Energy Policy ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Diffusion of solar water heaters in regional China: Economic feasibility and policy effectiveness evaluation

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HIGHLIGHTS

- We examine the economic feasibility of solar water heaters in 27 Chinese cities.
- We evaluate policy effectiveness of solar water heaters (SWHs) using panel data.
- Diffusion of SWHs is cost effective in fulfilling China's renewable energy target.
- Financial attractiveness of SWHs is limited without incentive programs.
- The existing subsidy policy is proved to be a failure and a new program is suggested.

ARTICLE INFO

Article history:
Received 18 December 2013
Received in revised form
8 April 2014
Accepted 10 April 2014

Keywords:
Solar water heater
Effectiveness
China

ABSTRACT

Whereas the technical feasibility of solar water heaters (SWHs) has long been established, the economic feasibility of SWHs in regional China remains to be examined. This paper constructs cost models to calculate costs per unit energy saving of SWHs in 27 Chinese provincial capital cities. The cost effectiveness of SWHs is examined at the national level. At a micro level, we analyze the financial attractiveness of consumers' investment in SWHs. A panel data model is employed to evaluate the effectiveness of a subsidy program in rural China. The results show that SWH costs, ranging from 0.305 to 0.744 CNY/kW h, are much lower than those of other major renewable energies across China. This finding indicates that the diffusion of SWHs is a cost-effective way to reach China's renewable energy target. For consumers, incentive programs for SWHs are needed to improve the financial attractiveness of the devices in China. Existing subsidy policies for rural China have failed to significantly enhance the deployment of SWHs. The causes of the failure are examined and a new incentive program is suggested for rural areas of the country.

1. Introduction

Solar water heaters (SWHs) are a mature technology for harnessing renewable energy compared with other solar energy technologies, such as solar space heating and cooling systems and solar PV power generation (Zhao and Zhao, 2009; Han et al., 2010). With the commercialization of SWHs over the past three decades, China has become the largest country using solar thermal power in domestic water heating. By the end of 2010, the country had installed 168 million m^2 (collector area) of SWHs, which accounted for more than 60% of SWHs installed in the world. In China, the average collector area of SWHs per capita was only 0.109 m^2 in 2009, much less than 0.155 m^2 in Germany, 0.330 m^2 in Australia, 0.361 m^2 in Greece, 0.514 m^2 in Austria and 1.073 m^2 in Cyprus (Mauthner and Weiss, 2012). There is also a wide gap within China. For example, the installation of SWHs per capita amounted to 0.072 m^2 in 2009 in rural China, less than half of that in urban areas.[1] With rich solar radiation and increasing demand for hot water in China, the country still has great potential for further diffusion of SWHs, which is especially important against the backdrop of environmental pollution and energy deficits. China has set an ambitious target for renewable energy. The National Development and Reform Commission (NDRC) published the country's renewable energy development goal in 2007. The ratio

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[1] The data we used to calculate the installation of SWHs per capita sourced from NBS (2010a; 2010b) and China Renewable Energy Academy (2010).

http://dx.doi.org/10.1016/j.enpol.2014.04.015
0301-4215/

of renewable energy utilization to total energy consumption is supposed to reach 15% by 2020 (NDRC, 2007). However, the ratio only amounted to 8.9% by 2010, failing to reach the target of 10% for the year (NDRC, 2012a). The massive application of SWHs will help the country to realize the national target for renewable energy development.

Although the technical feasibility of SWHs has long been established, the financial feasibility at the regional level must be carefully examined, especially in large countries experiencing various natural and socio-economic conditions (Chandrasekar and Kandpal, 2004). For example, Chandrasekar and Kandpal (2004) calculated the annual costs of SWHs by discounting future expected costs in different regions of India; Gillingham (2009) evaluated the financial attractiveness of SWHs in 16 regions of New Zealand using the internal rate of return (IRR) and payback period; and Cassard et al. (2011) employed break-even costs to analyze the economic performance of SWHs in 19 states in the United States.

Although China is rich in solar energy, its solar resources vary greatly among regions.[2] Other factors affecting the diffusion of SWHs also generally show gaps among provinces, for instance, income level and the price of alternative energies (Ma et al., 2012). Empirical studies on the economic performance of SWHs in China remain sporadic. To date, two city-level case studies, on Dezhou (Li et al., 2011) and Jinan (Zhao et al., 2008), and a provincial-level case study, on Zhejiang (Han et al., 2010), have been conducted. Although these studies provide rich empirical insights into case studies of SWH application in the country, systemic level studies remain to be performed to form a holistic picture of SWHs in China and reveal regional variation. Our study aims to bridge this gap by conducting quantitative studies that include 27 provincial capital cities[3] in China. First, we construct cost models to evaluate the average costs of SWHs within their life cycle. Cost-effectiveness analysis is conducted to illustrate the cost advantage in achieving the given renewable energy objective at a macro level. Then, at a consumer level, we compare the costs of SWHs with their alternative, electric water heaters, and calculate the internal rate of return (IRR) and payback period to reveal the financial attractiveness of SWHs in different regions. The effects are also simulated under different subsidy rates because incentive programs are popular worldwide in promoting the dissemination of SWHs.

In practice, some efforts have been made in China to promote the diffusion of SWHs in recent years. By 2009, China had added SWH products to the subsidy list under a comprehensive incentive program titled "Home Appliances Going to the Countryside Program" (HAGCP). This incentive policy is the only one that exists at the national level, and only targets rural China. Following economic feasibility analysis, we empirically evaluate the effectiveness of the subsidy policy to shed light on future policy design and improvement. Rather than using trend analysis to compare previously installed SWHs with those installed under incentive programs (Chang et al., 2006, 2011; Roulleau and Lloyd, 2008), this paper presents a new approach by establishing a panel data model based on Chinese provincial data to empirically test whether the policy effect is significant. To identify the net effect of the incentive program, the following main control variables are incorporated: SWH stock, net income, population migration and average family size. A series of statistical tests are run to select the proper estimation method. After the empirical analysis, barriers to and solutions for the subsidy policy problem are carefully examined.

We find that although the costs of SWHs per unit energy saving show great variability among Chinese regions, SWHs have general cost advantages over other promising renewable energies, indicating that SWH usage is cost effective in fulfilling the country's renewable energy target. Through a life-cycle assessment, the costs of SWHs are also determined to be lower than those of EWHs in most regions of China, whereas the financial attractiveness for consumers is proved to be limited and will be undermined because of unmet hot water needs[4] and much higher up-front costs. Therefore, an incentive program is required to improve financial feasibility at the consumer level. After estimating the panel data model, we conclude that the subsidy of 13% under the HAGCP failed to accelerate the diffusion of SWHs in rural China. We propose a new specific incentive program targeting SWHs as a means of renewable energy application in rural areas, with the subsidy rates ranging from 9 to 50% according to China's four large regions.

The rest of the paper is organized as follows. Section 2 estimates the economic feasibility of SWHs in 27 Chinese provincial capital cities by cost-effectiveness analysis as well as financial attractiveness analysis. Section 3 conducts a policy-effectiveness evaluation of rural China by estimating a panel data model and then explains the barriers to and solutions for the subsidy policy. Section 4 concludes the paper, provides policy implications and identifies some remaining issues.

2. Economic feasibility of SWHs in China

Economic analysis is carried out in this section first to prove that the diffusion of SWHs is the least expensive means, compared with other promising renewable energies, for fulfilling China's renewable energy target. Then, through a cost comparison with a non-solar alternative (electric water heater) and calculation of the internal rate of return and payback period of SWH usage in 27 Chinese capital cities, we attempt to determine the financial attractiveness of SWHs at the consumer level. The IRR and payback period are also simulated under different subsidy rates.

2.1. Cost-effectiveness analysis

When the national renewable energy development target is set in advance through a political decision-making process[5], a strict comparison between the benefits and costs of applying particular renewable energy is not necessarily required. In such cases, cost-effectiveness analysis can help to reveal the cost consequences of choosing or giving priority to a means for achieving that objective (Tietenberg and Lewis, 2011). To perform cost-effectiveness analysis, we will first establish cost models for SWHs at the Chinese city level.

2.1.1. Cost models

Because there are up-front costs, we utilize the life expectancy of SWHs as the basic assessment term. To estimate the cost per

[2] The extremely rich, very rich, exploitable and poor areas account for 17.4, 42.7, 36.2 and 3.70% of China's total land area respectively (Luo and Zhai, 2009).

[3] In China, a city represents an administrative region including not only the corresponding urban area but also adjacent rural area. For example, the city of Hangzhou in Zhejiang Province refers to its eight municipal districts (urban areas), two counties and three county-level cities (primarily rural areas).

[4] Generally, SWH cannot completely meet consumers' hot water needs because "heat supply" and "heat demand" are not always matched. For detailed analysis, one can refer to Section 2.2.1.

[5] According to NDRC (2007), the ratio of renewable energy consumption to total energy consumption is supposed to reach 10% by 2010 and 15% by 2020. By 2015, the ratio of non-fossil fuel consumption to total energy consumption should reach 11.4% (NDRC, 2012a).

Please cite this article as: Ma, B., et al., Diffusion of solar water heaters in regional China: Economic feasibility and policy effectiveness evaluation. Energy Policy (2014), http://dx.doi.org/10.1016/j.enpol.2014.04.015