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Socio-technical experiments from the bottom-up: The initial stage of solar water heater adoption in a 'weak' civil society

Abstract: Recent years have witnessed the proliferation of urban experiments in responding to climate change. There is a tendency of prioritizing the role of government interventions in transitions, while neglecting the agency of other parties. This is especially true in China, where authoritarian governance dominates the transition process. The Rizhao case, however, exhibited a distinct bottom-up pattern in the early-stage development of solar water heater (SWH) technology, when both the civil society and the market were still immature. Through this rare case of urban energy transitions in China, this study looks into the socio-technical experiments from the bottom-up. The study shows that before the intervention of local governments, through the mutual effects of both resident-led social experimentation and entrepreneur-led technological experimentation, a niche market of SWH technology was successfully established and consolidated in Rizhao. It further uncovers that in a less-developed civil society in China, the diffusion of novel innovations relied heavily on interpersonal social networks.

Keywords: urban energy transitions; socio-technical experiments; social network; solar water heater; China

1. Introduction

Cities are the frontier for forging low-carbon and sustainable transitions. UN Habitat (2016) reported that "cities consume 78 percent of the world's energy and produce more than 60% of all carbon dioxide and significant amounts of other greenhouse gas (GHG) emissions". Cities, therefore, possess tremendous potential as 'motors' for fundamental transitions or 'hubs' for radical innovations towards sustainability (Castán Broto and Bulkeley, 2013; Ernstson et al., 2010). Recent years have seen the proliferation of urban experiments in responding to climate change (Bulkeley and Castán Broto, 2013).

Urban climate change experimentation is increasingly situated within the domain of urban governance. Extant literature on urban climate change governance largely focuses on policy laboratories (governance experiments) and the design of urban futures (explicitly strategic experiments such as eco-city) (Bulkeley and Castán Broto, 2013), while the role of socio-technical experiments in urban interventions towards sustainability has gained less attention. An emerging area of debate has explicitly addressed socio-technical experimentation in urban areas (Hodson and Marvin, 2010; Rutherford and Coutard, 2014; Frantzeskaki et al, 2017). The imperative role of 'niche', in particular, is emphasized. Such protected space, according to Geels (2007), enables the nurturing and empowering of innovation. Niches can be made operational either through formally initiated and protected test beds such as pilot and demonstration plants (Raven, 2007, 2391; Nevens et al., 2013), or through bottom-up experiments by citizen groups and/or non-governmental organizations (NGOs) (Hegger et al., 2007; Witkamp et al., 2011).

Within the context of well-developed civil societies, the field of niche experiment has documented abundant empirical evidence on innovation and experiments from the bottom-up (Moulaert, et al., 2005; Seyfang, et al., 2014). Nevertheless, there is scant knowledge about niche experiments in a less-developed civil society, in terms of the key actors involved and the diffusion mechanisms. This is why Rizhao's case draws our attention.

Rizhao city was awarded by United Nations (UN) the 'World Clean Energy Awards' in 2007, for its outstanding achievements in the application of solar energy (Schroeder and Chapman, 2014). What is more remarkable is that this transitional process was made possible even before the official intervention of political players. In this sense, the Rizhao case might provide important insights into the role of bottom-up socio-technical experiments in a 'weak' civil society. It is therefore interesting to find out: 1) what actors have engaged in bottom-up experimentation towards the popularization of SWHs; 2) what is the mechanism for the translation of such urban innovations into concrete actions

and the successful formation of a niche of SWH technology.

The remainder of this article is organized as follows. In section 2, we review extant literature on socio-technical experimentation in cities. Section 3 presents a brief overview on the social, economic and institutional contexts against which a transition from the bottom-up emerged in Rizhao. Section 4 introduces the study area, the research method and data. Section 5 presents empirical study in Rizhao and traces back the early-stage SWH adoption in the city. In section 6, we further discuss the empirical findings uncovered in section 5. Concluding remarks are given in section 7.

2. Socio-technical experimentation in cities

In transition studies, 'socio-technical experimentation' is a central concept (Sengers et al., 2016a). Experimentation is an important step for incubating innovations, translating technology into market opportunities, and fostering profound shifts to more sustainable socio-technical configurations. Experimentation is often attached with specific ambitions and approached from differing perspectives, be it creating market niches (Smith and Raven, 2012), addressing societal problems and social needs (Seyfang and Smith, 2007), or more broadly engendering radical transitions towards sustainability (Berkhout et al., 2010; Wieczorek et al., 2015). As described by Sengers et al. (2016a), socio-technical experimentation "implies a more engaged and social constructivist position: society is itself a laboratory and a variety of real-world actors commit to the messy experimental processes tied up with the introduction of alternative technologies and practices in order to purposively re-shape social and material realities." (p. 1-2)

Socio-technical experimentation is increasingly examined within the urban contexts (Uyarra and Gee, 2013; Fallde and Eklund, 2015; Zhang et al., 2015; de Koning et al., 2016). Bulkeley and Castán Broto (2013) provide a systematic case review on climate change experiments in 100 cities. The authors categorize governance experiment as a key approach, while simultaneously highlight the constitutive role of fundamental socio-technical change and urban politics. Under the latter point of view, cities are not perceived merely as loci where experiments occur and develop, but rather as a dynamic space that consists of material, institutional, and political dimensions and is continuously shaping and shaped by such initiatives and practices (Huang et al., 2018; Huang et al., forthcoming).

There is, however, a tendency of emphasizing local government interventions in transition processes (Gustavsson et al., 2009; Quitzau et al., 2012), because policy-makers often possess substantial institutional and financial resources in orienting the trajectory of sustainability transitions. For instance, based on two case studies of Sweden and Denmark, Smedby and Quitzau (2016) show how local governments foster sustainability through a combination of different modes of governing: governing by provision, governing by authority and governing by enabling. This trend of authoritarian transitions is especially evident in developing countries, where a civil society is not yet mature and authoritarian decision-making is prevalent. In China, for example, the predominant view on urban experiments and transitions follows the 'command and control' paradigms (Cox, 2016), within which multi-level governments position themselves as "controllers" of the transition process (Li et al., 2016a). Many empirical case studies interpret the success of climate change policies in China as an adequate match between top-down objectives and appropriate approaches to policy action (Li et al., 2016b), and the multiple interactions between different policy actors (Francesch-Huidobro and Mai, 2012; Mai and Francesch-Huidobro, 2014; Wu et al., 2016). This trend of prioritizing governmental intervention, however, tends to neglect the transformative potential of other parties in the society. In many cases, the actual effects and mechanisms of bottom-up practices in urban transitions are still in a black box, especially in the early-stage of transition process.

This study argues that in cases where top-down incentives are absent, the important role of other urban actors that participate in the process of urban experimentation and transitions can manifest (Hamann and April, 2013; Forrest and Wiek, 2014; Frantzeskaki, et al., 2016; Voytenko, et al., 2016; Fallde and Eklund, 2015). The active agency of entrepreneurs, for instance, is often considered as a

main driving force (Moallemi, 2017). The well-recognized tradition of enterprises in producing radical innovations, at the same time baring the risk and uncertainty, represent their transformative potential in sustainability transitions. Markets and the private sector therein act as an important operational domain where innovative ideas are translated into actions (Burch et al., 2016). The mechanism for the diffusion of innovation is through both formal and informal networks (Musiolik et al., 2012). In addition, an emerging body of literature on grassroots innovation highlights the role of the civil society (especially local communities) in urban experimentation (grassroots experiments) (Seyfang and Haxeltine 2012; Smith et al., 2014). Grassroots experiments represent bottom-up solutions for sustainability transitions. Experimental activities are often motivated by unmet social needs that incumbent production and consumption systems and local governments fail to satisfy (Wolfram, 2016), and are initiated by a nexus of actors (activists, organizations, communities), responding to local institutions, interests, and values (Feola and Nunes, 2014). Grassroots innovation is generally operated within the civil society arena (Seyfang and Longhurst, 2013). It therefore goes beyond the conventional scope of experimentation initiated by firms or governments (Sengers et al., 2016a), and embraces a variety of social innovations (Seyfang and Smith, 2007: 585).

Understanding technological and social experiments in cities, therefore, requires bringing together the technology-based experimentation that emphasizes the path-breaking potential of entrepreneurs and the governance-based terms of experimentation that explicitly address the complexity of conflicts between varied urban actors. A latest call for identifying the role of the complex nexus of individuals in climate governance (Tosun and Schoenefeld, 2017) underscores the lack of attention on individuals and the structures that surround them: "in a world where everything is controlled by rigid and unmovable discourses, it seems futile to even begin to think of change emanating from individuals, but there are many examples where this does appear to happen (p.12)". However, no matter what mechanisms are uncovered, current insights are mainly gained from well-developed civil societies, where local communities and civil organizations possess strong agency in initiating urban experimentation (Hargreaves et al., 2013; Moulaert, et al., 2005; Seyfang and Smith, 2007; Seyfang and Haxeltine, 2012; Seyfang, et al., 2014). Considering that socio-technical experiments are highly contingent on the institutional contexts (Feola and Nunes, 2014; Hargreaves et al., 2013), experimentation in a less developed civil society might exhibit distinct patterns of actor interaction and innovation diffusion, which needs further exploration.

This brings us directly to the case of Rizhao city, where as aforementioned, under the absence of policy interventions, experimentation from the bottom-up emerged and diffused in a semi-civil society. Seen from this, the Rizhao case on the one hand provides precious insights into bottom-up urban experimentation in less-developed civil societies, and on the other hand challenges the predominant view of authoritarian environmental governance in Chinese cities. Specifically, this study intends to find out the main urban actors that have engaged in the bottom-up urban energy transitions in Rizhao and how novel innovations are translated into concrete actions. In next section, we present a brief overview on the social, economic and institutional contexts against which a transition from bottom-up was taking shape in Rizhao.

3. Background

Early in the beginning of the 21 century, when there were hardly any governmental documents guiding the development of SWH industry, the popularization rate of this technology in Rizhao had already reached 70% (Huang et al., forthcoming). This study aims to uncover the forming mechanisms behind this bottom-up diffusion process of SWH technology in Rizhao city. To trace back the underlying incentives for grassroots innovation, it first entails an understanding of the broader contexts within which those experiments were situated. Therefore, before diving into the empirical analysis, we first present background information on Chinese society in the 1980s and 1990s.

Before the structural economic reform in the late 1970s, the Chinese central government had launched large-scale state-mandated industrialization. In urban areas, many large state-owned

enterprises (SOEs) were established and working and residential space in cities was structured around these SOEs. Affiliated employees were provided with a comprehensive package of welfare and services, including housing, hospitals, schools, as well as bathing houses (Bjorklund, 1986). In the late 1970s, China launched a series of economic reforms (Lin & Ho, 2005) and a transition from a socialist economy to a market economy was started. Although till the 1990s many cities had experienced rapid economic growth, there was a general lack of resources, especially in less developed areas like Rizhao.

Moreover, compared to profound and radical reforms in the economic system, the political arena had been further tightened up, particularly in the 1990s. The Chinese society at that time was illustrated as economically free but politically passive (Zhao, 2014). A direct consequence was the under-development of the civil society. There was, for instance, strict control over the registration of NGOs. In the 1990s, Chinese civil society was still at the infant stage with a lack of empowerment of citizens and communities, and a very limited range of organizational types of NGOs. A key difference between this semi-civil society in China and more developed civil societies, we would argue, is that the society is not organized through formal networks or social organizations. Rather, in public affairs informal networks based on the pre-existing social structure were often resorted to.

The social structure of the Chinese society can be largely explained by the concept of '*guanxi*', which is the Chinese term for social connection or relationship (often based on reciprocity) (Peng, 2004; Puffer et al., 2010). Based on his insightful understanding of the Chinese culture and society, the Chinese scholar Liang Shumin (1949) asserted that, deeply rooted in the Confucian culture[1], Chinese society is neither individually-based nor group-based, but inherently relation-based (*guanxi benwei*). Another sociologist Fei Xiaotong (1947) conceptualized this particularity of relation-based social structure as '*chaxu geju*' (differentiated mode of association), which depicts a multi-layer egocentric network, extending from the family (the core), to relatives, friends, and so on (Peng, 2004). The inner circles represent stronger ties and the outer circles weaker ties (Huang, 2008). This structure is fundamentally different from western individualism (Herrmann-Pillath, 2010). Bottom-up initiatives and grassroots innovation in a "weaker" civil society, as what we will present in the following sections, might make meaningful use of pre-existing social networks and structures.

4. Study area and data collection

Rizhao city is located in the eastern coast of Shandong Province in China, with an area of 5358.57 km^2 and an urban population of 1.40 million[2]. The average annual insolation duration is more than 2540 hours, with approximately 330 days of sunshine a year. Abundant solar resources constitute a natural advantage for the utilization of SWHs in this city. Early in the beginning of the 21 century, the SWH popularization rate in the urban areas of Rizhao has reached 70%, when there was hardly any governmental guidance specifying the adoption of SWHs. Figure 1 is a photo of Rizhao in 1998 that shows numerous roof-mounted SWHs on the rooftops of residential buildings. The photo demonstrates that as early as 1998, there were already a substantial proportion of residents using SWHs in Rizhao, indicating the successful formation of a niche market in this city. This is remarkable considering the absence of both government-affiliated associations and NGOs (So, 2005).

[1] The core of Confucian philosophy is "differentiated attitudes toward parents, children, siblings, kinsmen, and friends, and so on" (Peng, 2004, p.1050).

[2] http://www.rizhao.gov.cn/sqlb.php?category_id=9

Fig. 1. A bird's eye view of the roof-mounted SWHs in Ju county, Rizhao. (Photo taken by Chengjun Ma, 1998)

Considering that online documentary materials were very limited in the 1980s and 1990s, we collected data mainly through semi-structured interviews. In total, we conducted 34 interviews with varied stakeholders in Rizhao and Shandong, which include government officials, SWH manufacturers, real estate developers, industry organizations, NGOs, and end-users (the average duration is around 30 minutes). Names of interviewees are not provided due to confidentiality reasons. Interviews with different stakeholders enable us to gain a more comprehensive view on the early-stage adoption of SWHs. As complementary materials, we also collected data through archival research (i.e. review of government documents and newspapers) and field observations.

5. The initial stage of SWH adoption in Rizhao city

5.1 Unmet social needs

Socio-technical experiments are in many cases induced by unmet social needs that incumbent production and consumption systems fail to satisfy. Relating to the function of water heaters, there had been long suppressed social needs for home bathing in China. Due to lack of domestic bathing facilities, people could only use stoves to heat water for bathing (usually in a big wooden bathtub) or pay for a bath in public bathhouses (Young and Grant, 1991). Before the 1980s, the majority of urban residents were employees of SOEs, which were equipped with bathing houses. Many of these bathing houses were also open to the public, whereas affiliated employees had the privilege of taking a bath there for free. However, after the reform of the planned economy in 1978, the original system was gradually abandoned and enterprises no longer shouldered the social responsibilities such as providing bathing facilities.

Along with the rise of private economy in China, privately owned public bathhouses mushroomed in urban areas. At that time, public bathhouses were particularly popular in the winter, when the weather was too cold to bear for a bath at home. However, these privately owned bathhouses were far from enough to meet the social needs of urban residents for bathing. The People's Daily, one of the oldest and most influential newspapers in China, reported frequently in the 1980s about the lack of public bathhouses in cities. Shandong was no exception. For instance, in 1985, it was reported in People's Daily that people living in Shandong province encountered substantial difficulties in taking a bath[3]. This situation was verified in our interviews. As recalled by an interviewee:

> "Back in the 1980s, there were limited public bathhouses in town, and we only went to bathhouses in bone-chilling winter. In days that were not too cold, we took baths at home. It usually took a lot of time to heat water for home bathing. It was quite inconvenient, but it saved money." (Interview, End-user)

Moreover, due to contextual factors such as resource accessibility, residents' unmet social needs for bathing were not addressed by other substitute technologies such as gas water heater (GWH) and

[3] The People's Daily (23/02/1985), http://58.68.146.102/rmrb/19850223/5

electric water heater (EWH) in Rizhao. For GWH technology, natural gas was not widely accessible to residential buildings in Rizhao until 2008, when a long-distance natural gas pipeline was constructed[4]. Even though the liquid gas tank for domestic use was available back then, residents in Rizhao had to fill up the gas tank at the city gas station, which was very inconvenient. There was also a serious lack of liquid gas at that time (Interview, End-user), which is a significant factor that has hindered the wide application of GWHs in Rizhao. Besides, energy cost is another consideration. At a time when the economy was underdeveloped and the general income of people was quite low, the cost for both GWHs/EWHs and natural gas/electricity were considered very expensive. Taking GWHs for example, as described by one interviewee:

> "As a teacher in a junior school, my salary was no more than 20 yuan per month in the 1980s, which increased to around 200 yuan in early 1990s. While a GWH at that time would cost me 400 to 500 yuan. That was a lot of money for me, let alone the gas bill that I had to pay." (Interview, End-user)

Expense considerations, combined with the tradition of frugality of local residents (Yu and Gibbs, 2017), were accountable for unpopularity of GWHs and EWHs.

Overall, back in the 1980s, there were yet any effective solutions to meet the long-suppressed social needs for home bathing in Rizhao, which "incidentally" helped the formation of a protected niche for the emergence and diffusion of SWH technology.

5.2 Resident-led social experimentation

As a result of the combination of unmet social needs for home bathing, the unavailability of (affordable) substitute technologies, and a favorable cultural base (Huang et al., forthcoming), residents in Rizhao have developed a long tradition of utilizing solar energy for water heating. That is to say, before the commercialization of evacuated tube SWHs (the first generation of SWHs), the social practices of using solar energy for water heating had already emerged in many areas in Shandong province, including Rizhao. This process manifested through versatile grassroots innovation activities among residents.

The most traditional practice of utilizing solar energy is the so-called "*Shai Shui*" (offering the water a sunbath), in which people use solar power to heat water for bathing, normally in the summer. They simply put a bucket of water under the sun, and wait for several hours while the water is absorbing heat from the sun (Interview, End-user). Before the late 1990s, the majority of residents in Rizhao lived in bungalow (one-storey dwelling house) with the availability of enough outdoor space for the social practice of "*Shai Shui*". All of our end-user interviewees expressed similar experiences, as described by an interviewee:

> "When I was little, my parents usually filled a water tank with water and put it in our courtyard to soak up the sunshine. Before the sunset, my family and I would use the water for bathing. The water was warm enough in summer. I think the water temperature was around 37 to 38 degrees. It might be not so convenient for adults, but I liked it very much as a kid. Shai Shui continued until we moved to the dormitory building [multi-storey dwelling house)." (Interview, End-user)

Besides this traditional approach of "*Shai Shui*", more efficient solar collectors were gradually developed. For instance, people put black-colored Polyvinyl Chloride (PVC) water bags on the roof to absorb solar energy. In the 1980s, these bags, called the "solar water bags", was very popular among local residents. With continuous grassroots innovations and experiments, PVC bags were gradually replaced by more durable materials, for instance iron tanks, which were considered as the embryo of integral passive SWHs. Our interviews in Rizhao verified the existence of similar social experiments in using solar energy for water heating, as recalled by one interviewee:

> "Before SWHs were popular, I made a SWH by myself, and it was around 1990. First, I bought one barrel, and flattened it. Then I painted it all black to absorb the solar energy. To better preserve the

[4] http://news.sina.com.cn/c/2008-01-20/003413290342s.shtml

heat, I put a glass cover over the barrel. Plastic foam was also used. After connecting to a pipe, a simple homemade SWH was completed. The parts of the homemade SWH were all purchased in the market. Several friends of mine all made their own SWH by themselves. We discussed frequently and made many improvements." (Interview, End-user)

Overall, driven primarily by unmet social needs, residents had actively engaged in various innovative activities in utilizing solar energy for water heating. These grassroots experiments were largely conducted by individuals or a group of residents based on their collective knowledge and experimentation. These practical experiments within the place-based contexts offered a crucial mechanism in enabling transformative knowledge development and social learning (Wolfram, 2016). An interesting pattern that can be observed is the diffusion of novel innovations through informal social networks, which were deeply rooted in pre-exiting social structure of the Chinese society, namely of the '*chaxu geju*' (Fei, 1947). This pattern is more evident after the involvement of entrepreneurs.

5.3 Entrepreneur-led technological experimentation

Against thriving resident-led grassroots experiments, radical innovation in terms of the evacuated glass tubes emerged, followed by the start-up of entrepreneurial activities. In 1984, Professor Zhiqiang Yin in Tsinghua University invented and patented the magnetron sputtering gradient aluminum solar selective absorbing coating and the production process to apply it to the evacuated glass tubes (Interview, Industry organization and Manufacturer). This technology breakthrough marked the beginning of large-scale production and commercialization of solar energy collector tubes, and thereafter SWHs (Hu et al., 2012). Two key pioneering enterprises were successively founded in Shandong province: Sang Le in 1987 and Himin in 1995 (Goess et al., 2015).

Back then, the new product of evacuated tube SWHs was new to most local people (Interview, Government). Therefore, a series of entrepreneurial experiments were conducted by these pioneering enterprises, so as to open up the niche market for SWH products. In the 1990s, there was very limited formal channel for marketing and selling household appliances (e.g. GWH and EWH) in China. In particular, for small and medium-sized city like Rizhao, the formal channels were dominated by state-run department stores, which prohibited the entrance of SWHs due to the fact that SWH products were not categorized by the government as household appliances (Interview, Manufacturer). In this case, the pioneering entrepreneurs had to use other informal ways of marketing. Typical examples are Himin's early-phase marketing activities. The company used various tactics, such as entertainment performances, to attract people's attention and create on-site opportunities to disseminate SWH related knowledge (Huang et al., forthcoming). Besides, other means of propaganda such as TV advertising and distribution of printed leaflets were also used, which mainly targeted local and provincial markets (Interview, Manufacturer). As a city in Shandong province, Rizhao was highly affected by these marketing activities. We have interviewed a former senior employee of Himin who vividly explained how they conducted marketing activities based on informal strategies:

"At that time, we could only distribute leaflets. Advertisement was printed on 4k papers, just like newspapers. There were no other ways, because, as a small enterprise, we could not afford big media. We printed millions of leaflets for every issue. Local dealers then distributed these leaflets in places such as stores and food markets. You know in the 1990s, there were no more advanced means of advertising. We were just like the Foolish Old Man who removed the mountains[5]… Through this way, little by little, we kind of 'nibbled' a niche market." (Interview, Manufacturer)

Due to extensive technological and marketing experiments by pioneering entrepreneurs, SWH products were recognized and accepted by more and more local residents. However, paying 1000 to 2000 yuan for a SWH was still too much for the averages (Interview, End-user), and till the late 1990s,

[5] An old Chinese fable, used to demonstrate the virtues of perseverance and willpower.

a completed machine of SWH only seemed to be accepted by a small group of residents with more stable income, such as the civil servants (Interview, Government).

In fact, the majority of residents went for cheaper SWHs without any brand that were assembled and sold by local self-employed businessmen (*ge-ti-hu*). These self-employed businessmen usually purchased accessories of SWH in the *Lan Tian* solar market in Linyi city, which was well-known as a wholesale market for selling parts and accessories of SWHs (Interview, Industry organization). Gradually, a group of self-employed businessmen emerged in Rizhao.

Different from large enterprises such as Himin, local self-employed businessmen were rather passive in marketing. In a time when the market was yet opened up, it was a common practice, especially for self-employed businessmen, to use their personal networks and sell the products first to acquaintances. This approach was used among SWH entrepreneurs and local dealers under the business jargon of "*Sha Shu*", meaning to start with the acquaintances. And the diffusion of SWH product was largely "from mouth to mouth", which is, again, based on personal networks. For instance, those who installed SWHs would recommend to relatives, neighbours or friends, who were then potential buyers of their products. As recalled by one interviewee who bought a SWH at that time:

> "After I installed it (SWH), lots of my friends and relatives visited my home and asked a lot of things about it. I told them it was very useful, and it did not consume electricity. Finally, they all bought SWHs." (Interview, End-user)

In short, a series of technological and marketing experiments conducted by pioneering enterprises and local self-employed businessmen opened up a niche market for SWH products in Rizhao.

6. Discussion

The empirical findings contribute to current debates of what actors are involved in the experimenting process and how such experiments lead to changes of the socio-technical system towards sustainability (Seyfang and Haxeltine, 2012; Ornetzeder and Rohracher, 2013; Bulkeley and Castán Broto, 2013; Smith et al., 2014). Research on socio-technical experimentation have been focusing on the role of local governments and NGOs as system builders, which are largely based on empirical cases in the western contexts (Uyarra and Gee, 2013; Fallde and Eklund, 2015). Although more and more attention is paid to urban experiments in developing economies, the involved actors are largely similar to those in the western-based cases that situate in well-developed civil societies (Zhang et al, 2015; de Koning et al., 2016). This research identifies the key role of residents and self-employed businessmen in nurturing a niche (other than NGOs and technology entrepreneurs) through the case of SWH adoption in Rizhao. This finding of the multiplicity of system builders nicely complements and extends our understanding about innovation actors and their practices in socio-technical experimentation.

In western contexts, the flourishing of community-level social experiments is largely due to growing community autonomy in energy issues and rapidly increasing community-based movements (Seyfang and Haxeltine, 2012; Ornetzeder and Rohracher, 2013). However, this is clearly not the case for China in the 1980s and 1990s. Chinese energy system was largely controlled by a few SOEs that affiliated to the central government. Local-level (urban and provincial level) authorities' governance capacity was relatively limited, not to mention the autonomy of communities. The Chinese society in the 1990s was economically free but politically passive, and the civil society was under-developed. It is in this situation that individual residents' leading role in social innovation and experimentation manifested. The finding is in line with recent calls for identifying the role of the complex nexus of individuals in climate governance (Tosun and Schoenefeld, 2017).

With regard to the role of the private sector, existing empirical studies identify the advocating role of a wide range of private actors, who act as both key partners, investors and knowledge brokers (Bulkeley and Castán Broto, 2013; Moragues-Faus and Morgan, 2015; Chu, 2016). It is also showed that

at the early stage of niche development, either large or small companies seem to be launched by technology entrepreneurs who are largely based on specialized technology and/or market knowledge that enable radical innovation and new product development to meet market demands (Sullivan and Marvel, 2011). In engaging with this argument, the Rizhao case uncovers the key role of non-technology grassroots entrepreneurs in urban socio-technical experimentation. In reality, these entrepreneurs are recognized as local 'self-employed businessmen', conducting simple and easy 'do-it-yourself' assembling work based on purchased components and parts (e.g. vacuum tubes). These businessmen were often in lack of specialized technology knowledge and large-scale production capacity, and, instead of developers, they primarily acted as knowledge and product brokers. While the market structure and institutions were still at the infant stage, it is worth noting that such group of grassroots entrepreneurs played an important role as intermediaries in bringing together the newly-emerging technology and end-users.

For socio-technical experimentation in a weak civil society, not only the key actors involved are different, but also the ways how they translate such experimentation into a niche vary. Previous empirical evidence on grassroots experiments highlights that coalition between disparate stakeholders is essential for the development and diffusion of such experiments, which is largely initiated by groups of activists based on, for instance, voluntary organizations, charities, and social enterprises. These organizations function well in well-developed civil societies, where there exist institutionalized channels for civic movements, enabling successful management of expectations, networks, and learning processes (Seyfang and Haxeltine, 2012). However, the situation is completely different for the Chinese society in the 1990s. The civil society was still at the infant stage, and there were hardly any formal channels for civil society movements, not to mention institutional or financial supports. It is under this context that pre-existing social structures and interpersonal relations proved to have played an alternative role in the successful incubation of a niche. Both resident-led social experiments and entrepreneur-led technological experiments were largely based on such informal institutions and networks, and grassroots innovation was successfully diffused through differentiated *guanxi* circles. This finding has significant implications for both grassroots innovation research and urban governance literature. It indicates that social innovation and bottom-up experiments are not merely deliverable in well-developed civil societies, which further questions current disproportionate emphasis on the role of NGOs. Furthermore, it cautions against simply applying western-based transition/governance theories in whatever contexts, because socio-technical experimentation towards sustainability is essentially a social activity in accordance with place-based institutions, rules and norms.

7. Conclusion

In urban energy transitions, contrasting with substantial attention devoted to the role of local authorities and urban governance, local communities and enterprises are often placed in a subordinate position. This is especially true in China, where authoritarian approaches dominate the transition process. Drawing upon a remarkable case of the early-stage SWH popularization in Rizhao, this article uncovers a bottom-up transition process, which was made possible through the dual practices of resident-led social experimentation and entrepreneur-led technological experimentation.

Before large-scale industrialization of SWHs, sporadic but sustained grassroots innovation and social experiments had already emerged. At the very beginning, grassroots innovation on solar water heating practices was primarily driven by long supressed social needs for bathing. It was against this general situation that grassroots ideas of utilizing solar energy for water heating flourished. Community-based experimentation contributed to the formation of a premature niche for SWH, which was then consolidated through market-based activities. Following the technology breakthrough of evacuated glass tubes, large-scale production of SWHs was made possible. This was when pioneering entrepreneurs actively engaged in further promotion of SWH technology in Rizhao. A group of grassroots entrepreneurs draws special attention, who, despite the lack of specialized knowledge and large-scale production capacity, acted as important intermediaries in bringing together the newly-

emerging technology and end-users. Eventually, a niche market of SWH technology was successfully formed and consolidated in Rizhao.

Back to the research questions raised at the beginning of the paper, the case study shows that at the initial stage of urban energy transitions in the context of a weak civil society, 1) residents, pioneering entrepreneurs, and local self-employed businessmen acted as key system builders; and 2) novel socio-technical experiments conducted by these actors were largely diffused, in a rather informal fashion, through pre-existing personal social networks. The findings indicate that sustainability transitions in a less developed civil society exhibit varying mechanisms from that in more well-developed civil societies. Social capital is viewed as an invaluable asset by transitions actors, including both individuals and entrepreneurs.

This research opens a window for using sociological concepts and theories in interpreting socio-technical experiments (a recent call by Smith and Seyfang, 2013), which have proved to be particularly instrumental when applied in the Chinese society. The role of interpersonal social networks in energy transitions in China needs further exploration, which might add valuable insights into currently dominant view of government-dominated transitions.

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