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# Development of photovoltaic power generation in China: A transition perspective

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ABSTRACT

Solar energy represents the largest source of renewable energy and is thus expected to play a crucial role in meeting our future energy demand. In China, solar energy utilization has made remarkable progress in recent years. In this paper, we reviewed the recent developments in the field of solar photovoltaic (PV) power generation from the perspective of transition theory, which was originally developed by technological innovation studies. The transition studies propounded three heuristic levels in a system, namely, socio-technical landscape, regime, and niche, and a transition of a system can only be fulfilled through the interactions among these three levels. With respect to the development of solar PV power generation in China, in this paper we initially examined specific situations within these three levels in the context of energy transition. In the subsequent sections, we paid attention to the response of government in promoting the solar PV development amid energy transition. Specifically, relevant policies and some niche level special programs were investigated. Then, we examined the phased achievements in the transition and offered solutions to some newly emerged problems. The final section concludes with some comments.



**Contents**



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## 1. Introduction: progress and problems

With the fast economic growth in China, the demand for electricity is rapidly increasing. This has given rise to severe environmental pollution, as approximately 67% of primary energy is derived from coal, which also results in a significant contribution to global warming. However, China is endowed with abundant exploitable solar resources. More than 60% of the country receives an annual total radiation of over 5400 MJ/m$^2$ with more than 3000 h of sunshine [1], particularly in the Qinghai-Tibet plateau, Xinjiang, Gansu, and Inner Mongolia, where large wasteland areas are widely available for the utilization of solar energy. In order to develop economically by sustaining its own energy demand without harming the environment, the Chinese government has the incentive to support the development of solar power generation.

China started research on solar cells in 1958, which were first applied on the satellite Dongfanghong no. 2 in 1971. The first terrestrial application was in 1973 (the 15 Wp solar-powered navigation light in Tianjin Harbor). During the 1980s, China introduced several photovoltaic (PV) cell production lines from the United States, Canada, and other countries, which eventually formed the solar PV industry in China [2]. By the end of the 1990s, a number of component packaging plants were built. However, before the 21st century, the utilization of solar energy in China was mostly concentrated on solar water heating systems and not solar power generation, mainly the result of technological constraints and high cost. Furthermore, solar power generation was primarily intended then for supplying power to remote areas that do not have access to electricity.

The major solar power technology currently available is the solar PV system, in which sunlight is directly converted into electricity via photovoltaic effect. The PV industry in China entered its period of rapid development during the 21st century because of the significant increase in global demand for PV products. In 2009, the production capacity of PV panels in China nearly reached 4000 MW; a remarkable increase compared with only 5.5 MW of output in 1997 [3]. China is now the largest manufacturer of solar PV products in the world [4]. In addition, the government is investing heavily into this field for relevant scientific research. For instance, in 2009, China invested over 33 billion USD in clean energy, edging out the United States from the top position for the first time; 10% of that sum was allocated to solar energy [5].

However, this rapid development of the solar PV industry in China is considerably affected by external factors or so-called “two outsides.” The first is dependence on imported raw materials, such as poly-silicon, because of the lack of relevant core technologies and equipment (technology and material outside), and the second is heavy reliance on the foreign market, especially Europe (market outside). As shown in Table 1, the installation total of PV is only 40 MW in China in 2008, whereas the total yield of Chinese-manufactured solar cells is over 2000 MW. As such, 98% of the solar cells are exported, predominantly to Europe and the United States, and only 2% are sold in the domestic market. By contrast, the solar water heating industry enjoys a huge domestic market and has developed into a mature industry independently. In 2008, the installed capacity of solar hot water reached 145 GW [7], making China the biggest producer and user of solar water heaters in the world, a ranking held since 2005 [8].

In recent years, the Chinese government has promulgated numerous policies to promote the PV industry. As the largest emitter of the greenhouse gases (GHG) in the world, China and its policies on solar and other renewable energy have a global impact, and have gained attention worldwide [9]. In this paper, we concentrated on studying solar PV power generation and its latest developments. So far, many studies have been conducted on solar PV developments in China, yet the majority of these focused on the top-down dimension, which is central government policy guidance, whereas the bottom-up dimension in the policy-making process, that is, the influence of PV enterprises and local governments on the central government, is overlooked. Furthermore, little attention has been paid to the interaction between policy and industry; and the interactions among all the relevant parties, such as government departments, PV enterprises, grid companies, and households, have not been examined and remains obscure.

This paper intended to fill the gap by introducing a transition perspective. Building upon previous studies, it tried to provide a more holistic and systematic analysis of the solar PV industry in China by placing the study in the context of energy transition. In discussing the development of the solar PV industry in China, this paper paid special attention to the interactions between government regulations and enterprise activities, between the government and market, and between macro-economical needs and energy policies.

## 2. Perspective of analysis: transition and its multi-level perspective

The concept of transition originated in biology and population dynamics [10]. A transition is defined as a gradual, continuous process of structural changes within a system, such as a society or cultural system [11]. This idea of transition perspective is unique for its multi-level perspective (MLP), which was first formulated by Rip and Kemp to analyze historical cases of technological transitions. As a heuristic model to understand changes in socio-technical systems, the MLP proposes three analytical levels, namely, niche (local), regimes (meso-level), and socio-technical landscapes (macro-level) [12].

Niches are crucial for transitions because they provide the seeds for change in the form of radical novelties, and are

**Table 1**
Annual output and annual installation of PV cells.
*Source*: [6].

| Year | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 |
|---|---|---|---|---|---|---|---|---|---|---|
| Output (MW) | 10 | 10 | 50 | 200 | 400 | 1088 | 2600 | 4000 | 8700 | 22,000 |
| Installation (MW) | 18.5 | 10 | 10 | 8 | 10 | 20 | 40 | 160 | 500 | 2500 |