be considered with to have a permanent existence as market rules may require updates periodically. This way, stakeholders will also be allowed to provide feedback continuously.

Recommendations

National co-ordination of the power sector

China's market reforms to date have made significant achievements: successfully raising investments and recently introducing increased competition between coal-fired plants and improving the environmental attributes of the power sector. Much of the progress in the 2015 reform has focused on the provincial level. Document No. 118 in 2022 recognised that better co-ordination among provinces and regions holds the potential to deliver significant improvements in power sector efficiency.

A well-functioning national market can contribute to efficient use of resources across the country during the rapid energy transition required to meet the dual carbon goals. The preservation of provincial autonomy and diversity of provincial power dispatch processes present obstacles to the establishment of a fully integrated primary national market. In this respect, secondary market models explored in this report, namely the surplus and CETO models, have the advantage of harvesting quickly the largest part of the reform benefits. These secondary models provide China with options to access the benefits of improved co-ordination of resources across the country while retaining provincial autonomy. This also allows the southern regional power market to continue its development.

A number of policy recommendations can help China to improve co-ordination at the national level within the framework of secondary market models:

- **A national surplus market built on the foundation of the existing interprovincial spot market can be a no-regret move enabling later further integration**. Provincial markets may preserve most of their current features and participation of their resources in the national market can be achieved in a number of ways enabling a gradual increase in transactions. While building on the existing setup, this model also enables more advanced integration models at later stages.
- **A strong national regulatory body is needed to supervise the implementation of national markets**. Strong national institutions can accelerate the implementation of a national market. Transparent and unbiased choices are needed in the design of the market, and once implemented, a supervision of the market will be required. Co-ordination and guidance of provincial markets also grows in importance as the prospects of integrating markets increase.
- Further co-ordinate nation-wide plans and operational protocols. Independent national institutions may need to take a stronger stance and favour convergence of practices. This goes from system planning to design of local markets. More

interconnections between adjacent provinces will be beneficial. Further thoughts on how to bring all provincial/regional designs closer together may be needed.

- Cross-provincial and -regional trades can be made more flexible. More flexibility in these arrangements – their original definition and enabling changes close to real-time – will require co-ordination between the mechanisms and adapting operational protocols. This will also increase the use of existing interconnections thanks to additional trades closer to real time.
- **Transmission pricing mechanisms can be improved and harmonised to avoid "tariff pancaking" and promote interprovincial trading**. The current energy-based interprovincial transmission pricing mechanism has shown limited efficiency in incentivising interprovincial transactions. Moreover, accumulation of charges across multiple regions or provinces can discourage transactions that would have been otherwise efficient for the system. As the Chinese national market becomes more integrated, transmission charges may change to congestion rents. This is the case in the European Union where transmission system operators receive congestion rents through auctions for cross-border capacity rights, while no transmission fees apply to interconnectors so as to maximise their use. In addition, it is essential that transmission charges are de-correlated from commercial transactions.
- **Planning of the power sector can be further articulated around markets**. Planning should provide the framework under which power markets operate, taking as essential inputs national policy objectives and existing market designs. However, letting administrative planning play a leading role in guiding investments and power system operations can result in sub-optimal investment decisions and overcapacity, which in return may require market design's adjustments (e.g. through capacity payments to coal plants). Thus, enhancing the role of power markets over planning will be crucial to determine in a cost-efficient manner the solutions and technologies needed towards decarbonisation goals.

Advancing regional and provincial markets

Under secondary structures for the national power market, the status of local market arrangements (provincial and regional) will remain critical to the efficiency of the Chinese power sector. Spot market pilots in China today already provide a number of good examples of how local arrangements can continue to evolve in the coming years. Applying a number of key principles will allow these markets to work in concert with increasing national-level co-ordination to deliver the best outcome for the Chinese power sector as a whole:

- **Maximise participation in local spot markets to improve price signals and achieve more efficient dispatch**. To this end, it is essential to enable an equal participation in spot markets of all market players, on both generation and supply sides, including distributed renewables, storage and demand response. This can help limit imbalances caused by "dual track" structures. Moreover, large benefits

come from moving towards market-driven dispatch in provinces, even beyond those of establishing a national spot market (improved efficiency, reduction of overall costs, better integration of renewable energy). Therefore, in parallel with the steps to implement the national market system, economic dispatch should be promoted. In the longer term, increasing shares of VRE may be a natural driver for accelerating deployment of short-term markets and participation from VRE, as the benefits associated with short-term market signals adapted to more flexible operations become increasingly evident.

- **Continue the move towards a liquid, competitive MLT market with financial contracts and minimise the impact of physical contracts on spot market function**. This is of particular importance considering recent policy requiring large consumers to secure 90% of their previous year's consumption through MLT contracts, which, if physical, could greatly limit the role of provincial spot markets. Expanding the use of financial MLT contracts, as have been introduced according to the spot market rules for China's provincial gross pool spot markets, can substantially improve the efficiency of the Chinese power sector and reduce emissions. Creating a set of standard products will help improve liquidity. Where physical contract structures persist, increasing their timescale granularity (with weekly and multi-day contracts) can help bridge the gap with spot markets by better reflecting the fuel price dynamics of power plants. In addition, it is recommended to gradually increase the range of price fluctuation of MLT contracts (currently set at +/-20% around the benchmark price for coal power) and eventually remove any restriction to enable MLT prices to gradually converge towards long-term trends of spot prices.
- **Complement MLT and spot markets with ancillary services and real-time markets**. Although MLT and spot markets will constitute the bulk of the trade in energy, keeping the system stable and in balance will require effective markets for regulation and balancing supply and demand at all time. These markets can be initially established at the level of the local markets. Provided the necessary transmission capacity allocation mechanisms are put in place, further efficiency can be obtained by establishing these markets at the level of the grid area (SGCC and CSG).
- **Properly compensate available capacity without distorting markets and contravening climate goals**. Renewables will take a growing role and peak prices on spot markets may not be sufficient to compensate thermal power plants for reduced operating hours. Thus, transition mechanisms are to be considered for legacy thermal plants. A first step in this direction was the requirement for generators to move to MLT markets. More recently, Document No. 118 let the door open to several solutions for future cost recovery mechanisms, such as capacity compensation mechanism, capacity market, and scarcity pricing, which should be established according to local conditions. Some provinces have already proposed or experimented with compensation schemes, with a per-kWh capacity payment for coal plants participating in the spot market (Shandong), or through a "two-part" tariff (based on kilowatt-hours and kilowatts) for gas-fired power plants

(Shanghai, Zhejiang, Jiangsu). When introduced, CRMs should be carefully designed to target only specific assets actually useful for the system and compatible with decarbonisation. In that purpose, they should also be open to all providers of capacity, including storage and demand response. CRMs should not hinder participation of these assets on spot markets nor lead to price distortion, with generators bidding below their marginal price. If put in place, it is recommended to promote market-based CRMs which remunerate available capacity based on actual performance, to incentivise flexible operation when the system needs are the highest. Competition through auctions can also allow identifying the cheapest resources.

Annex

Modelling methodology

To examine how different market models could impact the future Chinese power system, we have carried out techno-economic analysis using the International Energy Agency (IEA) Regional Power System model for the Announced Pledges Scenario (APS). The analysis focuses on a one-year "snapshot" in 2035 to reflect the benefits of power system reforms that can be realised when China is relatively advanced in its decarbonisation pathway. The national results for supply and demand come from the IEA World Energy Outlook (WEO) model and are disaggregated into six regions with regional transmission interconnection among them. Different cases are studied to explore the impact of varying levels of co-ordination and trade among the regions. Dispatch incorporating different levels of administrative allocation of full load hours (FLHs) and economic dispatch is also explored to highlight the interplay between China's move towards more economic dispatch and the role of a national market.

Representing levels of regional co-ordination

Four different options for regional co-ordination and trade are represented with increasing levels of co-ordination among the regions. Note that the model configuration is illustrative only of the dynamics coming from different levels of market integration. Due to the six-region representation of the Chinese grid, co-ordination within regions is effectively assumed and thus the results give only a conservative estimate of the full benefit of progressing from province-level markets to a nationally integrated approach.

Cases summary for different levels of regional co-ordination

Co-ordination case	Description
Low co-ordination	Limited flows between regions based on historical levels.
Surplus market	Unit commitment set within each of the six modelling regions, dispatch then allowed to adjust within the stable operating range of all generators to take advantage of trading between regions.
North-south surplus	Unit commitment set within the northern and southern grids, dispatch then allowed to adjust within the stable operating range of all generators to take advantage of trading between northern and southern.
CETO	Nationally integrated dispatch with flows optimised across the entire system.

Representing dispatching practices

Since increased economic dispatch is a large source of potential value from China's market reform, we also represent several different dispatch approaches in the modelling. The first option represents the historical approach of administratively allocated FLHs across all the provinces. This provides a baseline against which to observe the future benefit to be expected from the reforms China has already completed, and is used to fix the electricity flows between regions for all cases with historically-based trade. Second, in line with current progress in market reform where the market rules for certain provinces provide for a shift to financial contracts and economic dispatch for thermal generation (Guangdong, Zhejiang, Shanxi, Shandong, Sichuan, Gansu), we include a case where some regions only (central and southern) have transitioned to economic dispatch. This region selection is designed to cover a share of thermal generation in 2035 (27%) similar to the share of thermal generation that should be covered by financial contracts in 2021 (30%) since the provinces are distributed across the modelling regions and cannot be directly represented in the regional model.

Cases summary for different levels of economic dispatch

Dispatch case	Description
Historical FLH allocations	FLHs constrained on thermal generation in keeping with historical dispatch levels for all regions.
Partial economic dispatch	FLH constraints on thermal generation in north-western, northern, north-eastern and easter regions only. Central and southern regions have fully optimised economic dispatch.
Full economic dispatch	All dispatch determined on a least-cost basis without constraints on the operating hours for any generation.

Note: FLH = full load hours and refers to the operating levels of a plant over some period of time relative to its maximum output.

The partial economic dispatch case is intended to broadly reflect the dispatch practices expected in China today based on rules of the current spot market pilots in the provinces with financial contracts. Note that while these trials still allow for some generation types to be taken as firm inputs to the dispatch, since these are typically first in the merit order (solar, wind, hydropower, nuclear) or present in very low shares (gas), the dispatch could nonetheless be expected to come very close to a full economic optimisation.

The co-ordination cases and dispatch cases described above are then used together to produce different combined cases to illustrate the potential benefits of reform in both aspects. To ensure that changes in the FLH do not impact trade in the “low co-ordination” case, note that the interregional flows from the case combining low co-ordination and historical FLH allocations are used across both partial and full economic dispatch cases with low co-ordination. If not set in this manner, then the move to partial economic dispatch would result also in increased trade, while the current market trials are at the province level only and do not imply increased trade between regions. This approach also allows the benefits of trade and economic dispatch to be separated analytically.

Combined cases used for the analysis

Case description	Co-ordination level	Dispatch setting
Full load hour constraints with low co-ordination	Historical exchanges	FLH constraints in all regions
Partial economic dispatch with low co-ordination	Historical exchanges	FLH constraints in selected regions
Economic dispatch with low co-ordination	Historical exchanges	Economic dispatch in all regions
Partial economic dispatch with surplus trading	Surplus market	FLH constraints in selected regions
Partial economic dispatch with north-south surplus trading	North-south surplus	FLH constraints in selected regions
Partial economic dispatch with CETO trading	CETO approach – flows are optimised for the current dispatch	FLH constraints in selected regions
Economic dispatch with surplus trading	Surplus market	Economic dispatch in all regions
Economic dispatch with north-south surplus trading	North-south surplus	Economic dispatch in all regions
Economic dispatch with CETO trading	CETO approach	Economic dispatch in all regions

Notes: FLH = has full load hour constraints.

Regional setup and transmission capacity

The model includes six nodes corresponding with China's major grid regions, i.e. northeast, north central, northwest, east, central and south. Each region includes multiple provinces. Note that China can be considered to have seven regional grids with Sichuan, Chongqing and Tibet making up a southwest grid region, however based on data availability the six-region classification has been used for this study.

Division of six modelling regions by province

Region	Abbreviation	Provinces
Northwest	NWR	Gansu, Shaanxi, Tibet, Ningxia, Xinjiang, Qinghai
North central	NCR	Beijing, Hebei, Inner Mongolia, Shanxi, Tianjin, Shandong
Northeast	NER	Heilongjiang, Jilin, Liaoning
Central	CR	Henan, Hubei, Jiangxi, Chongqing, Hunan, Sichuan
Eastern	ER	Anhui, Jiangsu, Shanghai, Fujian, Zhejiang
Southern	SR	Guangxi, Guizhou, Hainan, Yunnan, Guangdong

Transmission capacity used in the model includes existing interconnectors and additional investments to 2035 based on a possible build-out trajectory of around 200 gigawatts (GW) of total capacity, particularly in corridors from regions with high VRE capacity. Capacities are generally aligned with the IEA China Power System Transformation study with the connection to the southern grid revised downward based on lack of current plans to expand these connections.

Transmission capacity (GW) assumed for 2035

Region	CR	ER	NCR	NER	NWR	SR
CR		41	11	5	115	5
ER			19.5	8	112	2
NCR				24.5	43.5	

Electricity demand

Annual electricity demand projections and hourly load profiles for each end-use sector are based on detailed bottom-up analysis from the WEO, which estimates hourly demand by end use for residential, services, agricultural, industrial and transport sectors. The projections rely on national macro indicators (e.g. population dynamics and economic growth), integrating the latest policies. The disaggregation of the load into the six modelling regions is based on regional projections considering key drivers of each end use and factoring in regional trends, policies and other conditions. The hourly potential for demand-side response by region is based on the projected demand by end use in each region.

Generation capacity

Power generation capacity in the APS is determined based on the projected evolution of the existing fleet in line with announced pledges and targets for emissions reduction. The model assumes that projected capacity for existing and new technologies is made available for dispatch. For the regional distribution both existing plans and the expected evolution of capacity in each region is taken into account, including considerations of maintaining regional security of supply. For the deployment of coal plants, a particular role is played by co-generation plants following the changing heat demand resulting from the shift of heavy industry towards the northern regions, and in particular towards the northwest. Co-generation plants are broadly divided into industrial steam and district heating operations, and a seasonal pattern was applied to the district heating plants. Gas-fired plants are developed in each region considering the evolution of the gas supply infrastructure. New nuclear reactors are deployed reflecting planned and proposed sites.

The hourly modelling includes detailed operating characteristics (e.g. operating costs, plant technical minimum operating levels, minimum up and down times, start-up times, and ramp rates).

Renewables generation profiles

Wind (on- and offshore) and solar PV (utility-scale and rooftop PV) capacity are allocated on the basis of over 4 000 representative sites considering resource potentials; population density; distance from power grids; exclusions based on land use, altitude or slope; and policies in place. Hourly wind and solar generation have been simulated from the selected wind and solar sites across China. Hydro capacity has been broken down in each region into four main types: run-of-river, run-of river with small storage, reservoir and pumped hydro storage. Different types of seasonal inflow have been considered for each of these types. The expansion of the remaining renewables technologies (bioenergy, concentrating solar power, geothermal and marine) was based on resources and capacity requirements across the different regions. Fuel prices were derived from the WEO, and for steam coal prices, the price differences between the regions were estimated considering current market trends and transport costs.

Abbreviations and acronyms

ACER	Agency for the Cooperation of Energy Regulators
APS	Announced Pledges Scenario
ATC	available transmission capacities
C&I	commercial and industrial
CETO	China Energy Transition Outlook
CfD	contract for difference
CNY	Chinese Yuan renminbi
CO_2	carbon dioxide
CRM	capacity remuneration mechanism
CSG	China Southern Power Grid
ETS	emission trading scheme
FLH	full load hours
HVDC	high-voltage direct current
IEA	International Energy Agency
IT	information technology
MCP	market-clearing price
MLT	mid-to-long-term
MO	market operator
NDAM	national day-ahead market
NDRC	National Development and Reform Commission
NEA	National Energy Administration
NEMOs	Nominated Electricity Market Operators
PPA	power purchase agreement
PV	photovoltaic
REMIT	Regulation on Wholesale Energy Market Integrity and Transparency
SADC	Southern African Development Community
SAPP	Southern African Power Pool
SASAC	State-owned Assets Supervision and Administration Commission
SGCC	State Grid Corporation of China
SIEPAC	Central American Electrical Interconnection System
VPP	Virtual Power Plant
VRE	Variable Renewable Energy
WEO	World Energy Outlook

Units of measurement

GW	gigawatt
GWh	gigawatt-hour
kWh	kilowatt-hour
MWh	megawatt-hour
TWh	terawatt-hour

International Energy Agency (IEA)

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