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# The governance of urban energy transitions: A comparative study of solar water heating systems in two Chinese cities

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ABSTRACT

This paper examines how urban energy transitions are unfolding in China, in relation to the deployment of solar water heating (SWH) systems in two Chinese cities, Rizhao and Shenzhen. Cities play a significant role in the energy transition in China. Scholarly efforts have looked into the translation of top-down visions into locally actionable policy. This article contributes to this body of research with an analysis of the urban governance of urban energy transitions in China, and how low carbon technologies are deployed in particular urban contexts.

The comparative analysis of Rizhao and Shenzhen suggests that specific socio-spatial arrangements shape the evolutionary trajectories of urban energy transitions of SWH systems in both cities. In the case of Rizhao, policy approaches have been erratic. Nevertheless, governmental and civil society actors have worked to forge alignment among political visions, built environment constraints, and social practices. The proximity of an industrial cluster supporting SWH technology and the early uptake of this technology by households are two key factors that explain the rapid spread of SWH systems in Rizhao. In Shenzhen, the local government has promoted SWH systems through regulation and incentives in a top-down and coordinated manner. These programmes have been, however, abandoned, after they did not deliver the expected results.

The two contrasting cases suggest that the urban energy transition in China is the result of the coordinated actions of multiple actors, and success depends on the fit between technologies and the urban development contexts, rather than on aggressive government-sponsored actions.

## 1. Introduction

This paper examines how urban energy transitions are unfolding in China, in the case of the deployment of solar water heating (SWH) systems in two Chinese cities, Rizhao and Shenzhen. In the context of the 2015 Paris Agreement, China has taken a leadership role in international climate policy (Nunez, 2017). For example, China's Intended Nationally Determined Contributions (INDCs) include ambitious targets, such as: reaching peak greenhouse gas (GHG) emissions, increasing the non-fossil fuel share of total energy to 20%, and reducing carbon intensity by 60–65% below 2005 levels all by 2030. Most commentators agree that such commitments will be significantly exceeded, considering that China has previously delivered on the country's commitments. During its 12th Five Year Period (FYP) there was a shift from broad goals and statements of priority to specific instruments for emissions reductions which had a dramatic impact on the country's emissions (Song et al., 2015; Robiou Du Pont et al., 2017).

City-based action has been a crucial part of China's climate change action frameworks, both in the 12th FYP (2011–2015) and the 13th FYP (2016–2020). China's low carbon province and cities program, for example, was launched in 2010, with a further extension in 2012. Pilot carbon trading systems were established in seven cities in 2011 (NDRC, 2011). The FYPs support both actions led

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by the local government and policies for local industrial development. In this context, this paper examines the delivery of climate mitigation action in Chinese cities and the mechanisms that facilitate urban energy transitions in Chinese cities.

The urban energy transition is a multifaceted process that entails multiple technical, organizational, institutional, and social changes in urban areas (Frantzeskaki et al., 2017). Urban transitions require transformations in governance (Hodson and Marvin, 2010). Governance refers to the multiple mechanisms that are used to steer action and processes. Climate change governance entails processes of building authority to respond to climate change within and beyond the state, i.e., multi-level governance (Bulkeley and Betsill, 2005, 2013; Castán Broto, 2017). These fundamental transformations also require the collective involvement of a range of local actors and the penetration of low-carbon practices and technologies in urban physical, economic and social systems (Okereke et al., 2009; Grin et al., 2017). *Urban energy governance*, in particular, has been defined as “the multitude of ways in which urban actors engage with energy systems, flows and infrastructures to meet particular collective goals and needs” (Rutherford and Jaglin, 2015: p. 174).

The governance of urban energy transitions also requires understanding the specific material processes through which such transformations are accomplished (Bulkeley, 2015; Moss et al., 2016). Rutherford (2011) suggests that socio-technical materialities help to explain the inherent tensions and contradictions between transition aspirations and the multiple forms of materiality, the array of concrete objects and their interactions with people, that shape such transitions. This is akin to explaining who can respond to this challenge and how. Accomplishing an urban energy transition involves non-trivial processes of material adjustment through which new governance arrangements are fitted to the actual landscape of intervention (Castán Broto, 2015).

For example, the success of climate change policies in China has been interpreted as an adequate match between top-down objectives and appropriate approaches to policy action (Li et al., 2016a). These studies have also reflected the diversity of processes that shape urban energy transitions in China. Research on China has revealed the multiple interactions between different policy actors in the transition process and how they shape transition trajectories (Francesch-Huidobro and Mai, 2012; Mai and Francesch-Huidobro, 2014; Wu et al., 2016). Two common themes already explored are: 1) the gap between national policy guidance and local policy implementation and; 2) how conflicting interests between urban departments hinder municipal intervention (de Jong et al., 2016; Li et al., 2016b).

There has also been an interest in the transfer of technologies through the implementation of government's future visions, taking into consideration non-state actors' responses to the implementation of such visions (Mol, 2009; Li et al., 2016, 2016c). For instance, Li et al. (2016) analyze the public-private interactions for electric vehicles (EV) deployment in Shenzhen (China). Their study conclude that the integration of business innovations and government regulations facilitates transition processes. Citizens, they argue, play a prominent role in adaptive strategies for governing urban energy transitions.

There is, however, a strong emphasis on how the different branches of the state apparatus govern the transition, without questioning the translation of top-down visions into actual material changes in the fabric of the city. The dominant view reproduces assumptions of ‘command and control’ paradigms in environmental policy (Cox, 2016). Within this paradigm, local governments in China emerge as “controllers” of the urban energy transition with an assumed capacity to govern directly transitions process (Li et al., 2016).

In this paper, we seek to extend this body of literature by examining how urban energy transitions unfold in context, without assuming that local governments play a controlling role, and questioning the translation of policy into actual material transformations. The paper focuses on a technology particularly successful in Chinese cities: solar water heating (SWH) systems. In SWH systems solar collectors are installed to absorb the incoming solar radiation and convert it to heat energy. Such heat is conveyed through a working fluid (air, water, refrigerant) and can be used to heat water for washing and other domestic uses (for a thorough review see: Buker and Riffat, 2015). SWH systems may help to reduce emissions, but they need to be fitted to both the requirements of the built environment and the practices of water use. Understanding these processes requires examining broader governance changes at the urban level related to that technological change and its impact in everyday life. The study of SWH systems thus constitutes an opportunity to examine the factors that shape the urban energy transitions in China and question dominant understandings of transitions governance.

The empirical analysis focuses on the case study of two contrasting cities, Rizhao and Shenzhen. Both have had policies to promote SWH technology. In Rizhao the adoption of SWH systems has been dramatic, heralding a broader shift in the constitution of energy services in the built environment. In Shenzhen, in contrast, such visible change has not happened. Examining the detail of the case studies, and how changes occurred, the paper shows that urban energy transitions depend not just on top-down visions and efficient regulatory instruments but also on the way flexible policies are embedded within the local contexts. Urban energy transitions herald a multi-dimensional change in governance in which institutions, actors, and spatial patterns change. Rather than playing a role in controlling the transition, local governments are essential mediators that orchestrate that process.

The findings of this paper challenge the most common explanation of China's success in reducing carbon emissions: that energy transitions depend on top-down regulatory action and strong governance capacity of local governments. Instead, the case studies suggest that multiple non-state actors play a vital role in low carbon transitions in urban China.

## 2. Research methodology and data

### 2.1. Mediating material transformations in the urban energy transition

Urban energy governance refers to the actors and modes of intervention that seek to steer the means to provide and use energy in the city. In the context of the global imperative for emission reductions, urban energy governance is central to bring about a low carbon transition (Hodson and Marvin, 2010; Rutherford and Coutard, 2014; Rutherford and Jaglin, 2015). Rutherford and Jaglin (2015) note that urban energy governance can take place both through policy strategies and instruments: policy strategies primarily aim at long-term objectives and plans, while policy instruments are more concerned with specific action plans and regulations.

Urban energy transitions are multi-dimensional processes, fundamentally political, in which different actors advance competing visions of the future by building governance networks within and beyond the city (Castán Broto, 2017; Grin et al., 2017). The governance of transitions is an experimental process (Frantzeskaki et al., 2017). Intermediation is required for the coordination of different future visions and the establishment of actor constellations (Hodson and Marvin, 2009; Hodson et al., 2013). However, urban energy transitions also require a process of material translation. Intermediaries play a central role in bringing technologies into a particular place-based context bridging social practices of citizens, the incumbent manufacturing structure, and urban infrastructure regimes (Truffer and Coenen, 2012; Bridge et al., 2013; Bulkeley et al., 2014a, 2014b).

Industry actors, in particular, act as intermediaries in transition processes, both in the development of policy and its implementation. Haarstad and Rusten (2016) highlight the importance of taking into account the interaction between political decision-making and industry innovation (interpreted as "policy/industry dissonance") in understanding the conditions of energy transitions towards sustainability. Urban energy governance is more than a collection of policy strategies and instruments and depends on pre-existing socio-spatial and material arrangements. In this case, we have looked at two processes whereby such socio-spatial and material arrangements shape the governance of urban energy: territorial proximity and socio-spatial embeddedness.

*Territorial proximity* denotes the "distance" (in both geographical, operational and cognitive senses) between a new technology and the urban development patterns that can shape the pathways of transitions to low-carbon energy systems. Territorial proximity poses advantages and disadvantages for the emerging niche of new energy technologies, representing the active relation of specific local institutional configurations (manufacturing structures, institutional support structures, and user profiles) and emergent processes of socio-technical experimentation (Truffer and Coenen, 2012). This territorial proximity may manifest in three aspects: *geographical proximity* refers to a locational dimension, e.g. accessibility to resources and clustering of industries; *institutional proximity* describes the compatibility between the emerging niches and the incumbent urban institutional environment, in terms of both formally determined rules and cultural norms (Boschma, 2005); *cognitive proximity* reflects the shared knowledge base of actors on certain energy technology, which might differ substantially across cities owing to varied consumer profiles.

*Socio-spatial embeddedness* represents the degree to which existing energy technologies are embedded into the urban physical environments and the daily social practices of energy use (Bridge et al., 2013). To foster urban energy transitions and to reconfigure urban socio-spatial arrangements, it first entails radical transformations of existing place-specific configurations (Monstadt, 2009; Rutherford and Coutard, 2014). Bridge et al. (2013) define embeddedness as "*the sunk costs of capital investment (represented by the built environment and the infrastructures of energy capture, conversion and consumption), and the place-based cultures of consumption that surround certain energy technologies (expressed, for example, in expectations and norms about the cost and reliability of supply, or the social practices associated with energy consumption)*" (p. 338–339). Central to this definition is a concern with the physical feasibility of a low-carbon transition and the intangible obstacles for providers and users to shift to low carbon regimes. Embeddedness is both material and social, as it is configured by lived social practices that are continually being shaped and reshaped around technologies. Socio-material interdependencies exist between such lived practices and the built environment (Walker et al., 2015). In this sense, a transition entails both the reconfiguration of the built environment and the reconstruction of everyday practices.

### 2.2. Analytical framework

The Dimensions of Urban Energy Transitions (DUET) framework is a tool to examine the multi-dimensional nature of urban energy transitions systematically (Huang et al., forthcoming). The framework points towards three cornerstones that promote or hinder urban change:

1) Socio-technical (entrepreneurial) experimentation refers to the multiple processes of innovation that are needed to introduce new ideas into a given context. In traditional approaches to transitions theory (e.g., Geels, 2002; Schot and Geels, 2008; Markard et al., 2012), this is referred to as 'niches', that is, protected spaces where experimentation is possible. For example, industry actors may conduct pioneering entrepreneurial activities of translating newly-emerging technology into concrete business opportunities.
2) Urban political processes include processes of steering (governance) and response (contestation) (Rutherford and Coutard, 2014). Even in the forms of experimental governance that are involved in urban energy transitions, politics are played both at the discursive level at which transition visions are formed and contested, and also at the everyday level in which transitions are maintained and lived (Bulkeley, 2015). A range of different public and private actors are involved, often playing ambiguous roles.
3) Socio-spatial arrangements represent the conditions of socio-technical experimentation and urban political processes (Coenen and Truffer, 2012; Coenen et al., 2012; Truffer and Coenen, 2012; Hansen and Coenen, 2015). Pre-existing socio-spatial arrangements manifest as spatial patterns of economic and social activity (Bridge et al., 2013). Such conditions may promote or inhibit experimentation and shape the dynamics of urban governance (Castán Broto and Bulkeley, 2013). In this sense, socio-spatial arrangements play the role of medium (contextual enabling/disenabling factors) of energy system transitions.

These three foci are the dimensions of urban energy transitions integrated into the DUET framework (Huang et al., forthcoming). The DUET framework also enables the analysis of specific patterns of interaction. Socio-technical (entrepreneurial) experimentation in the introduction of a new technology may induce changes in urban political processes, and vice versa (see ❶ in Fig. 1). Pre-existing socio-spatial arrangements may act as contextual factors that shape both urban process and experimentation, as well as their interactions (see ❷ in Fig. 1). Socio-spatial arrangements may be transformed in turn through continuous, sustained and in many cases long-lasting interactions between experimentation and urban processes (see ❸ in Fig. 1). Fig. 1 depicts an overview of DUET framework.

The DUET framework can be applied systematically to case studies to gain an overview of the interrelated processes that may lead to an urban energy transition. The DUET framework does not intend to substitute alternative framings of transitions and processes of change (e.g., the multi-level perspective), but instead, it attempts to characterize the constellation of actors and processes that make a transition possible in a given urban context. The

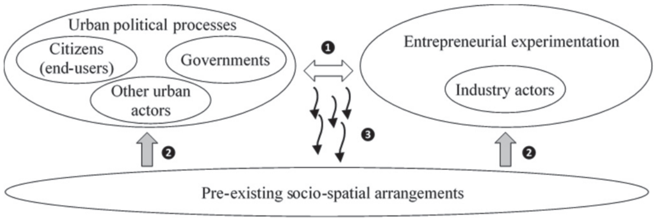

**Fig. 1.** An overview of the DUET framework.

systematic application of the DUET framework allows for an examination of specific factors within a broader context of urban development. In this case, we focus specifically on how pre-existing spatial arrangements shape socio-technical (entrepreneurial) experimentation and urban political processes (type ❷ of interaction).

### 2.3. Study area and data collection

Rizhao and Shenzhen are two Chinese cities with different spatial dynamics shaping urban energy transitions in China. Rizhao is a relatively small city of 2.88 million people[2] located on the eastern coast of China (Fig. 2). Shenzhen is a much larger city with a population of 11.38 million[3], located in the southeast of China (Fig. 2). Shenzhen has had rapid urban development following its designation as a protected economic zone in 1979. Table 1 illustrates the main characteristics of both cities. Although there is a difference in scale between the two cities (e.g., built-up area and population), the two cases enable a comparison of contrasting implementation outcomes of SWH systems in each city.

The comparative case study has been developed using a combination of a desk review, fieldwork observation, and semi-structured interviews. First, the two urban trajectories were analyzed using a literature review of policy documents and grey literature. Original documentation in Chinese was obtained from two government websites: the Housing and Construction Bureau in Rizhao (http://222.133.187.140:1252/rzqgb/index.asp) and the Housing and Construction Bureau in Shenzhen (http://www.szjs.gov.cn/). The review included 48 policy documents from Rizhao and 59 from Shenzhen. Fieldwork took place in Rizhao (October 2016) and Shenzhen (November 2016). We conducted 41 semi-structured interviews (27 in Rizhao and 14 in Shenzhen) with key stakeholders intervening in the transition to solar energy in Rizhao and Shenzhen, including major local SWH manufacturers, dealers, governmental officials, intermediaries (e.g., government-affiliated industry association) and end-users. The following two sections present the analysis. Section 3 compares the two different trajectories of socio-technical change of SWH technology in Rizhao and Shenzhen. Section 4 focuses on the two factors of territorial proximity and socio-spatial embeddedness and how they have shaped the transition in each city.

**Fig. 2.** Location of Rizhao and Shenzhen city.

**Table 1**
The main characteristic of the city of Rizhao and Shenzhen in 2015.

| | Rizhao | Shenzhen |
|---|---|---|
| Land area (km$^2$) | 5358.57 | 1997.30 |
| Urban area (km$^2$) | 682.57 | 1997.30 |
| Built-up area | 151.13 | 405.90 |
| Year-end permanent population (million) | 2.88 | 11.38 |
| Sunshine duration (hour) | 2197.6 | 1964.3 |

Source: Rizhao Statistical Yearbook, 2016; Shenzhen Statistical Yearbook, 2016

## 3. Differential trajectories of SWH policy implementation in Rizhao and Shenzhen

As explained above, the policy implementation of SWH systems in Rizhao and Shenzhen followed different trajectories with varying characteristics.

Rizhao and Shenzhen initiated the mandatory installation regulations of SWH systems in 2007 and 2006 respectively. In Rizhao, the regulation prescribed SWH systems in buildings of seven floors or below, extending it to all newly-built residential buildings. The limit in Shenzhen was buildings of 12 floors or below. In 2010, Shenzhen extended the mandatory installation regulation to high-rise buildings with a particular emphasis on roof-mounted SWH systems (GOSMPG, 2010; HCBSM, 2011). The outcome was entirely different. In 2010, 95% of residents in urban areas of Rizhao had adopted SWH technologies (PGR, 2011). In contrast, in Shenzhen, there were much fewer projects, and many of them were left unused.

The evolution of policy instruments also reflects these different trajectories in each city. In 2014, the local government in Rizhao continued to implement the same regulation passed in 2007 while also granting more flexibility to builders by allowing exceptions when developers could not meet the requirements for installing SWH systems. In Shenzhen, in contrast, the local government abandoned the mandatory regulation for SWH systems in 2014 and prioritized solar photovoltaic (PV) technologies instead (see core instruments in Fig. 3). Shenzhen also terminated a programme giving subsidies for the installation of SWH systems. The turn of technology focus meant that Shenzhen's municipal government no longer regarded SWH systems as part of their efforts towards a low-carbon energy system.

These different trajectories are also manifest in the dynamics of policy implementation in Rizhao and Shenzhen (Fig. 3). Most of the significant policies in Rizhao show consistency since enactment, and they are still taking effect. In contrast, the majority of instruments in Shenzhen have been terminated, especially the core instruments. Except for the mandatory installation regulation, all the other instruments in Shenzhen barely lasted three years, indicating discontinuity and fragmentation in policy formulation.

These contrasting trajectories are surprising in the context of governance in each city. Table 2 summarises the development of policy objectives from 2006 till now in Rizhao and Shenzhen. With regards to governance capacities *per se*, the Shenzhen government appears to possess significantly stronger capacity. For example, the Shenzhen government showed both clearer policy goals and stronger financial support than the Rizhao government did during the adoption of SWH systems. The policy strategies concerning the implementation of SWH technology in Shenzhen were consistent and specifically formulated. In contrast, Rizhao seems to lack effective and clear environmental policy goals. Despite a series of policy objectives and plans specifying short-term goals, many policy strategies severely lagged behind the policy term. For instance, plans such as the *“12th Five-year Plan on Renewable Energy Buildings”* should have guided the development of SWH technology

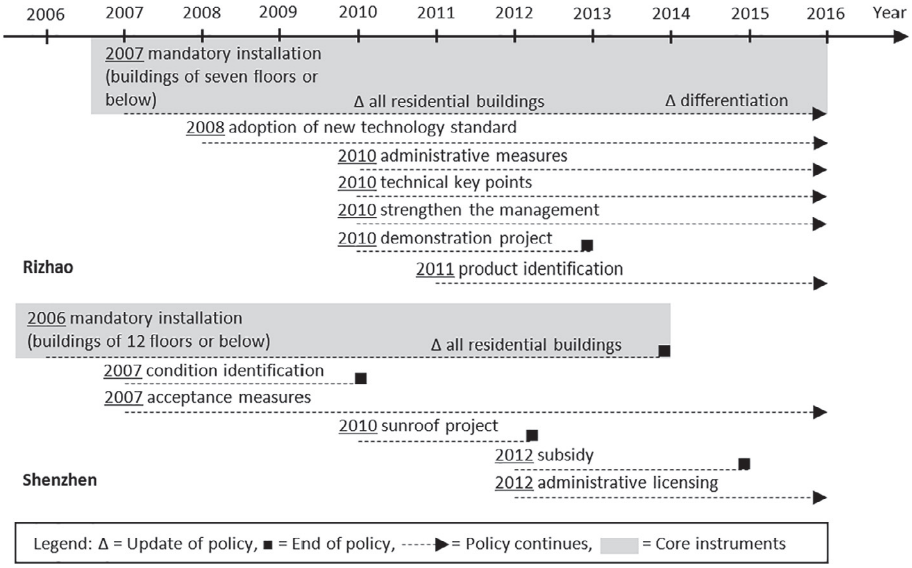

**Fig. 3.** Dynamics of significant policy instruments of SWH systems in Rizhao and Shenzhen.

**Table 2**
Policy objectives on the application of SWH systems in Rizhao and Shenzhen since 2006

| Policy term | Policy goals | |
|---|---|---|
| | Rizhao | Shenzhen |
| 2006–2010 | Mandatory installation of SWH systems in all newly-built low-rise and multi-storey residential buildings (GORMPG, 2007) | The application area for SWH systems should reach a minimum of 2 million m$^2$ (HCBSM and DRCSM, 2007; GOSMPG, 2008). |
| 2011–2015 | In 2013, the goal was set that the application area for SWH systems should reach a minimum of 4 million m$^2$ (GORMPG, 2013). In 2014, the goal set in 2013 was adjusted to 8.5 million m$^2$ (HCBRM, 2014). | The application area for SWH systems should reach a minimum of 8 million m$^2$ (HCBSM and DRCSM, 2011a, 2011b, 2012). |
| 2016–2020 | Policy objectives for this policy term are not released yet. | Specific objectives no longer set by the municipal government; policy orientation adapted to encouragement (HCBSM, 2015a, 2015b). |

for the policy term of 2011–2015, but these documents were not announced until mid-2014 (HCBRM, 2014). Moreover, the goals in different policy documents were inconsistent. For example, the goals for SWH deployment from 2011 to 2015 were set as 4 million m$^2$ in 2013, but somehow the goal was increased to 8.5 million m$^2$ in just half a year.

The same observation can be made for financial capacity. In Rizhao, financial incentives were rarely used, mainly due to limited public financial resources. Compared to Rizhao, the policy to facilitate the implementation of SWH systems in Shenzhen was comprehensive, in particular in the form of subsidies (GOSMPG, 2008). For instance, as a complementary instrument to the mandatory installation regulation in 2010, subsidies were provided to SWH implementation projects, with 375 CNY of subsidy to every square metre of solar collectors (HCBSM and FCSM, 2012). It is worth noting that, of the 375 CNY of subsidy, 225 CNY was provided by the Shenzhen municipal government, and 150 CNY by the central government. This example illustrates the higher financial capacity of Shenzhen, contrasting with a situation where policies rely on scarce resources in Rizhao.

These different characteristics of the policy approaches in the two cities and the mixed outcomes indicate that the policies (strategies and instruments) and the local government's capacity for urban governance alone do not explain the success of a particular sustainable technology. The local government is not a controller that can accurately manage the governance changes implied in an urban energy transition, which is affected by place-based contextual factors. Territorial proximity and socio-spatial embeddedness were configuring factors that are particularly relevant in the two different trajectories. The consideration of these two variables casts the local government, in a transition, as a mediator within given constellations of actors and emphasizes the need to look into the contextual dynamics that shape the possibilities for low carbon transitions.

## 4. Territorial proximity and socio-spatial embeddedness

From the perspective of territorial proximity and socio-spatial embeddedness, this section presents the mechanisms of: 1) how an energy transition unfolded in Rizhao, with the successful penetration of SWH technology into the urban physical environment as well as into social practices; and 2) how the same process failed to take shape in Shenzhen, even though stronger policy incentives were available, as discussed in the last section.

### 4.1. *Territorial proximity*

As explained above, territorial proximity depends on the proximity to natural resources and industry clustering, the closeness of local institutional environment, and the shared knowledge base between various urban actors. These factors have shaped the possibilities for a transition towards solar energy in both cities studied.

Proximity to resources (the availability and accessibility of solar resources) is a precondition for SWH deployment. According to the National Energy Administration classification of solar energy abundance, Rizhao and Shenzhen are both rich solar areas (NEA, 2014). However, the two cities contrast in the characteristics of the urban fabric (in particular building density and orientation), that affect the accessibility of solar radiation. The building density of Rizhao is very low, and the orientation of buildings is generally south-north (Fig. 4, left). These characteristics of the urban fabric contribute to improving the general accessibility of solar radiation and act as natural advantages for the bottom-up popularization of SWH systems in Rizhao. In contrast, Shenzhen's urban fabric to a great extent hindered the accessibility of solar resources. Shenzhen is a rapidly growing city, and it has a severe shortage of land resources. Land shortages result in high building density, with an average floor area ratio (FAR) of more than 1.3 (the average FAR of Chinese cities is less than 0.45) (Li and Gao, 2008). Most residential buildings in Shenzhen are high-rise buildings. According to statistics in 2006, the construction area of buildings lower than 12 floors only comprised approximately 20%–30% of the total construction areas (Liu, 2006). Moreover, the orientation of buildings is not always south-north (Fig. 4, right), which is entirely different from Rizhao. This factor would affect the accessibility of solar radiation. Therefore, in Shenzhen, to translate top-down visions into the urban materiality, it foremost entails the overcome of this natural disadvantage.

In high-rise buildings, there are three types of SWH system: central SWH system, central-distributed SWH system and distributed SWH system (Shi et al., 2013). For central and central-distributed SWH systems, solar collectors are installed on the rooftops of buildings. Due to limited space on roofs, these two types of SWH system can only provide hot water to residents living on higher floors, limiting the scale of application. Distributed SWH systems can solve this problem by installing solar collectors on the balcony slab or the wall between bedroom windows of every apartment (ibid.). Distributed SWH systems require a minimum level of sunshine duration to optimize the performance of solar collectors. Hence, they are more sensitive to architectural characteristics, particularly building orientation, layout, and density. As a result, the selection of technology in both cities depends on both pre-existing urban conditions of the built environment and technology characteristics. The selection of technology has had direct consequences for urban energy governance. For local governments, effective and efficient implementation is a primary concern. When the conditions allow it, distributed SWH systems are favored. In Rizhao, distributed systems spread rapidly. In contrast, in Shenzhen the large-scale application of distributed SWH systems was constrained by the physical structure of the urban fabric. Shenzhen's municipal policy thus favored rooftop systems, such as in the case of the “Solar Rooftop Project” launched in 2010 (GOSMPG, 2010; HCBSM, 2011).

Rizhao's transition also benefited from the proximity to an industry cluster of SWH systems in Shandong province (Huang and Liu, 2017). Following the technology breakthrough on the evacuated glass tubes in 1984, large-scale production and commercialization application of solar energy collector tubes started, giving rise to the SWH industry (Hu et al., 2012). Three pioneering enterprises were based in Shandong province: Sang Le in 1987, Himin in 1995, and Linuo Paradigma in 2001 (Goess et al., 2015). Since the late 1980s, a wholesale market emerged in Linyi city in Shandong. The LanTian solar market, for example, was well-known for selling parts and accessories of solar water heaters. Before its designation of a prefecture-level city in 1989, Rizhao was part of Linyi city. This proximity enabled residents in Rizhao to get the information and know-how not just to develop an interest in this technology, but also to learn how to install the technology in their households and maintain it over time.

In the case of China, geographical proximity, such as the proximity of the city to industry clusters, can contribute to the development of other aspects of proximity. Compared to Rizhao, Shenzhen lacked geographical proximity to industry clusters or leading enterprises of SWH technology. For instance, none of the top ten SWH manufacturers is in Guangdong province, in contrast with four SWH leaders in Shandong province (Himin, Linuo Paradigma, Sangle, and Ecoosolar).

Second, in Rizhao, the incumbent institutional environment is in alignment with the SWH technology, regarding both informal institutions (conventions and cultural beliefs) and formal institutions (regulatory rules and standards). Rizhao possesses the advantage of proximity to formal institutions in the implementation of SWH systems. On the one hand, the legitimacy of SWH products was gradually established through various marketing activities by leading enterprises, represented typically by Himin's early-phase activities in the late 1990s. For instance, in 1997, Himin initiated the “Long March for Solar Science Popularization” (*Tai Yang Neng Ke Pu Wan Li Xing*). The primary aim of this project was to disseminate the knowledge on solar technology all over the country. While Himin targeted the whole country, formal and informal business activities concentrated in the Shandong province. Other marketing means such as TV advertising and distribution of printed leaflets were also used.

The private sector also played a leading role in policy formulation and energy governance, especially the activities of critical enterprises. For instance, both Himin and Linuo Paradigma actively participated in the drawing up of a series of provincial product standards, which were essential components of the regulatory development of SWH systems in Rizhao. Several interviewees indicated that a technology standard enacted in 2007 (Linuo Paradigma was one of the drafters) on the application of SWH technology in residential buildings is more stringent than the national standard. This standard was then applied in the management of SWH technology in Rizhao, which technologically guaranteed large-scale implementation of SWH technology in high-rise buildings. Due to the absence of leading SWH enterprises,

**Fig. 4.** Examples of urban fabric in Rizhao (left) and Shenzhen (right) (source: Google Map).

Shenzhen lacks the capacity of perfecting institutions for SWH systems. For instance, Shenzhen lagged behind in the drawing up of strict technology standards, and it was not until 2012 that the Shenzhen municipal government started to draft some relevant standards (HCBSM and DRCSM, 2011b).

Even before the direct intervention of governance, the popularization rate of SWH systems in Rizhao had already reached 70% (Southern Weekly, 2009) only through grassroots activities. Rizhao has a long history of the 'Sun Worship Culture,' and is one of the world's five sun worship culture origins. Rizhao city's name ("日照") follows an old Chinese saying that it is the place illuminated by the first rays of the sun ("日出初光先照"). Citizens see the sun as an integral part of the city's identity, which contributes to an inherently favorable view of solar energy systems. In contrast, Shenzhen lacks this pre-existing cultural base for utilization of solar energy.

Cognitive proximity also played a role in the context of Rizhao, as the intermediation of the local government brought together multiple actors. SWH technology soon became well known across the city through markets, promotion activities, and direct installation. Often such cognitive proximity was related to a knowledge of the solar brand, as it is the case of Himin, commonly cited in the interviews with users of SWH systems in Rizhao. As described by one interviewee:

> *"The first SWH system we used was produced by Himin. Our dormitory building was constructed around 1998. At that time, the best SWH systems were produced by Himin."* (October, 2016)

In contrast, the interviews show that citizens in Shenzhen have little or no interest in SWH technology. The majority of our interviewees in Shenzhen said that they have never used SWH systems, and they expressed their lack of familiarity with the product. It matches the empirical data that shows that before 2007, the popularization rate of SWH systems in Shenzhen was less than 5% (NetEase, 2007). Overall, the qualitative interviews suggest that these interrelated dimensions of territorial proximity influenced the different outcomes of the implementation of SWH systems in Rizhao and Shenzhen.

### 4.2. Socio-spatial embeddedness

In addition to territorial proximity, social embeddedness plays a key role in the smooth enforcement of mandatory installation regulations of SWH technology in high-rise residential buildings. Even before the municipal government published the mandatory regulation in 2007, the majority of citizens in Rizhao had already used SWH systems for a long time. The consumption of SWH systems shaped residents' daily social practices. They thus had a higher tolerance for the inconveniences associated with this technology, such as the irregular provision of hot water. The interviews suggest, for example, that residents in Rizhao tend to take these inconveniences for granted, adjusting their needs to the expected performance of SWH systems. For instance, unlike gas water heaters, SWH systems require users to wait for hot water while keeping the water running. When we asked users how they dealt with this inconvenience and the waste of non-heated water that they needed to leave running, they showed a relative disinterest for this issue and had developed different practices of water use accordingly. As described by one interviewee:

> "*This does not bother us at all. While waiting for hot water, we normally use a bucket to collect the cold water, which can be then kept for other uses. We are used to it.*" (October, 2016)

A government official also indicated that one of the reasons for the extension of the mandatory installation regulation to medium- and high-rise buildings in Rizhao was that residents strongly demanded it (RZQGB, 2010). Residents living in high-rise buildings are not allowed to install SWH systems individually, and the installation of SWH systems has to be integrated into the design and construction of residential buildings. This partly reflects the embeddedness of SWH technology into the local context and its role in shaping urban governance concerning the implementation of this technology.

In contrast, Shenzhen's water heater market has long been dominated by gas and electric water heaters and their adoption has shaped social practices. As a result, users are intolerant to many of the common inconveniences of SWH systems, especially when they are compelled to use them. When asked about the need to wait for hot water to users of SWH systems in Shenzhen, the answers were radically different. For instance, one interviewee said:

> "*I always have to keep the water running for a long time until the hot water arrives. It is really inconvenient, and a huge waste of water resources.*" (November, 2016)

Unlike Rizhao, in Shenzhen, social practices are embedded in a different system of social and spatial organization, in which gas and electric water heaters dominate. The incumbent regime, as it manifests in the city, limits the adoption of SWH technologies.

In Rizhao, SWH technology was deployed through the coordination of multiple actors within local contexts, regarding both territorial proximity and social embeddedness. The private sector has led the formulation of industry regulations, paving the way for large-scale deployment of SWH system. End-users, open to the new product, are willing to reconstruct their daily way of living. The local government, responsive to market rise and social needs, plays an appropriate role in both regulation and implementation. The local government has taken advantage of the landscape of socio-technical change, reinforcing existing processes of technology adoption with the solar energy regulation and playing a coordinating role to facilitate its penetration. During the whole transitional process, industrial actors supported the development of both cognitive proximity and institutional proximity. The steady dissemination of the technology was also deeply rooted in local conventions and cultures, and even the city's identity. In the case of Rizhao, the local government acted as a mediator in forging alignment between social needs, industrial interests, as well as local contexts. This alignment was possible because of the long-term processes that had configured the SWH regime and supported the coevolution of the technology with social practices. The example of Rizhao also shows that short-term action (capital investments, promotion campaigns, local regulation) can support the consolidation of the new regime.

In contrast, in Shenzhen, despite the eager and ambitious enforcement of SWH system by the municipal government, the application of this technology in the city has encountered significant difficulties. The local government positioned itself as a controller and tried to direct the transition, which had triggered rapid and large-scale implementation in quite a short period, but there was no attempt to fit political visions to place-based socio-spatial arrangements. Arguably, these dynamics were the cause of the abandonment of SWH technologies in just four years. In 2014, the municipal government adopted the policy concerning the application of SWH systems from mandating to encouragement (HCBSM, 2014). In the next year, the subsidy for SWH technology was terminated (HCBSM, 2015c). Shenzhen's urban governance policies changed in response to local contextual factors, including the industrial setting, the materiality of the urban fabric, and the integration of daily practices with technological developments. Back to the DUET framework, the Shenzhen case suggests that local governance conditions and political pressures determine the possibilities to maintain action over time, and support the consolidation of the new regime.

## 5. Conclusion

China's success to deliver an urban energy transition may have a lasting influence on ideas about how such transition can take place. Our comparative case study of two Chinese cities suggests that the capacity of local government institutions to translate policy into real urban changes cannot be taken for granted because pre-existing spatial arrangements shape socio-technical experimentation and urban political processes.

The focus of this paper is the comparative analysis of SWH systems in Rizhao and Shenzhen. The two cities exhibit different trajectories. Both cities pioneered the mandatory installation of SWH systems, first in lower-rise buildings and later higher-rise buildings. Today, the mandatory installation regulation is still enforced in Rizhao, and an urban energy transition based on SWH systems is visible in the changing urban landscape and shifting social practices. In contrast, the Shenzhen municipal government terminated the mandatory requirement and subsidy for the installation of SWH systems in high-rise residences in 2014. Few SWH systems are installed and operative in Shenzhen.

The mixed outcomes point to the fact that top-down environmental policies *per se* do not explain urban energy transitions. Contextual factors impose critical constraints. Here we have looked at two families of factors: territorial proximity and socio-spatial embeddedness. In the case of Rizhao, both territorial proximity and pre-existing socio-spatial embeddedness acted as enabling factors for deployment of SWH technology. Rizhao is in proximity to an industrial clustering of SWH technologies, and the activities of leading industrial actors contributed to the development of both cognitive proximity and formal institutional proximity. Besides, Rizhao has a long tradition of utilizing solar energy. Social practices have evolved alongside the technology. With the early popularization of SWH technology in Rizhao, policy measures were directed to fit political visions into these local contexts. The technology was successfully embedded into the urban system.

In contrast, in Shenzhen, this anchoring process failed to take place even with greater governance capacity and financial resources. We show that Shenzhen lacks proximity in both geographical, operational and cognitive senses. Leading enterprises are absent, and institutions struggle to commit to long-term strategies as it happened in Rizhao. Consumption cultures and social practices incorporate gas and electric water heaters. Shenzhen eventually abandoned the large-scale implementation of SWH technology in 2014, and turned to alternatives such as solar PV, because of a combination of shifting policy priorities and a lack of results on the ground. Overall, this comparative study suggests that efforts to bring about an urban energy transition should take into consideration various territorial contextual factors to reach alignment between political visions and local contexts.

This research has direct implications for both local governments and the central government in China. First, the study demonstrates that both local governments and the central government can play a crucial role in enabling innovation. To do so, they need to select technologies that are suitable to the context of implementation. While local governments may have sufficient information to identify suitable technologies, the central government may be more effective through the promotion of flexible policy mechanisms that allow for a context-based technological selection. For example, in 2006, Shenzhen was designated as the "Pilot City for the Scaling-up of Renewable Energy (Solar Energy) Buildings." A period of radical initiatives for the implementation of SWH technology followed. What would have happened if the central government had not prescribed a specific technology that did not suit the context of Shenzhen? Would more flexibility have helped the municipal government to pursue alternative transitions pathways? Second, this study demonstrates that multiple actors facilitate innovation in urban China. In particular, the participation of city inhabitants in the design of low carbon policies may have a direct impact on the long-term adoption. Further research could explore how public participation is possible in China, and how bottom-up strategies can deliver sustainability transitions within the current top-down policy regime.

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