Draft version. Forthcoming publication in *Regional Studies*.

Sustainability transitions and leapfrogging in latecomer cities: the development of solar thermal energy in Dezhou, China.

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Abstract

Sustainability transitions in cities in emerging economic contexts are rarely addressed. The paper addresses this issue by investigating the drivers and barriers in the diffusion of solar thermal energy in two Chinese cities, Dezhou and Beijing. The findings suggest that latecomer cities such as Dezhou demonstrate several advantages over developed cities in environmental transitions. In particular they can 'leapfrog' to environmentally-friendly technologies as they are less locked-in by existing technological regimes. The paper thus contributes to debates over the role of both space and the urban scale in sustainability transitions research.

Keywords

Leapfrogging, Sustainability transitions, Multi-level perspective, Renewable energy, China

JEL Codes

Q42 - Alternative Energy Sources < Q4 - Energy < Q - Agricultural and Natural Resource Economics, R58 - Regional Development Policy < R5 - Regional Government Analysis < R - Urban, Rural, and Regional Economics

Introduction

Current global climate change is widely believed to pose unprecedented challenges in terms of scale and complexity, and thus calls for fundamental changes in economic and social structures (Geels, 2013). However, existing structures experience only incremental changes as a result of path dependence and lock-in (Åhman & Nilsson 2008). Since the 1990s, the emerging research field of sustainability transitions has focused on the role of innovative technological niches in effecting socio-technical transitions (Kemp, Schot & Hoogma, 1998). The strength of the sustainability transitions approach rests in analysing the co-evolution of technologies, markets, user practices, policy and cultural meanings (Geels, 2004; Smith, Voß & Grin, 2010). Consequently, it has gained increasing traction, not only in academic research, but also in political arenas (OECD, 2015; UNEP, 2011).

One of the major criticisms of sustainability transitions research is its lack of a geographical dimension, resulting in limited understanding about where transitions take place (Coenen, Benneworth & Truffer, 2012; Raven, Schot & Berkhout, 2012). Although there has been a growing interest in studying sustainability transitions in various geographical contexts, the focus has mainly been on post-industrialized European countries (Markard, Raven & Truffer, 2012). It is of value to examine whether this theory can maintain its theoretical purchase when applied to rapidly industrializing countries, which may have different pathways to sustainability (Berkhout, Angel & Wieczorek, 2009; Murphy, 2015). Research into 'leapfrogging' suggests developing countries may have latecomer advantages and could avoid environmental problems by leapfrogging to cleaner technologies from the outset (Perkins, 2003). Although some transitions literature has paid attention to the developing Asian context (Hess & Mai, 2014; Quitzow, 2015; Rock, Murphy, Rasiah, van Seters & Managi, 2009), there is little understanding about whether, and how, rapidly developing countries can take such latecomer advantages (Lachman, 2013). In addition, the majority of transitions research has focused on the national level, while the role of cities and regions is relatively neglected (Bulkeley, Broto, Hodson & Marvin, 2013; Späth & Rohracher, 2010). In the literature that does address urban scale transitions, the focus is on world or developed western cities (Hodson, Marvin & Bulkeley, 2013; Nykvist & Nilsson 2015), rather than cities in less developed economies.

This paper uses a case study of the development of the solar thermal energy industry to focus on transition processes in cities in urban-industrial China. As a consequence of the 'high input, high consumption and high emission' mode of industrialization and urbanization (Zhang, 2005), China is confronted with huge environmental problems and energy security issues. As one solution, China is committed to shifting from its coal-dominated energy mix towards renewable energy and has become the world's leading country in the manufacturing and utilization of solar thermal energy (80% and 67% respectively of global capacity in 2012) (Mauthner & Weiss, 2013). Solar thermal energy has been applied in industry, but the most common use is for domestic solar water heaters (SWH). Some cities and regions have become the main manufacturing bases of China's solar thermal energy industry, but they show considerable differences in their SWH adoption levels. The focus here is on the development of the solar thermal energy industry in Dezhou and Beijing. Compared to Beijing, Dezhou is a latecomer in industrialization and urbanization, but a pioneer in solar thermal energy utilization. Located in west Shandong province, Dezhou has a SWH cluster of national importance and a 75.4% installation rate (Li, Song, Beresford & Ma, 2011). Dezhou has important links with Beijing, the technology centre of China's solar thermal industry. Both China's flat plate and evacuated tube technology originated in Beijing and Dezhou's SWH cluster has benefited substantially from Beijing's technology spillover. However, despite Beijing's importance as a centre of technological development and possession of an important solar thermal industry cluster, the market penetration of solar thermal energy is much lower (installation rate less than 7% in 2009).

Drawing upon the multi-level perspective (MLP) framework (Geels, 2002), this paper investigates the factors that have facilitated or obstructed the diffusion of solar thermal energy in these two cities, and explores both how geographical context matters and the role of latecomer cities in sustainability transitions. Note that the term 'less developed cities' or 'latecomer cities' in this paper is a relative term, relating to development gradients within a country, rather than an absolute categorisation. The structure of the paper is as follows. The next section outlines the theoretical framework, including the MLP, the leapfrogging literature and the role of space. Section 3 provides the historical and institutional background to China's development of solar thermal energy. Section 4 briefly describes methods and section 5 provides an account of the drivers and barriers of the development of the solar thermal energy industry in Dezhou and Beijing. The final section summarises the findings and discusses theoretical implications for sustainability transitions research.

Sustainability transitions and leapfrogging

A sustainability transition is a "long term, multi-dimensional, and fundamental transformation towards more sustainable modes of production and consumption" (Markard et al. 2012: 955). Rather than modifying existing products or adopting end-of-pipe technologies, a sustainability transition is a shift of the deep structure of one system to another (Geels, 2011). Sustainability transitions research aims to understand how to unlock the highly institutionalized and mutually reinforcing processes in existing systems, and create path-breaking transformations towards more sustainable systems (STRN, 2010). It is vital to understand how environmental innovations develop and how they challenge, reconfigure and replace established unsustainable systems. So far, two conceptual frameworks: the multi-level perspective (MLP) (Geels, 2002; Rip & Kemp, 1998) and technological innovation systems (TIS) (Jacobsson & Johnson 2000; Bergek et al. 2008), have been well elaborated in transition studies. A TIS aims to develop, diffuse and utilize a new technology through the interactions of actors, networks and institutions in a specific technological field (Carlsson & Stankiewicz, 1991; Markard & Truffer, 2008). The earlier TIS literature focused on efforts to identify system imperfections or structural failures of TIS, but recent contributions have focused on the system functions or processes, such as entrepreneurial experiments, knowledge development and diffusion, market formation, resource mobilization and legitimation (Bergek et al., 2008). This is useful to examine the performance of a technology field and discover the obstructing factors in the system so that policy recommendations could be made for improvement (Markard, Hekkert, & Jacobsson, 2015). However, TIS has been criticised for its focus on system functions and discovering system weakness, rather than overall system change (Geels 2011; Smith et al.

2010).This paper draws upon the MLP approach, which involves more focus on the broader social, cultural and political factors that shape socio-technical transitions (Truffer & Coenen, 2012). The MLP provides a powerful framework in delineating sustainability transitions through its ability to order and simplify the analysis of complex and large-scale system transformations (Smith et al., 2010). Due to these strengths, several attempts have been made to incorporate TIS with MLP insights (e.g. Markard & Truffer, 2008), so that the combined framework could provide a better understanding of both the role of agency and system environment in transition processes.

The MLP conceptualizes transitions as shifts from one socio-technical configuration to another through the interaction of processes at three levels: landscape, regime and niche. *Regime* is the key concept in socio-technical transitions, referring to the "semi-coherent set of rules that orient and coordinate the activities of the social groups that reproduce the various elements of socio-technical systems" (Geels 2011:27). In addition to formal, normative and cognitive rules, a regime is comprised of material and technical elements, and networks of actors and social groups (Verbong & Geels, 2010). A regime is characterized by path dependence and lock-in as a result of "a logic and direction for incremental socio-technical change along established pathways of development" (Markard et al. 2012:957). A *niche* is a 'protected space' where path breaking radical innovations emerge to challenge the incumbent regime. Niches function as incubators, protecting new technologies from the selection pressure of existing systems. Niches are the seeds for transition, but they may also fail to survive in a hostile selection environment. Finally, *landscape* is the collection of external factors which affect the dynamics of niches and regimes, but is unlikely to be influenced in reverse in the short run. Changes in the landscape level are an important source of tensions in embedded regimes. The three levels refer to different degrees of stability, with niche being the most dynamic and landscape the most stable (Geels, 2011). However, the status of regime and niche is relative. A regime shift at one level may merely be seen as an incremental change from the perspective of a higher level (Berkhout, Smith & Stirling, 2004).

One of the criticisms of the MLP is its treatment of space and scale (Raven et al., 2012; Späth & Rohracher, 2010), with little understanding about where transitions take place, why transitions unevenly unfold, or how the transition process could be shaped by spatial contexts (Gibbs & O'Neill, 2014). Differences and linkages between scales are often overlooked and the fact that localized activities and resources are subject to external pressures can be neglected if the relations between scales are ignored. Coenen and Truffer (2012) argue that the MLP approach should focus more explicitly on territorial embeddedness and multi-scalarity in order to explore why environmental innovations perform differently in different geographical settings and whether success in certain localities can be upscaled into mainstream regime practice. More emphasis on multi-scalarity also helps to explain international and trans-local dynamics and reveal how local actors and resources grow with their networks across scales (Murphy, 2015; Truffer, Murphy & Raven, 2015). Current contributions to the geography of transitions primarily focus on niche innovations in various spatial contexts, while less attention is paid to how regimes response and how the variance of regimes across space contributes to the differences of transition processes (Hansen and

Coenen, 2015). Niche-regime relations are neglected, as most emphasis has been given to bottom-up niche processes. Though the notion of regime conveys high homogeneity, there exists significant variations of regime structure between nations as well as between cities and regions (Späth & Rohracher, 2012).

In addition to exploring multi-scalarity, this paper is concerned with two other aspects of the geography of transitions – the potential for innovations to 'leapfrog' in developing countries and the role of cities in transitions. First, linking leapfrogging analysis with a socio-technical perspective implies that environmental problems associated with urbanization and industrialization maybe avoided by leapfrogging to cleaner technologies from the outset (Perkins 2003; Goldemberg 1998; Binz, Truffer, Li, Shi & Lu, 2012). Latecomers do not necessarily follow the product life cycle of technology development, instead, they may jump over some stages and even create their own individual paths (Lee & Lim, 2001). Developing countries in particular may enjoy latecomer advantages that enable them to bypass the 'dirty' stage of economic growth through the use of a cleaner production paradigm (Perkins 2003). While developed countries have been locked-in by existing less efficient technologies due to the non-recoverability of sunk investment, developing countries have yet to install significant capacity, allowing them to choose between competing new technologies. Path dependencies that lead to specific regimes in developed countries may not exist or are much weaker in latecomers (Binz & Truffer, 2009) . Another source of latecomer advantage is learning investment, where developed countries bear the cost and risk of failure in the early stage of new technologies, while developing countries take advantage of this accumulated learning to diffuse new innovations faster and at less cost (Perkins & Neumayer, 2005; Iwami, 2005).

Second, neither the transitions nor the leapfrogging literatures give enough attention to the role of cities and regions. Transition studies have focused on the national level, because cultures, infrastructures, regulations and institutions are mostly believed to be national phenomena (Geels, 2013). Transitions approaches have said little about cities and whether the MLP perspective can help to understand urban transitions (Hodson & Marvin, 2010; Mans & Meerow, 2012). However, the current challenge of sustainability at the global scale can be substantially affected by local transition processes. Focusing on the urban scale allows the development of sustainable demonstration policies and initiatives to be up-scaled to wider spatial scales. Cities can not only provide seedbeds for niche experiments (Geels, 2013), but also "appear to bridge the niche-regime and provide 'social context' to integrate and implement socio-technical configurations which differ from the dominant regime and may be important for long-term transition processes" (Späth & Rohracher 2012: 475). Proximity between actors, networks and places at the city scale facilitates the creation of social ties and network formations that are necessary for niche development and makes it easier to achieve a low carbon transition than at the national level (Hodson and Marvin, 2010; Coenen, Raven, & Verbong, 2010). Nonetheless, the extra-local relations with distant places and actors, that contribute to local transition dynamics through the flow of knowledge, resources and technologies, should not be downplayed (Binz, Truffer & Coenen, 2016). Despite the increasing interest in sustainability transitions at the urban level, the role of smaller cities has been neglected. Large world cities have political aspirations to develop purposive system transitions, but what happens in cities that cannot mobilise similar resources? While large cities obviously have more impact on global environmental problems, small cities may also play a significant role as places of test-beds and experiments for new technologies or governance. Such cities do not necessarily have to grow to be technological innovation centres, but can provide supportive frameworks for the broad application of new sustainable technologies. In this respect, they may enjoy some latecomer advantages over large cities, for they may be confronted with less pressure from incumbent actors or established technologies. The leapfrogging literature has argued that regimes tend to be less ordered and stable in late-industrializing countries than developed countries, because their institutional and governance capacities have yet to be settled (Berkhout, Wieczorek & Raven, 2011). It is reasonable to assume that this principle may also be applied to the urban scale within a nation. Niches need not be exclusively local and regimes can either have transnational features or remain subnational in their spatial reach, rather than merely sticking to the national scale (Raven et al. (2012). For cities in the same country, landscape factors are similar at national and global level, but the regime and niche factors within them vary. Sustainability transition in a city can be viewed as a struggle between regime resistance (incumbent) and niche development (challengers). The strength of the regime may also vary between different places. While a strong regime exerts power on actors' behaviour and cognition and, to large extent, determines development pathways, a weak regime involves more competing logics and diminishes the overall structuration (Fuenfschilling & Truffer, 2014). Sustainability transition is more likely to happen in cities characterized by weak regime resistance and strong niche development, and a small, but growing, city might be the ideal place for environmental leapfrogging. Green niche innovations could be more empowered in less developed regions because they may coincide with local development in terms of national competitiveness and economic benefits (Essletzbichler, 2012). Before turning to an investigation of these ideas in the context of SWH in Dezhou and Beijing, the next section provides the background to the development of China's solar thermal energy sector.

The development of solar thermal energy in China

In response to the global oil crisis, in the 1970s China began research into solar thermal energy by establishing solar research institutions and supporting university research. In the 1980s, China imported Canadian flat plate solar collectors, which provided the start of China's SWH industry, but development was slow because of its high cost and poor performance in winter. In 1994 a breakthrough in evacuated tubes technology took place at Tsinghua University in Beijing, which also developed corresponding large-scale manufacturing equipment, and led the industry onto fast track growth. This indigenous technology enabled the mass production of SWH and significantly reduced costs. Since then, driven by increasing demand from urban and rural residents, China's solar thermal industry has grown rapidly.

By 2012, China accounted for 67% of total installed capacity and 80% of production of global SWH. In 2013, SWH accounted for 24% of China's installed water heaters, second to gas water heaters (GWH) (50%) and higher than electric water heaters (EWH) (16%) (Cheng, 2013). China's SWH market is dominated by evacuated tube SWH, with a market share of more than 90%. Recently, with the fast growth of high-rise buildings in China's cities, flat plate SWH have gained increasing market share because they can be incorporated into high-rise buildings more aesthetically and safely than evacuated tubes. SWH are increasingly being installed as collective installations in commercial and domestic building projects, with market share rising from 35% in 2007 to 45% in 2011. SWH manufacturing is spatially concentrated, particularly in Zhejiang, Shandong, Jiangsu, Yunnan and Beijing provinces. In terms of adoption, the installation rate varies widely ranging from 4% in Guangdong province to 20% in Shandong province (Song, Ma & Li, 2010). There is also a difference between large and small cities – although 90% of China's SWH is installed in urban areas, 30% of this is in large cities and 60% in smaller cities (Luo and Shi, 2004).

One feature differentiating China's solar thermal from other renewable energies is that market forces were the initial driver of development (Hu et al., 2012). Unlike PV, which received substantial government subsidies, no national incentive policies were in place for the SWH industry before 2006, and it was not listed in the national financial support catalogue. Only at the local level were some SWH firms listed in the high-tech enterprises catalogue by local governments and thus enjoyed favourable government support policies. By contrast, market forces and consumer demand played a key role. In the 1980s, SWH were initially adopted by urban residents. The market extended to rural areas in the 1990s, facilitated by the rising consumer power of rural residents, increasing demand for economic sources of hot water and the strategies of leading solar thermal enterprises to popularize SWH. Although the initial cost of SWH was higher than other water heaters, it was widely accepted by consumers due to savings on energy bills.

In 2005, China's National Congress promulgated the Renewable Energy Law, prioritizing renewable energy generation and utilization. Regarding solar thermal energy, it states that governments shall encourage the installation of solar water and heating systems and formulate technical criteria and economic policies to incorporate solar energy systems in building construction. Real estate developers are encouraged to take into account the requirements for using solar energy when designing and constructing buildings. Since then, a series of subsequent national and local policies have been enacted to promote the utilization of solar thermal energy, giving a powerful additional push to its popularization.

The most influential policy is that for mandatory SWH installation. Since 2007, 20 provinces and 80 municipal governments have issued the policy, requiring new building projects to incorporate SWH (Huo & Luo, 2012). Most local governments require that new residential buildings less than 12 stories should install SWH. In 2009, the central government initiated the *Household Appliance Going to Countryside* policy, which provides subsidies (13% of the product price) for rural residents to purchase new home appliances or to trade old appliances for new ones. SWH was listed in the subsidy catalogue. Some local governments provided extra subsidies for purchasing SWH, reducing its initial capital cost by up to two thirds of the price (Li et al., 2011). Furthermore, the central government launched *Renewable Energy Construction Application Demonstration City Plan*, which provides special subsidies to selected demonstration cities, aiming to motivate more cities to incorporate solar thermal energy into buildings.

Methods

The primary data source of this research involved fieldwork in China from November 2014 to March 2015. A total of 36 semi-structured interviews were conducted with representatives from solar enterprises, government officials, research institute staff and real estate developers in both Dezhou and Beijing (Table 1). The interviews focused on the factors that facilitated and obstructed the diffusion of solar thermal energy, respondents' experiences and opinions on the development of solar thermal energy, as well as how decisions were made and how these decisions influenced their development in the two cities. In addition, document analysis, site observations, and attendance at industrial conferences formed part of the data collection.

(Table 1 about here)

The Solar Thermal Energy Sector in Dezhou and Beijing

Against a background of fast industrialization and urbanization in China, both Dezhou and Beijing face landscape pressures from the global and national level to develop a green economy. This landscape legitimizes local green niches and champions their momentum and growth to challenge existing regimes. However, whereas Dezhou has been a supportive niche for SWH adoption, the application of SWH in Beijing has lagged behind that of Dezhou, despite it being an important manufacturing and technology development base. Beijing is one of the most urbanized and developed cities in China, but has been a harsh selection environment for SWH diffusion. Applying the MLP concepts, the factors influencing SWH diffusion in Dezhou and Beijing are listed in Table 2.

(Table 2 about here)

With the Chinese development of solar thermal energy research in the 1970s, Beijing became the technology centre of China's industry due to its high concentration of top universities and research institutes. It is home to China's indigenous evacuated tube SWH technology, which spilled over to other regions through industry-university cooperation and imitation. Dezhou was one of the cities that benefited from this spillover by cooperating with Beijing's universities. Geographical proximity and technology linkages with Beijing have been an indispensable part of the growth of Dezhou's SWH industry because Dezhou lacks universities and R&D talent. Most of Dezhou's large SWH firms have cooperation arrangements with Beijing's universities in order to exploit Beijing's technological advantage and its talent resources through outsourcing, technical cooperation, training and research consultancy. As a government official commented:

> We don’t necessarily seek to possess those talents in Dezhou, rather, we try to exploit their intelligence for Dezhou. It cost a lot to have them work in Dezhou and they may not be satisfied with Dezhou’s living and working environment…nowadays, we have convenient transportation and communication, we can simply strengthen the cooperation with them and invite them to guide us regularly [interviewee 19].

The key role of Himin in Dezhou

A key actor in Dezhou’s transition has been Himin, the largest SWH firm. At its inception in 1995 it was a regional manufacturing branch of Tsinghua Solar, a Beijing firm, which possessed the most advanced evacuated tube SWH technology at that time. Subsequently, Himin developed its own innovations and became the leading enterprise in China’s SWH industry. In the 1990s Himin made substantial efforts to popularize solar energy knowledge in China at a time when solar products were largely unknown by Chinese consumers. Since 1996, Himin has published more than 300 million copies of its Solar Energy Science Report and held activities such as Solar Science Tour and City Environment Protection Tour, in cities, towns and villages around China, to popularize solar energy knowledge and expand its market. These market promotion efforts are widely believed to have expanded China’s SWH market, helping to create a market segment (Binz et al., 2016). Many solar firms subsequently emerged in Dezhou because of Himin, constituting a complete SWH value chain. Together with Himin’s fast growth came an increasing market for related solar products and equipment, creating many opportunities for local entrepreneurs. A number of small firms were established as equipment providers for Himin in the early stages, but many became SWH producers as well because they benefited from technology spillover. Many solar firms’ founders and employees, not just technical researchers, but also managers and salespersons, gained experience working in Himin and the subsequent talent outflow increased spin-off activities and enhanced technology and tacit knowledge spillover. Himin’s focus on upgrading the value chain and providing high-end SWHs, left considerable market room for small SWH firms in Dezhou (Li et al., 2011). By 2010, the city was home to more than 120 enterprises engaged in solar related industries. The accumulated SWH sold by Dezhou enterprises accounts for approximately 70% of Shandong and 16% of China sales respectively.

As the industry grew rapidly, Himin’s role in Dezhou’s development became increasingly important. Himin exerted policy influence not only at the local level, but also at provincial and national levels. Himin successfully lobbied the Dezhou government to make the Solar City part of Dezhou’s future development strategy and to implement favourable polices towards the solar industry. Together with building design departments, it developed and pushed the design standard for solar energy and building integrated construction in both Dezhou and Shandong province. In 2003, Huang Ming, Himin’s founder, was elected to the National Congress for his company’s contribution in renewable energy and he was the main proposer of China’s Renewable Energy Law making. Since then, China’s solar thermal industry has enjoyed a favourable legal and institutional environment. Due to his contribution, Huang Ming was elected vice president of the International Solar Energy Society in 2008. Based on Himin’s influence Dezhou was designated China’s solar city and hosted the International Solar City

Congress in 2010. The growing SWH industry has brought a new green image to Dezhou, forming a positive feedback loop in the city:

> Visitors from all around the world come to Dezhou mainly for Himin, but when they are here, they find there are many other solar enterprises providing different advanced technology and products. When the visitors saw our firm's products, they were surprised...Himin did play an important role, it attracts a lot of attention to Dezhou, and we benefit from this [Interviewee 8].

Government support

As the SWH industry has grown in importance, it has received recognition and support from Dezhou's government. Growth brought Dezhou not only growing GDP and employment, but also a national and international green reputation. As a result, the municipal government decided to develop the industry into a key sector for local development and assigned a large area of land to the SWH industry, providing policy and financial support. In 2005, the government developed a Solar City Strategy to promote solar energy as the leading new industry. In 2009 it established Solar Industry Development Planning to build Dezhou as the solar city of China and a global player. The Strategy is led by the principal leaders of the municipal government and developed policies to encourage technological research, industry development and application of solar energy.

On the utilization side, Dezhou has officially encouraged the collective incorporation of SWH into buildings since 2005. In 2006, together with Shandong's Department of Construction, Dezhou created China's first standard schematic handbook of the integration of building and solar energy. In 2008, the municipal government enacted a mandatory installation policy, requiring all new buildings to integrate SWH in design and construction. Those projects that are not in accordance with the requirement will not be given permission for construction or completion inspection. Those projects that comply with the requirement enjoy privileges, such as priority in land use, a simplified approval process and mitigation in building urban supporting facilities. Dezhou's government also subsidized more remote rural residents to install SWH. Finally, the government hosts many solar cultural events, such as International Solar Expo and Solar Thanksgiving Day, to enhance communication with other countries and mobilize local citizens' enthusiasm for solar energy.

By contrast, many enterprises stated that they did not enjoy a favourable policy environment in Beijing. The SWH industry's output is so small in Beijing's economy that little attention has been paid to it by policymakers. Although the installation of SWH was not officially forbidden, most residential communities in Beijing did not allow the individual installation of SWH on safety and aesthetic grounds. Only when air pollution became very severe did the government require new buildings to incorporate SWH systems in 2012 - before then Beijing's SWH enterprises did not benefit from official encouragement. Many interviewees believed that big SWH enterprises in small and medium cities usually had close relationships with local governments, while in Beijing this was very unlikely to happen. As one Beijing entrepreneur said:

> Shandong and Jiangsu's SWH enterprises do perform well in the market, one reason is that they have close relationship with local governments, who have the power to support local enterprises. While in Beijing, this is one of the disadvantages we have…..we do not have such a good relationship with government, that's why we only have a rather stable growth path instead of big rise and fall [interviewee 33].

Substitute technologies and consumers

Existing substitute technologies in Beijing have also made the diffusion of SWH difficult, especially when new technologies are not mature enough to compete with them on performance. Compared to income, the cost of gas and electricity is very low for Beijing's residents. As a result, they buy EWH and GWH which have a better performance than SWH on convenience, safety and aesthetic grounds. In Dezhou, there has been a wide acceptance of SWH among local residents. The earliest adopters of SWH were the relatives of SWH entrepreneurs and residents with higher education levels, such as teachers and doctors, which led to a demonstration effect for other residents. As SWH technology matured, an increasing number of residents installed SWH because it saves on energy bills - local residents view SWH as convenient, economical and safe products. The average payback period of a SWH for a typical three-person household in Dezhou is 8.3 years, allowing 4 years free use before the end of its designed life expectancy (Li et al. 2011). Close interpersonal networks among local residents are also an indispensable part of the diffusion process, as these help to form and change attitudes towards new innovations and thus influence an individual's decision to adopt or reject the innovation (Rogers, 2003). Fei (1992) shows that close interpersonal networking or 'guanxi' is a significant characteristic of China's rural society. This characteristic may decrease, but is still evident in small urbanizing cities when compared to large developed cities such as Beijing. Dezhou has transitioned from being an agricultural city, but close kinship and neighbourhood relations remain an obvious characteristic, thus the verbal communication and social learning of SWH acceptance diffuses quickly among acquaintances. In such an acquaintance society, interpersonal networks exist not only between consumers, but also between consumers and producers, as well as between producers. As many acquaintances worked in the SWH industry, trust between producers and consumers was enhanced to facilitate SWH diffusion. Furthermore, many of Dezhou's SWH firms were established or spun-off with help from relatives and friends who were already operating businesses in the industry. Personal networks therefore played an important role in market creation and the formation of Dezhou's solar industry cluster.

Beijing was China's first city to have natural gas in residential buildings, and individual gas boiler usage has developed significantly. By the time the government started to encourage SWH installation in 2012, the market was dominated by EWH and GWH, making it difficult for SWH to replace these. Conversely, when SWH started growing in Dezhou, EWH and GWH had not been well popularized, leaving much room for SWH diffusion. As Hansen and Coenen (2015:98) argue "norms around consumption have important influence on the potential for upscaling of niche technologies". While saving on energy bills is viewed as the biggest advantage of SWH by most Dezhou residents, it is not the main concern in Beijing. Low energy costs and higher income levels make renewable energy less attractive in Beijing. Instead, comfort, safety, aesthetics and status symbols are the main priorities when purchasing water heaters. SWH was viewed as a low-end product by most Beijing residents because it was unable to satisfy their high level of demand.

Building infrastructure and estate developers

The real estate industry and existing urban infrastructures have also influenced the development of SWH in both cities. New residential buildings are springing up as a consequence of Dezhou's rapid urbanization, and real estate developers have considerable power to decide whether to install SWH on their buildings. At the early stage of SWH development, individual households made decisions to adopt SWH or not, and real estate developers did not pay much attention to this. Due to the lack of installation standards, individual SWH installations often damaged building structure and appearances and some developers began to take measures out of concern for building safety by installing SWH collectively to standardize installations. Other real estate developers began to see the growing SWH market as an opportunity and, after 2003, began to install SWH collectively as a sales strategy to attract consumers. However, many developers still viewed SWH installation as a burden because it increased their building costs and the complexity of installation and the unreliability of early technologies added to their concerns. After the implementation of the mandatory installation policy, although developers were forced to install SWH, this was also a response to growing market demand:

> For estate developers, installing SWH not only comply with government's regulation, but also respond to market demand as a selling point to attract consumers. If you don't have installed SWH, but other developers have, you may lose the competition. That's the market force [interviewee 13].

Indeed, some SWH firms were founded by developers who saw the SWH-building integration as a potential business. Though to some extent forced to do so, the growing real estate industry has been an indispensable part of Dezhou's SWH diffusion process. By comparison, in Beijing, by the time the SWH industry started growing, its urban built area had been largely covered with dense high-rise buildings. One barrier to the diffusion of innovation is the incompatibility with existing systems (Kemp et al., 1998). Residential buildings in Beijing are not only densely built, but also make full use of their vertical aspect, leaving little space for SWH installations. Though the city continued to sprawl with new residential buildings being constructed, they were not designed for SWH integration. When Beijing implemented a mandatory installation policy in 2012, building infrastructure in the urban area was locked-in and unable to be redesigned for SWH installation. The majority of SWH-building integration installation was achieved in government-led projects, and many estate developers do not abide with the regulations due to the lack of trust in SWH technologies:

> The mandatory policy [in Beijing] is nearly paused, many divergences appeared, many projects stopped. It is being turned from side to side. A lot of arguments… [interviewee 30]

By contrast, Dezhou's building type is characterized by low-rise buildings, leaving space for rooftop evacuated tube SWH installation. When high-rise buildings emerged in Dezhou, most were designed to incorporate flat plate SWH, as a result of both government regulations and market competition.

Discussion and Conclusions

This paper has responded to calls for a geographical perspective in sustainability transitions through an investigation of the socio-spatial embedding of transitions and those locations which are amenable (or not) for transitions and technologies (Truffer et al., 2015). Drawing on insights from both the MLP and leapfrogging literatures, this paper proposes that sustainability transitions have more potential to occur in small, latecomer cities which experience less regime resistance, but powerful niche development. Spatially locked-in capital investment and consumption norms constitute the major challenges for the substitution of fossil fuels, but developing world locations usually have not been locked-in in the same way and this can provide opportunities for the rapid uptake of renewables (Bridge, Bouzarovski, Bradshaw & Eyre, 2013). Such cities overall face less regime resistance for new technologies, leaving space for niche growth and ultimately regime changes if the niche actors are able to take full advantage of latecomer advantages. Actors and institutions at the local scale therefore play a key role in shaping niche development (Dewald & Truffer, 2012).

Evidence from Dezhou and Beijing supports this analysis, whereby different SWH adoption levels in the two cities is a consequence not only of place-specific factors, but also multi-scalar interactions (Raven et al., 2012). While the international consensus on climate change legitimized and encouraged the development of the SWH industry in both Beijing and Dezhou, this had greater purchase in Dezhou where the configuration of a dominant local firm, supportive local government and engaged consumers came together to form a protective niche. Dezhou's local practices were not only scaled up to national level, but also changed China's institutional landscape by promoting the making of the Renewable Energy Law, after which the industry enjoyed a favourable policy environment. Urban discourses can thus influence policy at higher levels reflecting the two-way relationship between policy levels (Hansen & Coenen, 2015). Links between the two locations are important as flows of technological know-how and individuals move between the two locations, a key factor in the development of Dezhou's SWH industry. As Carvalho, Mingardo and Van Haaren (2012) illustrate, local clean-tech innovations are co-evolved with local innovation milieus of actors, networks, and institutions, and higher order structures (e.g. national policies), as well as global knowledge mobility. These horizontal and vertical linkages and interactions between multiple scales can help to destabilize incumbent regimes and opens a window of opportunity for the growth of the niche (Murphy 2015).

The transition to solar thermal energy in Dezhou is the result of weak regime resistance and strong niche development. Suitable building infrastructure, less demanding but networked consumers and supportive local government policies formed a favourable selection environment for the SWH industry to grow and to align with other actors, gaining momentum to up-scale and replace the existing weak regime. In line with Dewald and Truffer's (2012) research into the German PV industry, locally bound market processes have provided a basis on which Himin’s promotional strategies could build, while trust between pioneering and other users has facilitated diffusion. Conversely, Beijing, in spite of its important role in SWH technology development, has failed to diffuse SWH widely because it has been locked-in by building infrastructure, consumer preferences and institutions that are hostile to SWH adoption. Different institutional logics in specific cities may therefore encourage or hinder transition processes (Hansen & Coenen, 2015). As Fuenfschilling and Truffer (2014) argue, niche growth needs not only an internal niche formation process, but also needs to coincide with specific regime institutional logics so that increasing support can be gained. In applying new green innovations, developed cities may be locked-in to existing unsustainable technologies in terms of knowledge, scale economies, institutions and consumer preferences. On the other hand, new green innovations often have some disadvantages in function (Kemp, 1994), making it difficult to meet the diversified demands of developed cities. Smaller, less developed cities are less locked-in by existing technologies, as infrastructure and rules have yet to be established. Urban infrastructure matters because it constitutes a part of the stable regime that constrains a city’s options of available technologies or solutions for sustainability (Haarstad, 2015).

Solar thermal energy research initiated in Beijing was based on perceived societal and environmental aims, rather than potential market demand. Though Beijing enjoys strong R&D capacity in solar thermal technology, it is not highly valued by local residents due to concerns over reliability, safety and aesthetic reasons. In such a demanding selection environment, the disadvantages of SWH are amplified. By contrast, in Dezhou the disadvantages of SWH technology are generally acceptable, compared to its economic benefits. The technology gained more momentum when Dezhou’s government mandated new buildings to install SWH systems. Government intervention and support are therefore an important factor in “fostering the protected niche markets where other resource formation and alignment processes could take shape” (Binz et al., 2016). Some interviewees believed it is precisely because Dezhou is a small less developed city without other dominant industries that the SWH industry has a significant role to play. The growth of this green industry has brought Dezhou a national and international reputation, empowering niche development.

There is also a thick network of SWH actors in Dezhou because each of them benefits from positive feedback loops. The powerful firm Himin successfully lobbied local government to support the development of the SWH industry and influenced national renewables policy. The local government then became an active driver of SWH diffusion. As Murphy (2015:79) argues “niche innovators who are also well connected to and/or legitimated in the eyes of actors in an incumbent regime can play a particularly important role in facilitating regime transitions”. Local residents were motivated and real estate developers installed SWH to comply with government regulation, as well as in response to market demand. Interpersonal networks were also important in Dezhou - these not only facilitated social learning about SWH among consumers, but also enhanced mutual trust between consumers and producers, and promoted diffusion. Thus engaged end-users and regulatory institutional arrangements supplement formal government support programmes in Dezhou (Dewald & Truffer, 2012). In Beijing’s SWH industry, the actors are mainly involved in technology development, such as in universities, research institutes and private SWH firms. The legitimacy of new industries or products rely on their alliance with relevant institutions of a given place, or they will suffer from high skepticism and lack user acceptance (Aldrich & Fiol, 1994). Without sufficient participation and support from local government, real estate developers and residents, the network is merely confined to technological exchange on the supply side. These results thus reveal the importance of consumer and local market formation in sustainability transitions, which so far have been only sporadically addressed in the geography of transitions literature (Hansen & Coenen, 2015). Moreover, a strong government-industry relationship seems more likely to take place in smaller cities, since the industry has a bigger role in the local economy and city branding. Thus, green entrepreneurs may enjoy more power to promote the penetration of green technologies, reflecting the importance of actors and their relations in shaping institutional structures (Murphy, 2003; Yeung, 2005). Drawing upon Smith and Raven's (2012) conceptualisation of niche protection, latecomer cities actually provide a passive space where regime selection pressures are kept at bay (shielding) and sustain the development of niche innovations (nurturing). The success of shielding and nurturing gives more potential to the niche innovations, empowering niche actors to gain more protective support, which in turn assists “in further nurturing, greater empowering, and eventually the institutionalisation of the innovation within a transformed selection environment”(p1034). The process involves not merely niche innovations gaining competitiveness in established regimes (fit and conform), but more importantly, undermining and restructuring incumbent regimes to facilitate niche growth (stretch and transform), in which niche advocates such as green entrepreneurs and local authorities have a critical role to play, as shown in Dezhou’s case.

Dezhou’s case shows the possibility that less developed cities and regions can leapfrog to sustainability. In an age of globalization and informatization, traditional disadvantages in talent and information in these cities can be compensated by the frequent flow of knowledge and talent from extra-local regions. If such cities are able to absorb technology spillover from developed cities, their latecomer advantages helps them achieve leapfrogging. It has to be noted though that this study is based on a less capital-intensive technology, SWH. Unlike wind turbines or photovoltaics, which are characterised by high R&D intensity, large investments and government-led, SWH is a low cost, less R&D intensive and market-driven green technology. This enables cities like Dezhou to compete with developed cities in the innovation and application of the technology. Choosing the appropriate technologies that suit local conditions is critical for leapfrogging (Goldemberg, 1998).

This paper also contributes to the debate on the confusing role of urban scale in MLP research (Hodson & Marvin, 2010). It is superficial to simply presume that niches, regimes and landscape represent the local, national and global level respectively. In line with Späth and

Rohracher's (2010) argument that cities are located at an intermediate level between niche and regime, this research shows cities can be the analytic level to incorporate both regimes and niches, but can also be a niche when considering its role in broader national transition. In analysing the diffusion of SWH in Dezhou and Beijing, cities are a scale where both regime and niche locate and interact. When looking at the transition from national level, both cities play the role of a niche. These roles of cities in the MLP are not contradictory, but complementary. Cities can be large enough to incorporate system properties, but meanwhile, they are small enough to take the advantage of proximity for niche innovations and building actor networks (Späth & Rohracher, 2012). The urban scale therefore offers a very helpful analytical arena for sustainability transitions and a multi-scalar perspective enhances the understanding of the role of cities in sustainability transitions.

Acknowledgements

Zhen Yu acknowledges the support of the China Scholarship Council and the University of Hull. Thanks are due to all the interviewees in China who gave up their time for interviews. We are grateful to two anonymous referees for their very helpful and insightful comments.

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Table 1 Respondent Types for Interviews.

Type	Dezhou[1]	Beijing	Total
Solar industry	14	7	21
Governmental officials	4	0	4
Research institutes	2	2	4
Industry associations	2	1	3
Estate developers	4	0	4
Total	26	10	36

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[1] Some of the interviews were conducted outside Dezhou but within Shandong provinces.

Table 2. MLP factors in Dezhou and Beijing

		Dezhou	Beijing
Landscape		Climate change, energy security, green economy	
Regime	Building Infrastructure	Low-rise buildings, later developed solar-integrated buildings	Early built dense buildings, not suitable for SWH installation
	Policy environment	Supportive	No incentive policies, even adverse before 2012.
	Substitute products	EWH/ GWH, not popular before SWH	EWH, GWH, low cost electricity, coal and gas
	Market demand	Low-end, economical hot water	High-end, diversified, safety, aesthetic, convenient, stable, status symbol
Niche development	SWH technology	Advantages valued	Not valued, deemed as low-end product
	SWH Industry	Important role in local economy and city brand building	Not important
	Actors	Powerful large firm, supportive government, motivated residents and estate developers	Universities, research institutes, private enterprises
	Network	Acquaintance society, positive feedback loop among actors	Thin, technology links among supply side