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Development forecast and technology roadmap analysis of renewable energy in buildings in China

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ABSTRACT

This paper reviewed the application of renewable energy in buildings (REIB) in China in the last decade. Based on the statistics during the 10th and 11th Five-year Plan period, the application of solar thermal, photovoltaic (PV) and ground-source heat pumps (GSHPs) in buildings for the next decade was forecasted via a transformed grey prediction model under three different development scenarios (Baseline, Reference and Aggressive Scenario). The results showed that, under Reference Scenario, 26.50 million tce (tons of standard coal equivalent) energy consumption in buildings could be replaced by renewable energy in 2015, and the share of renewable energy in building energy consumption would rise to 12.06% in 2020. However, according to domestic medium-term and long-term plans for renewable energy development, there would be some difficulties to achieve the 2015 and 2020 targets with current development trend in the construction sector. Therefore, the detailed technology roadmap of “improving the performance efficiency, expanding the technique scope and controlling the total amount of energy consumption” was thus proposed to evaluate the contribution of different technologies for achieving the medium-term and long-term targets.

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1. Introduction

With the rapid development of global economy, the fossil fuel energy consumption has been growing fast. Especially in recent years, energy crisis and environmental issues have drawn considerable attention around the world. In response to this situation,

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the concept of sustainable development has gradually become the consensus of the international community, and renewable energy as the major alternative energy for achieving sustainable development has been widely concerned. Nowadays, the development and utilization of renewable energy has already been considered as an important aspect of the energy strategy in a few countries, which also have created national targets or relevant laws and policies to encourage domestic renewable energy development [1]. For the application of renewable energy in buildings (REIB), after years of exploration and experiment, there are some mature technologies that have been proven to be suitable, such as solar water heating, photovoltaic (PV) and ground-source heat pumps (GSHPs) [2–6].

In China, REIB originated in the 1970s, but the rapid development started in 2006 since the demonstration projects of REIB were carried out jointly by the Ministry of Finance and the Ministry of Housing and Urban–Rural Development. After the implementation of a three-step development strategy (single building demonstration, city/county demonstration and provincial demonstration), briefly described as the point-line-surface strategy, the building areas of solar energy and geothermal energy application rapidly increased, while the technology level was enhanced [7–9]. Recently, there were a lot of studies on a certain technology and/or aspect of renewable energy development in China. However, few of them have investigated the possible contributions of renewable energy to China's future sustainable energy system, not to mention the assessment of the impacts and challenges of the latest ambitious renewable targets set by China's *Medium-term and Long-term Plan for Renewable Energy Development* and *Building Energy Efficiency Strategic Plan for the 12th Five-year Period*. For the building energy consumption, what are the possible shares of renewable energy and non-fossil fuels? How energy efficiency measures could influence the contribution of renewable energy to the building energy system? What are the possible challenges caused by interactions between renewable energy technologies and conventional energy technologies in the building energy system?

Therefore, the objectives of the paper were: (1) to introduce the development status of REIB; (2) to summarize the evolvement of renewable energy strategy targets in different renewable energy plans; (3) to make a preliminary prediction of the development of REIB in China under different scenarios; (4) to undertake a comprehensive analysis of the technology roadmap for REIB in China during the next decade.

2. Application of REIB in China

Common renewable energy resources include solar energy, wind energy, geothermal energy, ocean energy and biomass

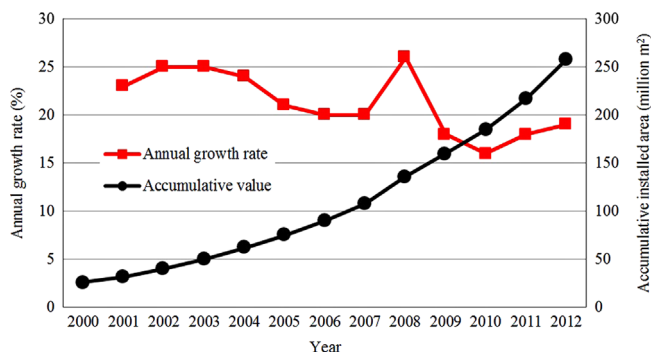


Fig. 1. Installed areas of solar water heaters in China from 2000 to 2012. (Part of the data from [24] and [25].)

energy featured with recyclability and low environmental pollution [10–14]. In buildings, there is a great potential to utilize renewable energy, and the related technologies are gradually mature. The utilization of solar energy has received an increasing number of attention worldwide due to its inexhaustible source and zero emissions of greenhouse gases. Solar energy can be utilized through PV, solar water heater and solar air-conditioning system in buildings [15–17]. Geothermal energy is another vast clean energy source, stored in the interior of the earth. It can be applied commonly through the heat pump technology in a variety of building energy systems, which use the soil, groundwater or surface water as the heat source [18–20]. Wind energy is mainly utilized for power generation. Britain, Sweden, Netherlands and some other developed countries have promoted the research and practice on wind energy generation in urban and rural buildings since 2001. It helps to avoid the remote transmission of electricity and lowers the investment cost of energy supply [14,21]. But in China, wind energy is not common to be used directly in buildings at present. Biomass energy can be generated from crop straws, firewood, livestock manures, industrial organic wastes and municipal solid wastes, etc. They can be utilized for heating or cooking through direct combustion or chemical conversion [22,23]. While, currently, the biomass energy is mainly applied in rural buildings in some simple or traditional ways in China.

In China, the solar water heater is the most widely used technology. China has become the biggest producer, market and holding country of solar water heaters in the world [24,25]. Fig. 1 summarizes the accumulative installed areas and annual growth rates of solar water heaters in China from 2000 to 2012. The installed areas increased nearly 10 times, from 26 million m² in 2000 to 257.7 million m² in 2012. During the same period, the annual growth rate of production and utilization of solar water heaters was maintained at above 16%.

The development of building-integrated photovoltaic (BIPV) in China fell behind developed countries, such as Japan, United States and Germany [26]. The accumulative installed capacities and the annual growth rates of BIPV in China from 2000 to 2012 are shown in Fig. 2. Because of the technical threshold and relative higher initial investment in the domestic market, there were few projects that used the PV technology in buildings until 2008. In recent years, with a series of financial subsidies and policy support as well as the maturity of the core PV technology, a complete industrial chain gradually formed. Accordingly the price of PV modules continuously reduced in China. Therefore, the annual installed capacity of BIPV increased 11 times in the last five years, from 45 MWp in 2008 to 543.4 MWp in 2012, and the accumulated capacity increased over 6 times during the same period.

GSHPs have been developed in China for more than twenty years. In South China they are mostly used for heating and cooling while in North China they are mainly used for winter heating. Three types of GSHPs are widely used in China, namely ground-coupled heat pump (GCHP), groundwater heat pump (GWHP) and surface water heat pump (SWHP). Above-mentioned GSHPs have received extensive attention from the society for being rich in resources, easy to exploit and available within a wide range. Fig. 3 summarizes the accumulative building areas using GSHPs and the annual growth rates in China from 2000 to 2012. The application of GSHPs grew slowly until 2006. Most related applications were resulted by the market spontaneous actions. But after 2006, as a consequence of the promulgation or revision of a series of laws, such as the *Renewable Energy Law*, *Energy Conservation Law*, *Medium-term and Long-term Plan for Renewable Energy Development* and *Regulation on Energy Conservation in Civil Buildings*, as well as the implementation of the nationwide demonstration projects funded by the Ministry of Housing and Rural–Urban Development and Ministry of Finance, the large-scale application

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