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How China became a leader in solar PV: An innovation system analysis

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ABSTRACT

In this paper we focus on understanding the rapid rise of the Chinese PV industry and its profound impact on the global PV industry. We investigate how it is possible that a nation that is still focusing on catching up in terms of industry, innovation and technology has been able to bring manufacturers from leading industrialized nations to their knees. This paper applies the framework of the Technological Innovation System (TIS), and also takes the context into account, in terms of the Chinese national innovation system (NIS) and the global PV TIS. It concludes that the rise of the Chinese PV TIS can be explained by the interaction of three context factors (the change in Chinese institutions, technology transfer, and the large European market) and specific PV TIS dynamics. The study empirically shows the importance of extending the national TIS studies by including the influences of context factors.

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1. Introduction

The market for solar photovoltaics (PV) is growing rapidly. In the past decade, solar PV generation has expanded by 50% per year worldwide. In 2012, solar PV generation reached almost 100 TWh, which is sufficient to cover the annual power supply needs of over 30 million European households. In the same year, the world's cumulative total installed capacity exceeded 100 GW, up from only 1 GW in the year 2000 [1,2].

This rapid market growth is mainly due to a massive reduction in production costs [3]. For example, the inflation-adjusted prices of crystalline-silicon (*c*-Si) PV modules have fallen from 5.0 USD/watt in 2000 to around 0.6 USD/watt in June 2014 [4,5]. This sharp drop in production costs has mainly been caused by process innovations in manufacturing technology [1], such as improvements in wire cutting technology. In addition, mass production has led to more efficient and cheaper solar cell production machinery. PV production lines have been optimized, for example by developments in intelligent and self-correcting control of process flow, and this has increased throughput volume. Furthermore, the efficiency of solar cells and modules has increased, resulting in higher returns on investments [6].

Lower prices are good for consumers and for governments that use financial instruments to support the adoption of PV technology. However, the PV industry is severely struggling, as many companies cannot make sufficient profits due to the low market prices. Specifically since 2011, some major global PV manufactures have suffered a sharp decrease in self-financing, including First Solar (USA), Kyocera (Japan) and Trina Solar (China) [7]. Moreover, some large global PV companies have gone bankrupt, including PV manufacturer Suntech (China) and PV panel producers Ever-green Solar and Solyndra (USA), as well as Q-Cells and Solon (Germany) [8–11].

This industry shake-out had a typical geographical pattern. In 2002, Japan became the world leader in PV manufacturing, with four companies in the top 10 largest PV manufacturers in terms of solar cell sales. In 2007, the German PV company Q-Cells took over first place, while the number of Japanese PV companies in the top 10 fell to three. From 2010, Chinese firms took over the top position at the cost of Japanese and German players [6]. In 2012, of the top 10 solar PV manufacturers in terms of actual production/shipments, seven were Chinese companies, and there were no longer any Japanese or German companies in the top 10 [12–15]. This shake-out is a typical pattern in emerging industries. The literature on industrial dynamics has empirically shown that in many emerging industries the number of firms increases at first, but that a shake-out occurs when process innovations instead of product innovations start to dominate the innovation direction of the industry [16–19]. However, in the case of the PV industry, which is heavily supported by government policies, this industry shake-out posed serious legitimacy questions regarding government support of the PV industry. More specifically, Germany's renewable energy policy was criticized for not delivering the vibrant industry that was hoped for. Subsequently, the blame for these losses was put on China and this eventually led to EU trade restrictions on PV from China [20].

The influence of Chinese PV manufacturing on the structure of the global industry is noteworthy. In general, Chinese industrial activities have replaced western production capacity in the past 20 years, due to low resource costs, including labor, land use and electricity, abundant human and material resources, and potentially massive markets. However, it is for the first time that Chinese industrial activities have had such a profound impact on a high-tech and emerging sector.

In recent years, there has been a sharp increase in the number of studies into Chinese PV technology, industry and policy, and these studies have uncovered some major factors contributing to the rapid rise of the Chinese PV industry. The great demand of global markets is believed to be one of the most important factors. Zhang et al. [21] showed that the Chinese solar PV industry has been influenced greatly by overseas markets, for example in European countries such as Germany. Another important factor is the active role of the Chinese government, with its various policy tools. Zhang et al. [21] found that China's top policy objective is to develop the emerging renewable energy industry, aiming to shift from a low-cost manufacturing-based economy to a more high-tech, high-value-added, innovative economy. Similarly, Zhao et al. [22,23] showed that the Chinese government aims to play a vital role in fostering an environment that promotes the development of the PV power industry.

In addition, a necessary factor seems to be the innovation and development of PV power technology. Zhao et al. [22] showed that China's PV power technology has improved dramatically, with technological advances in the efficiency, reliability, and reduced pollution of PV cells and PV power generation systems, leading to a rapid increase in both PV production capacity and the value of exports [22]. China seems to be at the industrial forefront of innovative PV production technology. However, it is as yet unknown how this process occurred. Zheng & Kammen [5] and Grau et al. [24] both reported that Chinese PV manufacturers tend to have lower R&D intensity than the PV manufacturers in other major countries. Current investment in Chinese PV is mainly focused on manufacturing and application rather than on R&D. This conclusion is in line with the findings of Lei et al. [25] and Wu & Mathews [26], both based on the USPTO (United States Patent and Trademark Office) data. In addition, De la Tour et al. [27] stated that the success of some Chinese PV manufacturers cannot be attributed to innovation.

Thus, even though several experts have studied the rise of the Chinese PV industry and a few factors have been singled out that explain the current dominance, we lack insight into the mechanisms that explain the emergence of the Chinese PV industry. Also there is still a debate on the role of domestic innovation in explaining the rapid rise of Chinese PV industry. In this article we therefore present a detailed historical review of the rise of the Chinese PV industry in relation to the context in which this industry emerged. For this purpose, we adopt the innovation system since this perspective allows us to analyze the complex nature of industry emergence and highlights the collective nature of innovation and the interdependencies between actors and institutions in the development and deployment of innovation [28]. Since we focus specifically on the innovation system around the Chinese PV technology and the Chinese PV industry we adopt the Technological Innovation Systems (TIS) framework [29]. To create insight into the mechanisms that explain the successful emergence of the Chinese PV industry we use a process method approach [30–32].

We also contribute to the conceptual development of the TIS perspective by explicitly differentiating the Chinese PV TIS and the context in which the innovation is embedded. We discern the international PV innovation system and the Chinese National Innovation System as context systems. By explicitly conceptualizing the context of an innovation system we answer to the call of Truffer & Coenen [34] for a better spatially conceptualized TIS analysis and the suggestions of Bergek et al. [33] to conceptualize different context systems of a TIS.