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China's wind industry: Leading in deployment, lagging in innovation

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ABSTRACT

China's massive carbon emissions and air pollution concerns have led its government to embrace clean energy innovation as a means of transitioning to a more sustainable energy system. We address the question of whether China's wind industry has become an important source of clean energy technology innovation. We find that in terms of wind capacity expansion, China has delivered enormous progress, increasing its wind capacity from virtually no wind capacity in the early 2000s to 140 GW by 2015. However, in terms of innovation and cost competitiveness, the outcomes were more limited: Chinese wind turbine manufacturers have secured few international patents and achieved moderate learning rates compared to the global industry's historical learning rate. Leading China-based indigenous producers are likely to remain important global players for the foreseeable future, but further progress in reducing the cost of capital equipment may slow relative to the recent past. However, opportunities in lowering curtailment rates and improving turbine quality can reduce China's overall levelized cost of electricity for wind.

1. Introduction

Given the environmental, health, and climate change costs associated with conventional electric power generation, and given the country's rich wind resources, China has embraced a greater role for wind energy with impressive speed. From a country with virtually no wind power capacity, China has pushed itself to the global forefront in less than a decade. In 2001, China's cumulative installed capacity was only a little over 400 MW. By 2012, it had surged to 75,000 MW, allowing China to surpass the U.S. as the country with the most installed wind capacity (GWEC, 2012). Through 2008, China experienced an annual wind installation growth rate of at least 60%. From 2009–2010, the growth rate slowed down to a still impressive level of 37% and accelerated again in recent years. China's wind resources are concentrated in its northern and northeastern regions (He and Kammen, 2014), and this is also where the majority of the country's wind power capacity is located (Fig. 1).

Over the same period, we have also observed tremendous growth in China's indigenous wind turbine manufacturing industry. Within China, Sino-foreign joint ventures and indigenous domestic enterprises commanded only 17% of the market as recently as 2004. However, as Fig. 2 shows, indigenous firms dominated the explosive growth of installed wind capacity after 2005. By 2010, these Chinese firms claimed a cumulative 90% market share. Today, five of the top ten global original equipment manufacturers in the wind turbine industry are based in China (GlobalData, 2016).

China has enacted a number of policies in recent years to boost its supply of renewable energy.[1] A key turning point arose with the Renewable Energy Law of the People's Republic of China, passed in 2005 and implemented in 2006, which empowered key government players at the national and provincial level to draft renewable energy development and utilization plans (Schuman and Lin, 2012). Currently, the government is planning for 20% of China's primary energy consumption to come from renewable energy sources by 2030 (UNFCCC, 2015).

Developments in China's wind energy industry have attracted a lot of attention, both in the popular press and in scholarly research. Many studies systematically review historical developments within the industry and relevant government support policies to explain the rapid rise of China's wind energy sector (Kang et al., 2012; Liu and Kokko, 2010; Wang et al., 2012; Zhang et al., 2013). Other studies examine the technological change of China's wind energy industry in terms of

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[1] Please see IEA (2016), Lewis (2013), and Gallagher, (2014) for reviews of relevant renewable energy policies.

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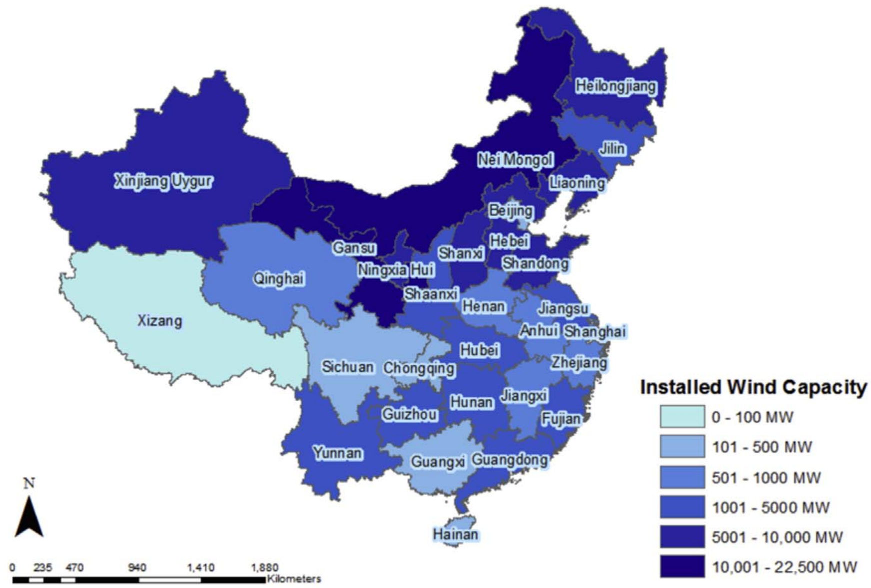

Fig. 1. China's wind power installation by province in 2014. Provinces with most wind power installed are also those that have significant wind resources. Data from CWEA (2015). Map produced by authors.

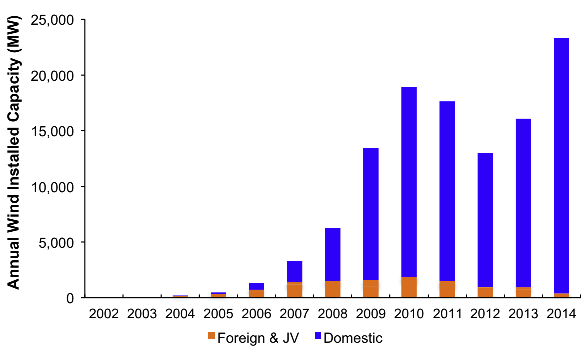

Fig. 2. Annual wind nameplate capacity installations in China by year, broken down by domestic versus foreign firms. Domestic firms dominate the market in recent years. Plot constructed by the authors using data from (CWEA, 2015).

turbine size, increases in domestic patenting and innovation activity, and cost reduction in turbine manufacturing (Lewis, 2013; Nahm and Steinfeld, 2014; Qiu and Anadon, 2012; Ru et al., 2012). The literature has consistently recognized China wind power industry's late-comer status and documented its successes in capacity building, technology transfer, and learning (Gosens and Lu, 2013; Lema and Lema, 2012; Lewis, 2013; Qiu and Anadon, 2012; Tang and Popp, 2014; Wang et al., 2012). Some studies assert that China's wind energy boom has been driven by indigenous innovation (Ru et al., 2012). Bettencourt et al. (2013) note the large number of wind turbine patents granted to indigenous producers by the Chinese Patent Office (SIPO), and conclude that these firms have engaged in robust and substantial innovation.

We build on this literature, empirically examining the contribution of Chinese wind turbine firms to the advance of the global technological state of the art. Using international patent data, we undertake an analysis of international innovation trends in wind turbine manufacturing technologies. We find that international patenting activity among Chinese firms and inventors has been minimal to date. China's top indigenous wind power manufacturers have not patented many new wind technologies in major markets outside of China. At the same time, Chinese patents are less likely to be cited than their foreign counterparts. Additionally, we find that while Chinese firms have managed to push the costs of current technology to low levels, the measured learning rate has been relatively modest, and further cost reductions may be limited.

The rest of the paper is organized as follows: Section 2 reviews the previous literature on energy innovation, with a focus on papers that use patents and estimated learning curves as metrics for progress in China's renewable energy technologies. Section 3 explains our data and methods. Section 4 presents our results. The paper concludes with a discussion of the results and implications.

2. Literature review

2.1. Energy innovation systems

Modern scholars view innovation as a complex process involving multiple linked stages with feedback loops between them (Kline and Rosenberg, 1986). Under this "chain-linked" model, knowledge does not flow only uni-directionally from basic science to applied technology, a sharp departure from the previous "linear model." Modern scholars also view innovation in the context of a system of multiple interacting agents and institutions. Carlsson and Stankiewicz (1991), for instance, propose a technological innovation system (TIS) framework, in which the systemic interplay of firms and other actors play key roles in the generation, utilization, and diffusion of various technologies or products. The TIS framework, which consists of seven system functions (Bergek et al., 2008; Hekkert et al., 2007) has been used widely to analyze various technologies, including clean energy (Markard et al., 2012). Some authors have taken this systems approach and adapted it to the challenges of energy innovation, creating an emerging literature on energy technology innovation systems (ETIS) (Gallagher et al., 2012). The innovation process is a collective and interactive activity that involves multiple linked stages (research, development, demonstration, market formation, and diffusion), and it is performed by a network of actors in their market, institution, and policy contexts. Systemic analysis of each phase can be important to understand the process of technological change and useful to inform policy (Gallagher et al., 2012). Elements of the Chinese energy innovation system have been characterized to various extents by previous studies (Gosens and Lu, 2013; Grubler et al., 2012; Zhao and Gallagher, 2007). When viewed in the systems perspective, this paper centers on the invention phase, or the knowledge development stage of the innovation process in China's wind turbine manufacturing industry.