Power Market and Pricing Mechanism Reform in China: A Vital Step Toward Zero-Carbon Electricity Growth and New Power System

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About RMI

RMI is an independent nonprofit founded in 1982 that transforms global energy systems through market-driven solutions to align with a 1.5°C future and secure a clean, prosperous, zero-carbon future for all. We work in the world's most critical geographies and engage businesses, policymakers, communities, and NGOs to identify and scale energy system interventions that will cut greenhouse gas emissions at least 50 percent by 2030. RMI has offices in Basalt and Boulder, Colorado; New York City; Oakland, California; Washington, D.C.; and in Beijing, People's Republic of China.

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Glossary

CAISO – California Independent System Operator
CfD – Contract for Difference
CSG – China Southern Power Grid
CSP – Concentrated Solar Power
DC – Direct Current
ERCOT – Electric Reliability Council of Texas
FERC – Federal Energy Regulatory Commission, USA
FIT/FIP – Feed-in Tariff/Feed-in Premium
FYP – Five-Year Plan
I&C – Industrial and Commercial
ITC – Inter-TSO Compensation
LCCC – Low Carbon Contracts Company, UK
LCOE – Levelized Cost of Electricity
M2L – Medium- to Long-term
NDRC – National Development and Reform Commission, China
NEA – National Energy Administration, China
NEM – National Electricity Market, Australia
PPA – Power Purchase Agreement
PV – Photovoltaic
RMB – Chinese currency (renminbi)
SDAC – Single Day-ahead Coupling
SIDC – Single Intraday Coupling
SOE – State-owned Enterprise
T&D – Transmission and Distribution
TSO – Transmission System Operator
UHV – Ultra-High Voltage
VRE – Variable Renewable Energy
WEIM – Western Energy Imbalance Market

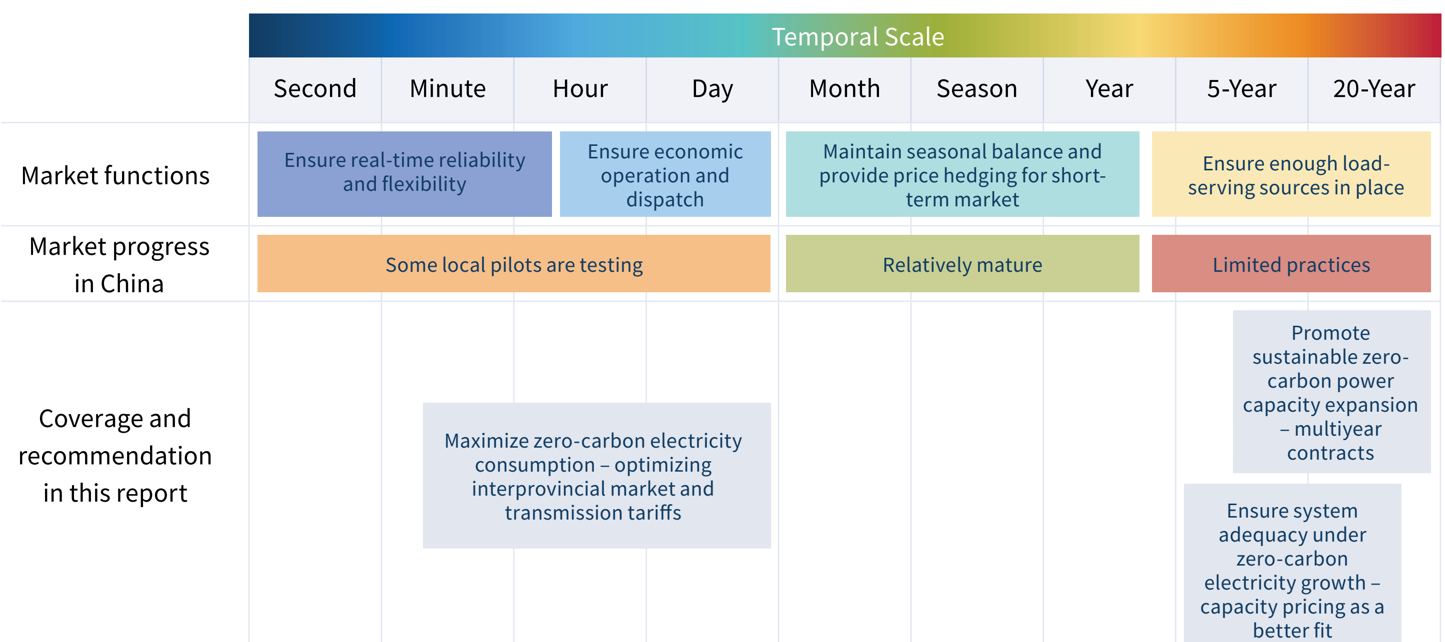
Executive Summary

Since China's announcement of achieving carbon peaking by 2030 and carbon neutrality by 2060 (also known as the dual-carbon target), it has accelerated power system transition and market reform by introducing the New Power System and the national unified power market system on the policy level. The power sector is the foundation to ensure social prosperity and economic development, and the key to realizing the dual-carbon target. Beyond ensuring safe and reliable operation, the dual-carbon target requires the power industry to be cleaner and greener, with an ultimate goal of constructing a reliable, economic, and green power system.

In China and the world, the cost of zero-carbon power generation technologies becomes competitive, and the technical solutions for real-time power balance and system reliability are maturing in the 2020s. The next key focus of power sector decarbonization is to effectively incentivize investment in certain technologies and establish power pricing mechanisms aligned with power system transition that guarantee returns on investment and reliable system operation.

Unlike other commodities, the power system needs to, under many physical constraints, achieve the balance of supply and demand at different time scales ranging from subsecond to decades, and achieve the balance from local level to national level. On the way toward the New Power System, the power industry's conventional "one mechanism fits all" pricing model will not fit in the new system due to the varying abilities and functions of different types of power generators. The refined market organization and pricing mechanism that provide proper trading products for balancing needs at different scales will help to better formulate a reliable, economic, and green power system. (See Exhibit ES1, upper and middle part.)

Exhibit ES1: Power Market Functions and Progress in China by Temporal Scale



Key tasks for advancing toward the New Power System could be summarized as continuing zero-carbon power capacity expansion and promoting zero-carbon power consumption while ensuring reliable and economic power supply. This report focuses on three challenges: (1) zero-carbon power capacity development, (2) zero-carbon power consumption, and (3) system adequacy in zero-carbon power growth. It also shows how market development and power pricing reform can help address the challenges (Exhibit ES1, lower part). To better facilitate greenhouse gas emissions reduction and low-carbon power system operation, the three core solutions studied in this report, i.e., (1) multiyear electricity contracts, (2) interprovincial trade and transmission tariff optimization, and (3) capacity pricing for system adequacy, should be the prioritized tasks for power market and pricing mechanism reform in the 2020s. Exhibit ES2 below summarizes the key challenges and solutions.

Exhibit ES2: Key Challenges and Solutions

Challenges and Purposes	Solutions and Recommendations
Promote sustainable zero-carbon power capacity expansion	**Provide auction-based multiyear contracts to renewable producers.** The government or system planner sets the annual capacity target and organizes auctions for renewable developers. The bid winners then sign multiyear contracts (e.g., 5–25 years) with the government, grid companies, or government-owned hedgers to ensure long-term price stability.
	Promote power purchase agreement–like multiyear green power transactions to leverage consumers' engagement. Expand green power market scope and allow an extended contract's duration (e.g., 5–25 years). Allow renewable projects under development to trade and secure their long-term revenue before connecting to grid.
Maximize the consumption of zero-carbon electricity	**Enhance trading flexibilities and promote a higher share of electricity to trade through interprovincial spot market.** Market-based interprovincial transactions are expected to replace planned transactions. Suppliers and consumers, rather than the provincial grids, shall be the major participants. Advance the spot power market development to better address renewable fluctuations and uncertainties.
	Optimize the transmission tariff mechanism to ease interprovincial power trade barriers. An interprovincial transmission tariff can disincentivize renewable power trade as it creates a dead band for power flow. In the long term, setting a unified transmission tariff scheme across the country or leveraging the congestion rent method could be a solution.
Ensure system adequacy under zero-carbon electricity growth	**Capacity pricing is a better fit than scarcity pricing, and capacity payment is the near-term choice.** The power market maturity, the tolerance to price volatility, the power consumption growth rate, and the market power in the supply side collectively determine scarcity pricing is not a fit in China's context. Capacity payment can serve as an interim solution before the power market is well-established.

Although some countries and regions have used power markets for many years, formulating a pro-climate and pro-transition power market paradigm is an ongoing challenge. We hope the findings and recommendations in this report can provide valuable ideas and solutions for stakeholders to formulate the national power market, support the New Power System, enable zero-carbon electricity growth, and provide a model for the global zero-carbon power transition.

China's Dual-Carbon Target Accelerates Power System and Market Reform

China's power system and market reform have undergone an extraordinary 20-year development. In 2002, the State Council's *Document #5* unveiled China's power sector reform and led to the separation of power generation utilities and grid operators.[1] In 2015, *Document #9* initiated the second round of market reform and promoted large scale implementations of medium- to long-term (M2L) markets and spot market pilots.[2]

Since China's announcement of achieving carbon peaking by 2030 and carbon neutrality by 2060 (hereinafter referred to as the dual-carbon target), China has accelerated power system transition and market reform on the policy level.

In October 2021, the Central Committee of the Communist Party of China and the State Council jointly released the dual-carbon target flagship policy, *Working Guidance for Carbon Dioxide Peaking and Carbon Neutrality in Full and Faithful Implementation of the New Development Philosophy*, proposing to construct the New Power System and improve the power grid's capacity to accommodate a high share of renewable energy.[3]

Later, in January 2022, the National Development and Reform Commission (NDRC) and the National Energy Administration (NEA) issued *Guiding Opinions on Accelerating the Construction of a Unified National Power Market System* to support the New Power System development.[4]

The power sector is the foundation to ensure social prosperity and economic development, and the key to realizing the dual-carbon target. In early 2021, RMI released *China Zero-Carbon Electricity Growth in the 2020s: A Vital Step Toward Carbon Neutrality* (hereinafter referred to as *Zero-Carbon Electricity Growth*), addressing the low-carbon development of the power system under the dual-carbon target.[5] The *Zero-Carbon Electricity Growth* report discussed the opportunities, challenges, and solutions for the low-carbon development of China's power sector in the 2020s based on levelized cost of electricity (LCOE), grid management, and hourly supply-demand balancing. The analysis showed that:

- The LCOE of solar photovoltaic (PV) and wind power has declined and will continue to decline, and the economics of investing in solar PV and wind power will become more prominent than investing in fossil fuels in the 2020s.

- Technologies are relatively mature to address the challenges of real-time power balance and system reliability, such as frequency control, voltage control, fault ride through, and long-distance high-voltage transmission.

- The balance of power supply and demand at the hourly, daily, and seasonal levels can be guaranteed under the condition of large-scale long-distance flexible dispatching of power resources.

With technical solutions maturing, the next key focus of power sector decarbonization is to effectively incentivize investment in certain technologies and establish power pricing mechanisms aligned with power system transition that guarantee returns on investment and reliable system operation.

In the past year, the government repeatedly emphasized the role of market and pricing mechanisms in renewables and other zero-carbon electricity growth.

- In March 2021, the NEA stated that one of the new features of renewable development during the 14th Five-Year Plan (FYP) period would be market-based approaches.[6]

- In July 2021, the national carbon emissions trading market covering the power generation industry was launched.[7]

- In October 2021, *Working Guidance for Carbon Dioxide Peaking and Carbon Neutrality in Full and Faithful Implementation of the New Development Philosophy* proposed to comprehensively promote power market reform and deepen power pricing mechanism reform from the perspective of energy conservation.[8]

- In January 2022, the NDRC and the NEA issued *Guiding Opinions on Accelerating the Construction of a Unified National Power Market System*, which proposed to construct the market mechanism adapted to the New Power System, improve market adaptability to a high share of renewables, and optimize power supply and demand within a large geographic range. It stated that a unified national power market system would be established by 2030 to meet the requirements of the New Power System with new energy sources fully participating in market-based transactions.[9]

However, as stated in *Guiding Opinions on Accelerating the Construction of a Unified National Power Market System*, the current power market still faces several practical problems and challenges. The current provincial power market structure and the market barriers of interprovincial transactions are not conducive to large-scale power flow and flexible power consumption. The M2L market, based on monthly and annual transactions, does not recognize the value of generators' flexibility and thus lacks the ability to incentivize investments in these generators. And the energy-based pricing mechanism cannot fully capture the value of key power generators that fulfill the peak demand. Finding solutions for these existing challenges would bring tremendous momentum to the development of zero-carbon power.

This report builds on *Zero-Carbon Electricity Growth* findings and aligns with the national target to establish a unified national power market system by 2030. The report analyzes the existing problems and future challenges, and discusses how to practically develop and optimize the power market in the 2020s by analyzing global practices and evaluating domestic conditions, aiming at better establishing a power pricing mechanism that is aligned with China's national conditions and is more conducive to zero-carbon electricity growth.

The key steps toward the New Power System are to continue zero-carbon power capacity expansion and to promote zero-carbon power consumption while ensuring reliable and economic power supply. Therefore, the following three sections discuss the corresponding pricing mechanisms that:

- Promote sustainable zero-carbon power capacity expansion
- Maximize the consumption of zero-carbon electricity
- Ensure system adequacy under zero-carbon electricity growth

We hope our analysis and recommendations can aid in developing the New Power System and the unified national power market system, and promoting zero-carbon power growth in the 2020s. We anticipate the report findings could better propel economy-wide climate actions in China and provide insights and lessons to the rest of the world.

Pricing Mechanism for Sustainable Zero-Carbon Power Capacity Expansion — Multiyear Contract as the Core Option

Globally, the cost of zero-carbon power continues to fall. The data shows that the LCOE for solar PV and onshore wind have fallen by 85% and 56%, respectively, over the past decade.[10] A key reason for the rapid declining cost is the economies of scale induced by the rapid expansion of installed capacity. According to BloombergNEF (BNEF), the LCOE of solar PV and onshore wind in China will continue to fall by about one-third over the next decade.[11] However, the downward trend will happen only if zero-carbon power installations continue to expand rapidly at the expected rate. Therefore, promoting the sustainable development of zero-carbon power capacity would be the key to maintaining this cost-reduction trend in the future.

New challenges in sustainable zero-carbon power capacity expansion

Renewable energy generation technologies in the 2020s have become more mature and economical than those in the past decade. At the same time, key renewable players in the market need to take more technical and financial responsibility to support power system operation and development. In *Zero-Carbon Electricity Growth*, we forecasted that by 2030, China's installed solar PV and onshore wind capacity would reach 850 gigawatts (GW) and 800 GW, respectively.[i] However, the following three characteristics of current and future trends in the power industry may bring challenges to achieving the estimated capacity in 2030.

1) **Revenue decline: The phaseout of renewable subsidies.** Renewable grid parity in China started in 2021, marked by the removal of the national subsidy for utility-scale solar PV and onshore wind projects.

Exhibit 1: Renewable Energy Tariff/Price Policy in China

As of 2018

- Onshore wind is categorized into four resource zones to implement wind benchmark price.
- Utility-scale solar is categorized into three resource zones to implement solar benchmark price.
- The gap between wind and solar benchmark prices and coal benchmark price is subsidized by the government, and the part below coal benchmark price should be settled by the grid company.

2019-20

- Onshore wind and utility-scale solar PV benchmark prices are turned to indicative prices.
- Investors would bid for projects with a price ceiling at the indicative price.
- The gap between competitive wind and solar benchmark prices and coal benchmark price is subsidized by the government, and the rest should be settled by the grid company.

Since 2021

- Onshore wind and utility-scale solar implement coal benchmark price without government subsidy.
- Subsidy for existing subsidized projects is capped as 20 years or its equivalent electricity volume.

i According to NEA, the installed solar PV and onshore wind capacity in China was 306 GW and 302 GW, respectively, at the end of 2021.

2) **Rising cost: New renewable projects are required to install or invest in a certain share of energy storage.** Starting in 2021, many provinces required new solar PV and onshore wind projects to install or invest in complementary energy storage systems at the same time. The energy storage system, usually chemical batteries, are generally required to match at least 10% of the renewable nameplate capacity with a duration of two hours or more.

Exhibit 2: **Energy Storage Requirement on Solar PV and Onshore Wind Projects in Selected Provinces**

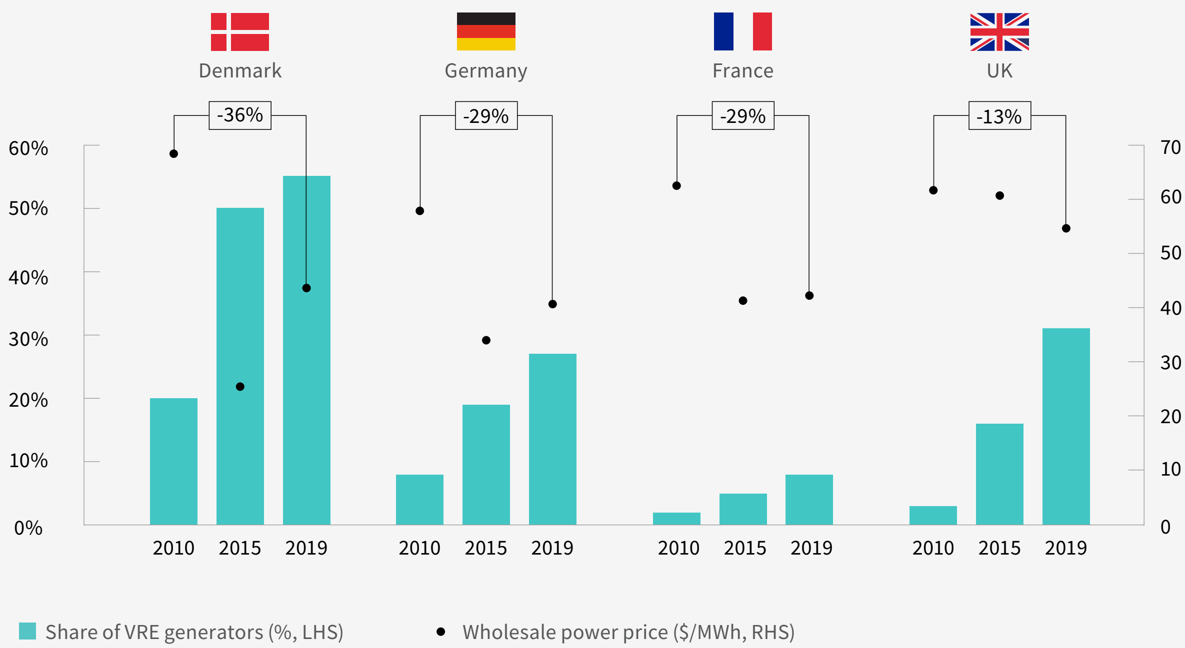
Province	Minimum capacity requirement	Storage duration
Shandong	10%	No less than 2 hours
Gansu	10% for Hexi region, 5% for others	No less than 2 hours
Jiangxi	10%	No less than 1 hours
Qinghai	10%	No less than 2 hours
Inner Mongolia	15%	No less than 2 hours
Shaanxi	20% for solar PV in Yulin, 10% for others	No less than 2 hours

3) **Exposure to market volatility: More renewable power will participate in market transactions as planned power generation gradually phases down.** On October 11, 2021, the NDRC announced that in order to get industrial and commercial (I&C) users to participate in the market, those that use 10 kilovolts or above must enter the market and other users must enter the market as soon as possible.[12] I&C users, representing about 84% of the national power consumption, will purchase power at market prices instead of regulated retail price. As all I&C consumers become deregulated, most of the generation side has to be market-based, and therefore renewable energy's participation in the power market and its exposure to market volatility will be a major trend in the power industry.

In shift to deregulated market, renewable development may be constrained by price uncertainties in short-term market

International power market experiences show that when renewable energy participates in the short-term power market, the increasing share of variable renewable energy (VRE) could reduce the market clearing price. Renewable energy has high investment cost but low marginal operating cost. In merit-order dispatch, the market is cleared by dispatching generators in the order of marginal cost from low to high until power demand is met. The price for a generator with the highest marginal cost among all generators to be dispatched (usually a thermal generator) is the settlement price for all. Due to the low marginal cost of renewable power, it will be prioritized in market clearing, replacing generators with higher marginal costs, thus reducing the settlement price of the market. Real-world evidence in the UK, France, Germany, and Denmark shows that wholesale power market prices fell by 13%–36% during the 2010s with the increasing share of VRE (see Exhibit 3).

Exhibit 3: Wholesale Power Price and Renewable Penetration in Europe



Source: Energy Transitions Commission, **https://www.energy-transitions.org/publications/making-clean-electricity-possible/**

The electricity rates during a power generator's project life cycle are one of the major parameters for measuring the internal rate of return on investment and making investment decisions. With the massive penetration of renewables, the short-term fluctuation of the market clearing price under merit-order dispatch, especially the downward risk of the clearing price, will have a negative impact on renewable investment and restrict the sustainable development of renewable installation.

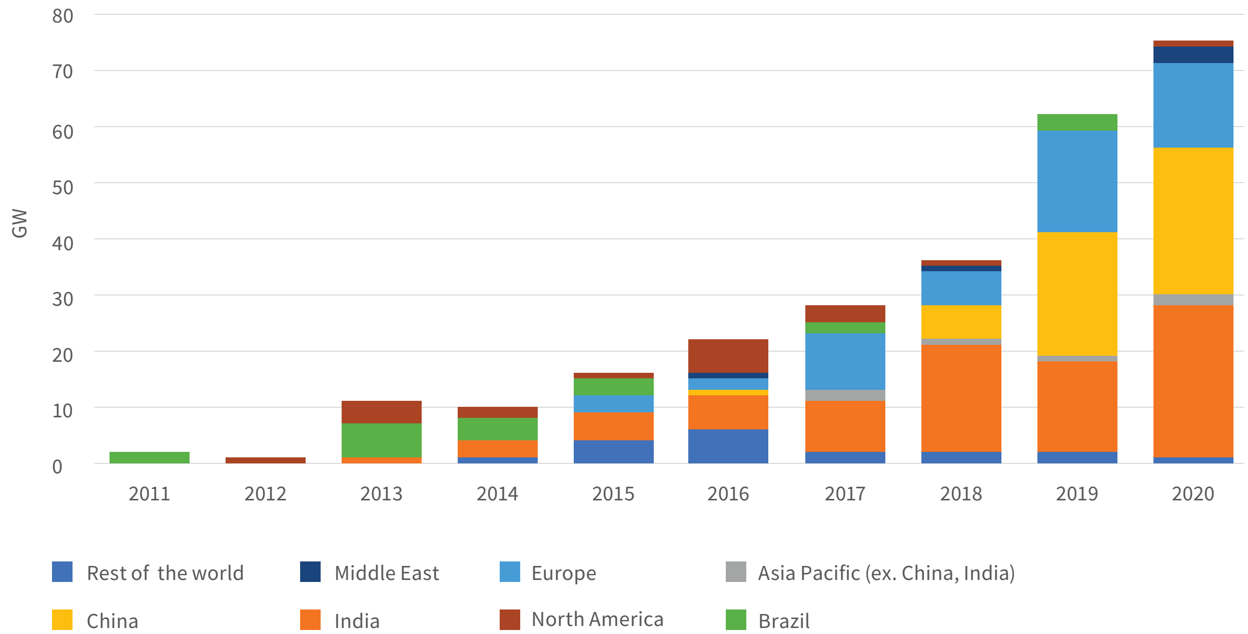
Global practice: Establish long-term (multiyear) contract to hedge renewable investment risks

International practice shows that establishing a long-term contract to ensure the price stability of renewable energy and reducing the short-term market impact on renewable energy revenue could be important solutions for promoting the sustainable development of renewables. In countries and regions with relatively mature power markets, market-driven power contracts with longer periods (e.g., 15–25 years) are playing an increasingly important role in increasing renewables in the power market.

- **Long-term contract by auction or competitive allocation**

Auctions and competitive allocations are important alternatives to feed-in tariff/feed-in premium (FIT/FIP) subsidies. The government or power trade organizers set the total installed capacity of renewable energy in advance, and investors bid for the development rights and get a long-term (e.g., 20-year) power purchase contract at the corresponding price. Many countries in Asia, Europe, and Latin America have used or are using this approach, or its variations, to optimize the allocation of renewable energy. Globally, auctions and competitive allocations are the main modes of market-based development of renewable energy installations, with more than 80 GW of renewable energy installations allocated in 2020 (see Exhibit 4). China, India, and Europe are the largest sources of competitive installations.

Exhibit 4: Renewable Electricity Competitive Auction Capacity by Award Date, 2011–20



Source: IEA, https://www.iea.org/data-and-statistics/charts/renewable-electricity-competitive-auction-capacity-by-award-date-2011-2020

The long-term contracts determined by auction need to be well-linked to the short-term market. In the competitive power market, the electricity under the long-term contract will also participate in the short-term power market and settle with the market clearing price, a price different from that of the long-term contract. **Therefore, bridging the long-term contract with the short-term market is a key issue that the power transaction organizers need to consider.**

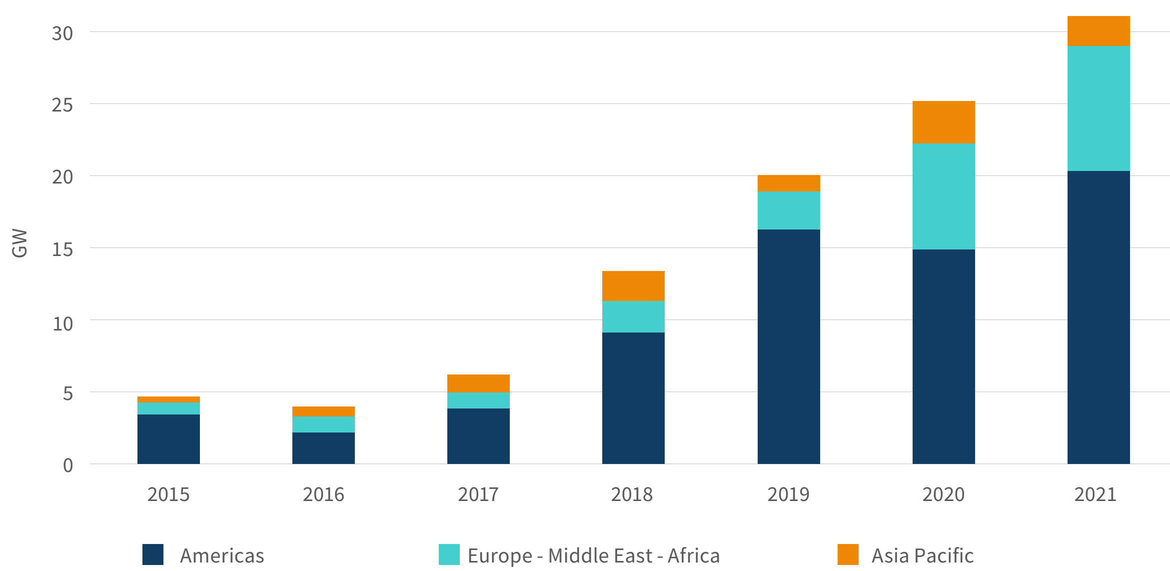
Power market organizers in some countries have outlined plans to link long-term and short-term power markets. For example, the UK adopted contract for difference (CfD) to overcome the problem. In this case, the UK government established the state-owned Low Carbon Contracts Company (LCCC) for this purpose. Investors participate in a centralized renewable energy capacity auction, and the bid winners sign a 15-year long-term CfD contract with the LCCC at the strike price.

In the short-term power market, the renewable energy generators compete with other generators in the market to form the short-term market price. If the short-term market price is lower than the strike price, the LCCC pays the difference to the renewable energy generators. If the short-term market price is higher than the agreed price, the renewable energy generators pay the difference to the LCCC.

- **Power Purchase Agreement (PPA)**

PPA is another renewable energy market development approach, which can be divided into physical PPA and virtual PPA from the perspective of power delivery.[ii] As of February 2022, about 100 GW of renewable installed capacity in the world have been developed through PPA. BNEF data shows that the vast majority of PPA projects come from the Americas (see Exhibit 5), and they are dominated by virtual PPAs. In 2020–21, the United States was the world's largest PPA market, while solar PPA projects in Spain and wind PPA projects in Sweden were rapidly increasing the volume of PPAs in Europe.

Exhibit 5: Corporate PPA Volumes by Region

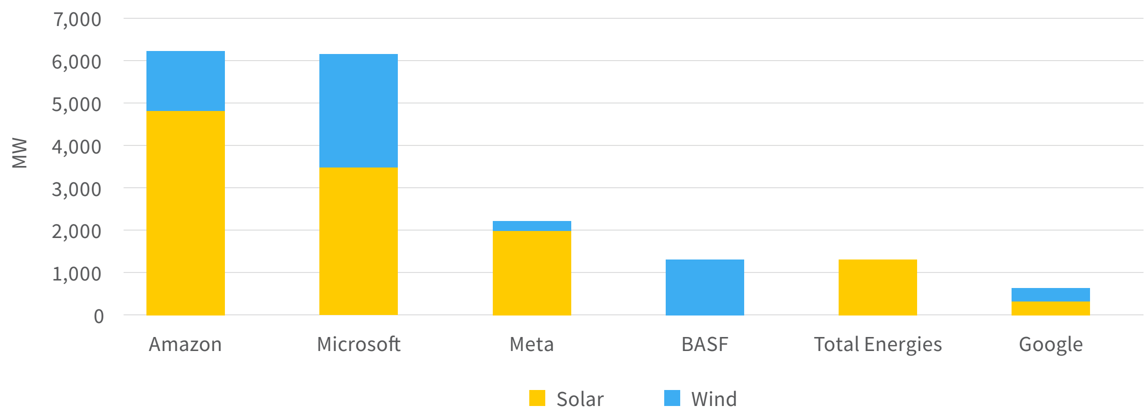


Source: IEA, https://www.iea.org/data-and-statistics/charts/corporate-ppa-volumes-by-region-2015-2020, and BNEF, https://about.bnef.com/blog/corporate-clean-energy-buying-tops-30gw-mark-in-record-year/

PPAs directly connect power users and renewable generators so that consumers' low-carbon requirements and preferences can be directly linked to the suppliers and promote the large-scale development of renewable energy. In international practice, buyers typically sign PPAs with renewable developers for 20 to 25 years to provide long-term stable revenue for renewable projects, thus facilitating the development of the projects and promoting the scaled development of renewable power generation. With increasing attention on the urgency of climate change, more large corporations have set their own carbon-neutral goals and time lines; their low-carbon initiatives become the catalyst for PPAs. Data shows that large corporations are the main buyers of PPAs at present: The volume of PPAs signed by Amazon, Microsoft, Meta, and Google has exceeded one-third of the cumulative total PPAs.

ii Regarding the PPA discussion in the report, we refer to the corporate PPAs contracted by industrial and commercial consumers, and exclude the first-party or third-party PPAs provided to residential users.

Exhibit 6: Top Six PPA Buyers around the World in 2021



Source: BNEF, https://about.bnef.com/blog/corporate-clean-energy-buying-tops-30gw-mark-in-record-year/

Nevertheless, corporations leading renewable developments involves internal limitations and implicit risks. Due to the prolonged characteristic of the agreement, extensive research into the corporation's credit background and paying ability is required. Such requirements limit the players entering the pool because small- and medium-sized corporations may find it difficult to enter the market. In addition, uncertainties in future developments are underlying issues for almost all corporations. Even though the agreements are signed with large corporations that passed the background check, the risk is still inevitable.

Exhibit 7: Comparison Between Long-Term Contracts by Auction and PPA

Role	Long-term contracts by auction or competitive allocation	PPAs
Government	• Government or relevant authorities predetermine annual installed capacity, which requires accurate analysis and target setting. • Nonmarket-led targets may lead to overdevelopment.	• Total capacity is not predefined as consumers are the main drivers for PPA capacity added. • Power users' demand for PPAs is usually below the capacity needed to achieve the renewable development goals.
Renewable power investors	• Participating auction events organized by the government can curtail business development costs. • Sign contracts directly with the government or designated entities rather than power users.	• Renewable power projects need to look for matched power users by themselves or through a third party. • Renewable power projects have more flexibility for price negotiation, as they directly transact with users physically or financially.
Grid/power trading institutions	• Grid operator may be involved early in the planning stage, and grid operation constraints may impact the auction bids.	• Virtual PPAs avoid physical deliveries and make transactions more flexible but require support from a more mature financial environment.
Electricity users	• More friendly to new users in the power market since users aren't directly involved in the auction. • Auction result may affect long-term spot power price, and users may need to bear the corresponding market risks.	• Users are directly involved in multiyear transactions and secure future transaction prices that can mitigate risks of price fluctuation. • Users need to have solid knowledge and experience before entering the power market.

Multiyear contract is key option for ensuring sustainable development of renewable energy under current power market reform in China

Since the second round of power market reform in 2015, China has established M2L market (monthly and annual transactions) as the main market component and created 14 provincial spot market pilots. The multiyear power contracts, however, are still lacking mature mechanism and universal practice.

The global practices of renewable energy entering power market transactions demonstrate that **the multiyear contract is a key option to supplement the short-term power market transaction and promote the sustainable development of renewable energy.** In the specific design of the multiyear contract mechanism in China, we believe that the following three elements should be covered.

- **Continue setting annual capacity target to ensure steady growth of renewables**

The rapid development of China's renewable power generation in the past decade has confirmed the effectiveness of government subsidies and zero-carbon capacity goal settings. As zero-carbon power becomes more and more competitive in the market, solar PV and onshore wind would be able to move forward without government subsidies in this decade. However, the growth in zero-carbon power may not be sustainable if it relies solely on market forces, without government intervention. The continued establishment of binding annual capacity targets and provision of multiyear contracts for renewable energy projects within the planning targets will continue to play an important role in the development of zero-carbon power over the next decade.

China has institutional advantages in setting and completing annual targets: It has mature experience in the forms of target setting and assessment in various economic segments, and the top-down centralized governance system is better than the decentralized system in the context of ensuring the capacity targets are met on time. As the main investors in and holders of renewable energy assets, central state-owned enterprises (SOEs) are the key drivers to making sure the capacity targets are met on time: They will consider not only the economic benefits of the project but also the contribution to the capacity target and social responsibility embedded in the project.

Exhibit 8: Administrative Hierarchy of Renewable Development in China

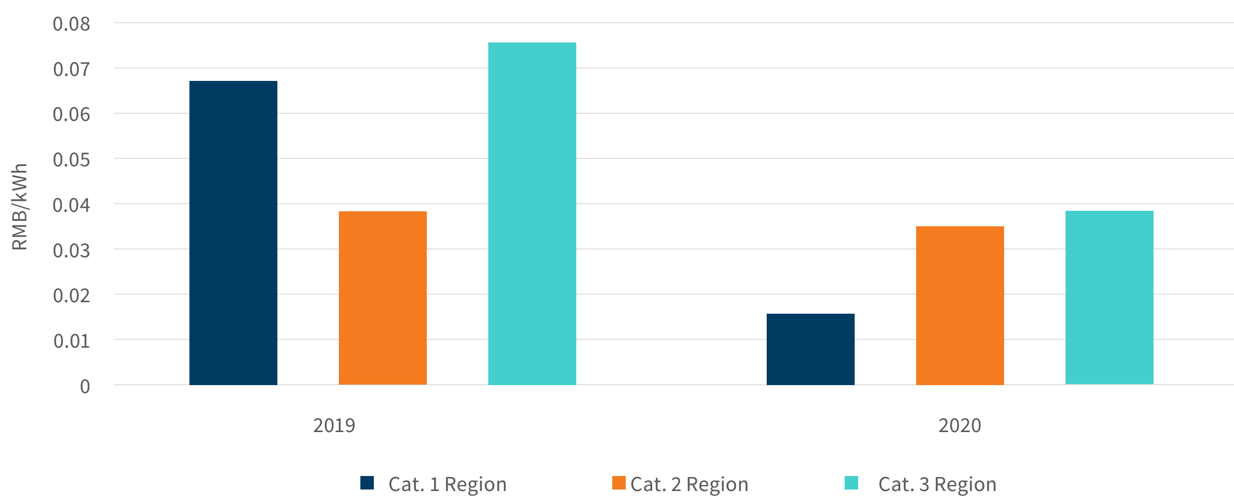
Central Government	• Set high-level energy and climate targets in Five-Year Plans (FYP) and nationally determined contributions.
NDRC and NEA	• Release renewable energy consumption requirement, also known as renewable portfolio standard, for each province on an annual basis, in accordance with FYP and NDC targets. • Release annual minimum capacity added, also known as guaranteed capacity, for solar and wind, based on the renewable portfolio standard requirement.
Local Governing Entity	• Organize competitive allocation for the guaranteed capacity with additional technological requirements. • Encourage additional qualified solar and wind projects.

- **Provide multiyear contracts to renewable investors through auctions**

In 2021, China adopted a price parity policy for electricity generated by solar PV and onshore wind. Many provinces have initiated a competitive allocation mechanism by evaluating factors like project preparation status, supplementary energy storage capacity, local social economic benefit, or strike price. Different provinces place different weights on their selected combination of factors, and project development approval awards those projects with the highest scores in the evaluation system. Projects approved through this competitive allocation process may be the least costly option — but not all the time. Some projects that have lower cost but are behind in other factors may be filtered out through competitive allocation. Therefore, the decision-making under competitive allocation may not be optimized.

In comparison to competitive allocation (which evaluates multiple noncost factors), we believe auction is a better alternative. Auction is a cost-effective approach to sustainable renewable development. In fact, China already made some attempts in renewable auction from 2019 to 2020, aiming at reducing the demand for government subsidies, but returned to FIT in 2021 as subsidies were phased out.[iii] According to the bidding results of solar PV projects in 2019 and 2020 released by the NEA, **auction significantly reduces the subsidy and power price, allowing society to share renewable technology cost reduction because of economies of scale** (see Exhibits 9 and 10).

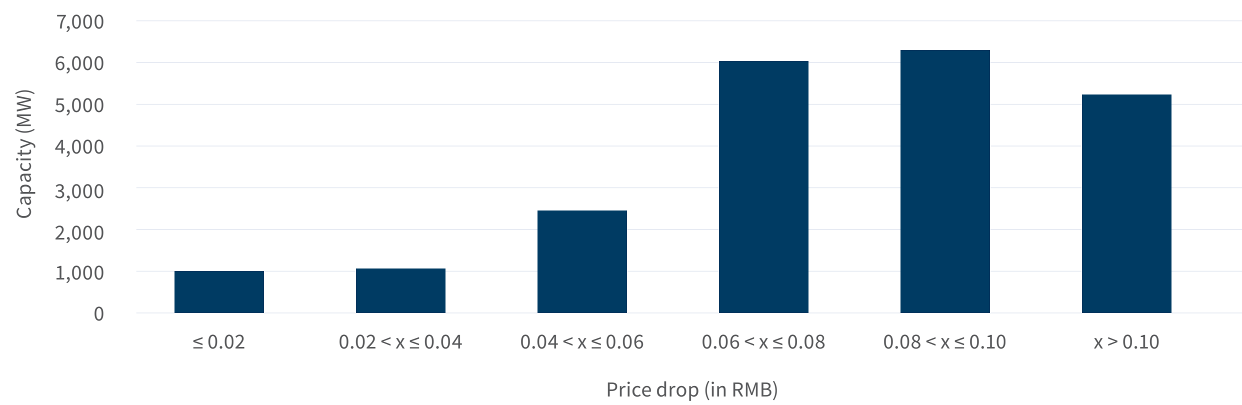
Exhibit 9: 2019-20 Solar PV Projects Auction Summary — Average Governmental Subsidy by Region



Source: NEA, http://www.nea.gov.cn/2019-07/11/c_138217905.htm and http://www.nea.gov.cn/2020-06/28/c_139172962.htm

iii Note that the strike price in the auction was still higher than the coal power benchmark price.

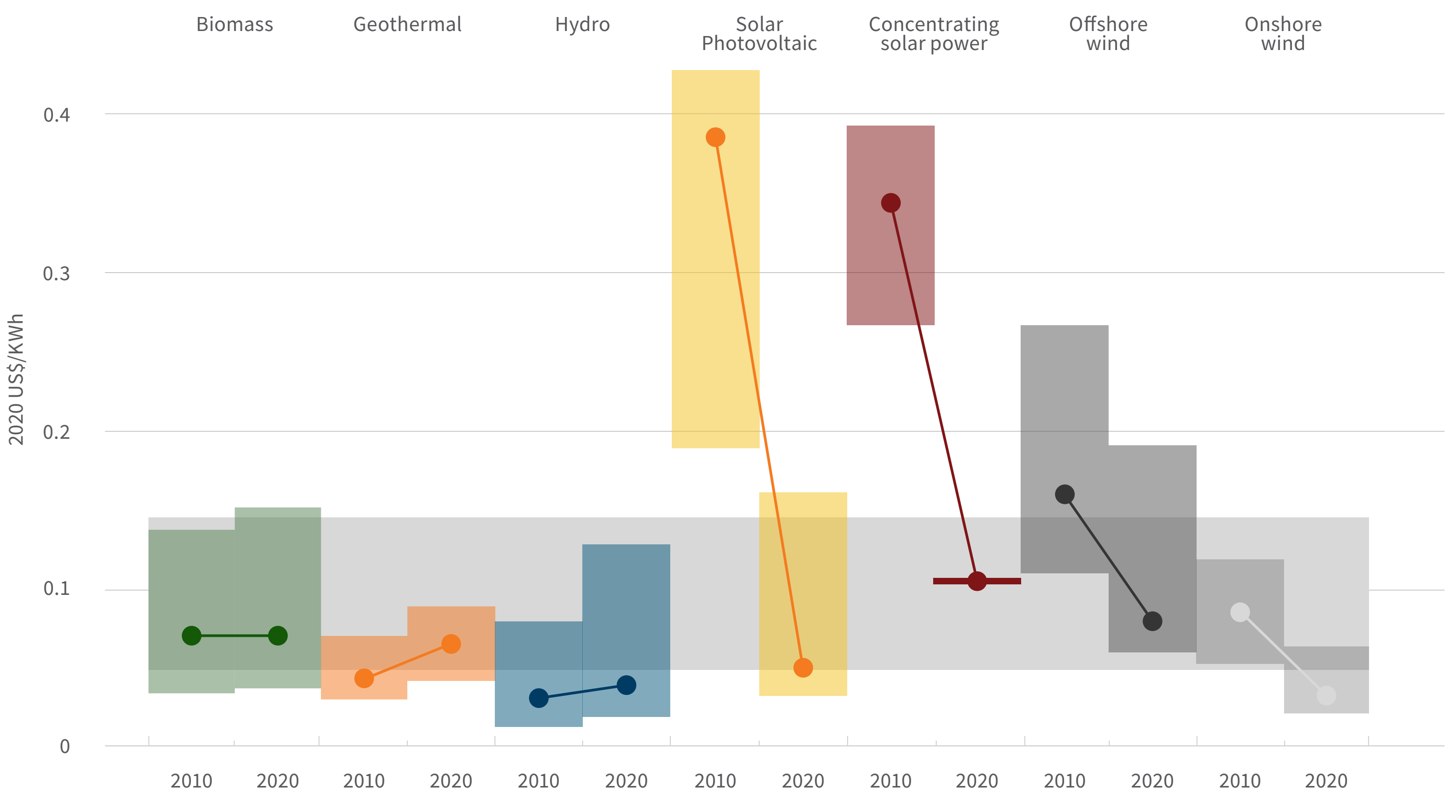
Exhibit 10: 2019 Solar PV Projects Auction Summary — Capacity Distribution by Price Drop Range



Source: NEA, **http://www.nea.gov.cn/2019-07/11/c_138217905.htm**

As for auction design, we recommend **time-based auction, which better reflects the varying value of renewable generation across hours and seasons**. This approach is more important for offshore wind and concentrated solar power (CSP), two critical zero-carbon power technologies yet to be cost-competitive as subsidies are ending (see Exhibit 11).

Exhibit 11: Renewable Power Generation Cost Trends in 2010 and 2020



Source: International Renewable Energy Agency, **https://www.irena.org/publications/2021/Jun/Renewable-Power-Costs-in-2020**

In time-based auctions, zero-carbon power generators can bid according to season and time of day, and the value of zero-carbon power generations during different periods is differentiated. In dry season or nighttime when zero-carbon generation is limited, higher transaction prices will be obtained in the market.[13] Zero-carbon generation technologies such as offshore wind and CSP could fully leverage their complementary advantages in these periods and scale with the help of the market rather than subsidies. The practice of time-based auction has enabled subsidy-free CSP projects in Chile, paving the way for the country's vision of meeting 25% demand with CSP by 2050.[14]

- **Promote PPAs or other direct multiyear contracts between consumers and renewable generators**

In September 2021, under the guidance of the NDRC and the NEA, the Beijing Power Exchange Center and Guangzhou Power Exchange Center prepared the *Green Power Trading Pilot Workplan* and organized the first nationwide green power trade between consumers and renewable generators.[15] **The current green power trading mechanism provides electricity consumers the opportunity to directly promote the sustainable development of zero-carbon power.** Based on domestic practice and experience abroad, we believe that the current green power pilot program and trial implementations can be optimized and improved in the following four ways to make better and more comprehensive use of users' intentions to promote the faster development of zero-carbon electricity.

1. **Make the contract term cover a longer time to ensure the stability of project revenue over a long-time scale.** For the transactions in the 2021 green power pilot, monthly and annual transactions were still the main models adopted by sellers and buyers, with a few multiyear transactions that were nonbinding or without a strike price. Enabling a multiyear contract will lock in a long-term (e.g., 5–25 year) price for renewable investors, thus making the investment more attractive.

2. **Grant renewable projects in development the eligibility to sign PPAs or other multiyear contracts**. Taking Guangdong as an example, only renewable projects in operation are eligible to trade in the green power market. As costs of renewable power projects mainly occur before completion and grid connection, certain trading rules can deter non-SOE investors. Allowing zero-carbon power projects to sign multiyear contracts during project development could increase investment, financing, and construction of zero-carbon power projects by non-state-owned enterprises.

3. **Establish and improve the risk assessment mechanism, default penalty mechanism, and contract transfer mechanism for power buyers to ensure the fulfillment of multiyear contracts**.

4. **Promote direct interprovincial green power trade between suppliers and consumers.** According to the NDRC, the current interprovincial green power transaction is essentially an indirect transaction between power users and zero-carbon power generators via grid companies.[16] However, some power producers have doubts about whether the green premium can be transparently and fully transmitted by grid companies. Therefore, enabling direct interprovincial green power trading between suppliers and consumers will be a plus for the growth of zero-carbon power.

Pricing Mechanism to Maximize Zero-Carbon Electricity Consumption – Optimizing Interprovincial Market and Transmission Tariff

The provincial power grid is the centerpiece in China's power system operation. System planning, load balance, frequency control, and power market design all primarily rely on the provincial grid. With large-scale zero-carbon energy penetration, the spatial mismatch between zero-carbon resources and power load will make interprovincial transmission increasingly important in balancing power supply and demand.

According to estimates by the State Grid Energy Research Institute, transmission capacity and transmission volume are expected to increase from 156 GW and 650 terawatt hours (TWh) in 2020 to 270 GW and 1,500 TWh in 2030, an 73% and 130% increase, respectively.[17] At the same time, as required by the *Action Plan for Carbon Dioxide Peaking Before 2030*, renewable power will be the key driver to accelerate the expansion of the interprovincial transmission network.[18] Therefore, improving and optimizing the interprovincial price mechanism to benefit the consumption of zero-carbon energy will be one of the keys to boost the growth of zero-carbon electricity in the next decade.

Optimizing interprovincial power flow is prerequisite for large-scale zero-carbon electricity consumption

China proposed constructing the New Power System in 2021. Although experts are still debating on its specific characteristics, there is a consensus that utilizing the abundant wind and solar resources in Western China and building a reliable interprovincial transmission network are essential. **The necessity of optimized interprovincial utilization in zero-carbon power consumption is reflected in two ways: connecting the supply and demand in different geographies, and enhancing the power grid tolerance to fluctuating power resources**.

- **Long-distance power transmission: From optional to necessary**

Traditionally, power plant locations were selected based on demand proximity or fossil fuel source proximity. Investors or system planners would make decisions based on the trade-off between power transmission and fossil fuel transportation. In the past, long-distance transmission projects were usually developed alongside a coal production and power base, acting as an alternative to coal transport. In the New Power System, to ensure best utilization of the rich solar, wind, and hydro resources in Western China, electricity must be able to flow effectively a long distance. Long-distance power transmission in the New Power System, however, becomes a necessity rather than a supplement due to the immobile nature of renewable energy resources.

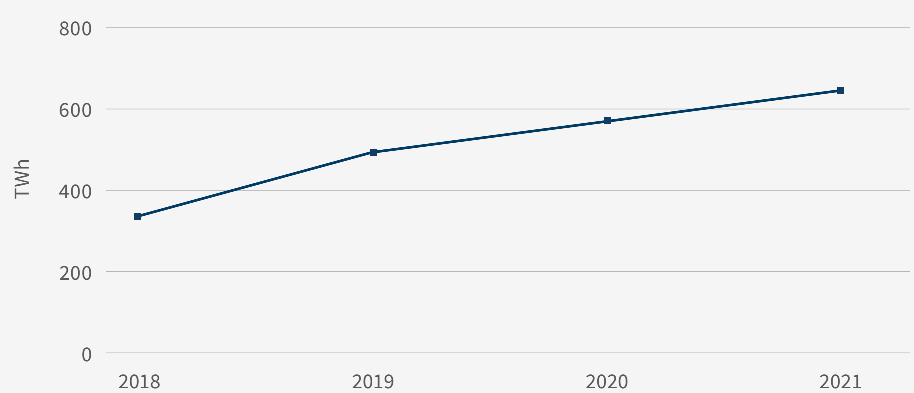
- **Interprovincial power transmission to address volatility and uncertainty**

As wind and solar PV are passive power sources, the system needs to actively address the volatility and uncertainty of their output. Expanding geographic scope of the balancing area can flatten the output curve as renewable resources are heterogeneous across wide geographies. The enlarged balancing area provides a wider buffer zone for grid operation as it would include more generators to mutually act as the backup solution.

Existing practices and challenges of interprovincial trading in China

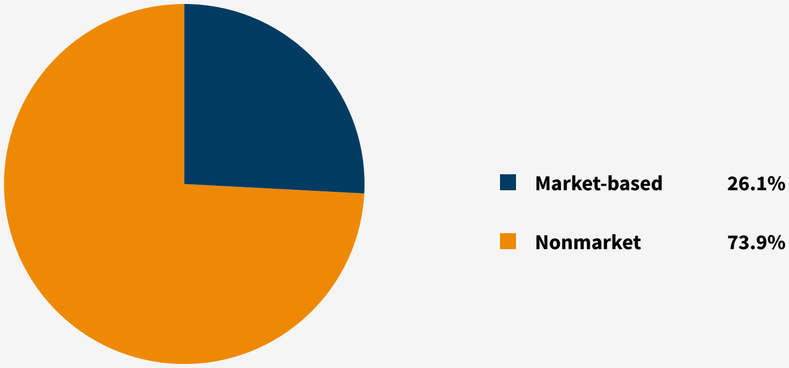
Similar to intraprovincial transactions, interprovincial transactions are also divided into M2L trading and spot trading, with **M2L trading being the more mature and the main component of current interprovincial practices**. The Beijing Power Exchange Center and Guangzhou Power Exchange Center have compiled the interprovincial power trading rules for the State Grid and China Southern Power Grid (CSG) service areas, respectively. The share of market-based transactions in interprovincial power trading is increasing rapidly. Since the implementation of the first version of interprovincial power trading rules in 2018, the volume of market-based interprovincial power transaction has increased by 102% cumulatively as of 2021 (see Exhibit 12). However, **nonmarket and planned transactions are still the majority of interprovincial transactions** (see Exhibit 13).

Exhibit 12: **Interprovincial Electricity Trading Volume**



Source: China Electricity Council, https://cec.org.cn/detail/index.html?3-277103 and https://www.cec.org.cn/detail/index.html?3-306005; BJX News, https://shoudian.bjx.com.cn/html/20190313/968589.shtml

Exhibit 13: Interprovincial Trading Breakdown in China Southern Power Grid (January to September 2021)



Source: BJX News, https://shoudian.bjx.com.cn/html/20211105/1186147.shtml

In terms of spot market, the Beijing Power Exchange Center issued *Trading Rules for Cross-Regional-Grid Interprovincial Spot Market of Surplus Renewable Power (Trial)* in 2017, allowing renewable power that fails to obtain M2L contracts to exercise spot trading.[19] As of 2021, this piloted spot trading has increased the utilization rate of renewables by about 1.1%.[20]

Based on the pilot, the State Grid Corporation of China issued *Trading Rules for Interprovincial Spot Market (Trial)* at the end of 2021. According to the published rules, the interprovincial power spot market will include day-ahead and intraday physical transactions using the remaining transmission capacity after the M2L volumes are settled.[21]

Transmission tariffs have a greater impact on interprovincial power flow compared with intraprovincial transactions. In intraprovincial transactions, power users of the same group and the same voltage pay the same transmission and distribution (T&D) fees based on the Postage Stamp Method,[iv] and the transmission tariff does not affect the market clearing results. However, in interprovincial transactions, due to the use of a higher voltage interprovincial grid, power providers or recipients need to bear additional transmission costs. In an extreme case around 2015, the additional transmission cost reached around 25% of the settlement price at the receiving grid and was a nonnegligible part of interprovincial power transactions.[22]

- **Transmission costs undermine willingness of interprovincial zero-carbon power consumption in some regions**

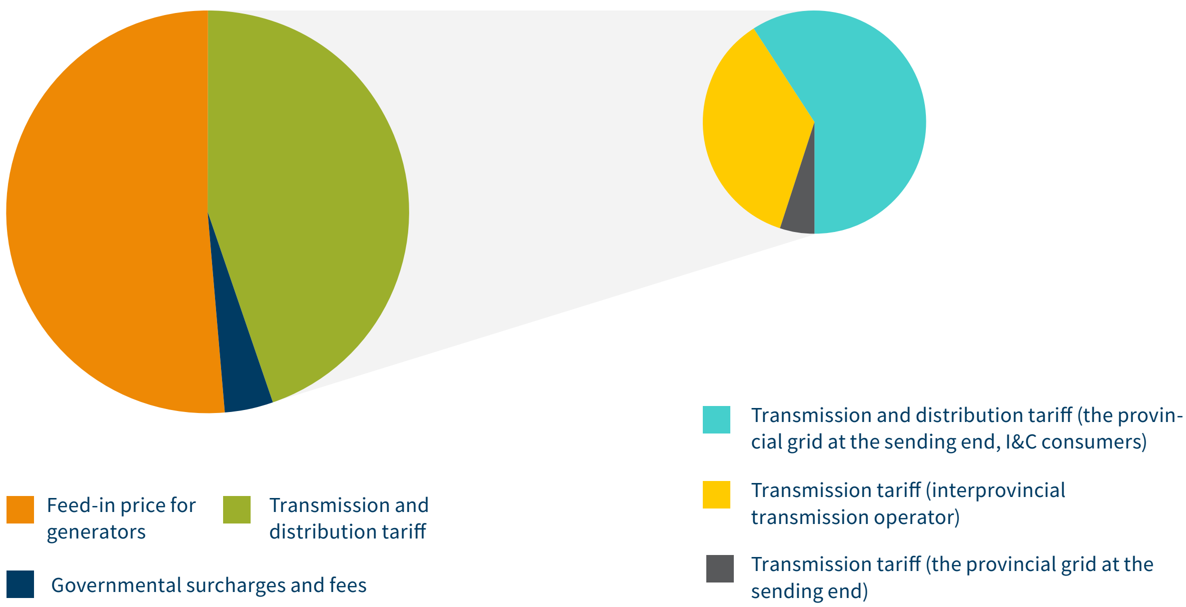
In practice, the current interprovincial transmission costs and the embedded rate pancaking issue are some of the challenges to optimizing zero-carbon energy utilization and achieving smooth flow of zero-carbon electricity within the vast China territory.

Rate pancaking is the stacking of transmission charges for service that uses the transmission lines of different grid owners. For example, according to an announcement by Huaneng Hydropower, for the electricity generated from a hydro generator in Yunnan and transmitted to Guangdong, when the electricity

iv Postage Stamp Method charges fixed per-unit transmission and distribution fees to the consumers within a particular region, regardless of distance and network usage.

arrives at the Guangdong grid, Guangdong grid's payment can be broken into three segments: electricity feed-in price paid to the hydro power company, transmission tariff within Yunnan province paid to the Yunnan grid, and interprovincial transmission tariff paid to the CSG Extra-High-Voltage-Line company.[23] When the Guangdong grid sells the hydroelectricity to end-users, the grid additionally charges the users local transmission and distribution tariffs. Exhibit 14 presents this electricity rate structure.

Exhibit 14: Breakdown of Electricity Price by Beneficiary



- **Ultra-high voltage (UHV) transmission lines are not fully utilized in current trading mode**

With the increasing number of zero-carbon power bases being planned and developed away from load centers, the development of supporting facilities for zero-carbon power transmission has become one of the necessary paths for zero-carbon power consumption. According to the Global Energy Interconnection and the NEA, the utilization rate of some UHV transmission projects is low under the current interprovincial transaction rules, where only limited transactions in selected lines are market-based.[24] For example, the actual maximum use of the Jiuquan-Hunan UHV line and the Jinbei-Jiangsu UHV line are only 4.5 GW and 4.8 GW, respectively, out of the rated transmission capacity of 8 GW.[25] There is still much room for improvement in the utilization of power transmission lines, the interprovincial flow of electricity, and the consumption of renewable energy.

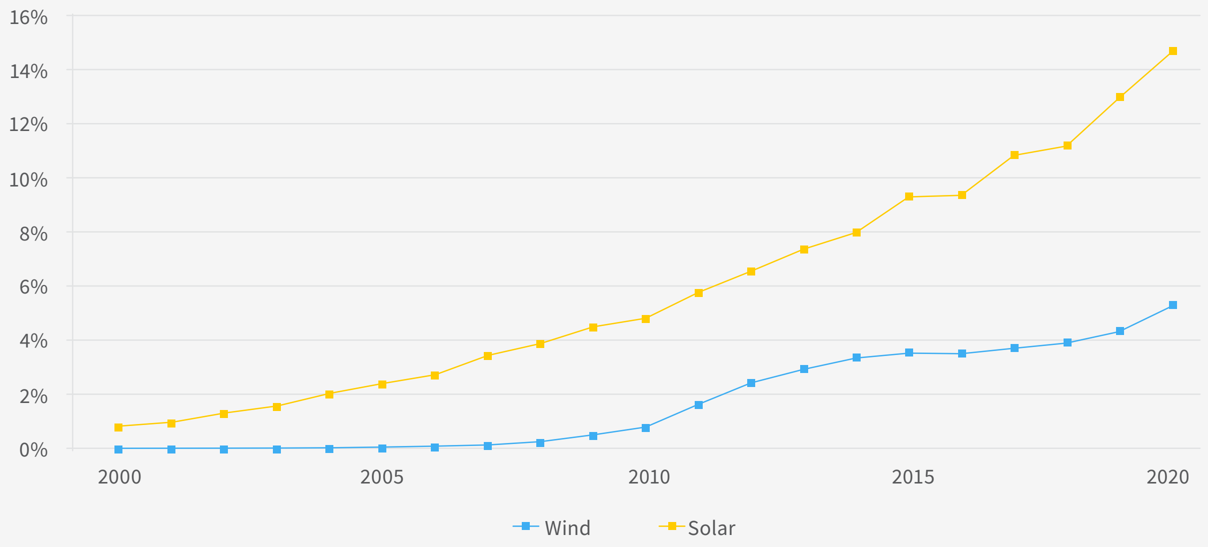
Global practice: Establish interregional power trading market, optimize interregional transmission pricing mechanism

The establishment of an interregional power trading market is a key support to increasing the penetration of renewable energy in many countries or regions around the world. The Single Day-ahead Coupling (SDAC) market and the Single Intraday Coupling (SIDC) market in Europe, as well as the Western Energy Imbalance Market (WEIM) established on the west coast of North America, are examples of interregional market practices.

- **Climate benefit of interregional power market**

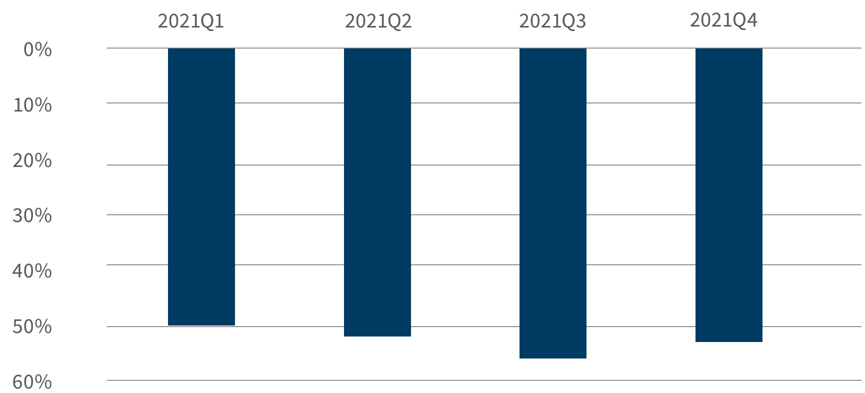
The European power markets and the WEIM have played positive roles in enhancing renewables consumption. The cross-border power markets in Europe allowed EU-27 countries to fulfill about 19.7% of their power demand by wind and solar in 2020, well above the global average of about 9.3% (see Exhibit 15). The economic benefits of the WEIM exceeded $740 million in 2021, reducing CO_2 emissions by nearly 100,000 tons and lowering the flexibility reserve requirement by 50%–60% (see Exhibit 16).

Exhibit 15: **EU-27's Solar PV and Wind Power Share by Generation, 2000-20**



Source: Ember, **https://ember-climate.org/data/data-explorer/**

Exhibit 16: **Average Reduction in Flexibility Reserves across the Footprint (WEIM)**



Source: California Independent System Operator, **https://www.westerneim.com/Pages/About/QuarterlyBenefits.aspx**

- **European practice: Cross-border transmission fees based on congestion revenue**

Since power market reform started in the 1990s, European countries have established a relatively unified power market system. As renewables penetration increased at a rapid rate, the EU accelerated unifying the power market in the 2010s. Most European countries are now part of the SDAC or SIDC market. At the end of 2021, there were 26 countries participating in SDAC and 23 countries participating in SIDC (see Exhibit 17).[26]

Exhibit 17: European SDAC and SIDC Time Line

	2014	2015	2016	2017	2018	2019	2020	2021	
MRC	France, Germany, Spain, Great Britain, and 13 other countries	Italy, Slovenia	Bulgaria, Croatia		Island of Ireland	Greece		Great Britain exited. MRC coupled with 4M MC.	SDAC
4M MC	Czech Republic, Hungary, Romania and Slovakia							4M MC coupled with MRC.	SDAC
SIDC					France, Germany, Spain, Norway, and 11 other countries	Poland, Romania, and 5 other countries		Italy	SIDC

Note: MRC: Multi-Regional Coupling; 4M MC: 4M Market Coupling
Source: entso-e, https://www.entsoe.eu/network_codes/cacm/implementation/sdac/ and https://www.entsoe.eu/network_codes/cacm/implementation/sidc/

Exhibit 18: SDAC Market Coverage

Source: entso-e, https://www.entsoe.eu/network_codes/cacm/implementation/sdac/

According to EU regulations, market members using cross-border transmission interconnectors are not naturally obliged to pay for the interconnectors. The transmission tariff of the interconnectors is preset as zero in order to allow free electricity flow among any regions with price differences.[27] The goal of interregional power trading organizers is to maximize social welfare (the sum of producer surplus, consumer surplus, and congestion rent) and achieve the maximum efficiency of the interregional interconnectors.

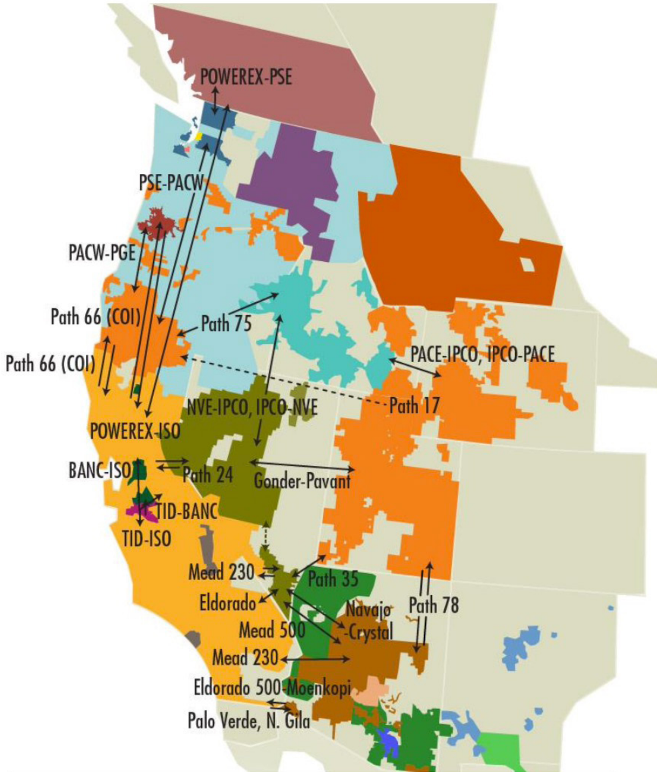
While interconnector owners cannot charge a fixed transmission fee, transmission system operators (TSOs) can recover the cost of cross-border transmission by charging two fees: (1) the inter-TSO compensation (ITC) mechanism to compensate for the additional losses caused by transmission power using the power infrastructure of intermediate countries, and (2) the congestion-related revenues such as the transmission right auction revenues and congestion rents. The congestion revenue is the dominating piece of TSOs' transmission income, with a volume at around 2 to 3 billion euros per year, while ITC mechanism is about one-tenth of the congestion revenue.[28]

Transmission tariff and congestion rent methods both reflect the payment for the use of transmission lines, but their design logic and economic effects are significantly different. Transmission tariff is usually regulated by administrative departments and is determined on the basis of costs and assumptions prior to when transactions are settled. Therefore, the existence of transmission tariff creates a dead band for transactions when the price difference between two regions is smaller than the transmission tariff. On the contrary, in the implicit auction model adopted in Europe, the congestion rent is calculated when the market is cleared, which therefore reflects the reasonable income level of the transmission line at maximized social welfare and enables the maximum flow of electricity among regions.

- **WEIM in North America: Interregional transmission tariff based on principle of reciprocity**

Initiated by the California Independent System Operator (CAISO), the WEIM organizes real-time power exchange among CAISO and surrounding power balancing authority areas (BAAs). Since 2014, 17 members have joined WEIM. By 2023, WEIM expects to have 22 members, covering 79% of electricity consumption.[29]

Exhibit 19: **WEIM Coverage**



Source: CAISO, https://www.westerneim.com/Documents/ISO-EIM-Benefits-Report-Q4-2021.pdf

WEIM organizes real-time power transactions by using the remaining unused interregional transmission capacity, namely the transmission capacity not obtained by any participant, or the excess of obtained transmission capacity donated by any participant.

Market designers believe that participants in the WEIM could be better off both when the electricity is sent or received, and avoiding rate pancaking is necessary for better power flow. In this context, **the Federal Energy Regulatory Commission (FERC) approved WEIM to operate based on the principle of reciprocity, meaning that each consumer only pays local transmission tariff in its own balancing authority area and does not pay additional transmission costs for the interregional transaction.**[30] Therefore, in the WEIM there is no rate pancaking.

Optimize interprovincial market and transmission tariff to activate interregional consumption of zero-carbon electricity

Globally, the development of an interregional power market is closely related to the booming development of renewable energy. Expanding the scope of power flow and trading creates favorable conditions for achieving a higher share of additional renewable power. With the development of renewable energy in the 2010s, Europe and the west coast of North America each launched interregional power markets in 2014 that not only monetized climate benefits but also enhanced the economy and efficiency of the power system.

In China, accelerating the development of an interprovincial power market is also an inevitable choice for the sustainable development of renewable energy in the 2020s. The *Zero-Carbon Electricity Growth* report noted that increasing the flexibility of interactions among provinces could drive more efficient renewable consumption and provide flexible resources for provincial power balancing. China is also accelerating the construction of a UHV transmission network, with 13 lines planned in 2022 alone.[31] The rapid expansion of a UHV transmission network also urgently requires the formation of an interprovincial power market in this decade.

Based on domestic characteristics and international practice, we believe the major efforts in the decade should be to provide more flexible transaction models for buyers and sellers, and to optimize the transmission price models on interprovincial transactions.

- **Enable flexible transactions and expand market-based interprovincial transactions**

In view of the existing interprovincial power transactions, which are usually monthly or annual and with nonmarket features, we believe that the pace of market construction should be accelerated incrementally via the following three steps:

1. Continue to expand the share of market-based transactions and reduce the share of planned transaction.
2. Promote the practice of interprovincial direct transactions between renewable generators and electricity consumers, and replace the current grid-to-grid interprovincial transaction model.
3. Expand the scale of the interprovincial spot trading market to promote the real-time consumption of renewables.

- **Optimize transmission pricing mechanism to alleviate interprovincial trade barriers for renewables**

The dead band in market clearance and rate-pancaking issues will affect power flow and lead to low utilization level of transmission lines. Based on existing national and international practices, we believe that transmission price optimization should follow four basic principles:

1. **Practical**: The method should be based on the current state of the Chinese power industry.
2. **Enhancing welfare**: The total social welfare should be enhanced in price optimization.
3. **Optimizing power flow:** More sufficient and flexible power flow and renewable flow should be achieved.
4. **Fair allocation**: The transmission cost should be allocated among participants fairly and transparently.

Based on these principles and the goal of promoting interregional renewable consumption, we identified the following five possible approaches to optimize the interprovincial transmission price mechanism. The advantages and constraints of each approach are described in Exhibit 20.

Exhibit 20: Pros and Cons of Approaches to Interprovincial Transmission Tariff Optimization

	Approach	Pros	Cons
1	Grant grid companies the discretion to adjust (lower) transmission fees.	• Government supervision and grid companies' decision-making are both relatively simple. • The government supervision process could remain unchanged. • The power grid companies have sufficient interprovincial supply and demand information and are able to determine the optimal pricing strategy.	• This approach can only optimize interprovincial transmission line transactions where price elasticity is high and utilization rate is low. • The social welfare is not optimized.
2	For transmission lines dominated by renewables, adopt nationwide or region-wide surcharges or fees to recover the cost and reduce transmission tariff.	• The approach can effectively reduce the per-kWh transmission price and narrow the price dead band of interregional power transactions.	• There are already some problems in the existing surcharge system on renewable development subsidies. • The approach requires additional efforts on rule design, project approval, and accounting. • Cash flow may also be slowed down as an extra stakeholder, the government, participates in the process.
3	Continue using the Postage Stamp Method to calculate transmission tariff but expand the geographical boundary from provincial to regional or national.	• The approach employs the same methodology as the existing transmission tariff accounting method, hence has a lower learning cost for regulators. • The approach also favors the design of a national unified power market.	• There might be resistance from local stakeholders as some provincial grids may receive less transmission income as the boundary expands. • Since the transmission tariff is cost-based, there is a possibility of excessive investment and overexpansion in transmission lines.
4	Exercise price coupling among provincial markets, adopt implicit auction method, and grant congestion revenues to grid companies.	• The approach can give the optimized market clearing results that maximizes social welfare. • No transmission charges are preset so buyers and sellers could trade without a dead band. • Provincial and interprovincial markets are integrated, and participants do not need to bid in a separate market. • Transmission prices are still settled within provincial grid boundaries, allowing price differences between provinces to continue to exist.	• This approach requires the exchange centers to process a large amount of transaction data, and all the exchange centers need to have sufficient computing capacity to complete large-scale integrated clearing. • Congestion revenue is negatively correlated with transmission line capacity, which requires additional supervision to guide grid investment and avoid transmission deficit.
5	When the share of spot or real-time transaction is low, adopt a zero transmission fee for real-time transactions made through residual interprovincial capacity.	• This approach makes full use of the remaining capacity, improves the utilization rate of existing lines, and eliminates the dead band between buyers and sellers. • The transaction operation is simpler compared with the price coupling and congestion rent approach.	• It applies only to a small fraction of transactions based on the residual transmission capacity. • It could only achieve local rather than global optimization. • Grid companies are not better off in this approach.

Considering the real-world situation and the power market reform process, we believe that differentiated optimization strategies could be adopted in the near term (before 2025) and in the long term (around 2030).

In the near term, as provincial and interprovincial power markets are still under construction and are not mature, transmission price optimization efforts could focus more on approaches with fewer requirements on market maturity and lower implementation difficulty. Approaches 1 and 5 are better fits for the near term. Considering the M2L market would be the main battlefield and the spot market would serve as a supplement, **our recommendation would favor Approach 1 in the M2L market and favor Approach 5 in the spot market.** However, both approaches can only serve as an interim option as they are not sustainable for all stakeholders.

In the long term, with the construction of the New Power System and the national unified power market system, the trend for transmission price is to form a unified scheme at the national level. Approaches 3 and 4 align more with this development trend. **We would favor Approach 4 when the power market is more mature and favor Approach 3 when it is less mature.** In approaches 3 and 4, the grid companies' tendency to over-invest (Approach 3) and under-invest (Approach 4) in transmission facilities require strong supervision from the government.

Pricing Mechanism to Ensure System Adequacy Under Zero-Carbon Electricity Growth — a Choice Between Capacity Pricing and Scarcity Pricing

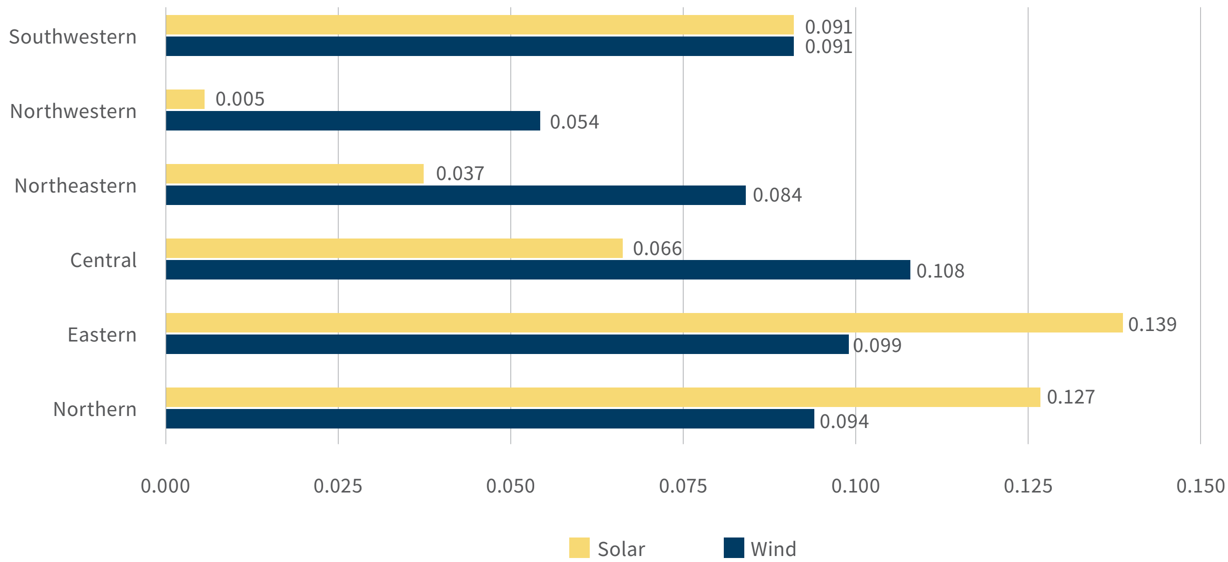
The basic logic of power system operation is to balance supply and demand in all time scales. Therefore, capacity planning should be based on the peak load rather than average electricity consumption. System adequacy depicts the ability of the system's aggregated power capacity meeting the system's peak load. The rapid expansion of zero-carbon power and power demand growth in the next decade raise the uncertainties in supply-demand balance, and therefore policymakers need to pay more attention to system adequacy.

System adequacy risks are emerging in some places in China

Power shortage has already emerged in some provinces and regions in 2021: In May, Guangdong province implemented a rolling power consumption limitation policy through which certain industrial users in certain regions could operate only four days a week to cope with the short-term power supply shortage.[32] As zero-carbon electricity continues to expand over the next decade, the following three features of zero-carbon electricity may lead to local system adequacy challenges.

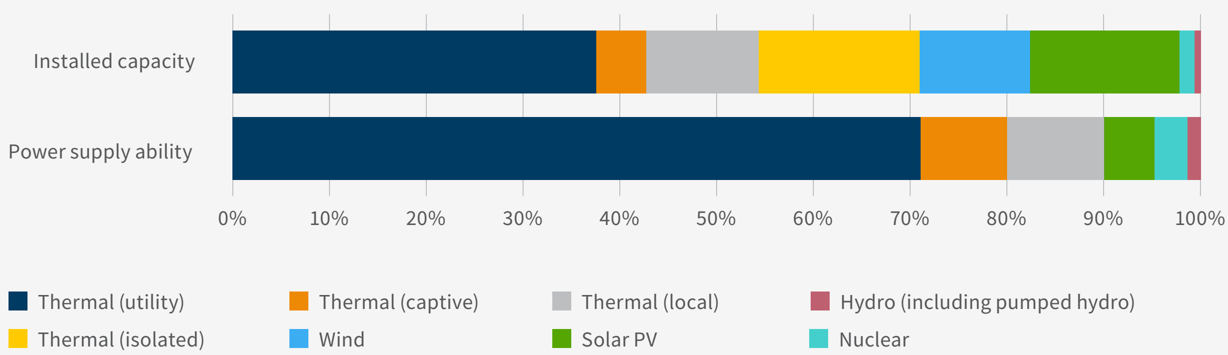
- **The relationship between installed capacity and power supply ability is shifting from deterministic to probabilistic.** Traditionally, a thermal generator's nameplate capacity represents its ability to feed power into the grid. However, the nameplate capacity of a solar or wind project only labels its nondispatchable maximum output. The State Grid Energy Research Institute examined the capacity credits of solar PV and wind by regional grid in China (see Exhibit 21). The result shows the average capacity credit was only about 0.1. An extreme case was seen in Shandong: The capacity credit for wind was evaluated as zero during the summer peak season, indicating wind power cannot provide reliable power supply during the period (see Exhibit 22). The probabilistic feature between nameplate capacity and power supply ability brings more complexity to system adequacy issues.

Exhibit 21: Capacity Credits in the State Grid Service Area by Regional Grid



Source: State Grid Energy Research Institute

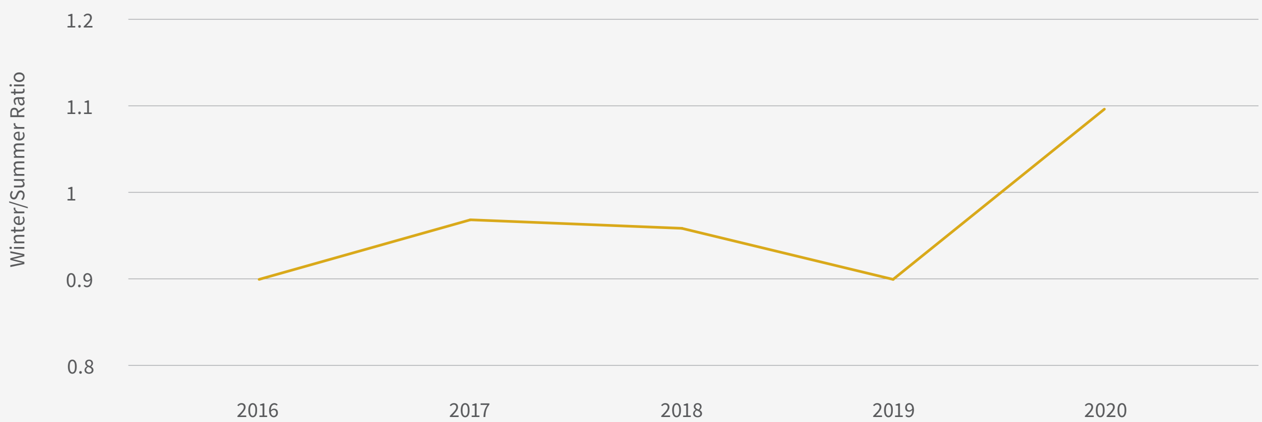
Exhibit 22: Comparison Between Capacity and Power Supply Ability in Shandong



Source: Shandong Energy Administration, http://nyj.shandong.gov.cn/module/download/downfile.jsp?classid=0&filename=4514bcc56de84eab8b63338ed699c4ff.pdf

- **From single peak load in summer to dual peak load in summer and winter.** Summer is usually the peak season for electricity use and experiences the annual maximum load. However, as electric heating expands its penetration in China, the wintertime peak load is approaching the summer peak and will exceed it in this decade. State Grid revealed that the winter of 2020–21 marked the first-ever winter in history with a higher peak load than the preceding summer (see Exhibit 23). As solar, wind, and hydro power all have seasonal fluctuations, addressing system adequacy issues with peaks in both summer and winter will be more complicated than in a single peak scenario.

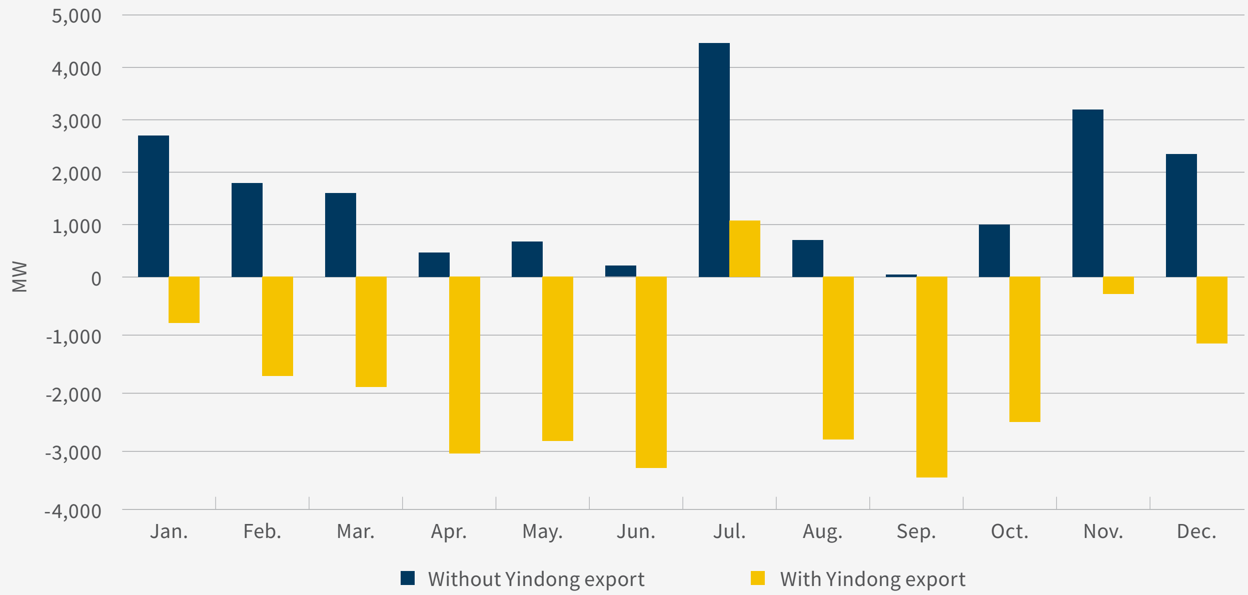
Exhibit 23: State Grid Service Area Winter-to-Summer Ratio of Seasonal Peak Load



Source: State Grid Energy Research Institute

- **Interprovincial power contract leads to power shortage in the power-supplying province.** System adequacy reflects whether or not the installed generation capacity has the ability to fulfill the peak load. In China, since the provincial grid is the primary entity for supply-demand balance, system adequacy is usually evaluated by province by comparing the local installed capacity and demand. But there are exceptions: Some power plants in Western China do not feed power into the local grid but directly send power to provinces in Eastern China via UHV lines based on interprovincial contracts. Therefore, a province with ample power supply may experience power system adequacy issues forced by inflexible interprovincial trade. Exhibit 24 explains how the Yindong UHV-DC line will affect system adequacy in Ningxia.

Exhibit 24: **Monthly System Adequacy in Ningxia**



Note: Positive values indicate surplus and negative values indicate shortage.

Source: BJX News, **https://shoudian.bjx.com.cn/html/20210511/1151832.shtml**

Existing practices and potential challenges in ensuring system adequacy

In the past 20 years, China mainly relied on planning and administrative measures to ensure system adequacy. The recent paradigm was that the provincial government granted approvals to local fossil power projects while the NEA provided guidelines to local authorities with a traffic-light warning system. This administrative solution to system adequacy was comanaged and interacted by both national and local authorities. The national-level administration evaluated system adequacy of each province, supervised potential overcapacity problems, and prevented excessive investment through warning mechanism. The local-level administration guided sufficient power plant investment through project approval to ensure system adequacy.

With the ongoing power market reform and the zero-carbon power expansion, market competition and reduced capacity factor will force marginal conventional generators to retire and limit future fossil fuel generator investment, leading to potential system adequacy issues. The common reason is that the current pricing mechanism based on M2L and spot market does not realize the capacity value. **Establishing a pricing mechanism that reflects true capacity value will be the solution to the system adequacy challenge in the zero-carbon electricity growth scenario over the next decade.** Using pricing mechanism to replace direct administrative measures also aligns with the direction of power system reform.

Global practice: Scarcity pricing vs. capacity pricing

Scarcity pricing and capacity pricing are the mainstream practices to secure system adequacy.

Scarcity pricing is based on an energy-only market and is represented by the Electric Reliability Council of Texas (ERCOT) in the United States and the National Electricity Market (NEM) in Australia. Under the scarcity pricing mechanism, market clearing price will go above the marginal cost during the peak load periods. Marginal generators can utilize scarcity pricing to recover their investment costs, and potential investors can also rely on this price signal to make investment decisions.

The **capacity pricing** mechanism forms an isolated capacity pricing system in addition to the energy pricing. The capacity pricing mechanism is used in Pennsylvania-New Jersey-Maryland Interconnection, New York Independent System Operator, and other regions in the United States, as well as in European and Latin American countries such as the UK, Belgium, Sweden, Finland, and Chile. Capacity pricing can be established through market or administrative measures. Under the market measure, power system operators or administrative authorities usually determine the capacity demand curve in advance, and investors determine the capacity price through auctions. Under the administrative measure, administrative authorities determine the capacity price through cost estimation and pay the price to the project owners or investors.

Exhibit 25 below summarizes the pros and cons of scarcity and capacity pricing.

Exhibit 25: Pro and Cons of Scarcity Pricing and Capacity Pricing

Approach	Pros	Cons
Scarcity pricing	• Scarcity pricing is most economically efficient theoretically. • Power consumers are more familiar with the scarcity pricing design as it remains as an energy-only market and follows the pay-per-kWh rule. • Customers pay less under the scarcity pricing mechanism when the supply is sufficient, typically during nonpeak hours.	• The scarcity pricing mechanism can result in extremely high short-term prices, causing negative socioeconomic impacts (e.g., high bills for some residential customers and bankruptcies of power retailers). • Grid authorities need to pay extra attention to potential monopolies in the market as supply-side monopolies can affect market prices with market power. • The uncertainty of scarcity pricing brings difficulties to capacity investment decisions because cash flow and price spikes under scarcity pricing are difficult to predict.
Capacity pricing	• The capacity pricing mechanism can effectively prevent blackouts as it directly plans total power generation capacity in advance. • Capacity pricing brings a higher level of certainty of return that encourages investment decisions. • The capacity pricing mechanism can reduce volatility of the power market, avoiding price spikes and high power bills.	• The capacity pricing mechanism may cause excess capacity investment and unnecessary capacity installations. • The capacity pricing mechanism is typically designed for the supply side and may weaken the demand-side motivations to participate in system balancing.

Capacity pricing mechanism is better fit for China

We believe that a more guaranteed and lower-risk pricing mechanism will be a favorable choice for China to address system adequacy in the zero-carbon electricity growth scenario over the next decade. Therefore, the capacity pricing mechanism, rather than the scarcity pricing mechanism, is the preferred choice due to the following key factors:

- **Maturity of the power market.** China's power market is still in its early stage, with the M2L market being the main component. The spot market is still far from mature operation. As the scarcity pricing mechanism is entirely based on spot market signals, China's current power market does not have the basis for applying scarcity pricing in the next decade.

- **Tolerance to price volatility and social impact.** Allowing a wide range of spot price fluctuations is the prerequisite for peak load pricing. The upper-bound spot prices in ERCOT and NEM are US$9,000/MWh and A$13,500/MWh, respectively, both equivalent to more than 100 times the average local power price. Since extreme price rise is often caused by extreme weather such as a heat wave or winter storm, the corresponding price hikes will cause significant negative social impact. Such phenomenon deviates from China's planning philosophy on electricity that it should be affordable to society and demand should be met by guarantee.

- **Power growth rate.** Data shows that the growth rate of Texas' peak load is relatively mild, with a cumulative increase of 32.6% in 2020 compared with 2002, equivalent to an average annual growth of only 1.6%.[33] Slow growth in power load is considered one reason for the success of Texas' scarcity pricing mechanism. Compared with developed countries or regions, China is still in its developing stage, with the peak power load and total power consumption still growing rapidly. It is estimated that China's power consumption in 2030 will increase by nearly 50% compared with that of 2020, and the peak load growth of local provincial networks is likely to be even higher. As a developing economy with rapid power growth, choosing the scarcity pricing mechanism is riskier in terms of avoiding power shortages.

- **Market power.** The peak price is based on the value of loss load rather than the marginal cost of power generation. As electric power is more time sensitive and less elastic compared with other commodities, the demand side is usually the price taker in the market and is therefore vulnerable to market power. China's power generation assets are concentrated in major power generation groups, and the high concentration is more likely to lead to failure of the scarcity pricing mechanism.

Key aspects of designing capacity pricing in 2020s

In the zero-carbon growth scenario, wind and solar power generation will account for about 28% of China's total power generation by 2030. Global experience has proved that the capacity pricing mechanism can effectively guarantee system adequacy in power systems with a certain share of renewable penetration. Considering China's specific national conditions and its power market development progress, the following aspects should be considered in the design of a power pricing mechanism:

- ***Capacity pricing measure: Administrative or market-based***
  Administrative pricing is a better fit than market pricing in the zero-carbon electricity growth scenario over the next decade. Market pricing is more efficient, but it requires a well-established power market. Considering the power market is still under development and the spot power market is still in its early stage, market pricing may not be the best fit for now. Given that the system adequacy problem has emerged locally while power market development is yet to mature, the administrative capacity pricing mechanism could be easier and more realistic to implement. Market-based solutions could replace administrative pricing in a later phase as the power market becomes more mature.

- ***Capacity pricing's beneficiaries***
  In theory, all technologies that can supply power have capacity value to enter the trading pool. We believe capacity pricing should be nondiscriminating regarding technology types but also be focused on the technologies' ability to output power.

  Dispatchable power sources tend to gain more than nondispatchable power sources. Dispatchable technologies, like coal, natural gas, nuclear, and biomass generators, are most valuable to the system and are the most profitable suppliers as their output ability typically matches their nameplate capacity with great dispatching potential. Hydropower and solar thermal, with some dispatching ability, are also valuable to the system and can be profitable technologies to a certain extent. However, passive generation technologies like wind turbines and solar PVs could only obtain limited to no benefit from capacity pricing due to their low capacity value: In Sweden, Denmark, Germany, and Belgium, wind turbines are not eligible to receive capacity payments. Beyond generation technologies, energy storage technologies that provide capacity services should also be included in the capacity pricing system.

- ***The spatial scale of capacity pricing***
  In China, both power system operation and economic activity are based on the provincial level. Therefore, the provincial level naturally becomes the best geographical scale for capacity pricing mechanism design, hence **establishing that capacity pricing mechanism at the provincial level should be the first choice.**

  However, in regions such as the China Southern Power Grid, Beijing-Tianjin-Hebei region, and Yangtze River Delta (Jiangsu, Zhejiang, Shanghai, or East China Power Grid) **where the network structure and transaction relationship are closely linked, the establishment of a unified regional capacity pricing mechanism could be prioritized.**

  With the large-scale application of long-distance transmission technology, some generators are not connected to their local power grids but to the load centers via UHV. In this case, it is the grid connections rather than geographical locations that determine the capacity payments.

  Exhibit 26 below summarizes the supply-demand conditions by regional grid. Provinces with higher system adequacy risks, for example provinces in Southern China and Central China, should be prioritized in formulating capacity pricing.[34]

Exhibit 26: Supply-Demand Conditions by Regional Grid in 2020

Regional	Supply-demand conditions
Northern	Balanced in general
Northeastern	Supply in surplus
Eastern	Balanced in general
Central	Some supply deficit
Northwestern	Balanced in general, with some surplus
Southwestern	Balanced in general
Southern	Balanced in general, with some supply deficit in selected places and time durations

- ***Temporal scale of system adequacy evaluation***
  In the traditional power system, the key period for evaluating system adequacy is usually from afternoon to evening in the summertime when the air-conditioning load approaches the peak. In the zero-carbon electricity growth scenario, due to changes in power mix and consumption structure, the following three key factors should be considered for evaluating system adequacy:

1) **Seasonal peaks rather than single peak**
   From afternoon to evening in the summertime: Similar to the traditional situation, the peak space cooling demand will lead to pressures on system adequacy. However, the increase of solar PV installations may delay the peak of net load to around sunset and result in more severe challenges to balance supply and demand during this period.

   From late afternoon to night in the wintertime: With the application of electric space heating, especially its adoption in southern China, the power demand for space heating in winter is growing rapidly. The space heating power demand as a factor drove the wintertime peak load within the State Grid service area to surpass the summertime one for the first time in 2020. Meanwhile, renewables like hydro and wind also have significant seasonal patterns among seasons: Hydropower output is limited, and hydro generators are less available in winter; wind power in winter is usually better than in summer, and wind generators are more available in winter. Based on the practices of New York Independent System Operator and ISO New England, the period from late afternoon to night in wintertime shall be prioritized when the maximum load is most likely to occur.

2) **Annual variation of renewable resources**
   Hydropower is a dispatchable power source within days, but its operation is constrained by seasonal patterns and annual variation. The annual variation of the wet season, in terms of both time and water flow, will contribute to the local system adequacy challenge. Since hydropower usually provides baseload in wet season, the power supply may be in trouble if the wet season arrives late. Provinces with a high share of hydropower need to formulate system adequacy plans for years with unconventional wet season times.

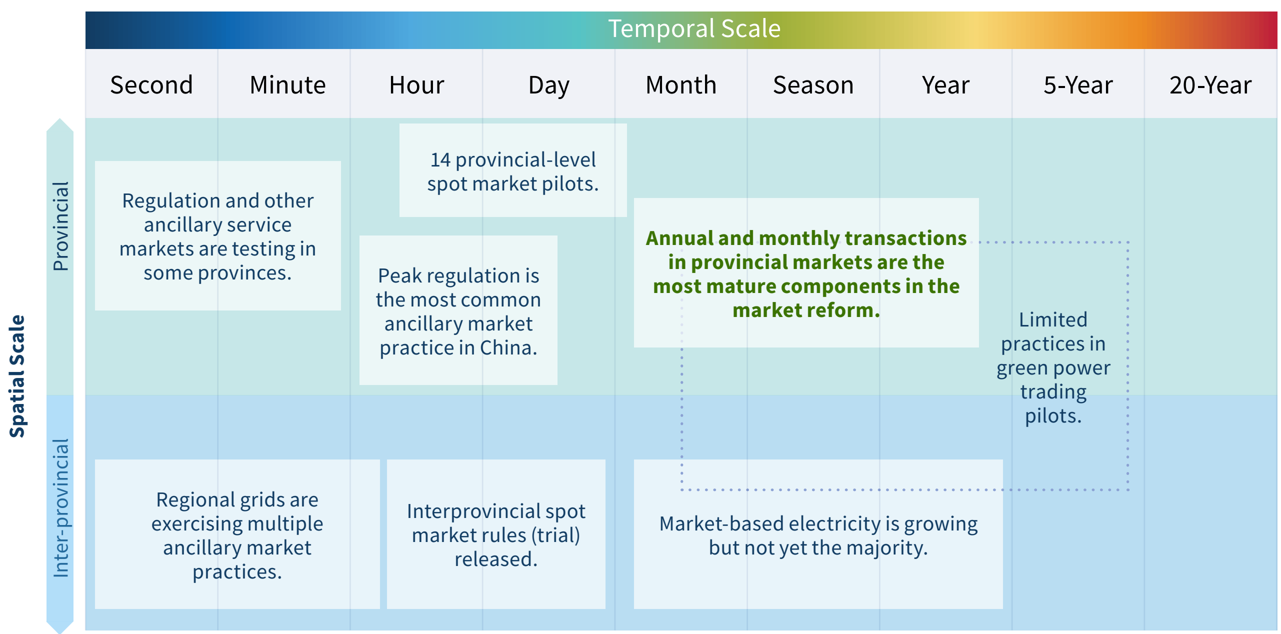
3) **Extreme weather events with low occurrence but high risk**
   In the context of climate change, the frequency and intensity of extreme weather events (such as heat waves, heavy rainfall, and drought) have significantly increased. In the next 10 to 30 years, we may face conditions that go beyond the extremes of historical weather records. In the evaluation of system adequacy, it is necessary to strengthen the assessment of climate change and extreme weather events to make the power system adequacy more climate resilient.

Outlook and Recommendations

Unlike other commodities, the power system needs to, under many physical constraints, achieve the balance of supply and demand at different time scales ranging from subsecond to decades and achieve the balance from local level to national level.

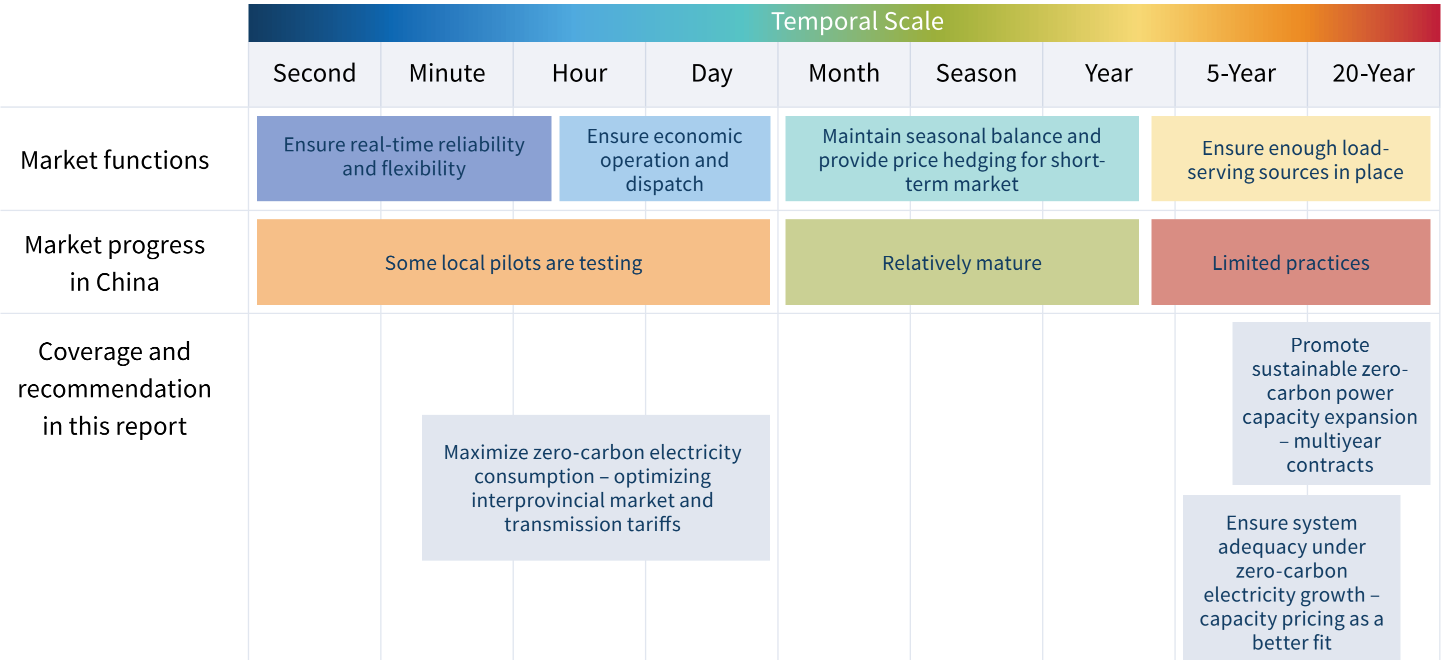
Exhibit 27 outlines the current power market practices in China. The provincial level mid- to long-term (annual and monthly) markets are relatively mature and the major segments of the power market. Provincial spot trading and regional grid ancillary service markets have also carried out many practices. Interprovincial direct power transactions and multiple types of paid ancillary services in provincial grids are still in the early stages of development.

Exhibit 27: Power Market Development Progress in China by Temporal and Spatial Scale



On the way toward the New Power System, the power industry's conventional "one mechanism fits all" pricing model will not fit in the new system due to the varying abilities and functions of different types of power generators. The refined market organization and pricing mechanism that provide proper trading products for balancing needs at different scales will help to better formulate a reliable, economic, and green power system (see Exhibit 28).

Exhibit 28: Power Market Functions and Progress in China by Temporal Scale



The key steps toward the New Power System are to continue zero-carbon power capacity expansion and promote zero-carbon power consumption while ensuring reliable and economic power supply. This report focused on (1) zero-carbon power development, (2) zero-carbon power consumption, and (3) system adequacy in zero-carbon power growth to reveal how market development and power pricing reform can further address the challenges. Exhibit 29 summarizes the key challenges and solutions.

Exhibit 29: Key Challenges and Solutions

Challenges and Purposes	Solutions and Recommendations
Promote sustainable zero-carbon power capacity expansion	**Provide auction-based multiyear contracts to renewable producers**. The government or system planner sets the annual capacity target and organizes auctions for renewable developers. The bid winners then sign multiyear contracts (e.g., 5–25 years) with the government, grid companies, or government-owned hedgers to ensure long-term price stability.
	Promote PPA-like multiyear green power transactions to leverage consumers' engagement. Expand green power market scope and allow an extended contract's duration (e.g., 5–25 years). Allow renewable projects under development to trade and secure their long-term revenue before connecting to grid.
Maximize the consumption of zero-carbon electricity	**Enhance trading flexibilities and promote a higher share of electricity to trade through interprovincial spot market.** Market-based interprovincial transactions are expected to replace planned transactions. Suppliers and consumers, rather than the provincial grids, shall be the major participants. Advance the spot power market development to better address renewable fluctuations and uncertainties.
	Optimize the transmission tariff mechanism to ease interprovincial power trade barriers. An interprovincial transmission tariff can disincentivize renewable power trade as it creates a dead band for power flow. In the long term, setting a unified transmission tariff scheme across the country or leveraging the congestion rent method could be a solution.
Ensure system adequacy under zero-carbon electricity growth	**Capacity pricing is a better fit than scarcity pricing, and capacity payment is the near-term choice**. The power market maturity, the tolerance to price volatility, the power consumption growth rate, and the market power in the supply side collectively determine scarcity pricing is not a fit in China's context. Capacity payment can serve as an interim solution before the power market is well-established.

To better facilitate greenhouse gas emissions reduction and low-carbon power system operation, the three core contents studied in this report, namely multiyear electricity contracts, interprovincial trade and transmission tariff optimization, and capacity pricing for system adequacy, should be the prioritized tasks for power market and pricing mechanism reform in the 2020s.

Although some countries and regions have used power markets for many years, formulating a pro-climate and pro-transition power market paradigm is an ongoing challenge. We hope the findings and recommendations in this report provided valuable ideas and solutions for stakeholders to formulate the national power market, support the New Power System, enable zero-carbon electricity growth, and provide reference for the global zero-carbon power transition.

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