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Should China focus on the distributed development of wind and solar photovoltaic power generation? A comparative study

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HIGHLIGHTS

- This paper conducts a comparative study on the LC scheme and the LSLDT scheme.
- The LC scheme can achieve a higher renewable energy electricity integration ratio.
- The development of the LSLDT scheme hinders the development of the LC scheme.
- The LC scheme will generate cheaper electricity than the LSLDT scheme.
- The LC scheme, especially distributed solar PV, should be focused on in China.

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ABSTRACT

Major wind and solar photovoltaic (PV) power generation are being developed in China. The following 2 development schemes operate in parallel: large-scale wind and solar PV power is generated by 10-GW wind and solar PV power bases in Western China and then transmitted to the central and eastern load centres through cross-regional long-distance transmission lines; wind and solar PV power are also generated and consumed locally in the load centres across the central and eastern regions of China. The first scheme can be called the "large-scale and long-distance transmission" (LSLDT) scheme, and the second can be called the "local consumption" (LC) scheme. The choice of development scheme has significant effects on China's industrial sector. To determine which is better, we compare the two development schemes from the following 2 perspectives: in the view of renewable energy electricity integration ratio (REIR), 3 development scenarios, i.e., only adopting the LC scheme, only adopting the LSLDT scheme and adopting the LC and LSLDT schemes in parallel, are compared; in terms of total social cost, 4 specific schemes, i.e., developing wind power by centralized wind-thermal bundling with long-distance transmission (Scheme A), developing solar PV power by centralized solar-thermal bundling with long-distance transmission (Scheme B), developing wind power with the distributed wind power generation (Scheme C), and developing solar PV power with the distributed solar PV power generation (Scheme D), are compared. Scheme A and Scheme B belong to the LSLDT scheme, and Scheme C and Scheme D belong to the LC scheme. Mathematical models to calculate the maximum REIR are proposed, and methods to calculate the total social cost are introduced. To establish a mathematical model of the maximum REIR of the LSLDT scheme, a method to make reasonable bundling plans of the LSLDT scheme is suggested. To solve the mathematical models, a two-stage strategy is proposed to search for feasible solutions to unit commitment. Additionally, as many engineering problems related to the renewable energy power generation of China are still under discussion, 15 hypotheses are proposed to overcome the difficulties arising from various uncertainties. Under given assessment conditions, we find that the maximum REIR of only adopting the LC scheme is much higher than only adopting the LSLDT scheme or adopting the LC and LSLDT schemes in parallel. Additionally, the values of total social cost per kilowatt-hour electricity of Scheme A and Scheme B will be lower than those of Scheme C and Scheme D soon. Therefore, in the case of providing the main regulation capacity by thermal power units, the LC scheme, especially distributed wind and solar PV power generation, should be focused on in China.

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Nomenclature

Acronyms and nomenclature

GDP	gross domestic product
NDRCERI	Energy Research Institute of Chinese National Development and Reform Commission
REPG	renewable energy power generation
LSLDT	large-scale and long-distance transmission
LC	local consumption
SSPS	sending-side power system
RSPS	receiving-side power system
UHVDC	ultra-high voltage direct current
REIR	renewable energy electricity integration ratio
RPL	renewable energy power penetration limit
RCR	renewable energy electricity curtailment ratio
UH	utilization hour
UC	unit commitment
R_{rej}	renewable energy electricity curtailment ratio
$R_{\mathrm{ei,1}}$	the maximum renewable energy electricity integration ratio when only adopting the LC scheme, i.e., the ratio of the annual supplied electricity by renewable energy power generation in a power system to the annual electricity consumption of the power system
$R_{\mathrm{ei,2}}$	the maximum renewable energy electricity integration ratio when only adopting the LSLDT scheme
$R_{\mathrm{ei,r}}$	the maximum ratio of the annual bundled electricity of the LSLDT scheme to the annual electricity consumption of RSPS
$R_{\mathrm{ei,3}}$	the maximum renewable energy electricity integration ratio when adopting the LC and LSLDT schemes in parallel
$R_{\mathrm{ei,3c}}$	the maximum renewable energy electricity integration ratio achieved by the LSLDT scheme when adopting the LC and LSLDT schemes in parallel
$R_{\mathrm{ei,3d}}$	the maximum renewable energy electricity integration ratio achieved by the LC scheme when adopting the LC and LSLDT schemes in parallel
k_{s}	the maximum ratio of annual renewable energy electricity of SSPS to annual bundled electricity of the LSLDT scheme
r_{ca}	capacity ratio, the ratio of the transmitted power of SSPS to the peak load of RSPS
r_{b}	bundling ratio, the ratio of the installed capacity of wind turbines and solar PVs to the capacity of thermal power units in SSPS

1. Introduction

China has been enjoying the world's fastest economic growth, with more than 10% annual growth in the gross domestic product (GDP) over the past 30 years [1]. The need for energy is self-evident. China has been the world's biggest CO_2 emitter since 2007 and the largest energy consumer since 2010 [2,3]. According to the blueprint drawn by the Energy Research Institute of Chinese National Development and Reform Commission (NDRCERI), the electrification ratio will reach 62% by 2050, up from the current 23%, and the electricity consumption in 2050 will be three times the 2015 level [4]. To achieve sustainable development in China, rapid development of renewable energy, especially renewable energy power generation (REPG), is necessary. Solar PV power generation and onshore wind power generation are mature and economical REPG technologies. Thus, only solar PV power and onshore wind power are considered here. The renewable energy electricity integration ratio (REIR) refers to the ratio of the annual renewable energy electricity supplied to end users in a power system to the annual electricity consumption of the power system. NDRCERI suggested that the 2050 targets of wind electricity REIR and solar PV electricity REIR are both approximately 30% and the sum of them will be up to 63% in China [4]. At present, the total installed capacities of both wind turbines and solar photovoltaic (PV) in China rank first in the world. Therefore, the extensive literature focuses on China's REPG, e.g., the potential of renewable energy [5], the challenges [6], the investment policy [7], the international environment [8] of the solar PV industry, and the wind power supply cost of China [9].

In China, there are 2 different development schemes for REPG. Large-scale wind and solar PV power are generated by 10-GW wind and solar PV power bases in Western China and then transmitted to the central and eastern load centres through cross-regional long-distance transmission lines; wind and solar PV power are also generated and consumed locally in the load centres across the central and eastern regions of China. The first scheme could be called the "large-scale and long-distance transmission" (LSLDT) scheme, and the second could be called the "local consumption" (LC) scheme. The typical examples of the LSLDT scheme are so-called "wind-thermal power bundling and long-distance transmission" and "solar-thermal bundling and long-distance transmission". For example, several 10-GW wind and solar PV power bases have been or are being built in the western regions. The installed and approved capacities of wind turbines and solar PVs in these bases constitute the majority of the national total. As the electricity demand in the western regions is relatively small, the renewable energy power cannot be completely consumed locally. The surplus electricity is transmitted to the central and eastern load centres through long-distance ultra-high-voltage, e.g., ±800 kV, transmission lines longer than 2000 km. This is the LSLDT scheme. The LC scheme usually refers to distributed wind turbines and distributed solar PVs that are integrated into the local power grid widely and discretely. Under this condition, the LC scheme is known as the "distributed generation" scheme. However, the LC scheme does not reject the centralized wind turbines and solar PVs, as long as the wind and solar PV power generated is consumed locally. For instance, the large-scale wind power generated by the Zhangbei wind base, which is in the northern part of Hebei Province, is integrated into the 500 kV transmission grid of the Jibei Power Grid. The power is consumed locally, mainly in the Jibei Power Grid and no power is transmitted over long-distance. Though wind and solar PV bases with local consumption are permitted, distributed wind turbines and solar PVs are the major subject of the LC scheme in this paper.

Regarding the national strategy decision, adopting the LC or LSLDT scheme or both will have significant effects on smart-grid development and industry structure [10]. It is very important to carry out a comparative study of the 2 development schemes from the perspectives of technology and economy. Technology refers to determine which development scheme could achieve a higher maximum REIR, and economy refers to determine which development scheme generates cheaper electricity.

The maximum REIR of a power system is closely related to the maximum capacity of renewable energy power generators that can be installed in the power system. The ratio of the maximum installed capacity to the biggest load of the assessed system is usually called the renewable energy power penetration limit (RPL) [11]. Extensive previous studies focus on the assessment of RPL.

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