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■ research article

Aligning emissions trading and feed-in tariffs in China

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In 2013, China launched its domestic pilot emissions trading scheme (ETS) as a cost-effective strategy to reduce CO_2 emissions. Theoretically, the ETS can interact with the feed-in tariffs (FITs) applied to renewable energies (REN). This article presents a simple method to demonstrate how FITs can be adjusted based on the evolution of ETS carbon prices in order to provide a cost-effective climate policy package in China. First, by using provincial data and wind and solar power as examples, it calculates the implicit carbon prices that FITs generate in different Chinese provinces and finds that they are much higher than current carbon prices in the pilot ETS. This shows the necessity of using both instruments to guarantee current level incentives to develop REN for climate change purposes, at least in the short and medium terms. Second, by keeping the annual total carbon price level stable (the sum of the implicit FIT carbon price and the ETS carbon price), and taking into account the cost evolution of REN development, this article demonstrates, for the 2018–2020 period, that FIT should decrease at an annual rate of 3.04–4.63% (for wind) and 7.84–8.87% (for solar) based on different growth rates for progressive national ETS carbon prices.

Policy relevance

There are a number of studies and debates on the interactions between climate policies in Europe in particular, ETS and subsidies for REN. The key issue is that a climate policy package should be cost-efficient and the implementation of one policy should not jeopardise the performance of another. For a country like China, a considerable scale effect on climate target achievement and total cost savings could be produced by the careful design of the climate policy package. FIT and ETS, which are cost-efficient policies if implemented separately, will very probably constitute a major climate policy package in the future in China, which is aiming to limit the use of command-and-control policies. So far, there is some debate on how to reduce FIT for wind power in China due to development cost changes. But discussions are lacking on the linkage between FIT and ETS. This paper fills this gap.

Keywords: China; emissions trading; feed-in tariff; solar power; wind power

1. Introduction

As the world's biggest GHG emitter and the second largest economy, with considerable international trade activities throughout the world, China is now striving to develop a low-carbon economy in a cost-effective manner. The increasing number of economic and market-based instruments can justify this cost-effectiveness rationale. During the 11th Five-Year Plan (FYP) period (2005–2010), a renewable energy (REN) target was introduced in order to ensure coherence with the mid-term REN target aimed at achieving 15% REN in total energy consumption by 2020. In recent years, feed-in tariffs (FITs) on REN

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electricity prices, accompanied by tax abatement policies on the production of REN equipment, have been a dominant factor in the rapid development of REN in China, in particular wind and solar power. In the 12th FYP (2011–2015), a carbon-intensive target has been added as an obligatory target together with the REN target. The CO_2 emissions trading scheme (ETS) is clearly stated in the 12th FYP as a cost-effective instrument to contribute to the achievement of climate targets. To date, seven pilot ETSs have been implemented at city and provincial levels, with a nationwide ETS to be implemented during the 12th FYP period in China. The carbon price can be expected to increase progressively, provided that the Chinese government strongly supports the development of national ETS.

So far, there has been some debate on how to reduce FITs for wind power in China due to development cost changes (although no real changes have been made to FITs). However, discussions are lacking on the linkage between FITs and ETSs. After the introduction of an ETS, the carbon price generated by the ETS can interact with REN policies and lead to welfare impacts. Theoretically, when a pollution externality is accompanied by knowledge spillovers (REN in our case), an optimal policy mix is pricing the pollutant with subsidies (FITs in our case) to support the development of clean technologies (Bennear & Stavins, 2007; Jaffe, Newell, & Stavins, 2005; Lehmann & Gawel, 2013). In the real world, the lack of efficient design and coordination between carbon pricing and subsidies can lead to cost-inefficiency in the climate policy package. For example, the EU ETS was implemented in the EU first, and then followed by the REN target. According to some studies (Guerin & Spencer, 2011; Rathmann, 2007), the introduction of REN targets with FITs as a major support policy has accelerated the deployment of REN in Europe. However, this increase in REN development was not taken into account in the design of the EU ETS, and could reduce the demand for CO_2 quotas in the EU ETS, thereby reducing the carbon price as an unwanted result of the EU ETS design.

The coherency of climate instruments is similar in China, but the order of implementation differs from the European context. FITs for REN now encounter the carbon price from the pilot ETS and will interact with a nationwide ETS later. In China, final consumers of electricity pay for the gap between the FITs applied to wind and solar power and on-grid tariffs for conventional power, with an additional charge (per kWh consumption) in their electricity bills. One possible scenario is that power producers who benefit from FITs for REN could build more REN installations and sell CO_2 emissions quotas on the carbon market. Because FITs already cover the external cost of REN, the revenue generated by selling CO_2 emissions quotas is therefore a windfall profit. In such a scenario, final consumers at least partially underwrite the windfall profits of power producers. This is a distortion of the allocation of the costs of emissions reductions (against consumers) and produces cost inefficiency in the market-based climate policy package with carbon pricing and FITs.

FIT levels should be adjusted in accordance with carbon prices in the ETS in order to provide a cost-efficient economic instrument package to deal with climate change. There are several articles dealing with this objective. Zhang and Bauer (2013) assess the target coherency between energy intensity and REN in China. Buckman and Diesendorf (2010) examine the design limitations of the Australian REN market, and one of their analyses argues that the ETS cannot provide sufficiently high carbon prices to foster the development of REN technologies. Blanco and Rodrigues (2008) calculate a minimum carbon price of at least €40/tCO_2 to maintain the incentive level of financial support policies for wind power in Europe. They argue that carbon prices only reflect the beneficial impact of wind on climate change and fail to clarify its contribution to the security of supply or job creation. Wittmann (2013) and Sorrell, Harrison, Radov, Klevnas, and Foss (2009) provide an in-depth theoretical (and graphical) analysis on the correlation of white certificate schemes and the EU ETS. However, to date there is no quantitative analysis of the co-existence of ETSs and FITs for REN in China, or of how FIT and ETS policies can be managed to ensure cost-effective CO_2 emissions reductions and REN development.

Provided the anticipated development of FIT and ETS policies in China continues to grow in the future, this article provides a simple methodology using the equivalent carbon prices that ETSs and FITs generate as an indicator to demonstrate how ETS and FIT policies cooperate at the provincial level in China. It is beyond the scope of this article to demonstrate the optimal equivalent carbon prices for ETSs and FITs in order to support the development of REN. The article is organized as follows. Section 2 reviews ETS and FIT policies in China, Section 3 presents the methodology, assumptions and data, and Section 4 describes results and discussions, before conclusions are presented in Section 5.

2. Review of FITs for REN and ETSs in China

2.1. ETS implementation in China

Seven pilot ETSs have undergone rapid development in China as a result of considerable government attention and support. Following China's 12th FYP, which promotes the implementation of national ETS, the National Development and Reform Commission (NDRC), the leading ministry in charge of climate policy in China, released a notice proposing the establishment of pilot ETSs in five cities (Beijing, Tianjin, Shanghai, Chongqing, and Shenzhen) and two provinces (Guangdong and Hubei). Less than two years later, Shenzhen's pilot ETS came into force on 18 June 2013. This was rapidly followed by the implementation of pilot ETSs in Beijing, Shanghai, Guangdong, and Tianjin in 2013, and in Hubei in April 2014.

So far, most trade in CO_2 quotas has occurred in the secondary market. Interestingly, the CO_2 price level remained relatively high at the time this article was written. Table 1 summarizes the average CO_2 price and trade volume on the secondary market for the pilot ETSs as of 15 April 2014. As can be seen, Shenzhen city leads the way in terms of quota prices, with an average price of roughly €8/tCO_2, compared to the carbon tax starting rate of €1/tCO_2 proposed in China in 2010 (Wang, Li, & Zhang, 2011).

TABLE 1 Trade volume and average CO_2 price of pilot ETSs in China

	Trade volume (ktCO_2)	Average CO_2 price (yuan/tonne)
Shenzhen	245.64	69.19
Shanghai	238.63	37.69
Beijing	89.97	52.12
Guangdong	126.03	60.18
Tianjin	98.52	40.01
Hubei	1354.70	23.92
Total	2153.48	34.65

Source: www.tanpaifang.com

In general, as a newly established policy, current market liquidity is low in most pilot ETSs. However, a liquid and active market can be expected, as more measures have been and are expected to be implemented to ensure the effective functioning of ETSs. An increasing CO_2 price trend could be expected, as ETSs are seen to be a key instrument to ensure a cost-effective low-carbon transition in China.

2.2. REN development and FITs

REN is considered not only a means of sustaining economic growth, but also a key element to ensure a low-carbon transition in China. Since 2000, China has implemented massive development of REN. In particular, wind and solar power have produced significant results in terms of both manufacturing capacity and deployment. Ambitious targets were set to guide the mid-term development of wind and solar power development (as well as other REN). According to China's Renewable Energy Development Plan for the 12th FYP period, wind and solar power installations are set to produce 100 GW and 21 GW, respectively, by 2015. As Figure 1 shows, China could very probably achieve these targets, given the rapid development of wind and solar power in recent years.

FITs have undoubtedly made an important contribution to the rapid installation of wind and solar power in China. FITs were first introduced for wind energy in August 2009 at the national level. Four tariff levels, 0.51, 0.54, 0.58 and 0.61 yuan/kWh, were set in different regions for new on-shore wind power. These tariffs remain unchanged today. Different pilot ETSs are largely a reflection of the different wind resources and development costs in different regions in China. A FIT was first applied to solar power (stations) in China in July 2011, when the central government announced the nationwide two-category FIT for photovoltaic (PV) projects: 1.15 yuan/kWh and 1.10 yuan/kWh for projects approved before and after July 2011, respectively.[1] Due to the cost reductions for PV power, in 2013 the NDRC introduced a new nationwide three-category FIT: 0.9, 0.95 and 1.0 yuan/kWh for different regions (for details, see Appendix 1). These tariffs remain unchanged today.

For the period assessed in this article, solar power development was mostly in the form of solar power stations. In 2012 the Chinese government began to encourage the development of distributed solar power. A large proportion of the electricity generated by distributed solar will be for own use by installers (commercial, public, and private buildings) and the electricity surplus can be sold to the electricity

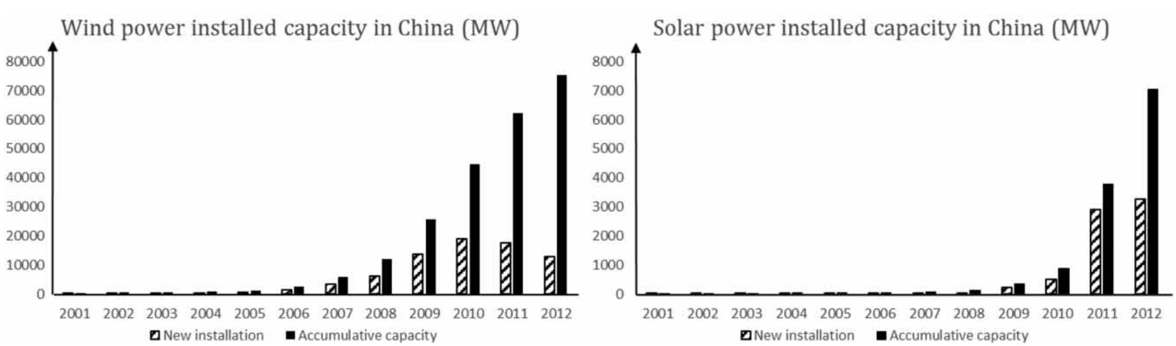

FIGURE 1 Wind and solar installed capacity in China
Source: China wind energy association, European Photovoltaic Industry Association.

grid. The latter also benefits from high FIT and electricity VAT abatement. This FIT is not examined in this article for the following reasons: (1) distributed solar power development is negligible for the period assessed here, and (2) the change in ETS carbon prices in general will not directly affect installers of distributed solar power (because most of them are small operators and will not be included in the ETS). A reduction in FIT for distributed solar power will therefore only reduce the cost incentive for distributed solar power installation as long as installers of distributed solar power cannot participate in the ETS.

3. Method and data

3.1. The model

Wind and solar power are taken as examples in the modelling work. Currently, the main financial support for wind and solar power in China is FIT policy. Theoretically, FITs should cover the exact level of additional costs of REN compared to conventional electricity. As China has introduced an ETS policy, which explicitly covers the electricity industry, such a policy coexistence scenario may lead to double incentives for power producers, thus affecting the cost-efficiency of the climate policy package. In this section a model is presented to ensure FIT cooperate with carbon prices in ETSs. The equivalent CO_2 price is used as an indicator of the total carbon price generated by FIT and ETS policies, which should be exactly equal to the extra costs for REN development in China. Other benefits of implementing REN, such as reduced local environmental pollution and ensuring energy security and access, are not taken into account because CO_2 is considered the only negative externality in this article. They can, however, be integrated into our methodology when related benefit levels are available from other studies.

For policy implication and simplicity it is assumed that only a nationwide ETS is in place, and that this has a progressive carbon price. FIT levels at the provincial level should be adjusted in order to avoid cost allocation distortions between power producers and consumers produced by uncoordinated ETS and FIT policies (as described in the introduction). Equation (1) estimates the equivalent carbon prices (or implicit carbon prices) that current FIT policies generate in different provinces of China.

$$\mathrm{FIT}^{i}_{\mathrm{REN},t} - \mathrm{FIT}^{i}_{\mathrm{C},t} = eP^{i}_{\mathrm{CO_2},t}(E^{i}_{\mathrm{Baseline}} - E^{i}_{\mathrm{REN}}) \tag{1}$$

where i indicates the province, t indicates the year, $\mathrm{FIT}^{i}_{\mathrm{REN},t}$ denotes the FIT level for wind or solar, $\mathrm{FIT}^{i}_{\mathrm{C},t}$ is the conventional electricity price purchased by grid companies, $eP^{i}_{\mathrm{CO_2},t}$ is the equivalent carbon price to be calculated, $E^{i}_{\mathrm{Baseline}}$ denotes the CO_2 emissions per unit electricity produced by the current power generation style and is calculated according to

$$E^{i}_{\mathrm{Baseline}} = \beta_i \times M_{\mathrm{C}} \times \theta \times \gamma_{\mathrm{CO_2}} \tag{2}$$

and E^{i}_{REN} denotes the per unit electricity CO_2 emissions from REN, and is set at zero, as we regard wind and solar as clean technologies. Because FIT is implemented at the provincial level, equation (2) is used to calculate provincial-level per electricity production carbon intensity.[2] In equation (2), β_i denotes the ratio of coal electricity in province i, M_{C} is the average amount of coal used to produce 1 kWh thermal

TABLE 2 Related data and sources

Parameter	Value	Source
FIT^{i}_{REN} FIT^{i}_{C}	Varies in different provinces (see Appendix 1)	NDRC (www.ndrc.gov.cn)
M_C	330 g/kWh	Annual Report of China Electricity Generation 2011 (National Energy Administration)
θ	0.725 kg/kg	IPCC (2006)
γ_{CO_2}	3.667	
r_{REN}	− 2% for wind	World Bank (2011)
	− 7% for solar PV	Xie et al. (2009)
r_C	2.3%	Li and Wang (2011)

electricity in China, θ is the carbon ratio of coal, and γ_{CO_2} is the ratio of molar mass between carbon and CO_2. For values of the parameters in equations (1) and (2) see Table 2.

For each province, equations (3) to (5) are introduced to calculate corresponding FIT adjustment rates when the carbon price changes in the ETS:

$$FIT^{i}_{REN,t_1}(1 + r_{REN})^{t_2-t_1} - FIT^{i}_{C,t_1}(1 + r_C)^{t_2-t_1} = eP^{i}_{CO_2,t_2}(E^{i}_{Baseline} - E^{i}_{REN}) \quad (3)$$

$$FIT^{i}_{REN,t_2} = (eP^{i}_{CO_2,t_2} - P_{CO_2,t_2}) \times (E^{i}_{Baseline} - E^{i}_{REN}) + FIT^{i}_{C,t_1}(1 + r_C)^{t_2-t_1} \quad (4)$$

$$R_{FIT} = 1 - \sqrt[t_2-t_1]{\frac{FIT^{i}_{REN,t_2}}{FIT^{i}_{REN,t_1}}} \quad (5)$$

Here, t_1 and t_2 are the base and end years of the calculation, r_{REN} and r_C denote, respectively, the annual change rate for REN and conventional electricity prices due to cost evolution, P_{CO_2,t_2} is the assumed CO_2 price in the national carbon market in 2018–2020 (see Table 3). $E^{i}_{Baseline}$ is assumed to be the same between t_1 and t_2, because the share of REN in the total energy mix is negligible in terms of its contribution to CO_2 emissions change. Equation (3) first calculates $eP^{i}_{CO_2,t_2}$, equation (4) then estimates

TABLE 3 Different scenarios in the policy mix design

Scenario	CO_2 price 2018 (yuan/tonne)	CO_2 price 2020 (yuan/tonne)	Average growth rate (%)
S1: Low development of carbon price	40	48.4	10
S2: Medium development of carbon price	40	67.6	30
S3: High development of carbon price	40	90.0	50

r_C, and equation (5) gives the change level for the FIT at the provincial level. Related data and sources for equations (3) to (5) are provided in Table 2.

3.2. Data and scenario setting

For simplicity of calculation and demonstration, several assumptions are made. First, the carbon price increases with a fixed annual growth rate. This can be understood to be a result of a progressive annual cap with a fixed rate of reduction for the total cap level (reference third phase of EU ETS). Second, unit electricity CO_2 emissions are considered to be fixed due to the dominant share of coal (and other fossil fuels), which is unlikely to change significantly in the short term in the electricity sector. Third, the on-grid electricity price for conventional energy is anticipated to increase at an annual rate of 2.3% for the 2015–2020 period in China (Li & Wang, 2011). Fourth, it can be expected that the cost of wind and solar energy will fall annually by 2% and 7%, respectively (World Bank, 2011; Xie, Gao, & Han, 2009). This is partly due to the projected massive installation of wind and solar power in 2014–2017 with the goal of meeting REN targets, which could consequently reduce the deployment costs of wind and solar power. As the FIT is obtained based on the REN investment return and per unit REN electricity generation cost, it is assumed in this article that FIT levels for wind and solar will also fall annually by 2% and 7% from 2015 onwards. Such an assumption is also consistent with the increasing calls to reduce the FIT for wind power, which has not changed since 2009 (CNENERGY, 2013). Finally, as mentioned in Section 2.2, installers of wind and solar power are supposed to participate in ETSs. This is generally the case in China, where major wind and solar power developers are electricity production groups.

The following scenarios were adopted to calculate equations (3) to (5). The period is 2018–2020 and a national ETS is assumed to be in place from 2017, that date being supported by more than half of all experts in a recent carbon pricing survey in China (Jotzo, Dimitri, & Hugh, 2013). For the business-as-usual (BAU) scenario, FIT levels are assumed to be adjusted based on the rates mentioned above until 2020 for wind and solar power, and there is no ETS policy. Table 3 includes three alternative scenarios assessed with different annual carbon price growth rates of 10%, 30%, and 50%.

4. Results and discussion

4.1. Equivalent CO_2 price

Based on data for the year 2011 ($t = 2011$ in equation (1)), Figure 2 shows equivalent CO_2 prices for FIT to generate the current level of support incentives for wind and solar power development at the provincial level in China. These prices are also used as total carbon prices at the provincial level for later calculation. Four regions price categories (explained in Appendix 1) are used to simplify the presentation of results. Details of the calculation are provided in Appendix 2. In general, the equivalent CO_2 prices for FIT vary significantly among regions, for both wind and solar power. For wind they range from 191 yuan/tCO_2 in Hebei to 1523 yuan/tCO_2 in Qinghai province, while most provinces in eastern China have a price level in the range 200–400 yuan/tCO_2. For solar, equivalent CO_2 prices vary considerably, from a lowest level of 626 yuan/tCO_2 in Shanghai to 3477 yuan/tCO_2 in Qinghai, with an average level of 860 yuan/tCO_2. The higher price level for solar power indicates higher general development costs for solar power than for wind power in China, and this is the case in reality today.

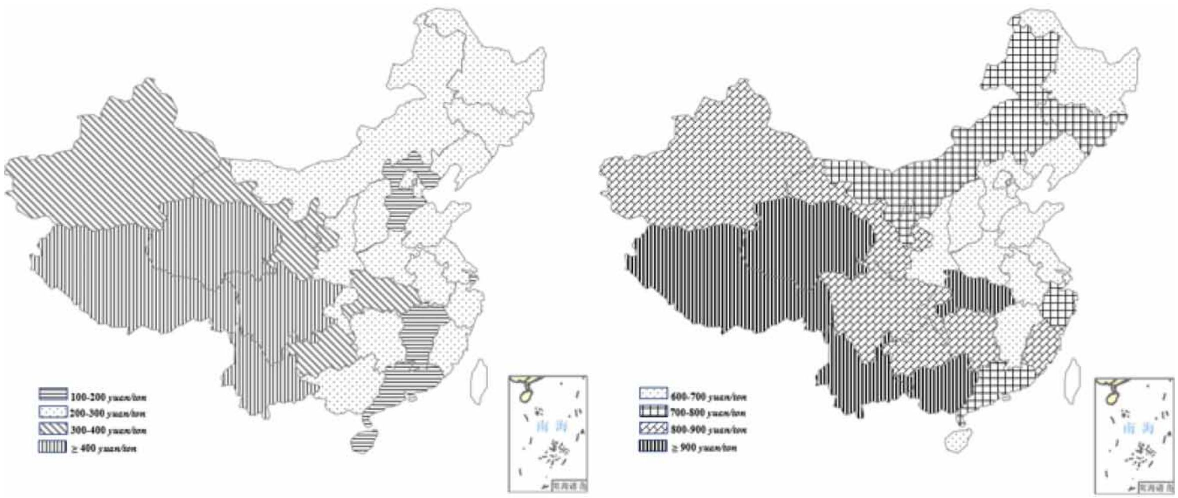

FIGURE 2 Equivalent CO_2 prices for wind power (left) and solar power (right) in provinces of China
Source: Authors.

In general, the equivalent CO_2 prices generated by FITs are much higher than the current average CO_2 price level of 35 yuan/tCO_2 in China from the pilot ETS (Table 1), as well as the CO_2 price in some Clean Development Mechanism (CDM) projects (see Table 4). The current carbon price level (35 yuan/tCO_2) only accounts for 23% and 6% of the lowest equivalent (implicit) CO_2 prices that FITs generate at the provincial level for wind and solar, respectively. Moreover, because the CO_2 price fluctuates in the ETS, it can only reflect the carbon cost at the moment the CO_2 emission quota is sold, and is not fully comparable with the FIT, as the latter provides stable cost anticipation for a firm. Therefore, unless the average ETS carbon price is higher than the equivalent FIT carbon price, the FIT will combine with ETS to generate incentives for developing REN. This confirms the short- and mid-term necessity of using a policy package (ETS and FIT) to carry out cost-efficient CO_2 mitigation.

TABLE 4 CER price of wind CDM project in selected provinces in China in 2011

Wind farm	CER price (yuan/tonne)	Equivalent CO_2 price in the province (yuan/tonne)	Ratio of CER price to equivalent carbon price
Fujian Liuao	68.3	254	26.9
Liaoning Fakushijianfang	82.9	257	32.3
Neimenggu Zhuozi	80.9	269	30.1

Source: Data collected by interviewing wind farm owners.

TABLE 5 FIT adjustment rates based on carbon price increase

	Wind power (%)				Solar power (%)		
Regions	I	II	III	IV	I	II	III
BAU	3.00				7.00		
S1	3.40	3.30	3.15	3.19	8.01	7.46	7.94
S2	3.99	3.84	3.63	3.69	8.43	7.65	8.33
S3	4.70	4.49	4.20	4.28	8.93	7.87	8.79

Note: See Table A1 in Appendix 1 for details of region categories.

4.2. FIT coherence with the ETS carbon price

Table 5 shows the results obtained using equations (3) to (5) in different scenarios. These results were obtained using the installed capacity of wind and solar power in each province in 2011 as a weight. Detailed provincial level results are given in Appendix 3. Under scenario S1, FITs for wind power are supposed to be reduced at annual rates of 3.4%, 3.3%, 3.15%, and 3.19% for regions I, II, III, and IV, respectively, and 8.01%, 7.46%, and 7.94% for regions I, II, and III, respectively, for solar power.[3] Compared to the reference scenario, where FITs for wind and solar power are assumed to fall by 3% and 7% per year, respectively, this will require provinces to further reduce their FIT levels on an annual basis by 0.4%, 0.26%, 0.18%, and 0.04%, respectively, for regions I to IV for wind power, and by 0.98%, 0.84%, and 0.86% for regions I to III for solar power, as a result of the introduction of a national carbon market. With the same type of calculation based on the data in Table 3, we can obtain annual FIT adjustment rates of 3.94%, 3.79%, 3.67%, and 3.47% for regions I to IV for wind, and 8.39%, 8.19%, and 8.22% for regions I to III for solar power under scenario S2; and 4.63%, 4.42%, 4.26%, and 3.99% for regions I to IV for wind, and 8.87%, 8.60%, and 8.64% for regions I to III for solar power under scenario S3.

Taking wind power as an example, Figure 3 provides an illustration of how the FIT develops in the future based on our calculation. Starting from 2011, the BAU scenario for FIT levels is identical to the FIT level that takes into account the carbon price changes in the ETS. Because we assume in this article that the FIT will fall from 2015 due to cost reductions, the FIT levels in both the BAU and S1 scenario fall. As the carbon price is assumed to increase 10% annually from 2018 until 2020, this requires further adjustment of the FIT levels applied to wind power relative to BAU FIT levels.

4.3. Discussion

The total (or equivalent) carbon prices calculated in Section 4.1 can be used as an indicator of the general development of wind and solar power in different provinces in China. The lower the equivalent CO_2 price for a province, the lower the level of cost incentives (and financial support) needed, and therefore the more significant the development of wind and solar power in the province. Based on provincial-level equivalent CO_2 prices and the specific development and energy contexts in each province in China, the extent to which a given province provides support can be explained by its electricity generation structure and the installed capacity of wind and solar power.

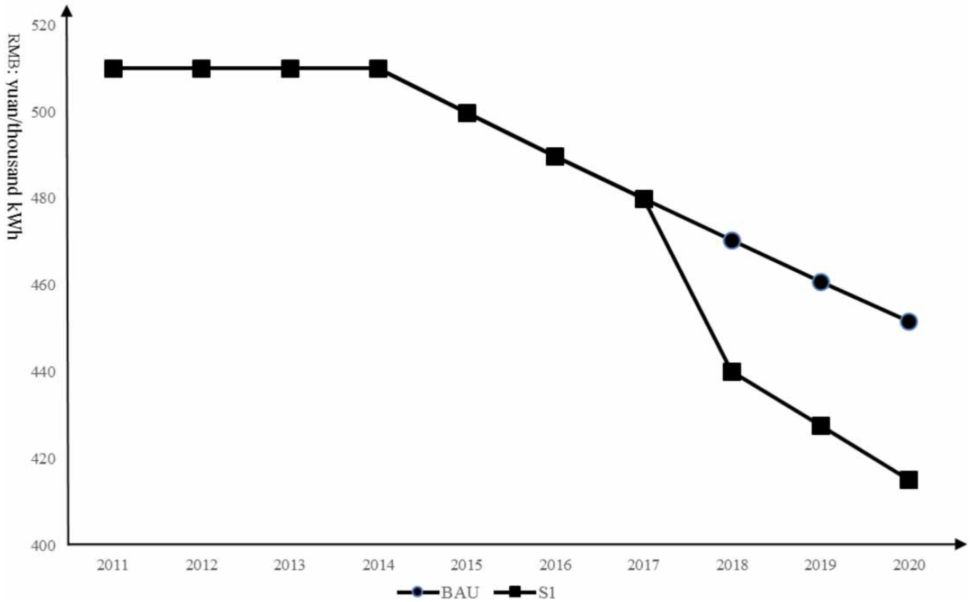

FIGURE 3 Wind power FIT changes under scenario S1 in region I: 2011–2020
Source: Authors.

First, in terms of the electricity generation structure, China's power sector is dominated by thermal power, followed by hydropower. For provinces where hydropower generation accounted for more than 20% of total electricity production in 2011 (see Figure 4), the equivalent FIT carbon prices for wind and solar are almost in a positive correlation with the share of hydropower in the electricity generation mix. This can be explained first by the fact that regions with comparative advantages in hydropower tend to provide more support for hydropower. With limited budgets and administrative capacities, this could increase the cost of developing other REN. Second, due to the design of the method, provinces with a higher share of hydropower in their electricity generation mix have a lower level of CO_2 emissions per unit of electricity (E^i_{Baseline} in equation (1)), and therefore a higher level of equivalent CO_2 price.

A major exception to the generally positive correlation between the equivalent CO_2 price and the share of hydropower in the electricity generation mix is Yunnan province (Figure 4). Its share of hydropower is lower than in Sichuan province, while its equivalent FIT CO_2 prices for wind and solar power are much higher than in Sichuan province. This can be explained by the lower on-grid conventional electricity price ($\text{FIT}^i_{C,t}$ in equation (1)) for Yunnan and the identical FIT level for wind and solar in Sichuan and Yunnan. Coal prices and grid companies' service costs are major contributors to the different conventional electricity on-grid prices.

Guangxi and Hunan provinces (Figure 4) are minor exceptions. The shares of hydropower in total electricity production in Guangxi and Hunan provinces are 39.99% and 34.08%, respectively, while their equivalent CO_2 prices are lower than those of Guizhou and Gansu provinces, the latter having

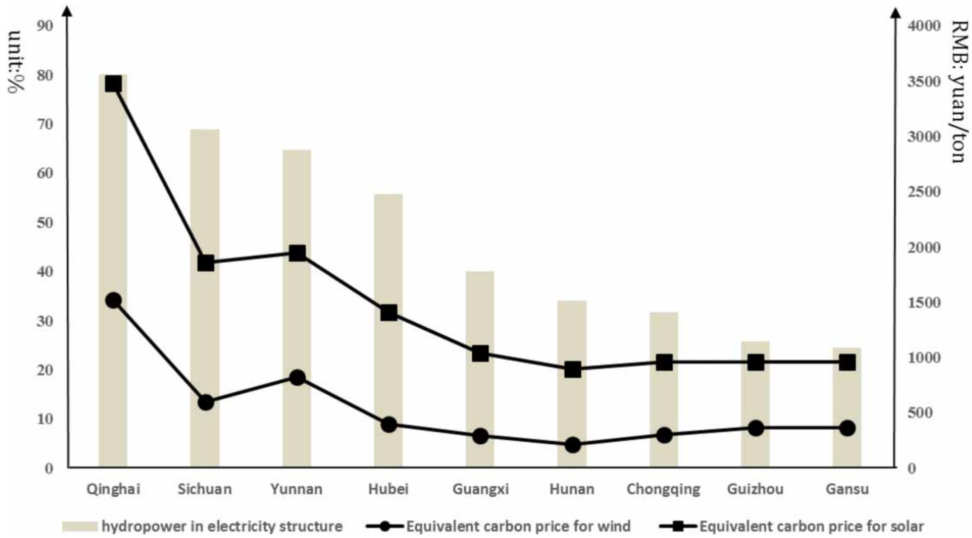

FIGURE 4 Hydropower and equivalent CO_2 price in 2011
Source: Authors.

a lower share of hydropower in electricity generation. This can be explained partly by the low total installed capacity of wind and solar in Guangxi and Hunan provinces, which cannot provide a sufficient scale effect. Consequently, more financial support is required in these provinces to deploy wind and solar power.

Second, equivalent FIT CO_2 prices for wind are generally in a slightly negative correlation with installation capacity at the provincial level. Figure 5 shows accumulated provincial-level wind power installation and the corresponding equivalent carbon prices generated by FITs. The scale effect of wind power helps to reduce the development and operational costs of wind power, which will require less financial support (a lower equivalent CO_2 price). However, there are a few exceptions that require further explanation. For example, Hainan and Jiangxi provinces both have lower equivalent CO_2 prices and accumulated wind power installation. This is due first to the dominant share of thermal power, which produces a lower equivalent CO_2 price in these provinces. Furthermore, the lack of onshore wind power resources is also a determinant of low installation capacity in Hainan. This is in accordance with the general relation between installed wind capacity and wind power resources at the provincial level. For example, Inner Mongolia (Neimenggu in Figure 5) is the leader in both wind power installations and resources. Yet, for Tibet and the western part of Qinghai province, where wind power resources are abundant, the limited development of wind power installations is a consequence of their distance from residential areas.

Third, for solar power, there is no evident correlation between the equivalent CO_2 price and installed capacity at the provincial level (Figure 6). This is primarily due to the relatively slow development and low total installed capacity levels of solar power for the period analysed (see Figure 1).

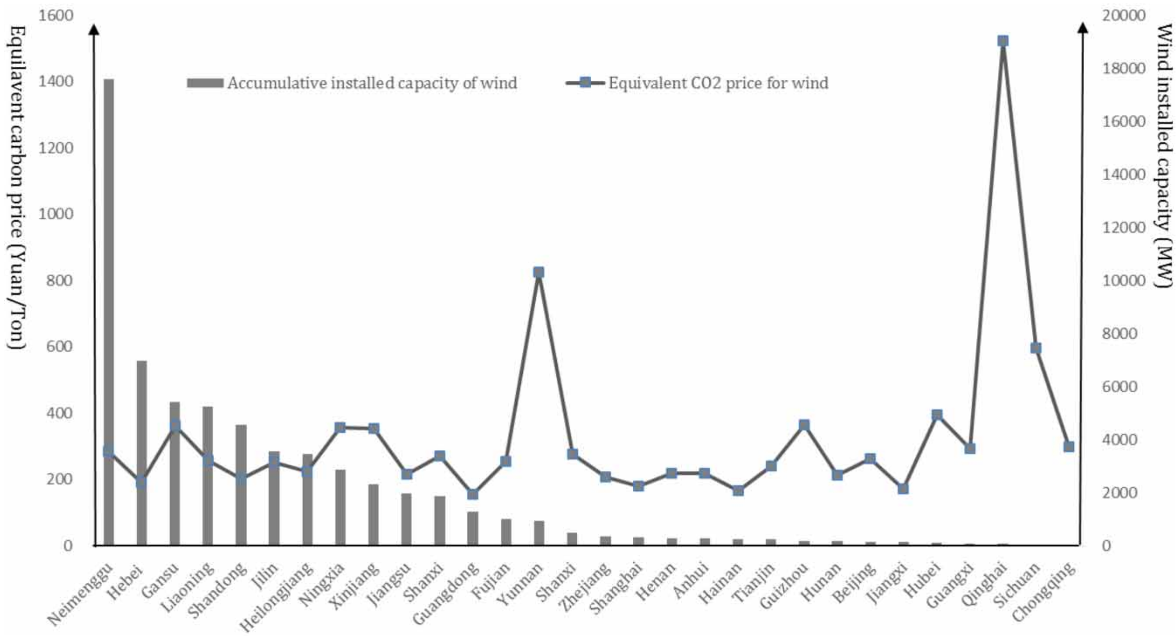

FIGURE 5 Wind accumulative installed capacities and equivalent CO_2 price in 2011
Source: Authors.

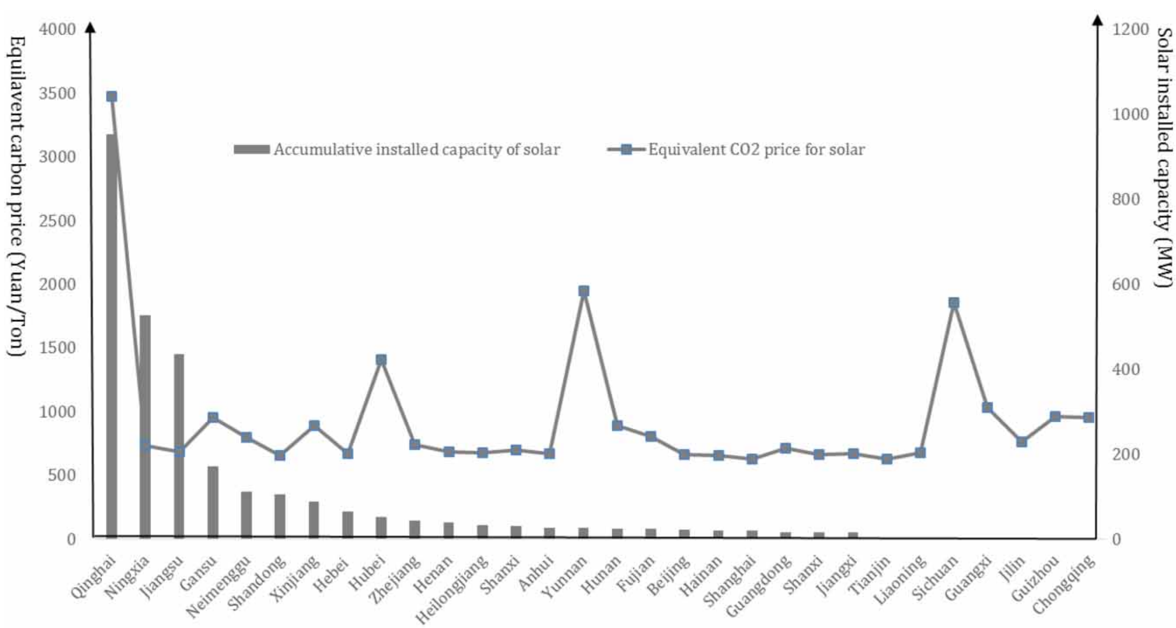

FIGURE 6 Solar accumulative installed capacities and equivalent CO_2 price in 2011
Source: Authors.

5. Conclusions and policy application

This article strikes a balance between simplicity and accuracy and provides a feasible methodology for China in order to ensure a coherent market-based climate policy package with a reasonable cost of policy management. One key message is that the carbon price impact should be added to FIT policy making to ensure that the FIT–ETS climate policy package remains cost-efficient. The method proposed in this article can be adapted to different FIT and ETS designs in China:

1. *One single nationwide ETS without ETS carbon price intervention*. In this case, the method presented in this article can be directly adopted to adjust FIT levels as the carbon price fluctuates. One additional point to note is that, in this article, we assume that the carbon price increases constantly every year. In reality, these might not be constant, and there may be positive, zero, or negative ETS carbon price changes from year to year. The real ETS carbon price change can be used to calculate the FIT adjustment level and to set this level for REN in the coming years.
2. *One single nationwide ETS with ETS carbon price intervention*. This scenario is due to the fact that some of the current pilot ETSs have established a government mechanism to release additional quotas in the case of insufficient quota supply or to buy back quotas in the case of oversupply. This carbon price intervention mechanism could be further applied to a nationwide ETS. In this case, the authority can either adjust ETS quotas without further changes to FIT levels, or amend FIT levels while making no ETS quota adjustment.
3. *Current pilot ETSs*. This method can also be applied to the current pilot ETSs (at seven local levels) in China. Two options can be considered: first, the central government adjusts FIT levels only in provinces conducting pilot ETS; second, FIT levels can remain unchanged (as they are in the real current context in China), while local pilot ETS designers should adjust quotas in the current ETS and baselines for further ETS design. In both cases, the optimal total carbon price (as used in this article) must be guaranteed. This can prevent investment leakages for REN among regions with or without ETS.

The indicator of total carbon price as a sum of the ETS carbon price and the implicit carbon price that a FIT for REN generates can be either fixed or variable based on the additional assessment of optimal or cost-effective policy instrument packages. This is of particular interest to the current debate on adjusting FITs for wind power in China due to development cost changes. Furthermore, a FIT was only implemented in 2011 for solar power. Despite the fact that there are presently no similar debates about adjusting FITs for solar power in China, the method proposed in this article could be helpful in the short term when the costs of solar power decrease.

However, as pointed out in the introduction, the major limitation of this article is the use of the equivalent CO_2 price as a proxy to adjust FIT levels when the ETS carbon price changes. There is no evidence that the current level of the equivalent CO_2 price generated by FIT policies is optimal to ensure policy cost-efficiency. This does not refute the feasibility of the method proposed in this article. Other complex modelling works can somehow obtain this optimal level. Finally, further studies can either focus on theoretical work on the co-existence of FITs and ETSs in the Chinese context, or on specific sectoral-level analysis.

Notes

1. Except PV projects in Tibet province, which can still receive the FIT at 1.15 yuan/kWh for projects implemented after July 2011.
2. Grid-wide analysis may be more appropriate in terms of methodology. However, as shown in equation (1), the data for the conventional electricity price purchased by grid companies, $FIT^{i}_{C,t}$, is classified and published at the provincial level by the NDRC in China. This is the major reason why a provincial analysis is adopted in equation (2) instead of a grid-level analysis.
3. Regions I, II, III, and IV for wind, and regions I, II, and III for solar, indicate different groups of provinces based on FIT levels. For details, see Appendix 1.

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Appendix 1. FITs for wind and solar in Chinese provinces

TABLE A1 FITs for wind and solar power in China

For wind power

Region	Feed-in tariff (yuan/kWh, tax included)	Provinces
I	0.51	Neimenggu, Xinjiang
II	0.54	Hebei, Neimenggu, Gansu
III	0.58	Jilin, Heilongjiang, Gansu, Xinjiang, Ningxia
IV	0.61	Others

For solar power

Region	Feed-in tariff (yuan/kWh, tax included)	Provinces
I	0.90	Ningxia, Qinghai, Gansu, Xinjiang, Neimenggu
II	0.95	Beijing, Tianjin, Heilongjiang, Jilin, Liaoning, Sichuan, Yunnan, Neimenggu, Hebei, Shanxi, Shanxi, Qinghai, Gansu, Xinjiang
III	1.0	Others

Notes: In China, considering to conditions of wind and solar resources and deployment costs, the central government developed a four-region FIT policy for wind power development and a three-region FIT policy for solar power development. Each region includes different provinces.For some provinces there are two or more FIT levels for a sub-region within the jurisdiction.For solar power, the Tibet (Xizang) province in not included in the table.

Appendix 2. Equivalent CO_2 price for wind and solar

Province	Equivalent CO_2 price (wind power) (yuan/tCO_2)	Equivalent CO_2 price (solar power) (yuan/tCO_2)
Qinghai	1523.26	3477.64
Ningxia	357.67	734.29
Jiangsu	216.70	686.23
Gansu	361.63	955.83
Neimenggu	284.50	798.20
Shandong	201.85	652.21
Xinjiang	354.73	886.84

(*Continued*)

Appendix 2. Continued

Province	Equivalent CO_2 price (wind power) (yuan/tCO_2)	Equivalent CO_2 price (solar power) (yuan/tCO_2)
Hebei	191.40	670.50
Hubei	395.05	1409.99
Zhejiang	208.46	739.83
Henan	219.52	685.30
Heilongjiang	223.41	679.85
Shanxi	277.58	699.66
Anhui	218.68	670.17
Yunnan	824.72	1949.04
Hunan	212.85	892.70
Fujian	254.18	806.14
Beijing	262.00	660.92
Hainan	167.05	656.15
Shanghai	180.33	626.31
Guangdong	155.09	715.12
Shanxi	270.80	665.46
Jiangxi	172.92	673.19
Tianjin	241.89	630.37
Liaoning	257.46	678.71
Sichuan	597.72	1857.65
Guangxi	294.28	1035.68
Jilin	253.32	759.13
Guizhou	364.09	962.73
Chongqing	298.24	955.76

Notes: Data are unavailable for Tibet province. For provinces with two or more FIT levels we show the arithmetic average value.

Appendix 3. Detailed results of provincial-level FIT adjustments: scenarios S1–S3

Note that ‘A’ and ‘B’ indicate different FIT levels for the same province (i.e. FITs for different regions within a province).

New FITs for wind consider the CO_2 price in the national carbon market

Scenario 1 (S1): 10% increment of CO_2 price per year

Province	Initial FIT level (yuan/MWh)	2018 (yuan/MWh)	2019 (yuan/MWh)	2020 (yuan/MWh)
Qinghai	610	555.69	543.74	531.94
Yunnan	610	550.55	538.09	525.73

(*Continued*)

Appendix 3. Continued

Province	Initial FIT level (yuan/MWh)	2018 (yuan/MWh)	2019 (yuan/MWh)	2020 (yuan/MWh)
Sichuan	610	551.85	539.52	527.30
Xinjiang B	580	505.66	492.02	478.31
Gansu B	580	510.74	497.62	484.46
Hubei	610	547.27	534.48	521.77
Guizhou	610	536.59	522.73	508.83
Gansu A	540	473.84	461.46	449.03
Ningxia	580	500.99	486.89	472.66
Xinjiang A	510	441.09	428.75	416.31
Neimenggu East	540	466.93	453.85	440.66
Chongqing	610	538.92	525.29	511.66
Guangxi	610	541.60	528.25	514.90
Shánxi	610	530.42	515.95	501.38
Shanxi	610	528.18	513.49	498.67
Neimenggu West	510	439.26	426.73	414.09
Beijing	610	528.55	513.89	499.11
Heilongjiang B	610	530.22	515.72	501.13
Liaoning	610	530.36	515.88	501.30
Fujian	610	534.38	520.30	506.17
Tianjin	610	527.64	512.88	498.00
Hebei South	610	529.25	514.65	499.95
Heilongjiang A	580	502.55	488.61	474.55
Henan	610	529.15	514.55	499.84
Anhui	610	528.09	513.38	498.56
Jiangsu	610	529.42	514.84	500.16
Hunan	610	539.70	526.15	512.60
Zhejiang	610	533.29	519.10	504.84
Shandong	610	528.01	513.29	498.45
Shanghai	610	527.66	512.91	498.04
Jiangxi	610	531.46	517.09	502.63
Hainan	610	530.75	516.31	501.77
Guangdong	610	534.79	520.75	506.66
Hebei North	540	464.68	451.38	437.94
Jilin A	580	505.72	492.09	478.39
Jilin B	610	533.39	519.21	504.96

Scenario 2 (S2): 30% increment of CO_2 price per year

Province	Initial FIT level (yuan/Mwh)	2018	2019	2020
Qinghai	610	555.69	542.35	528.60
Yunnan	610	550.55	535.67	519.92
Sichuan	610	551.85	537.36	522.12
Xinjiang B	580	505.66	486.16	464.24
Gansu B	580	510.74	492.77	472.83
Hubei	610	547.27	531.41	514.39
Guizhou	610	536.59	517.51	496.32
Gansu A	540	473.84	456.61	437.40
Ningxia	580	500.99	480.09	456.35
Xinjiang A	510	441.09	422.89	402.23
Neimenggu East	540	466.93	447.62	425.71
Chongqing	610	538.92	520.55	500.27
Guangxi	610	541.60	524.04	504.80
Shánxi	610	530.42	509.50	485.91
Shanxi	610	528.18	506.59	482.13
Neimenggu West	510	439.26	420.50	399.13
Beijing	610	528.55	507.07	482.75
Heilongjiang B	610	530.22	509.24	485.57
Liaoning	610	530.36	509.42	485.80
Fujian	610	534.38	514.65	492.60
Tianjin	610	527.64	505.88	481.20
Hebei South	610	529.25	507.98	483.92
Heilongjiang A	580	502.55	482.12	458.99
Henan	610	529.15	507.85	483.76
Anhui	610	528.09	506.47	481.97
Jiangsu	610	529.42	508.20	484.21
Hunan	610	539.70	521.56	501.59
Zhejiang	610	533.29	513.23	490.75
Shandong	610	528.01	506.36	481.82
Shanghai	610	527.66	505.92	481.25
Jiangxi	610	531.46	510.85	487.67
Hainan	610	530.75	509.93	486.46
Guangdong	610	534.79	515.18	493.29
Hebei North	540	464.68	444.70	421.91
Jilin A	580	505.72	486.24	464.34
Jilin B	610	533.39	513.36	490.92

Scenario 3 (S3): 50% increment of CO_2 price per year

Province	Initial FIT level (yuan/MWh)	2018 (yuan/MWh)	2019 (yuan/MWh)	2020 (yuan/MWh)
Qinghai	610	555.69	540.95	524.71
Yunnan	610	550.55	533.25	513.15
Sichuan	610	551.85	535.20	516.08
Xinjiang B	580	505.66	480.30	447.82
Gansu B	580	510.74	487.92	459.26
Hubei	610	547.27	528.34	505.78
Guizhou	610	536.59	512.30	481.73
Gansu A	540	473.84	451.77	423.83
Ningxia	580	500.99	473.29	437.32
Xinjiang A	510	441.09	417.02	385.81
Neimenggu East	540	466.93	441.39	408.26
Chongqing	610	538.92	515.80	486.98
Guangxi	610	541.60	519.83	493.02
Shánxi	610	530.42	503.06	467.87
Shanxi	610	528.18	499.70	462.83
Neimenggu West	510	439.26	414.27	381.69
Beijing	610	528.55	500.25	463.66
Heilongjiang B	610	530.22	502.75	467.41
Liaoning	610	530.36	502.96	467.72
Fujian	610	534.38	509.00	476.77
Tianjin	610	527.64	498.88	461.60
Hebei South	610	529.25	501.30	465.22
Heilongjiang A	580	502.55	475.64	440.83
Henan	610	529.15	501.15	465.01
Anhui	610	528.09	499.56	462.62
Jiangsu	610	529.42	501.55	465.61
Hunan	610	539.70	516.97	488.74
Zhejiang	610	533.29	507.35	474.31
Shandong	610	528.01	499.43	462.43
Shanghai	610	527.66	498.92	461.66
Jiangxi	610	531.46	504.62	470.20
Hainan	610	530.75	503.55	468.60
Guangdong	610	534.79	509.61	477.69
Hebei North	540	464.68	438.02	403.21
Jilin A	580	505.72	480.39	447.96
Jilin B	610	533.39	507.50	474.53

For solar

Scenario 1 (S1): 10% increment of CO_2 price per year

Province	Initial FIT level (yuan/MWh)	2018 (yuan/MWh)	2019 (yuan/MWh)	2020 (yuan/MWh)
Qinghai	950	703.69	653.25	606.22
Yunnan	950	698.55	647.60	600.00
Sichuan	950	699.86	649.03	601.58
Hubei	1000	732.68	678.78	628.39
Gansu B	950	686.41	634.25	585.32
Guangxi	1000	727.01	672.54	621.53
Guizhou	1000	721.99	667.02	615.46
Gansu A	900	649.01	599.46	552.97
Chongqing	1000	724.33	669.59	618.28
Xinjiang B	950	681.33	628.65	579.17
Hunan	1000	725.11	670.45	619.23
Xinjiang A	900	643.93	593.87	546.82
Neimenggu East	950	679.50	626.64	576.95
Fujian	1000	719.79	664.60	612.79
Neimenggu West	900	642.10	591.85	544.60
Shánxi B	1000	715.83	660.24	608.00
Jilin	950	681.39	628.72	579.24
Zhejiang	1000	718.69	663.39	611.47
Ningxia	900	639.26	588.73	541.17
Guangdong	1000	720.20	665.05	613.29
Shánxi A	950	678.43	625.46	575.65
Hebei South	1000	714.65	658.95	606.58
Jiangsu	1000	714.83	659.14	606.79
Henan	1000	714.56	658.85	606.47
Heilongjiang	950	678.22	625.24	575.41
Liaoning	950	678.36	625.39	575.58
Jiangxi	1000	716.87	661.39	609.26
Anhui	1000	713.50	657.68	605.18
Shanxi	950	676.19	623.00	572.94
Beijing	950	676.56	623.40	573.39
Hainan	1000	716.16	660.60	608.40
Shandong	1000	713.41	657.59	605.08
Hebei North	950	677.25	624.17	574.23
Tianjin	950	675.64	622.40	572.28
Shanghai	1000	713.07	657.21	604.66

Scenario 2 (S2): 30% increment of CO_2 price per year

Province	Initial FIT level (yuan/MWh)	2018 (yuan/MWh)	2019 (yuan/MWh)	2020 (yuan/MWh)
Qinghai	950	703.69	651.86	602.88
Yunnan	950	698.55	645.18	594.20
Sichuan	950	699.86	646.87	596.40
Hubei	1000	732.68	675.71	621.01
Gansu B	950	686.41	629.40	573.68
Guangxi	1000	727.01	668.33	611.43
Guizhou	1000	721.99	661.81	602.95
Gansu A	900	649.01	594.61	541.33
Chongqing	1000	724.33	664.84	606.89
Xinjiang B	950	681.33	622.79	565.09
Hunan	1000	725.11	665.86	608.21
Xinjiang A	900	643.93	588.01	532.74
Neimenggu East	950	679.50	620.41	562.00
Fujian	1000	719.79	658.95	599.23
Neimenggu West	900	642.10	585.62	529.65
Shánxi B	1000	715.83	653.80	592.54
Jilin	950	681.39	622.87	565.19
Zhejiang	1000	718.69	657.52	597.38
Ningxia	900	639.26	581.94	524.85
Guangdong	1000	720.20	659.48	599.91
Shánxi A	950	678.43	619.02	560.19
Hebei South	1000	714.65	652.27	590.55
Jiangsu	1000	714.83	652.50	590.84
Henan	1000	714.56	652.15	590.39
Heilongjiang	950	678.22	618.75	559.84
Liaoning	950	678.36	618.93	560.08
Jiangxi	1000	716.87	655.15	594.29
Anhui	1000	713.50	650.77	588.60
Shanxi	950	676.19	616.11	556.40
Beijing	950	676.56	616.58	557.03
Hainan	1000	716.16	654.22	593.09
Shandong	1000	713.41	650.66	588.45
Hebei North	950	677.25	617.49	558.20
Tianjin	950	675.64	615.39	555.48
Shanghai	1000	713.07	650.21	587.87

Scenario 3 (S3): 50% increment of CO_2 price per year

Province	Initial FIT level (yuan/MWh)	2018 (yuan/MWh)	2019 (yuan/MWh)	2020 (yuan/MWh)
Qinghai	950	703.69	650.47	598.98
Yunnan	950	698.55	642.76	587.42
Sichuan	950	699.86	644.71	590.35
Hubei	1000	732.68	672.63	612.41
Gansu B	950	686.41	624.55	560.11
Guangxi	1000	727.01	664.13	599.65
Guizhou	1000	721.99	656.60	588.36
Gansu A	900	649.01	589.77	527.76
Chongqing	1000	724.33	660.10	593.61
Xinjiang B	950	681.33	616.93	548.68
Hunan	1000	725.11	661.27	595.36
Xinjiang A	900	643.93	582.14	516.33
Neimenggu East	950	679.50	614.18	544.55
Fujian	1000	719.79	653.29	583.40
Neimenggu West	900	642.10	579.39	512.20
Shánxi B	1000	715.83	647.36	574.49
Jilin	950	681.39	617.02	548.81
Zhejiang	1000	718.69	651.65	580.93
Ningxia	900	639.26	575.14	505.82
Guangdong	1000	720.20	653.91	584.32
Shánxi A	950	678.43	612.57	542.14
Hebei South	1000	714.65	645.59	571.85
Jiangsu	1000	714.83	645.85	572.23
Henan	1000	714.56	645.45	571.63
Heilongjiang	950	678.22	612.27	541.68
Liaoning	950	678.36	612.48	542.00
Jiangxi	1000	716.87	648.91	576.83
Anhui	1000	713.50	643.86	569.25
Shanxi	950	676.19	609.21	537.10
Beijing	950	676.56	609.77	537.93
Hainan	1000	716.16	647.85	575.23
Shandong	1000	713.41	643.73	569.05
Hebei North	950	677.25	610.81	539.50
Tianjin	950	675.64	608.39	535.87
Shanghai	1000	713.07	643.22	568.29