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Review

Electricity Market Reforms for Energy Transition: Lessons from China

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Abstract: In response to the rising importance of the climate agenda, many countries have restructured their electricity markets to facilitate the utilization of renewable energy. China is an interesting case because it has expanded its utilization of wind and solar energy with unmatched speed. This review starts with an analysis of the 2002 reforms that uncoupled electricity production from transmission. The investigation covers the period leading up to the 2022 proposal, which aimed to build a nationally integrated electricity market. The analysis suggests that a careful alignment of incentives for key market players to produce and consume renewable energy is vital during the process of energy transition. The introduction of feed-in tariffs in 2009 for wind energy, which were subsequently extended to solar energy, stimulated a high growth in installed capacity. However, a high electricity curtailment rate resulted. Since 2018, the Chinese government has resorted to curtailment caps and renewable portfolio standards to increase the utilization of renewable electricity. After the announcement of the "dual carbon goals" in 2020, the Chinese government launched a series of reforms that aimed to nurture growth in the green electricity market and the formation of a nationally integrated electricity market. The removal of interregional trade barriers is a key element of China's current electricity market reforms and will be crucial to determining whether China can achieve its climate goals.

Keywords: electricity market; renewable energy; solar PV; wind; China; feed-in tariff; renewable portfolio standard

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1. Introduction

Decarbonization of the energy sector is one of the most important means of achieving climate goals. Facilitating the deployment of renewable energy has become a core element of electricity market reforms. Some developed countries started to encourage the use of renewable energy three decades ago. For instance, the US Congress authorized a production tax credit for certain kinds of renewable electricity in 1992. Likewise, Germany experimented with an early version of the feed-in tariff (FiT) in 1991 and formalized the system in its Renewable Energy Sources Act in 2000 [1]. Under the FiT system, the government guarantees to purchase renewable electricity at fixed tariff rates above the normal electricity price over a long period of time. These support policies primarily aimed to raise the returns on renewable electricity production, which involved higher production costs than coal-fired electricity. More countries moved in this direction in the early twenty-first century. As well as finding engineering solutions to mitigate the inherent supply instability of renewable energy, various measures were designed to incentivize the deployment of renewable energy for electricity generation. New instruments such as renewable portfolio standards (RPS), curtailment caps, and capacity subsidies were adopted to accelerate the energy transition [2–5].

China was comparatively late to the transition to clean energy, though it is a leader amongst developing nations. China's electricity system was still being criticized as unsuitable for the integration of renewable energy as recently as a decade ago (see, among others, [6,7]). However, once it started to boost the development of renewable electricity technology, it moved at a speed unmatched by any other country. In terms of installed capacity, China accounted for about 39% of the total wind energy and roughly one-third of the total solar electricity of the entire world in 2020 [8,9]. One reason for China's progress has been the unique advantage afforded to it by its technological capabilities. With the support of industrial policies, Chinese manufacturing capacity devoted to renewable equipment has expanded dramatically, and technological progress has been fast enough to drive down production costs. Without a domestic supply of relatively cheap renewable equipment, the observed outcomes of recent years could not have been achieved.

However, while the expansion of installed capacity has been impressive, China's overall energy transition process has not kept pace with capacity increases. There have been misalignments of incentives at almost every stage of reform over the past two decades. The inefficiencies incurred by these misalignments could have been avoided had China formulated a better strategy.

This paper reviews China's electricity market reforms of the past two decades, with a focus on measures relevant to the utilization of renewable energy. China's first attempt to establish a modern electricity market can be traced back to the 2002 reforms, under which electricity transmission was unbundled from independent electricity producers. Although market fragmentation has remained, the new system allows for the connection of new electricity generators to the grid, and thus facilitates the entry of renewable electricity producers to the transmission network. The Chinese government started to take serious steps to reduce pollution in the mid-2000s and launched many measures to incentivize local governments to improve the environment [10–12]. Recognizing the environmental impacts of the energy sector, the Renewable Energy Law was enacted in 2006. This law provided a rudimentary policy framework to encourage the use of renewable energy.

The pace of climate action in China increased in the late 2000s, especially after the signing of the Copenhagen Accord in 2009, the first international agreement on climate change that involved developing countries [13,14]. Reinforcement and clarification were provided by the revised version of the Renewable Energy Law that was approved in 2009 and enacted in 2010. China introduced FiT for wind energy in 2009 and for solar energy in 2011. Despite subsequent revisions to the FiT policies and the expansion of installed capacity, deployment of renewable energy failed to rise correspondingly. Without an RPS policy, increased installed capacity was accompanied by a high curtailment rate. The problem was further complicated by the geographic diversity and regionally unbalanced development of China; the western region has rich renewable energy resources but experiences slow economic growth [15–17]. With the absence of an integrated national electricity market, the renewable electricity generated in the western region cannot be efficiently utilized in other regions. China made further efforts to nurture the growth in the green electricity market and the formation of a nationally integrated electricity market with the announcement of the dual carbon goals (peak carbon emissions in 2030 and carbon neutrality in 2060) in 2020 [18]. The outcomes have yet to be fulfilled.

China's reforms suggest that careful alignment of incentives is vital if relevant market players are to produce and consume renewable energy. Although there have been many general reviews of China's electricity market reforms [19–21], to the best of our knowledge, there is no comprehensive or up-to-date examination of Chinese reforms surrounding the transition to clean energy. This paper attempts to fill this void. Section 2 investigates China's 2002 reforms and its approach to developing renewable energy by examining the two versions of the Renewable Energy Law. Section 3 analyzes how the Chinese government attempted to rescue its renewable equipment manufacturers with FiT policies in response to the protective trade measures of developed countries. The new policies triggered a huge expansion in installed capacity in China after 2013. The subsequent

inefficiencies in the market for renewable electricity were largely due to the lack of a nationally integrated electricity market. As will be explained in Section 4, further reforms started in 2015, but remain incomplete. In Section 5, China's belated adoption of RPS and its renewed efforts to develop a green electricity market with the announcement of the dual carbon goals are examined. In the Section 6, we draw lessons from China's reform experience that may be useful to other countries.

2. The 2002 Electricity Market Reforms and the Renewable Energy Law

China's economic reforms of the 1980s unleashed a period of high economic growth that resulted in serious electricity shortages [22]. Over the next two decades, the Chinese government encouraged local authorities to invest in power generation. Foreign investors were also granted access to the domestic electricity market. Nevertheless, by the end of the century, the electricity sector was dominated by the State Power Corporation, which controlled 46% of the country's installed capacity and 90% of the transmission assets [23]. Regarding the production of renewable electricity, the Chinese government experimented with the connection of wind power to the grids as early as 1994. However, the scale at the time was very small [24]. The 2002 reforms marked China's first attempt to build a modern electricity market, with electricity production unbundled from the transmission infrastructure. Under the new system, the market consisted of two grid operators, namely the State Grid Corporation of China and China Southern Power Grid Company. There were initially five electricity producers and four providers of auxiliary services. The new system allowed independent power generators to sell electricity to grid operators [25]. This made space for the subsequent reforms that facilitated the direct sale of renewable electricity to the transmission grid [26].

The enactment of the Renewable Energy Law (REL) in 2006 signified China's commitment to a transition towards the use of clean energy [27]. The REL laid down the general strategy for promotion of renewable energy and specified the responsibilities of various levels of administrative departments in the planning and implementation of relevant strategies. According to this version of the REL, fiscal resources and low-interest loans were to be dedicated to the development of renewable energy and the production of renewable equipment. General principles for the pricing of on-grid renewable energy were also formulated. The idea was similar to the feed-in tariffs (FiTs) adopted by many other countries. Specifically, the REL stated that the procuring price of electricity generated by renewable sources should be determined by the responsible department of the State Council. The additional costs of such a procurement over the normal electricity price would be borne by surcharges levied on electricity users. The measures mandated that government support should be given to a wide range of activities and projects, including research and development, renewable energy projects for rural consumption, independent electricity generation systems in remote areas and islands, information systems for surveying and assessing the availability of renewable energy resources, and the domestic production of renewable energy equipment (for the full text of the Law, see [28]).

The 2006 version of the REL, however, was too general from the perspective of policy implementation. It reflected the fact that Chinese officials only had rudimentary plans for the country's future energy landscape. There was neither a concrete roadmap for the development of the various kinds of renewable energy nor any operable mechanism for sharing the costs associated with renewable power generation at that time [29]. Without workable supporting policies and measures, the REL failed to bring about any progress in China comparable to that of the European electricity markets. In 2007, the central government released the "Renewable Energy Medium- and Long-Term Development Plan," which set a goal of installing 30 GW of wind power capacity and 1.8 GW of solar PV power capacity by 2020 [30]. It also called for the establishment of comprehensive renewable energy equipment manufacturing between 2010 and 2020. What happened was a significant expansion of Chinese manufactured renewable energy equipment. China had become a major manufacturer of solar PV equipment by the end of the 2000s, but sold most of the

equipment to overseas markets. Domestic demand remained negligible, although the Chinese government did implement the Golden Sun Program in an attempt to nurture the domestic market for solar PV equipment between 2009 and 2013. The large production scale of renewable energy equipment contrasted sharply with the tiny domestic utilization of renewable energy. Instead, Chinese renewable products had supported the rapidly growing installed capacity in Europe. In particular, Germany became the world's largest solar PV installer in 2008 [31].

The REL was revised in 2009 and the updated version was enacted in 2010. It set forth clearer operative measures. Three particularly important measures affected the growth in renewable energy in the electricity mix over the subsequent decade. Firstly, the updated version called for the establishment of a protective procurement system for electricity generated from renewables. It mandated that electric utilities would have to purchase all of the renewable electricity generated in the areas covered by their grids. This aimed to prevent the rejection of renewable energy by grid operators because of the lower reliability and higher instability of renewables when compared to power generated by fossil fuels. The concrete measures for implementation of this system were announced in 2016 [32]. Secondly, it stipulated the establishment of the Renewable Energy Development Fund (REDF), which was a major funding source for the FiT measures. The REDF was to be financed by a surcharge levied on the consumption of electricity nationwide and an annual fiscal allocation dedicated to the development of renewable energy. It provided subsidies for the electric utilities to purchase renewable power at a price higher than the ongoing market price for thermal power, as the cost of renewable power was higher than that of thermal power at that time. The survival of renewable power was thus guaranteed. The policy also encouraged investment and technological development that might drive down long-term costs. The REDF was formally established in 2012. Thirdly, a new article in the Law mandated that the government should set the RPS in electricity production, indicating the policy direction. However, no operable mechanism was put forward at the time [33].

3. The Introduction of FiTs during 2009–2013

Over the subsequent years, FiTs became the most important instrument for stimulating the generation of renewable electricity. FiT rates were first introduced to support the development of terrestrial wind power in 2009. The National Development and Reform Commission (NDRC) categorized the cities and prefectures into four wind resource zones. For each zone, a FiT rate for wind power station projects was determined (see Figure 1). Border areas, such as Inner Mongolia, Xinjiang, Gansu, Ningxia, and part of the north-eastern provinces, have relatively abundant wind resources, and they were offered lower FiT rates of RMB 0.51/kWh, RMB 0.54/kWh, or RMB 0.58/kWh. Coastal areas with relatively fewer terrestrial wind resources were offered a higher FiT rate of RMB 0.61/kWh [34]. China became even more eager to adopt the FiT policies for renewable energy in the early 2010s. The anti-subsidies and anti-dumping tariffs on wind and solar energy equipment imposed by the US and the EU in 2011 and 2012 triggered a crisis for domestic manufacturing firms. The problem was especially serious in the solar PV sector. Driven by their optimism for the industry's prospects, some Chinese solar PV manufacturers had expanded quickly in the 2000s. Many such companies faced a sudden funding chain rupture after a severe market shrinkage in developed countries. They could not repay the huge loans borrowed from policy and commercial banks. Concerns were also raised over the possible financial instability arising from large-scale bankruptcy in the solar PV sector.

To address this crisis, the Chinese government adopted a series of electricity market reforms that aimed to provide incentives for investment in solar PV power generation. An important measure was to introduce FiT rates for solar PV power generation. As the cost of investment in solar power stations could be recovered by selling electricity at the FiT rates, huge domestic demand for renewable energy equipment was stimulated, allowing domestic manufacturing firms to survive and even to expand the production capacity.

As mentioned, the FiT policy for wind energy was already in place in 2009. In July 2011, the NDRC introduced a fixed FiT rate for solar PV projects, with different rates for those completed before and after the end of the year, and a special rate for projects in Tibet [35]. In 2013, the NDRC refined the policy by setting differential FiT rates based on the solar radiation resources and construction costs applicable to distinct locations. China was divided into zones delineated by solar energy resources, and an FiT rate for solar PV power station projects was determined for each classification (see Figure 2). Solar radiation-rich areas, such as Haixi Prefecture of Qinghai Province and Dunhuang of Gansu Province in the northwestern part of China, would enjoy lower FIT rates (RMB 0.9/kWh). In contrast, areas with less solar radiation (mostly eastern and southern provinces), would be granted a higher FiT rate (RMB 1.0/kWh). Areas with middling solar radiation resources were offered an FiT rate of RMB 0.95/kWh. For distributed solar PV power systems, all the electricity generated was subsidized at a unified rate of RMB 0.42/kWh. Surplus electricity in excess of self-consumption could be sold to the grid at the coal-power benchmark tariff [36,37].

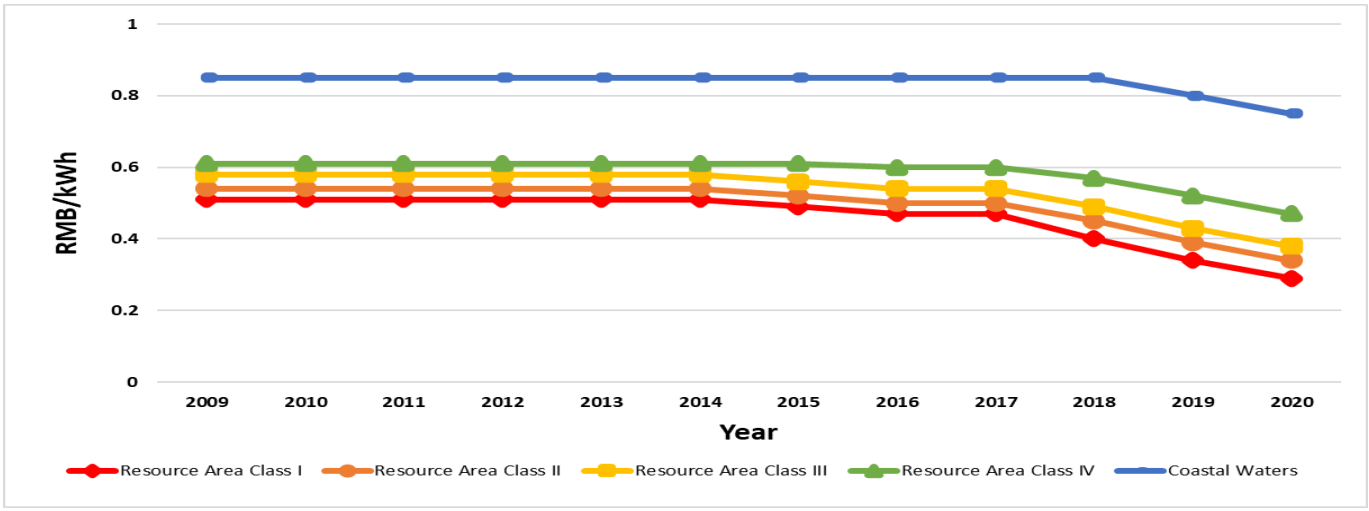

Figure 1. Feed-in tariff rates for wind power in China. Source: Xu (2019) [38].

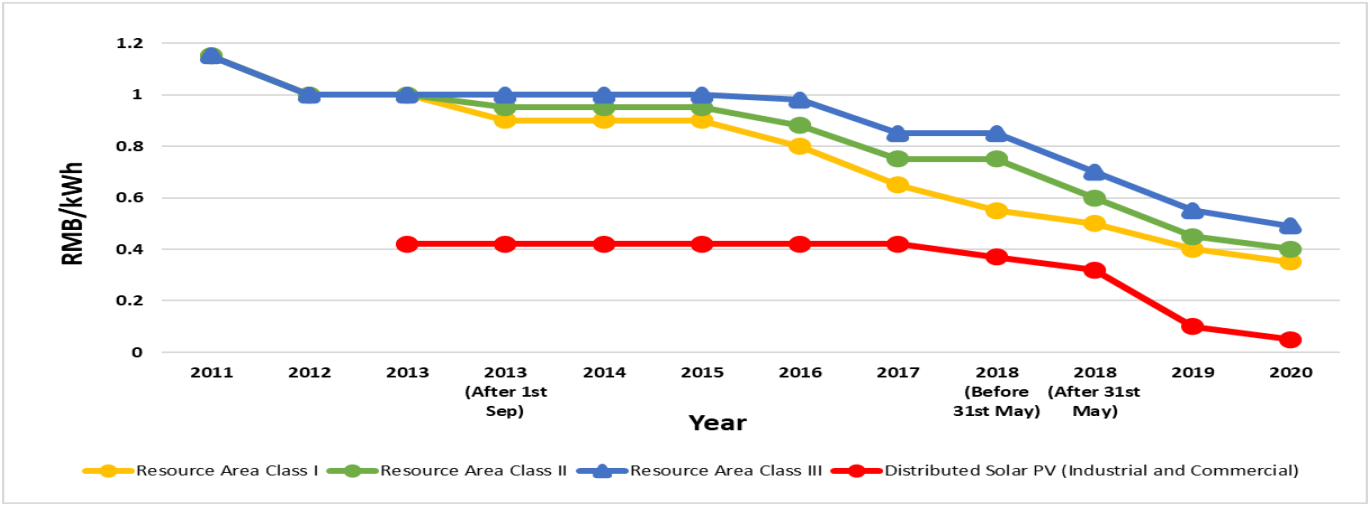

Figure 2. Feed-in tariff rates for solar PV power in China. Notes: Based on annual equivalent utilization (AEU) hours of solar energy, China divided distinct locations into three broad categories of "resource areas", each applying a specific level of on-grid tariff. Class I refers to those areas with 1600 AEU hours; Class II refers to those with 1400–1600 AEU hours; and the remaining areas belong to Class III. Source: Shui (2020) [39].

Following the 2010 version of the REL, the Chinese government officially launched the Renewable Energy Development Fund in 2012 to fund the necessary subsidies. While a small share of the money came from the central budget, the major share was raised in the form of a surcharge above the electricity price [40]. All electricity consumption, except that in Tibet and that of agricultural production, would be billed with a surcharge of RMB 0.008/kWh. The surcharge would be collected by the electric utilities on behalf of the government, and then a designated provincial government office (called the financial supervision commissioner's office) would collect the sum based on the amount of electricity sold and remit it directly to the national treasury.

The new policies therefore set out the market infrastructure for various market players to participate in the supply of solar PV energy. Thanks to the subsidies, the internal rate of return on solar power station projects increased to over 10%, providing a lucrative opportunity for solar PV manufacturers to expand their production [41].

Many solar PV equipment manufacturers quickly adopted a strategy of vertical integration by extending their businesses to the building of solar PV power stations. Apart from investing heavily in large-scale solar PV power stations across China, they also began negotiations with relevant parties to obtain rooftop spaces for the installation of smaller-scale solar PV systems. This was boosted by the Chinese government's launching of a solar PV poverty alleviation campaign, which aimed to increase the income of the rural poor by generating and selling solar power. The Chinese government helped people in about sixty thousand poverty-stricken villages to build solar PV power stations on hillsides and over greenhouses [42]. At the end of 2019, the Chinese government announced the completion of the "Poverty Alleviation by Solar PV" program. The cumulative installed capacity of solar PV stations was 26.36 GW, which generated an annual revenue of RMB 18 billion from the sales of electricity and benefited 4.15 million households [43].

The FiT had a decisive impact on the structure of the Chinese electricity market. In the subsequent years, the installed capacity for wind and solar power increased dramatically (see Figure 3). Since 2013, China has overtaken Europe and become the world leader for newly installed solar PV capacity. Indeed, China's cumulative installed capacity has exceeded that of the whole of Europe since 2016 [44]. During the 13th Five-Year Plan period (2016–2020), the cumulative capacity of solar power increased by about 5 times, while that of wind power more than doubled [45–47]. The electricity generated by solar and wind power also increased substantially during the same period (see Figure 4). By the end of 2020, the share of renewables in total installed capacity was 42.5%, accounting for 29.1% of China's total electricity. Around one-third of such electricity was generated by solar PV and wind powered systems [47].

Nevertheless, many private companies gradually retreated from the market as profitability decreased. To encourage cost reduction through innovation and reduce the dependence of the industry on subsidies, the Chinese government announced a scheduled phasing out of the FiT, and a stoppage of central subsidies for solar PV power stations registered after 31 May 2018 [48]. Since then, large SOEs have become the major force in developing solar PV power stations. With abundant capital and low-cost financing channels, the SOEs have been able to develop large-scale power stations and they have also purchased many privately owned power stations [49].

There were also concerns about the financial sustainability of the FiT policy. The subsidy-driven growth in renewables in China led to a large amount of subsidy arrears [50]. As the actual installed capacity of solar PV systems had grown more quickly than expected, the demand for subsidies outpaced the growth in surcharges collected from electricity consumers. The problem was not solved even after the Chinese government gradually increased the surcharge to RMB 0.019/kWh. The gap continued to widen and the arrears grew. According to an estimation by the Chinese Wind Energy Association (CWEA) of the China Renewable Energy Society (CRES), the total subsidy arrears were as much as RMB 400 billion in 2021, and were forecast to peak by 2028 [51]. Without the subsidies, many enterprises in the sector found themselves under tremendous financial pressure [52].

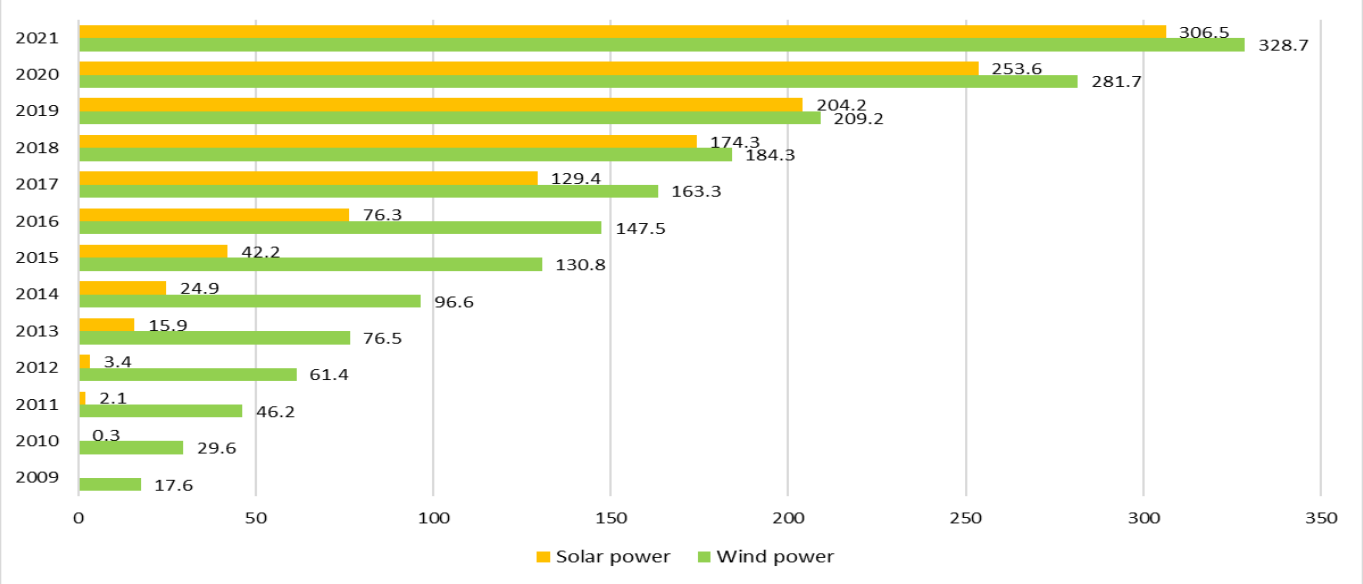

Figure 3. Installed capacity of wind and solar power in China (unit: GW). Notes: The data for solar power in 2009 are not available due to the dataset's negligible size. Source: National Bureau of Statistics of China, China's Statistical Yearbooks, various issues, available at http://www.stats.gov.cn/tjsj/ (accessed on 31 December 2022).

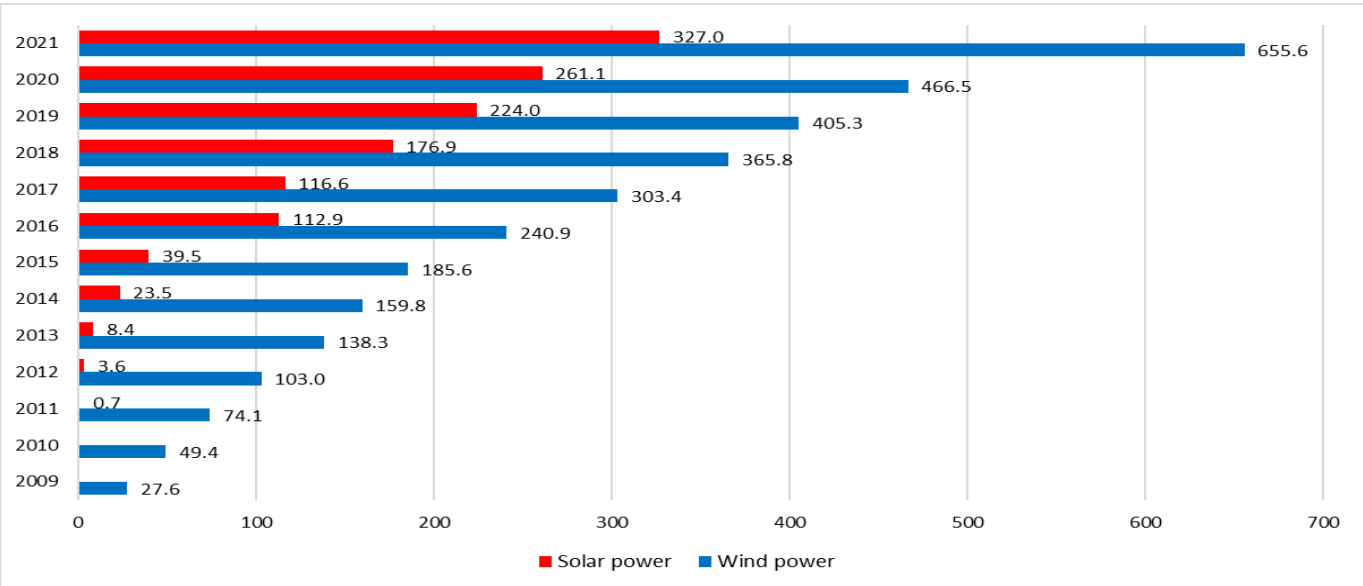

Figure 4. Electricity generated by wind and solar energy in China (unit: TWh). Notes: The data for solar power in 2009–2010 are not available due to the dataset's negligible size. Source: China Electricity Council, Statistical Digest of China's Electricity Industry, various issues, available at https://cec.org.cn/menu/index.html?542 (accessed on 31 December 2022).

Most importantly, the dramatic increase in the installed capacity of renewable electricity did not lead to a quick energy transition. One major problem was the high curtailment rate, which was due to the insufficient demand for renewable energy in the producing regions. In 2015, the Chinese government introduced an experiment to promote local consumption of renewable energy in Gansu and Inner Mongolia [53]. However, a more reasonable solution was to supply the energy to other regions that needed more energy. This cannot be achieved because of the regional fragmentation of the electricity market.

4. The 2015 Reforms to Set Up a Multiple-Layered Market

In 2015, China launched new reforms that aimed to establish a domestic multi-layered electricity market. The government sought to establish a non-discriminative, competitive market featuring electricity generation by diversified producers by gradually liberalizing the price of the transmission and delivery market segments. The grid enterprises would no longer monopolize the sale of electricity, and they would be transformed into regulated platforms responsible for maintaining the stability of the electricity supply. The government also relaxed controls over electricity generation, except those serving public interests and those critical to supply stability [54,55].

The Chinese government established relatively independent entities to facilitate electricity trading. Provincial trading centers were established to facilitate mid- and long-term trading and spot trading of electricity within the provinces. Green electricity was one of the products on the market. Regional centers in Beijing and Guangzhou were established to deal with the interprovincial and interregional trade of electricity, with an objective of achieving better allocation of resources at a national level. Eight province-level centers were also established in the initial stage.

Pilot tests were carried out in several provinces. However, transactions of renewable electricity in the interprovincial electricity market were limited. At the time, most of interprovincial electricity transmission was governed by national plans and agreements between local governments. The government's protective procurement mechanism covered most of the power generated from renewable sources. The procurement price was also determined by the government. Interprovincial transmission of renewables was also achieved through inter-governmental agreements. Only the renewable electricity produced and consumed outside the protective procurement system could be traded in the market [56]. Therefore, the market was very thin during the initial stage.

However, the building of a nationally integrated electricity market is not easy. Although the central government tried to connect provincial and regional electricity trading centers, cross-province trade was hindered by differences in trade rules. Since the standards for transaction technology and the data interface have not been unified, there has been a substantial increase in transaction costs that has prevented enterprises from participating in the interprovincial electricity market [57].

The aforementioned problem of the high curtailment rate of renewable electricity was a result of the non-integration of the regional electricity markets. In some renewable-rich inland provinces, such as the "Three North" regions (Northwest, Northeast, and North China), curtailment rates were particularly high. For instance, the curtailment rate of solar and wind power in Xinjiang was 21.6% and 29.8%, respectively, in 2017 [58]. To tap the potential of the solar radiation resources, the installed capacity of the "Three North" regions grew to a high of about 230 GW, but a relatively low level of regional development limited local demand for energy. In theory, this problem might be solved by transmitting electricity to the energy hungry coastal provinces. However, while the implementation of the FiTs encouraged investment in installation capacity in the "Three North" regions, insufficient incentives were provided for consumption of renewable power at the terminal markets in other regions. As such, the increase in supply was not matched by a corresponding increase in demand. The problem was further aggravated by the capacity constraints of cross-province transmission. The total capacity of such transmissions was only 42 GW, about 18% of the installed capacity of the "Three North" regions [59]. As a result, a lot of renewable energy has been wasted.

Before an integrated market could be built, the Chinese government had to deal with separate problems in both supply and demand. On the supply side, the Chinese government imposed new restrictions on investment in 2017 and 2018 to prevent the growth in excess capacity. Specifically, the Chinese government temporarily stopped the subsidies for the solar PV capacity installed after 31 May 2018 [48]. The annual installed capacity of renewable electricity for each province would be determined by the National Energy Administration (NEA) and based on the total amount of a province's own consumption

and the pledged purchase of renewable power by other provinces [30]. Additionally, as mentioned above, the Chinese government announced a scheduled phasing out of the FiTs for solar PV and wind power. The growth in investment in solar PV and wind power decreased substantially in 2018 and 2019 [60].

On the demand side, the Chinese government set renewable electricity utilization targets for major provinces, aiming to increase the utilization efficiency of renewable energy. The Action Plan for Consumption of Clean Energy (2018–2020) released by the NDRC (2018), required those provinces to gradually lower curtailment rates to 10% or below, so that China as a whole would be able to cap the curtailment rate of solar and wind power below 5% by the end of 2020 [61]. The local agencies of the NEA would formulate plans with energy departments in provinces with serious curtailment problems to increase the utilization rate of renewables.

It was also seen to be important to increase cross-province transmission capacity, so that electricity from renewable sources could be sold to energy hungry provinces. In the short term, the Chinese government worked to increase the share of renewables in total cross-province power transmission using the existing "power passages". The target was to increase the share to 30% by 2020. In the long term, the Chinese government aimed to strengthen the role of the national grid in efficient power allocation across regions. It planned to construct outbound "power passages" with a high share of renewable power transmission in resource abundant areas, such as Inner Mongolia and Qinghai. It also planned to alleviate the lack of internal transmission capacity in provinces including Gansu, Guangdong, Guangxi, Xinjiang, Hebei, Sichuan, and Yunnan [61].

5. Acceleration of Reforms since 2020

The Chinese government's announcement of the "dual carbon goals" in September 2020 represented a milestone in China's climate action. At about the same time, a series of significant action plans were also released. The reform of the electricity market to enhance energy transition was a core element of these plans. To tackle existing problems in the electricity market, the Chinese government adopted a two-pronged strategy. Firstly, it pushed the provinces to gradually reduce the wasting of renewable power by imposing the RPS. Secondly, it augmented the 2015 reforms to speed up the development of a multi-layer and nationally integrated electricity market with an increasing share of renewables.

5.1. Renewable Portfolio Standards (RPS)

The Chinese government decided to introduce the RPS in 2019. The accounting methods and the procedures used to set the targets for each province were announced. The specific targets for 2020 were determined and the assessment of provincial performances were slated to start in the same year [62]. After the "dual carbon goals" were announced, China also set long-term targets. To make sure that the share of non-fossil fuels in primary energy consumption would reach 25% by 2030, all provinces were expected to increase their share of renewable electricity consumption to at least 40% over the period. According to a consultation document released in 2021, the specific target for each province in each year was to be determined by an equal increment in the share of renewable electricity, such that the 40% target could eventually be achieved [63].

It is not clear whether the policies proposed by the consultation document have all been adopted. Nevertheless, the targets for the period of 2021–2025 have been operationalized in the NDRC and NEA (2021) [64]. In this document, the Chinese government set up RPS for every province except Tibet. The target for 2021 is mandatory, while the target for 2022 is predictive. If progress in 2021 is higher than a specified level, the relevant province will be rewarded. If a province does not meet its 2021 target due to uncontrollable factors, the unmet balance will be transferred to the next year. The provinces are free to negotiate and collaborate with each other to jointly achieve combined provincial targets. The same mechanism is to be applied in the subsequent years. The targets for 2025 must be met, regardless of the progress made in previous years.

China also reformed the Green Electricity Certificate (GEC) system to accommodate the implementation of the RPS in 2021. When the GEC system was introduced in 2017, the government planned to link it to the RPS, due to be introduced at a later date [65]. In doing this, China was apparently following the model of many Western countries, which aimed to encourage energy transition with similar complementary measures.

However, the development of the GEC market was not successful. This was a somewhat reasonable outcome; a GEC system without RPS does not work. Still, there was an additional reason for China's failure to develop the GEC system. When it was introduced, the Chinese government intended to use it as a tool to reduce the financial burden of the REDF. It was designed so that once the GEC was sold, the corresponding amount of electricity would no longer qualify for subsidies from the central government. Without subsidies, the price of GEC would be so high that few companies would have an incentive to buy it. Only those companies keen to demonstrate their willingness to fulfill social responsibilities might have enough reason to buy it on a voluntary basis. As a result, since 2019, the Chinese government has tried to link the GEC system to RPS. At the beginning of 2021, the Chinese government further tightened the link between the GEC and the actual consumption of green electricity (see below).

5.2. Market for Green Electricity

Relying on the basic market infrastructure developed after the 2015 reforms, the Chinese government put further efforts into establishing a unified, multi-tier national electricity market system which would promote the consumption of renewable power. The blueprint had been to build efficient provincial and regional green electricity markets which are integrated to form a national market with significant interprovincial trade in renewable electricity. The plan aims to foster trade and pricing mechanisms by 2025 and to achieve complete marketization of renewable power allocation by 2030 [64,66].

Pilot tests were carried out to promote the trading of green electricity. The State Grid Corporation of China and the China Southern Power Grid Company each formulated a work plan for a pilot test of green electricity trading under the leadership of the NDRC and NEA in August 2021. The policies were initially applied to solar and wind power and were to be extended to hydroelectric power when appropriate. There had been provincial and regional initiatives to establish the green electricity market [67,68], but these national pilot schemes represented a high-level decision that would also take more care of interprovincial trade issues.

Green electricity would be transacted under the "unification of issuance of GEC and actual consumption of green electricity". This arrangement aimed to overcome the inherent shortcomings associated with separating purchasers of GECs from the consumers of renewable power in the initial years. Before 2021, the GECs were issued by the platform administered by the National Renewable Energy Information Management Center. They could be purchased by individuals, government agencies, and enterprises on a voluntary basis. It was not necessary for the GEC-purchasing firms to know what the green electricity was ultimately being used for. This flexible model is common in Western countries, as it can offer more flexibility to producers and consumers of green electricity. However, it is not guaranteed that the green electricity represented by the GEC is actually consumed. Therefore, starting from 2021, GECs would be directly issued to green electricity consumers. Under this regime, green electricity could be traced over its entire "life-cycle": from production and transaction to consumption.

There would be two broad categories of transaction. The first was direct transaction. Green electricity consumers and electricity retail companies would transact with power generation companies based on rules and regulations. The second was transaction though agents. The electric utilities would act as an agency to purchase green electricity. The Guangzhou and Beijing Power Exchange centers would collaborate with the provincial-level exchange centers or electricity utilities to deal with cross-province green electricity trading, while provincial-level centers would be responsible for within-province trading.

These pilot tests aimed to develop the spot-, mid-, and long-term markets for green electricity. In previous years, most of the electricity that was open to market trade was generated by fossil fuels. Renewable power enterprises did not participate in the market. Instead, the electricity generated by them was purchased under protective procurement schemes. Development of the mid- and long-term markets aimed to enhance price stability for consumers and increase the certainty of return for the developers of power stations. Enterprises were encouraged to agree on five- to ten-year electricity purchasing agreements with power enterprises.

The development of the spot market for green electricity is complicated by the inherent instability of the supply of renewable power. In many coastal provinces, renewable power has simply not been included in pilot tests for the electricity spot market. Although there are spot markets in some inland provinces, the huge surplus of green electricity in peak power generation periods drives down prices, undermining the incentive for the power generation companies to join the market. The demand generated by other provinces has not been able to stimulate the price of green electricity because of the lack of cross-province electricity transmission capacity. This explains why the Chinese government is eager to remove inter-regional trade barriers and maximize the surplus capacity of the interprovincial and inter-regional transmission channels.

The nascent green electricity market has been characterized by the dominance of within-province transactions. On the first day (7 September 2021) of pilot green electricity trading, a total of 259 enterprises from 17 provinces participated in the market. Over 7.9 TWh of green electricity was sold, of which only 20% was interprovincial trade [24]. Another characteristic of the nascent market was its small scale. About 6.9 TWh was transacted in the areas covered by the National Grid on 7 September 2021 [69]. Although green electricity seems to have been actively traded in the earliest stages, few transactions were registered in subsequent months. By April 2022, the accumulated volume of green electricity transactions in the areas covered by the National Grid was just 9.5 TWh. That means the total transaction volume of green electricity between September 2021 and April 2022 was only 2.56 TWh [70].

Nonetheless, there are new players joining the market. Large enterprises, especially the sectoral giants and foreign-owned multinational corporations, have demanded more green electricity to fulfil social responsibilities and decarbonization goals. For instance, BASF (China) Company Limited and China Resources signed a 25-year green electricity purchasing agreement with SPIC Guangdong Power Company Limited, and the companies completed a transaction of about 2.5 GWh of green electricity at Guangzhou Power Exchange Center in June 2021. Encouraging those provinces with a lot of outward-oriented enterprises to use more green electricity is one of the most important strategies aimed at boosting demand, as reflected in the Chinese government's Implementation Plan For Promoting Green Consumption, issued in 2022 [71].

The Chinese government has also made efforts to enhance the electricity grid for a more efficient utilization of renewable power at a national level. Particularly, it will increase the delivery capacity of the existing ultra-high voltage transmission lines of the "Three North" regions to the design level as soon as possible. This will enable the "Three North" regions to supply more renewable power to other provinces.

6. Concluding Remarks

Increasing the use of clean energy is one of the most important methods of achieving the climate goals set by the Paris agreement. Facilitating a transition to a clean energy structure is a common theme in electricity market reforms around the world. We have analyzed the last two decades of reform experiments in China and have particularly emphasized the importance of aligning the incentives aimed at both the supply and the demand sides of the market.

China's experience suggests that a coordinated approach is necessary. China started with a supply-oriented policy that encouraged investment and production in the renewable

energy sector. However, RPS were not introduced until relatively recently. Due to a lack of demand-oriented policies, a large share of the installed capacity was under-utilized, leading to the waste of a lot of resources and fiscal subsidies. A better strategy would include the simultaneous deployment of both supply-side and demand-side policies. A reasonable RPS should be formulated as early as possible in accordance with a country's situation, and appropriate FiT rates are necessary to encourage the supply of green electricity.

The development of China's renewable energy sector also suggests that energy transition requires policies that go beyond the narrow domain of electricity market reform. To many countries, making progress in the energy transition means imposing higher energy costs on production and consumption activities, as renewables are more costly than fossil fuels. However, China has tried to benefit from its own energy transition by developing a manufacturing industry devoted to renewable power production equipment. As a large country, the energy transition requires a large volume of equipment that can produce affordable clean energy. To achieve this goal, China has implemented industrial policies that ensured the survival of its industry, forced manufacturing firms to advance technological progress by subsidizing research and development, and gradually phased out FiT policies. By doing this, China has benefitted from the process of the energy transition. According to a research report from the International Energy Agency (IEA), China has dominated many segments of the global supply chains on solar PV products [72]. Other countries may not have the industrial capacity to achieve this, but they can now benefit from China's low-cost renewable energy technologies. It might also be desirable for them to participate in the value chain of this manufacturing sector wherever possible.

With regard to demand, there is still a lot of room for the applications of solar energy to increase. China has been innovative and proactive in this regard. For instance, the Chinese government is further increasing the environmental value of renewable technology by integrating it with sand control [73]. Solar panels operating in deserts can create a more favorable environment for plants through sun shading and provide incentives to revegetate the deserts. The rural poor of China are beginning to make best use of their space by growing value-added cash crops and Chinese medicinal herbs. The Chinese government is also narrowing the regional imbalances of the digital era by encouraging the use of solar PV technology to power "green" internet data centers (IDC). The Chinese government is turning the rich solar resources of western provinces into ideal locations for establishing IDCs under the "Eastern Data and Western Computation" Program. In addition to decreasing carbon emissions, the new IDCs have also brought a growing number of well-paid information industry jobs to relatively underdeveloped and remote areas [74]. In China's 14th Five-Year Plan (2021–2025) on renewable energy development, aggressive capacity and consumption targets were announced, with detailed measures to support renewables consumption. Interestingly, provincial plans are even more aggressive than the national plan, with aggregation of provincial targets far exceeding the corresponding national targets [75].

Moreover, the technological nature of solar PV energy also provides an opportunity for low-income countries to alleviate poverty whilst achieving a higher utilization rate of clean energy. Administered properly, distributed solar PV systems could be installed in rural areas to provide affordable energy to poor households and, where possible, to generate income from solar energy generation.

To conclude, facing the current climate crisis, electricity market reforms in various countries should be designed to enable a faster and more efficient energy transition. China has provided some useful lessons for other countries. China's experience has also demonstrated how economic and social policies complement electricity market reforms to achieve better energy transition outcomes and socioeconomic progress.

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