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Learning curves for harnessing biomass power: What could explain the reduction of its cost during the expansion of China?

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ABSTRACT

To explain the factors influencing the cost of biomass power in China, we applied an improved model of learning curves in this paper. The impact of cumulative installed capacity of biomass power and other factors on the cost of biomass technology were investigated. The results showed that installed capacity expansion has led to significant cost reduction. Meanwhile, the effect of economies of scale was observed in the analysis of generation cost. The ownership structure of the firm and the size of the developer had no influence on the learning effects and stronger policy support may, ironically, produce negative incentive effects on technology improvement.

1. Introduction

The economy of China had the “strongest growth” among the world's major economies in recent years. However, this spectacular economic performance has inevitably led to energy shortage and ecological environment deterioration. Due to the environmental pollution and large amount of greenhouse gas emissions, the increasing threat of global warming and climate change has attracted great attentions across the world. These concerns have shifted the focus of economic development towards the use of alternative energy. As the largest energy consumer in the world, China is facing more and more pressure to implement energy conservation methods and emission reduction measures. To meet the requirement of energy for economic growth, the development and utilization of low carbon renewable energy is becoming a strategic choice for China. After prompting a series of policies to increase energy efficiency and develop low-carbon economies, China has currently positioned itself as a dominant player in the renewable energy industry. Among various kinds of renewable energies, biomass has been considered one of the most promising sources dues to its near-carbon neutrality, ample availability and convenience of conversion into various liquid or gas fuels. Moreover, in the renewable energy power generation fields, biomass power is a predictable and non-intermittent technology [1], which does not have the supply issues of wind and solar technologies. According to the analysis of the International Renewable Energy Agency, biomass will account for 60% of global renewable energy use in 2030. In the utilization of biomass energy, biomass power generation has the largest industrial scale. The biomass power industry in China started in 2004, and it has experienced a rapid growth between the years 2007 and 2009 due to strong policy support [2].

However, the growth rate of biomass power in China has shown a declining trend after 2008. The development of biomass power has become slower than other renewable energies, such as wind power in recent years. With strong policy support, wind and solar energy in China has expanded greatly during the past few years. Biomass power has received relatively little attention and its proportion of installed capacity is lower than those of other large consumption countries. In 2012, the installed capacity of China's renewable energy reached about 100,180 MW while the installed capacity of biomass power was only 7660 MW, accounting for 7.65% of all renewable energy power. The relatively high cost of biomass power is a main obstacle for its development, since it is not economically competitive with conventional energies without policy support. Therefore, it is very important to study the factors that influence the cost of biomass power. Understanding the

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relationship can help enterprises and government to formulate a comprehensive development plan. One method to measure technical change and costs reduction is based on the notion of learning curves. The concept of learning effect was firstly presented by Wright [3]. There is no natural law that says the cost of a technology would follow a learning curve, however, the decrease of unit cost with increasing experience has been observed empirically numerous times. This can also be referred to as a progress curve, experience curve, or learning by doing [4–6]. Lindman and Soderholm [7] performed economic analysis of the effect of cost reduction due to cumulative production or capacity. For the past few years, the learning rate analysis has been commonly applied in energy technologies to estimate costs reduction with increasing experience gained from cumulative production. The concept of learning rate has been widely used in renewable energies technologies, especially in wind and solar power. In the field of biomass energy, we only found two articles using the learning-curve model before 2006. The reason might be the lack of detailed data for biomass power, which is varying in scale, fuel type, region etc. In this paper, we use the learning curves approach to quantify the impact of cumulative installed capacity and other factors of biomass power on the cost of the technology in China. This paper measure the change in price of biomass power, which on one hand would be helpful to enact biomass generation policy. On the other hand, the learning curve model constructed would be a good attempt to specify the relationship between the experience of a technology and its cost in the renewable energy field, especially for biomass energy, which has a complicated system compared with other renewable energy technologies.

In the following part, Section 2 is the literature review. Section 3 discusses the data and model specification issues. Section 4 presents and discusses the results. In Section 5 conclusions are drawn.

2. Literature review

Current studies on China's biomass power industry have mainly focused on the present situations, problems and policies. These studies analyzed the industry from several aspects such as resources, market operations, policy environment etc, pointing out the lack of raw materials, technological innovations, and imperfect policies, as the main obstacles preventing large-scale biomass production in China; and offering several suggestions for relevant strategic planning and policy formulation [2,8–10]. The study of Zhang et al. [11] collected and sorted supporting policies of biomass power generation from 2006 to 2013, and found the problems facing the development goal to be huge, including tax policies which are difficult to implement. Some other studies also discussed the technology and cost of biomass power production. Ma et al. [12] presented the development situation of power production technology such as the maximum power efficiency, and analyzed the challenges of increasing biomass cost. Ouyang [13] systemically studied the levelized costs of electricity (LCOE) of main renewable energies, including biomass and calculated the required subsidies for renewable power generation. In addition, a few studies have conducted investment analysis. The study of Wang et al. [14] employed a real options model to evaluate investment of biomass power, and provided information for enterprise decision-makers on whether and when to invest in biomass power production. Sun et al. [15] constructed a spatial planning framework including spatial analysis technology, economic model and scenario analysis to perform detailed technical, economic and priority analysis of the developing areas. These methodologies can be used by the authorities to formulate plans for future biomass energy development at the regional level.

With the increasing importance of energy issues, economists have employed various economic analysis methods, including the learning curve method, to study energy technology improvements. The most common form of this method is to set up the cost of a technology as a power function of a learning curve in installed capacity or production [16]. The learning curve method was first used in the study of product manufacturing [17]. Such learning curve method has also been called one-factor learning curve, for it only considers cumulative experience to be a factor. Recently, in an extensive literature review focused on the effect of R&D on technological improvement, the two-factor learning curve was introduced. It simultaneously considered the effect of cumulative experience (learning by doing) and accumulated knowledge (learning by searching) [18]. In comparison with conventional energy, the learning curve method has been more widely used in conjunction with renewable energy. The reasons might include the expectation of continuing technology development and the pressing needs for policy analysis of renewable energies, which usually require supporting policy [19]. The studies on learning curves of renewable energies have mainly concentrated on wind energy and solar photovoltaic, based on the one-factor learning curve [20–23] and the two-factor learning curve [24–27]. Some studies set up a local model of the learning curve to analyze the effects of local learning, mostly in developed countries, while other studies used aggregated data to estimate the global technology learning curve. For biomass energy, the energy systems are often more complex than wind and solar energy, as it requires fuels and more human labors accounting for a large part of the final cost; and the local condition may also affect their costs [5]. Due to the lack of detailed data, it is very difficult to devise empirical learning curves for biomass power. We only found the studies of Junginger [5,28]and Goldembreg [29] before 2006 in terms of the learning rate for biomass energy. In this paper, the learning curve method will be applied to explain the cost of biomass power in China. Currently, biomass gasification power and co-combustion technologies are less used in China. Therefore, this paper focuses on biomass direct combustion, which is widely used in biomass power plants.

3. Methodology

3.1. The basic learning curve model

The most common specification of the learning curve model is to estimates the learning rate, with which the cost of the energy technology has decreased as a function of cumulative installed capacity or production. The basic model is defined as in Equation (1)

$$\mathrm{cost_t} = A * \mathrm{cum}_t^{\alpha} \tag{1}$$

where $\mathrm{cost_t}$ is unit cost of the technology at time t, $\mathrm{cum_t}$ refers to cumulative installed capacity or production[2]. The logarithmic functional form of equation (1) is as follow,

$$\mathrm{Lncost_t} = \mathrm{LnA} + \alpha \mathrm{Lncum_t} \tag{2}$$

$$\mathrm{PR} = 2^{\alpha} \tag{3}$$

$$\mathrm{LR} = 1 - 2^{\alpha} \tag{4}$$

The PR (progress rate) expresses the rate of the cost declining

[1] The biomass power in Figs. 1 and 2 includes waste incineration and biogas.

[2] According to the data collected and other similar studies, the cumulative installed capacity will be used as a measure of cumulative experience in this paper.