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Analyzing the penetration barriers of clean generation technologies in China's power sector using a multi-region optimization model

Jingxuan Hui [a], Wenjia Cai [a,*], Can Wang [a,b], Minhua Ye [b]

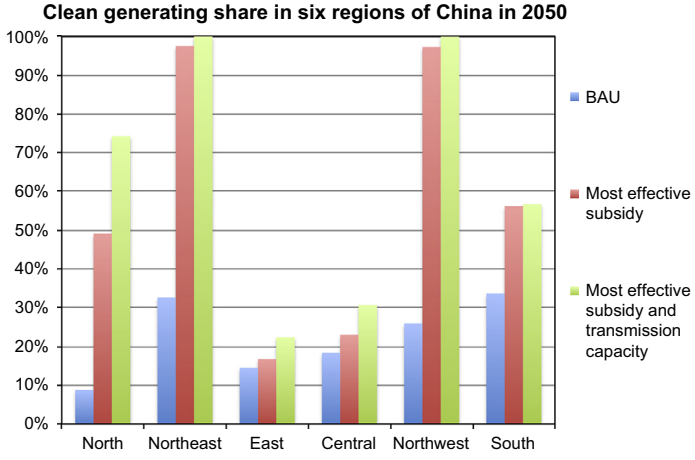
[a] Ministry of Education Key Laboratory for Earth System Modeling, and Center for Earth System Science, Room S925, Meng Minwei Science Building, Tsinghua University, Beijing 100084, China

[b] State Key Joint Laboratory of Environment Simulation and Pollution Control (SKLESPC), and School of Environment, Tsinghua University, Beijing 100084, China

HIGHLIGHTS

- A quantitative method for the penetration barriers of clean power is developed.
- This study offers a subsidy level by region for each clean generation technology.
- This study suggests an interregional transmission capacity plan for 2050.
- The clean power share in China can achieve 59.6% by 2050 with suggested solutions.

GRAPHICAL ABSTRACT



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ABSTRACT

In order to peak emissions before 2030, achieve the goal of 2 °C temperature rise and protect people's health, China's power sector urgently needs to increase its share of clean energy. However, high generation costs and an inadequate grid transmission capacity still impedes clean generation technology development. It is still unclear which conditions would enable the large penetration of clean generation technologies in China's power sector. Thus, this study develops a quantitative calculation method to find the most effective regional subsidy and interregional transmission capacity levels, so that the penetration barriers can be overcome and clean energy resources in China can be fully used. The simulation results indicate that the most effective subsidy for each clean generation technology differs from region to region. Using solar power as an example, the most effective subsidy in the north, northeast and northwest regions is 0.4 RMB/kW h and in the south region it is 0.7 RMB/kW h. If these subsidies are implemented, the share of solar power in the Chinese power sector can reach 24.7% by 2050. Additionally, the results also indicate that the most effective interregional transmission capacity in 2050 is about 13 times of the current transmission capacity plan. Under the most effective regional subsidies and interregional transmission capacity, the share of clean energy generation in the Chinese power sector can reach 59.6%.

* Corresponding author. Tel.: +86 010 62792509; fax: +86 010 62794115x8008.
E-mail address: wcai@tsinghua.edu.cn (W. Cai).

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1. Introduction

In recent years, China has quickly risen to the top ranks in global energy demand and its energy consumption is still growing at an alarming speed. This energy-intensive development has brought China a number of serious environmental problems, such as haze and the greenhouse effect. Given the importance of reducing energy intensity, protecting people's health, peaking emissions earlier than 2030 and achieving the goal of 2 °C temperature rise, China needs to shift to a cleaner energy structure. The Chinese power sector, the largest energy-related emission sector which consumes approximately 50% of China's coal and emits more than 40% of China's CO_2 from fossil fuel combustion, plays a vital role in this transition. Within the power sector, the role of clean generation technologies is vital. Although China has already created a number of policies to support the large-scale development of clean generation technologies (as elaborated upon in Section 2), there are still many barriers and challenges.

Previous studies have identified the barriers which impend clean generation technology development in China. Wang did an in-depth study on China's wind power technology [1]. He found that high generation costs is one of the major barriers in wind's deployment, and cost reduction policies can successfully help increase the installed capacity. However, success in wind-generated electricity has yet to be achieved for the backward grid system. To further shed light on the transmission barriers for clean generation technologies, Wang and Chen present an assessment of clean generation reserves in China [2]. Although the distribution of clean energy resources in China differs by technology, most of the potential clean energy resources, such as hydroelectricity, wind power and solar energy, are distributed in the northern and western parts of China, far away from the energy load centers. The unbalanced spatial distribution between energy resources and demands creates many challenges. The above evidence indicates that high generation costs and inadequate grid transmission capacity has considerable negative impacts of China's clean energy development.

Several studies made a step forward, offering detailed methods to help overcome these barriers. Lam et al. found that large scale wind power development in China is perceived to be driven by factors that can have an immediate, certain impact on a developer's cash flows, such as high FIT (Feed-in-tariff) [3]. Zhao et al. [4] also put forward a similar view suggesting that the feed-in tariff has to be increased to around 0.6 Yuan/kW h to ensure that wind power projects are profitable in China, as the current electricity price is too low. In terms of transmission, in order to strengthen grid transmission capacity and avoid wind power waste in Inner Mongolia, Zeng et al. suggested that the government should develop a new ultra-high voltage transmission channel from the Meng Xi power grid to the Beijing–Tianjin–Hebei region, construct UHV DC channels between Ordos and central China and between South Huhhot and Nanchang, and the two channels connected to Mengxi grid [5]. Although numerous studies have identified the development barriers of clean generation technology and offered detailed suggestions to overcome them, to the best of our knowledge, until now, no study has quantitatively calculated these barriers or offered a quantified solution considering various technology and region differences. Therefore, it is still unclear which conditions would enable a large penetration of clean generation technologies in China. Due to the lack of this information, there has also been an inadequate policy response. In other words, the penetration barriers of clean generation technologies are unclear.

The motivation of this study is to fill this gap by calculating the penetration barriers of various clean generation technologies in different regions and put forward policy suggestions with varying time scales for breaking the barriers. Taking the Chinese power sector as the targeted sector, we try to recognize and quantify the crucial barriers of clean generation technology development under the pressure of deep decarbonization. Furthermore, we calculate the subsidy and transmission capacity that will adequately help clean generation technology overcome the barriers. While there are many studies that analyze the penetration barriers of clean generation technologies [1,2,5], very few use the quantitative calculation method to analyze what exact conditions would enable the large penetration of clean generation technologies. In Section 2, we will introduce the current policy framework for clean generation development in China. In Section 3, we will describe the analysis framework and methodology in detail. In Section 4, we will discuss the scenario analysis of penetration barriers of clean generation technologies. Lastly, in Section 5, we will offer policy implications for clean energy development.

2. Current promotional policy framework

(i) Renewable portfolio standard

The National Development & Reform Commission (NDRC) introduced renewable portfolio standards in 2007 in China, linked to the country's mid-term (2007–2010) and long-term (until 2020) development plans. In regions served by centralized power grids, the share of power generation form non-hydro renewable sources should reach 1% of the total by 2010 and 3% of the total by 2020, according to the plan [6]. However, due to the lack of monitoring and compliance requirements, none of the six largest generators had met the 3% renewable energy target in 2010. To address these problems, the NDRC began to develop an improvement plan in 2011. This draft plan for renewable portfolio standards was released in May 2012 for public consultation. State-owned enterprises have thus far resisted these new requirements, which were still under debate in mid-2014. The renewable portfolio standard is expected to be implemented by the end of 2015 or in 2016.

(ii) Tariff based support mechanisms

According to the Renewable Energy Law, the purchase price of renewable electricity generation is determined by the NDRC. Two main methods have been adopted; competitive tendering (government-guided pricing using an auction mechanism) and Feed-in Tariff (FIT). Under the concession program, investors and developers are selected for renewable energy projects such as large wind farms or solar plants through a competitive bidding process. The government is committed to coordinating connection to the power grid and purchasing all the electricity generated by the concession projects. These auctions were the basis for setting the level for the FIT as the government was able to gather cost information from various renewable energy projects. A categorized on-grid price setting for each individual source of renewable energy generation connected to the grid has been implemented to determine the FIT from 2005 onwards. To set the price, the following factors are taken into account [7]:

- Techno-economic performance of different renewable energy technologies
- Geographic location
- Availability of renewable energy resources
- The FIT rates evolution over time and their continuous reduction according to the cost of development.

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