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Who are leading the change? The impact of China's leading PV enterprises: A complex network analysis

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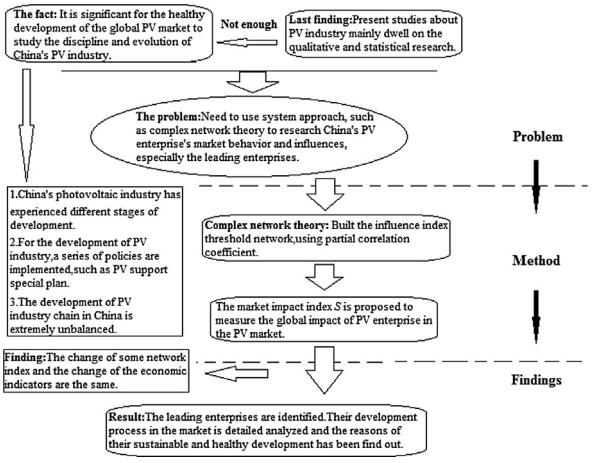
HIGHLIGHTS

- An enterprises' influence index threshold network model is formulated.
- Discussion of the heterogeneity of PV enterprises in the constructed network.
- Identification of the leading enterprises.

GRAPHICAL ABSTRACT



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ABSTRACT

In this paper, China's PV market is studied from a new perspective of complex network theory. An influence index threshold network (IITN) model is been built by using partial correlation coefficients. Complex network theory is then used to provide a detailed description of the interactions of enterprises, their inherent influencing ability to conduct and control the interactions of the enterprise in the PV industry. This paper also analyses the diffusion effect of the inherent influencing ability and the conduction effect of the relationship of the enterprise in the PV industry. In addition, the leading enterprises in the industrial chain are been identified using their degree, degree centrality, betweenness and net profit ranking. The results show that the average betweenness of the top enterprises is contrary to the evolution of new installed PV capacity globally. Finally, the reasons for identifying leading enterprises are stated in detail and policy suggestions are made to promote the sustainable development of the World's PV market.

1. Introduction

With the increasing pressure to prudently manage its energy and environment, China has initiated the development and utilization of new and renewable energy sources [1]. One of such ventures is the solar photovoltaic (PV) industry, which is growing rapidly and mainly supported by the national policy [2–5]. However, China's PV market entered a state of uncertainty after 2011 due to external factors such as the European debt crisis and trade protection measures.

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Anti-dumping and countervailing are the major measures used in international trade. Its main function is to protect the fairness of trade and to safeguard the legitimate interests of trader, which has been of widespread attention in these years [6,7]. Regardless of the pressure of the "anti-dumping and anti-bribery investigation" and excessive capacity, some leading PV enterprises have still developed quickly. In this context, identifying these leading PV enterprises by exploring the reasons for their development and illustrating the evolution of these enterprises in the market has become the key for the sustainable development of the whole PV market. In the following sections, we will first and foremost review the relevant policies and challenges of the history of China's PV industry market development. The research gap and main contribution of the paper are also touched on.

1.1. The developmental trajectory of the global and China's PV industry

The PV industry has experienced phenomenal growth in recent years due to its prioritized development in the world, technological improvements and cost reduction. In 2003, the global accumulated on-grid installed PV capacity was 2.61 GW and increased rapidly to 15.80 GW and 242.26 GW by 2008 and 2015 respectively. Meanwhile, the on-grid newly installed PV capacity increased from 0.564 GW in 2003 to 6.65 GW in 2008, and reached 53.46 GW in the year 2015. The global newly and accumulated on-grid PV installed capacity and their growth rates are shown in Fig. 1(a). The global installed PV capacity started to grow significantly in 2006, and reached its peaks in 2008 and 2011. Before 2012, European countries such as Germany, Italy and Spain lost their leading positions due to a substantial increase in the demand for PV power plants in countries, such as China, the United States, Japan, India and South Africa. In addition, Fig. 1(b) shows the top 10 productive countries with newly installed PV capacity in 2014, with China, Japan, the United States and Britain ranked as the top four [9]. The total installed capacity of these 10 countries accounted for 81.5% of the global installed PV capacity, totalling 38.3GW. In 2015, the growth of the global PV power generation was mainly concentrated in emerging markets like China, the United States and Japan. Therefore, it is important to study the evolution of China's PV industry, especially the leading PV enterprises to ensure their healthy development in China's PV market.

China's PV industry appeared late on the global scene, compared with that of developed countries, but with a faster growth rate than the world's average in recent years. In 2008, China's accumulated on-grid installed PV capacity was 0.14 GW. However, it increased to 28.05 GW in 2014, with a growth rate of 312.5%, 106.6%, 166.18% and 54.97% during 2011–2014 respectively. In addition, the on-grid newly installed PV capacity increased from 0.04 GW in 2008 to 9.95 GW in 2014. China's newly installed PV capacity, accumulated installed capacity and their growth rates are shown in Fig. 2(a). Fig. 2(b) shows that, China's newly installed PV capacity is mainly located in the Neimenggu (15.5%), Jiangsu (14.3%), Qinghai (9.6%), Gansu (9.1%) and Hebei (9.1%) provinces. By the end of 2015, China had become the world's largest PV power generation country, with an amount of 43.18 GW accumulated installed PV capacity and newly installed PV capacity was 15.13 GW. This accounts for more than 1/4 of the world's total newly installed capacity.

In the first half of 2009, the number of projects constructed, those under construction or those proposed for domestic polysilicon projects was more than 50. The capacity that had been built was nearly 60 thousand tons with a total investment of more than 100 billion CNY. In 2011, China's PV market started going through recession due to the saturated market and overcapacity problems. As a result, in 2013, the Wuxi Suntech giant became bankrupt, and more than 80% of polysilicon enterprises across board suffered losses. The research report released by Maxim Group indicated that, China's top ten solar enterprises had a total debt of USD17.5 billion. The implementation of the "11th Five-Year plan" has enabled China's solar PV industry to develop rapidly, with an international leading technology and highly competitive advantage compared to foreign enterprises. This was sourced from the "China PV industry development status and key business layout in 2016", Industry Research Information Bank (http://www.irinbank.com).

1.2. Chinese incentive policies for PV development

The "Interim Measures for the administration of financial subsidy funds for solar photovoltaic construction applications" and the "Decision on accelerating the cultivation and development of strategic emerging industries" were released in 2009 and 2010 respectively. Thereafter, China's newly installed PV capacity increased substantially in the year of 2011 under the adjustment of these two incentive policies, as shown in Fig. 2(a). According to the "Energy development strategy action plan (2014–2020)" issued by the State Council, the ratio of non-fossil energy to primary energy consumption will reach 15% by 2020. "The draft for consultation on solar energy utilization in the 13th Five-Year plan" has set a target for China's PV installed capacity to be 150 GW by 2020. This means that, an added 20 GW of newly installed PV

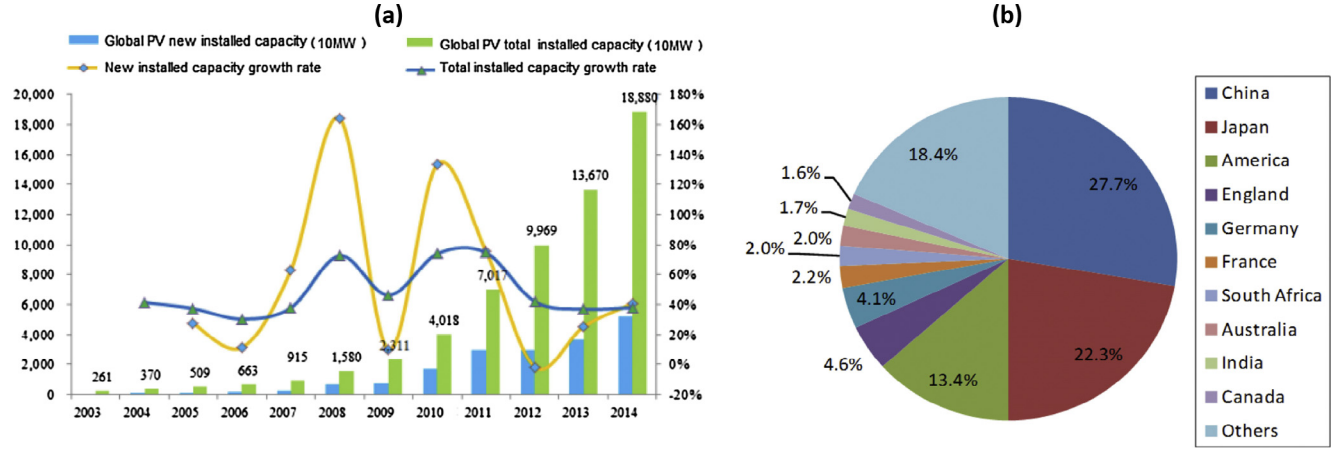

Fig. 1. Global PV installed capacity. Note: (a) shows global PV new installed capacity, accumulated installed capacity and their growth rates [8] while (b) shows the top 10 countries with new installed capacity in 2014.

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