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Toward carbon neutrality in China: A comparison between traditional and emerging forms of renewable energy

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Abstract. With a rise of global collective efforts to confront the climate change, China has announced to contribute to the common future by achieving carbon neutrality by 2060. Since the country's largest portion of energy consumption is fossil fuels, there are great opportunities to mitigate carbon emissions by promoting a wider use of renewable energy and realizing a green transition. Therefore, this study aims to compare China's progress in terms of the traditional and emerging renewable energy sources, which are represented by solar photovoltaic (PV) and hydrogen power. The study approaches these objects by evaluating their opportunities and challenges respectively. On the one hand, it indicates that while traditional renewable energy demonstrating great potential and dominating the present market, the challenges also encourage people to consider exploring new forms of renewable energy. On the other hand, the emerging forms of renewable energy are far from being commercially available and require support for future breakthrough. The study also suggests that if the government emphasize the technical innovation, financial support, and clearer guidance for the renewable energy industry, it would further set off the future of China's green development.

Keywords: carbon neutrality, renewable energy, solar PV, hydrogen power.

1. Introduction

Due to the increasing intensification of climate change, countries around the globe are forced to directly cope with the challenge. Long-term actions were launched and guided ever since 2015, when the Paris Agreement was adopted. As one of the largest energy consumption and carbon emission entity, China's carbon emission per capita is much higher than the figure of worldwide average, and fossil fuels represented by coal and oil still occupy the largest share of China's energy consumption structure, urging the government to promote a transition toward green and low-carbon energy development [1]. As a result, on the 75th United Nations General Assembly in 2020, the Chinese government announced to achieve a peak of carbon emissions by 2030 and strive to realize carbon neutrality by 2060. In order to reach the balance between climate change and economic development, renewable energy sources gradually attract people's attention on account of their effectiveness in lowering carbon intensity and satisfying energy demand. At present, in China, while there are new sources of renewable energy emerging and entering the domestic market, there are forms of renewable energy that have been widely used for decades and takes the leading position in the world. Thus, one of the most crucial objectives toward China's carbon neutrality may be to promote a replacement of renewable energy sources over the traditional forms of fossil energy.

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Nevertheless, although China's ambition toward greener development is firm and rigorous, much of its new renewable energy market remains in an exploratory stage. On the other hand, according to International Energy Agency (IEA) [2], during the five-year period of 2022 to 2027, China's existing cumulative renewable power capacity is expected to double, which is to increase by almost 1070 GW, mainly owing to the rigorous development of solar PV and wind development. On the other hand, the solar PV and wind projects are also challenged by revenue risks caused by curtailment if there is a lack of subsidies and the burden of rising investment costs, which reduced the profitability and bankability of certain projects, particularly for the solar PV projects. The developers may also get discouraged when exposed to fluctuations in the market price for green certificates and environmental attributes. Therefore, while continuing promoting the progress of traditional forms of renewable energy, it is also urgent to detect alternatives with high potential for a long-term cause.

In the following sections, this study provides a comparison between China's traditional and emerging forms of renewable energy, represented by solar PV power and hydrogen power respectively, under the pursuit of carbon neutrality. First, it discusses the history as well as the potential of solar PV in China. second, it goes into the progress of hydrogen energy. By lucubrating these two sources, the study aims to arrive at a clearer picture of China's status in the renewable energy industry. It eventually arrives at recommendations for policymakers regarding the overall development of renewable energy.

2. Solar PV power – traditional renewable energy

2.1. Opportunities for solar PV Power

To begin with, China is rich in solar resources, enabling the country great potential to boost its solar energy industry. The sum of China's potential for solar energy may be equivalent to an annual 1.7 trillion tons of standard coal [3]. Dating back to the 1960s, China has started to employ solar PV projects and is mainly used for power generation. In the past 10 years, the solar PV industry has realized vigorous growth and become the largest solar PV market worldwide. For instance, the cumulative installed capacity achieved 392 GW by the end of 2022, of which almost 40 percent is realized by the eleven leading state-owned enterprises in order to strive to push forward the Fourteenth Five-Year Plan [4].

So far, the government has issued favorable policies corresponding to the prosperous development of solar PV. The policy incentives are promoted from the central level government down to the provincial level governments. For example, as is listed in Table 1, National Development and Reform Commission has planned clearer and clearer from the period of the Eleventh Five-Year Plan to the Fourteenth Five-Year Plan ever since 2017. The clearer goal the Five-year Plan set, the better it would promote the advancement of the industry.

Moreover, the solar PV industry obtains the potential of combining with other national strategies and gain wider support. To be more specific, the Chinese government observed opportunities in applying "solar + industry" to alleviate poverty since 2014. This measure not only provides more stable income to the poor population, but also benefits the expansion of the solar PV market. By the end of the Thirteenth Five-Year Plan, the overall installed solar PV capacity for poverty alleviation reached about 26 million kW [5]. Although by the announcement of the Thirteenth Five-Year Plan, the solar PV projects generally faces problems of project management and subsidy arrears, under the push of dual objectives, the local government managed to prioritize the construction of relevant projects and ensures their progress.

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Table 1. Roadmap of evolution in China's solar PV policies.

Period	Policy guidance
The Eleventh Five-Year Plan [6]	• Emphasize the development of renewable energy with high resource potential and mature technology. • Promote its large-scale industrialization utilization.
The Twelfth Five-Year Plan [7]	• Explore global first-class efficient solar thermal power generation technology. • Facilitate upgrades for its power generation equipment.
The Thirteenth Five-Year Plan [5]	• Lay the foundation for the 2030 non-fossil energy goal by steadily advancing renewable energy industries. • Promote a diversified utilization of solar energy.
The Fourteenth Five-Year Plan [8]	• Realize a coordinated development of solar power generation with other industries. • Improve supply by prioritizing its local consumption.

2.2. Challenges for solar PV power and other traditional forms of renewable energy

Because of the urgency to push forward the transition of expanding renewable energy driven by the carbon neutrality target, there is also pressure to challenge the existing forms of renewable energy. To begin with, the task for energy sectors is particularly heavy since they are responsible for nearly 90% of the greenhouse gases emissions that are supposed to be mitigated in terms of the carbon neutrality scenario [9]. Much research reveals that the proportion of renewable energy of primary energy would be raised from 10% in 2020 to approximately 70% in 2060 [10], implying that the energy supply should not only shift from a fossil-fuel-based structure to a renewable energy-based structure, but also arrive at a transition to a stage where renewable energy takes the dominant place. Secondly, there are also technology flaws acting as obstacles. To be more specific, renewable energy sources such as solar and wind are of low energy density, featured by low land-use efficiency and heavy reliance on natural conditions. As a result, it calls for improving efficiency and exploring new sources of renewable energy to overcome these obstacles.

3. Hydrogen energy – emerging renewable energy

3.1. Opportunities for hydrogen energy

Hydrogen, as a clean alternative exhibits long-term advantages when it comes to future energy choices. The reason why people place hope in hydrogen energy is that hydrogen energy obtains characteristics of higher energy density than fossil fuels with products of water and oxygen only after reaction. As a result, hydrogen power is expected to diversify China's current energy supplies and leave a positive impact on its national energy security and environment as well. However, Hydrogen is also known as an energy carrier that must be produced as a secondary form of energy relying on various feedstocks such as water, fossil fuels, and biomass. Although China has acquired the foundation of industrial chain for hydrogen energy and mature manufacturing technology, the problem is that hydrogen production in China heavily relies on fossil fuels as raw materials. To be more specific, almost 70% of hydrogen production are from fossil fuels, releasing a large amount of carbon emissions along with the production and violating its carbon neutrality pursuit [11]. Therefore, green hydrogen, which is produced using renewable energy especially through water electrolysis, should be regarded as the most prosperous approach.

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The potential for green hydrogen is thus enormous and there are already projects exploring the market. According to a prediction by China Hydrogen Alliance [12], the total demand for hydrogen in China would reach 37.15 million and 130 million tons in 2030 and 2060 respectively, among which the market penetration for hydrogen made from water electrolysis would reach up to 3%, 10% and 70% in 2025, 2030 and 2050 correspondingly. In particular, as is listed in Table 2, in 2023, numbers of large-scale hydrogen energy projects are signed [13]. Among all the hydrogen production projects, green hydrogen projects account for the largest proportion. This wave of investment may further set off the coordinated and accelerated development of the overall renewable energy industry.

Table 2. Major recent green hydrogen production projects.

Project	Location	Investment (in RMB)	Hydrogen production scale
Demonstration project integrating green hydrogen production and ammonia synthesis using solar PV and wind in Da'an	Northeastern China	0.29 billion	A production capacity of 10000 Nm^3/h
Integrated project of green hydrogen using solar PV with grid load storage in Xinjiang	Northwestern China	8.146 billion	A production capacity of 2000 m^3/h
Integrated project of hydrogen production using solar PV in Shanghaimiao	Western China	0.089 billion	An annual production capacity of 6750 t
Demonstration project of hydrogen production integrating solar PV and wind power in Zhangjiakou	Northern China	0.635 billion	An annual production capacity of over 9000 t
Integrated construction project of green electricity and green hydrogen production and storage in Daye	Central China	5.2 billion	An annual production capacity of 4500000 Nm^3
Integrated project of renewable hydrogen and photohydrogen storage in Rudong	Eastern China	5.2 billion	A production capacity of 4000 m^3/h

3.1.1. Challenges for hydrogen power. In the past decades, although people can observe significant progress in hydrogen development, to transform into hydrogen economy, there are several major challenges to solve. From the technological perspective, China still lacks key technologies that limit advancement in hydrogen production. At present, key materials such as certain catalysts and other materials for PEM water electrolysis still rely on imports. For instance, although WUT New Energy has developed a PEM that fulfills the requirement of PEM fuel cells, the product is far from entering the commercial stage for massive production. Moreover, regulations and compliance regarding hydrogen quality are incomplete for the hydrogen economy in China [14]. From an economic aspect, high costs for both producing hydrogen and building corresponding infrastructure largely restrict the wide use of hydrogen energy. For instance, in China, the hydrogen refueling stations built and officially operated

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cannot be qualified for commercial operations but mostly remain to be the demonstration type. Furthermore, from the geographical perspective, due to the geographical differences in resource distribution and demands, the storage and delivery of hydrogen also become a trouble. To be more specific, in China, the center for power demand is in its east part, while the power supply center is in its central and western part. Although the central and western part of China is rich in other forms of renewable energy to support hydrogen production, the high cost to deliver hydrogen from its place of production to its place of consumption deprive local incentives for hydrogen development. Therefore, it appeals to the government to respect distinct regional features and adjust strategies for the energy transition.

4. Conclusion

In light of the discussion above, both traditional and emerging forms of renewable energy obtain outstanding potential while demonstrating weakness as well. On the one hand, solar PV power, as a representative of traditional renewable energy sources, takes up the largest share in China's renewable energy market thanks to the support from a series of favorable policies over the past several years. However, this track of renewable energy is threatened by the enormous pressure urged by the energy transition and the technical bottleneck, thus calling for efforts to develop better sources. On the other hand, in terms of new forms of renewable energy, hydrogen power has demonstrated nonnegligible potential considering its high energy density and green products after being consumed. There has been a wave of investment to establish projects to expand the market size around China. Nonetheless, challenges ranging from technical immaturity, financial burden, to unevenly distributed resources largely restrict its application in the market. Although this study has a limitation in that since the hydrogen power industry is newly emerged in China, there lack thorough data to explicitly indicate its market growth, this problem would be solved gradually with more and more participants joining the market. data would be naturally accumulated with more intense activities and thus contribute to the academic research.

In view of the agenda for the future in China, to secure the prosperous development of the renewable energy industry, the following recommendations are worth considering. Firstly, enhance technical innovation. Policy incentives should support green technology and stimulate their commercial application by facilitating joint efforts among universities, enterprises, and research institutes. Secondly, relieve financial risks. To relieve the initial investment and operation cost of renewable energy, it is possible that the government issues more special industry tax reliefs as well as subsidies, while funding more infrastructure. Furthermore, design clearer guidelines. To arrive at an ultimate carbon-free society, the government should design appropriate emission benchmarks and baseline thresholds to facilitate success in a relatively short term.

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