Encircling cities from rural areas? Barriers to the diffusion of solar water heaters in China's urban market

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A R T I C L E   I N F O

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A B S T R A C T

Researchers have contributed a fruitful understanding of the facilitating factors for solar water heaters (SWH) diffusion in China at different governance levels. However, the barriers to its further diffusion in the urban environment have so far not been addressed. One feature of SWH diffusion in China is that it emerged from the rural market, mainly driven by market demand. This article explicitly focuses on China's diffusion of SWH from rural areas to urban cities and explores the problems and barriers obstructing its full potential in cities. Applying the Multi-level Perspective (MLP) framework, the results find that the technological niche is still not mature enough, and the urban regime is still powerful in terms of building infrastructure, consumer demand, policy coordination and vested interests. SWH development in China is promoted more as a business opportunity, while environmental discourses have not been powerful enough to promote further diffusion in the urban context. We suggest there is a need to focus on technology innovation with higher industry standards and to implement more benefit-based incentive policies to motivate incumbent actors.

1. Introduction

Solar thermal energy is a form of technology for harnessing solar energy to generate thermal energy or electrical energy. In 2016, the global installed capacity of solar thermal heat had reached 456 GWth (Weiss et al., 2017). Besides conventional renewable energies (e.g. hydropower and biomass), the contribution of solar thermal heating in generating green energy is second only to wind power and much higher than solar photovoltaic (PV), but this fact is underestimated in many countries’ energy policies (Mauthner and Weiss, 2014). In response to its environmental challenges, China is committed to altering its coal-dominated energy mix by promoting the development of renewable energy. As the world’s largest developing economy and largest carbon emitter, China’s transition to renewable energy not only addresses its national sustainability concerns, but may also significantly contribute to combating global warming through carbon mitigation and exporting transition experiences. By 2016, China had become one of the world’s leading countries in the renewable energy industry with the largest installed capacity in hydropower, wind, photovoltaic (PV) and solar heating globally (REN21, 2017). In particular, China’s solar thermal heating accounted for approximately 80% of global production and 71% of global installed capacity in 2015 (Weiss et al., 2017). Solar thermal energy has been applied in industry for heating, cooling and drying, but the most common usage of solar thermal energy is for solar water heaters (SWH) in residential and commercial use.

One feature of China’s SWH popularisation is that it is mainly driven by market demand for economical sources of hot water, especially from rural areas and small cities (Hu et al., 2012). In addition, with the rising importance of environmental imperatives in China, policy incentives have begun to play an important role in promoting SWH in the urban market. In particular, projects which involve SWH-building integration have witnessed a rapid growth in urban markets in the latest decade and China’s cities are believed to have leapfrogged over their international counterparts in the application of SWH ( Schroeder and Chapman, 2014). Nonetheless, the technology still faces many severe barriers to fulfil its potential in the urban market, especially in large cities.

Previous research, particularly that published in Energy Policy, has contributed a fruitful understanding of the diffusion of SWH in various countries, such as Greece, the UK and Germany (FaIers and Neame, 2006; Mills and Schleich, 2009; Sidiras and Koukios, 2004). These works have mainly been concerned with the drivers and barriers from a user perspective, finding that economic saving is the main driving force and financial cost is the primary barrier. In addition, peer behaviour and environmental awareness also matter in diffusion, although they are not as important as economic factors (Woerderscher and Kaus, 2011). In the case of China, researchers have explored the facilitating factors of SWH diffusion at the national (Hu et al., 2012), provincial (Goess et al., 2015; Han et al., 2010), and city levels (Li et al., 2011). This work...
shows that economic saving and convenience are the overarching considerations in adopting SWH, and environmental concern is not viewed as critical (Yuan and Zuo, 2011). Moreover, compared to Israel and Australia for example, the SWH industry in China is seen by local governments more as a business opportunity, rather than a response to energy security or environmental responsibility (Li et al., 2013). While there has been an absence of national incentive policies, some local governments have economic motivations (e.g. employment and fiscal revenue) to support local SWH industries through measures such as mandatory installation policies and subsidies.

The existing literature focuses on either user preferences or policies (for an exception, see Goess et al., 2015), which we believe is not sufficient to depict China's SWH development. Other key factors such as infrastructure, institutions, vested interests, and technology on the supply side are overlooked. Given that SWH has been widely adopted in the less wealthy rural market, it is doubtful that financial cost constitutes the main obstacle for SWH diffusion in China's urban market. Instead, we contend that we need a more systematic approach to understand the diffusion covering both production and consumption issues. To this end, the present paper argues that the analysis of SWH diffusion can benefit greatly from sustainability transitions research, which investigates fundamental transformations towards more sustainable modes of production and consumption (Markard et al., 2012). The Multi-level Perspective (MLP) is one of the dominant research frameworks in sustainability transitions research because it provides a straightforward and simplified way to depict complex structural transformations of a system (Smith et al., 2010). The MLP has also been widely applied to purposively promote transitions in desired directions by assessing and diagnosing current ongoing transitions (e.g. Kern, 2012; Liu and Shirayama, 2013; Nykvist and Nilsson, 2015). The barriers and drivers of transitions identified at the three conceptual levels of the MLP (niche, regime and landscape) allow transition managers to consider the complex factors that are co-evolving and co-determining one another across different scales (Rock et al., 2009).

Another gap we attempt to address is the neglect of spatial difference in SWH diffusion, especially from the perspective of rural-urban divisions in China. The rural and urban markets constitute different selection environments for SWH diffusion, but this is under-researched. Conventional diffusion paths suggest that innovations originate in urban markets and then diffuse to rural markets, from central places to the peripheries. By contrast, SWH in China has been mainly popularised in rural areas and small cities, and was only recently encouraged in large cities due to environmental imperatives. In the process this relatively low-tech product is diffusing to a much harder selection environment. Encircling the cities from rural areas is a famous philosophy of revolution by Mao Zedong, which believes armed revolution should start from places where obstructing forces are weak (the rural areas) and then entering harder places (the cities) after power growth in the former place. China's SWH popularisation seems to have followed the same development path, however, the technology has encountered many obstacles on the way from peripheries to the core areas.

Though different cities constitute different selection environments for SWH diffusion (see the contrasting study of SWH diffusion in Dezhou and Beijing, Yu and Gibbs, 2018), this paper aims to explore the general system barriers to the diffusion of SWH in China's urban market. Following this introduction, the next section outlines the SWH industry's development history, policies and problems in China. Section 3 introduces the MLP analysis framework and our research methods. The results are presented and discussed in Section 4. Finally, Section 5 concludes the paper and provides implications for future research.

2. The development contexts and problems of China's SWH industry

2.1. Development history

One feature distinguishing China's SWH industry from other renewable energies is that market demand was the main driving force of its development. Government support played a role in both early and recent years, but it was absent in the interim period. China's central government played a key role in developing the SWH technology before its commercialization in the 1990s (Urban and Geall, 2014). Research on solar thermal technology was continuously supported by the national project of science and technology such as Project 863. After entering the civil market, SWH has been developed mainly at the local level without much support from central government. Its industrialisation was largely attributable to the efforts of private entrepreneurs and household consumers (Luo, 2012). Only at the local level were some SWH enterprises listed in the high-tech enterprises' catalogue by local government, and thus enjoyed some favourable policy treatment (Hu et al., 2012). The industry's development path is divided into three phases:

1. Start-up phase: 1978–1994. In response to the global oil crisis, China started its research into solar energy by establishing solar research institutions and supporting solar research in top universities at the end of the 1970s. In 1986, Beijing Solar Energy Research Institute imported the Canadian flat-plate copper-aluminium composite production line, which marked the start of China's SWH industry. With the core technology solved, private entrepreneurs began to enter the SWH sector as they realised the potential market demand for hygienic lifestyles and hot water associated with China's rapid economic development. The improvement of flat-plate SWH technology met this demand and dominated China's SWH market in this phase. However, due to the high cost of flat-plate SWH and its low efficiency in winter, as well as the low consumption power of Chinese consumers at that time, the industry grew very slowly (Hu et al., 2012).

2. The rapid growth of evacuated tube SWH: 1994–2005. In 1994, a technological breakthrough in all-glass evacuated tubes by Tsinghua University, which also developed the corresponding large-scale manufacturing equipment, led the industry into a new era. This indigenous technology enabled the mass production of SWH and significantly reduced its cost (Luo et al., 2013). Some leading SWH enterprises initiated massive popularisation of solar energy knowledge around the country. The SWH market quickly expanded in rural areas, facilitated by the rising consumer power of rural residents. Although the initial cost of SWH was higher than electricity water heaters (EWH) and gas water heaters (GWH), it was widely adopted due to the savings on energy bills and the higher price/performance ratio. The following decade witnessed the rapid growth of China's SWH market, with an annual growth rate of 30% (Wang and Zhai, 2010). During this phase, the evacuated-tube SWH grew to be the dominant SWH, with a market share of more than 90%.

3. Fast development of SWH-building integration projects: Since 2006. Since the Renewable Energy Law took effect in 2006, many provinces and cities have implemented mandatory installation policies that require new residential buildings to incorporate solar water systems into building design and construction. Accelerated by the rapid growth of the building industry in China's urbanisation, the SWH-incorporated building project market (hereafter, project

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1 Project 863 or China's State High-Tech Research Development Plan was started in March 1986. It aims to develop advanced technologies in a wide range of fields for the purpose of reducing technology dependence on western countries.
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