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# Costs and benefits of renewable energy development in China's power industry

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ABSTRACT

China's power sector has become the largest contributor to China's carbon emissions because of its coal-dominated power structure. Replacing fossil fuels with renewable energy is an effective way to reduce carbon emissions and, therefore, a series of targets for renewable electricity generation have been put forward in national plans. However, how these targets will be reached is unclear. This paper uses a Long-range Energy Alternative Planning system (LEAP) model to explore the optimum development path of China's power sector from 2015 to 2050, taking into consideration the impacts of the renewable energy targets. Three scenarios are designed to examine the costs and benefits of developing renewable energy and improving the technologies for renewable power generation, comprising a base scenario, a renewable energy policy scenario and a technological progress scenario. The results show that the power generation cost would increase by at least 2.31 trillion RMB and that $CO_2$ emissions would be reduced by 35.8 billion tonnes during 2015–2050 if power generation follows current planning. Furthermore, every 1% increase in the capacity factors of renewable electricity would on average result in the cumulative $CO_2$ emissions decreased by 979 million tonnes and average $CO_2$ abatement cost decreased by 5.56 RMB/t$CO_2$ during 2015–2050. Based on this study, several policy implications are proposed for the development of power sector in China. Firstly, government may reconsider the current planning for gas-fired power and nuclear power to reach low-carbon electricity generation. Secondly, adjusting the carbon price can offset the additional cost of renewable electricity generation. Thirdly, promoting advanced technologies to match renewable electricity generation can obtain greater economic and environmental benefits. Finally, from the perspective of development potential, reducing the costs of solar power would be the emphasis at this stage.



## 1. Introduction

China has become the largest contributor to $CO_2$ emissions around the world, accounting for more than a quarter of global $CO_2$ emissions since 2009 [1,2]. This results mainly from the large amounts of fossil fuels that are being consumed in progressing China's economic development. In order to mitigate the associated environmental issues, the Chinese government has set targets to cut $CO_2$ emissions per unit of GDP by 40–45% by 2020 and 60–65% by 2030 relative to those of 2005 levels [3,4]. The power industry is the largest contributor to China's carbon emissions. In the past decade, $CO_2$ emissions in the power sector have accounted for about 49.1% of China's $CO_2$ emissions and 32.1% of the world's $CO_2$ emissions because of the industry's coal-dominated power structure [5]. Therefore, turning to low-carbon electricity generation would have a significant impact in terms of reducing emissions [6]. Due to the lack of natural gas and the safety of nuclear energy, replacing fossil fuels with renewable energy could be an option for achieving sustainable development of China's power sector [7–11].

At present, coal remains the main source for electricity generation in China. The share of coal-fired power in total electricity generation was about 69% in 2015 (see Fig. 1), which is much higher than developed countries [12]. For instance, in 2015, the coal-fired power accounted for 34%, 23% and 2% of the total power generation

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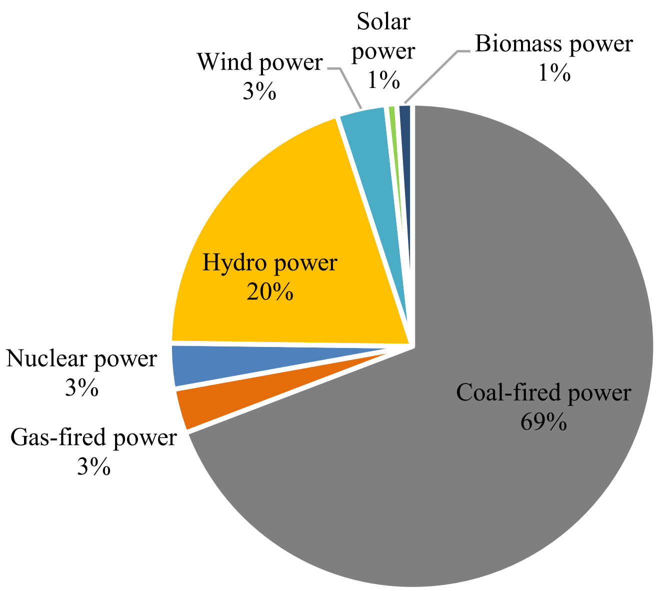


**Fig. 1.** Share of electricity generated by different technologies in China in 2015 Data source: Planning and Statistics of China Electricity Council.

in the United States (US), the United Kingdom and France, respectively [13]. There is a large gap between China's performance in clean power generation and that of other countries. In order to improve its share of clean energy power generation, the Chinese government has set a series of plans for nonfossil energy. These targets aim to increase the share of nonfossil energy in the total primary energy to at least 15% by 2020, according to China's 13th Five Year Plan, and to 20% by 2030, according to US-China Joint Presidential Statement on Climate Change [3,4]. More detailed medium- and long-term planning for renewable electricity generation has been put forward. For example, there are plans for the capacity of wind power and solar power to reach 210 and 110 GW respectively, by 2020. However, there is no clear instructions guiding the deployment of power generation technologies (including both renewable and non-renewable technologies) to achieve these plans. Moreover, the capital requirements and environmental impacts accompany with these proposed plans are unknown.

To answer these questions, this paper simulates the optimal development path for the power sector, based on minimum costs, using the Long-range Energy Alternative Planning system (LEAP) model. First, the strategies for investment and operations under current planning are proposed. The impacts of renewable electricity planning on costs and $CO_2$ emissions are determined by comparing a base scenario (BAU) and a renewable energy policy scenario (REP). Further, technological progress in relation to renewable electricity generation is considered. By comparing the REP and a technology progress scenario (TechImp), the impacts of technological progress on costs and $CO_2$ emissions are assessed.

The structure of this paper is as follows. Section 2 provides literature review and Section 3 presents the methodology and data. In Section 4, we determine the optimal development path for China's power sector and provide a discussion. Section 5 summarizes the main conclusions and Section 6 puts forward corresponding policy implications.

## 2. Literature review

A myriad of studies have highlighted the importance of renewable energy in decarbonizing electricity generation worldwide by examining the relationship between renewable energy use and $CO_2$ emissions. Some of the existing studies have analyzed the impact of pollutant emissions targets on the power development path. For instance, Koltsaklis (2014) presented a mixed-integer linear programming (MILP) model for the optimal long-term energy planning of power generation system in Greece considering the national environmental policy. The results show that the installed capacity of wind turbines and solar plants need to reach 5452.4 MW and 2123.7 MW in 2020, and 8452.4 MW and 2723.7 MW in 2030 [14]. Barteczko-Hibbert (2014) developed a multi-period MILP model to explore future pathways for electricity supply in the United Kingdom considering the carbon reduction targets. The results show that the percentage contribution of renewable electricity will reach 40% in 2060 [15]. Anandarajah (2014) analyzed the role of renewables to meet India's climate change mitigation targets in 2050 using a multi-region global energy system model called TIAM-UCL. The results show that renewable energy can play an important role to decarbonize the economy, especially the solar and wind. The renewables will contribute 63% of total $CO_2$ reductions by 2050 [16]. Muis (2010) developed a MILP model for the optimal planning of electricity generation schemes to meet $CO_2$ emission target in Peninsular Malaysia. The study predicted that Malaysia has potential to generate up to 9% of electricity from renewable energy based on the available sources [17]. Further studies have directly analyzed the impact of renewable energy consumption targets and capacity planning on power development paths. For example, Park (2016) explored the optimum renewable energy portfolio in Korea considering the 3rd Renewable Energy Basic Plan using TIMES model, which is one of the leading bottom—up models. The study projected that the annual electricity generation amounts would achieve 7205 GWh by solar power and 12268 GWh by wind power in 2030 [18]. Georgiou (2016) proposed MILP energy model for the long-term electricity planning of Greek power supply sector considering renewable energy penetration target. The results show that the share of renewable electricity generation will reach around 50% after 2020 [19]. All these studies showed that developing renewable energy can play an important role for reducing fossil-fuel consumption and $CO_2$ emissions, and national planning could effectively promote the utilization of renewable energy.

Renewable energy development has attracted much attention in China and many factors influencing electricity generation have been considered. Some studies focus on the promulgated environmental policy, particularly the pollutant emission target and the nonfossil fuels consumption target. For instance, Qi (2014) analyzed the impact of renewable energy development on energy and $CO_2$ emissions considering renewable electricity target at that time. And the computable general equilibrium (CGE) model, which is a top-down model, is chosen and applied. The study found that temporal renewable electricity targets result in significant additional renewable energy installation and 1.8% reduction of cumulative $CO_2$ emissions from 2010 to 2020 [20]. Pan (2017) explored how to transform China's energy system towards the 2 °C target until 2100 using GCAM model. The results show that renewable power would dominate the electricity supply, accounting for 47–49% in 2050. In 2100, almost 90% of power is provided by non-fossil sources [21]. Zhang (2012) put forward a multi-period modelling and optimization approach to layout the development of power generation technology considering carbon dioxide mitigation. The study shows that renewable power and nuclear power accounts for more than 1/3 and 1/2 of power generation by 2050, respectively [22]. In addition, other factors, such as taxes, subsidies and GDP growth have been considered. Wu and Zhen (2016) evaluated the effects of implementing two different subsidy programs for renewable