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From "transitions in cities" to "transitions of cities": The diffusion and adoption of solar hot water systems in urban China

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Abstract: Urban china provides a unique setting to examine the urban energy transitions. Rizhao, the Chinese 'solar city' is known for the rapid spread and popularization of solar hot water systems since the 1990s. In this paper we seek to understand how the specific urban conditions in Rizhao have favored the adoption of solar hot water systems to the extent that we can speak of an urban energy transition towards solar energy. To do so, this paper introduces a novel framework - the Dimensions of Urban Energy Transitions (DUET) framework - building upon theoretical thinking of both transitions studies and urban studies. The Rizhao case illustrates the dimensions of the DUET framework, analyzing specially the dynamic interactions between urban development processes and energy transitions. The case of Rizhao shows that transition possibilities are continuously shaped by the ongoing conflicts and alignments between industry interests and territorial priorities.

Keywords: urban energy transitions; socio-technical experimentation; urban political process; socio-spatial reconfigurations

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1. Introduction

The expansion of solar hot water systems in urban China has been spectacular. It has the world's largest installed capacity of solar water heaters (SWHs). The annual consumption of SWHs in China has increased from 80 million m^2 in 2005 to 440 million m^2 in 2015 (Huang and Liu, 2017). In the city of Rizhao, particularly, the spread and popularization of solar hot water systems can be dated back to the 1990s. Already in 2007 all of the 650,000 residents living in the city's downtown used SWH[2]. Up to October 2013, the SWH popularization rate in urban areas of Rizhao had reached 90%[3]. Rizhao has gained international recognition because of its achievements in the use of SWHs (Schroeder and Chapman, 2014). In June 2007, Rizhao was awarded the "World Clean Energy Awards" by United Nations (UN), for its outstanding achievements in the application of solar energy. In January 2017 China unveiled its 13th Five-Year-Plan on Renewable Energy Development[4], which established the focus on renewables and an ambitious target of 20% for renewable energy's share of national energy consumption by 2030. As the case of Rizhao shows, the Chinese energy transition is also an urban transition. Thus, urban China provides a unique setting to study the interaction between urbanization and energy transitions.

In urban areas, energy transitions involve reconfigurations of systems of service provision and the built environment (Monstadt, 2009; Rutherford and Coutard, 2014). Such reconfigurations follow complex processes of social and institutional change. There is increasing evidence of the possibilities to

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[2] http://www.cleanenergyawards.com/fileadmin/redaktion/factsheets/factsheet_webversion_6.pdf
[3] http://www.fdi.gov.cn/1800000121_21_53322_0_7.html
[4] National Development and Reform Commission (NDRC), 2016. The 13th Five-Year-Plan on Renewable Energy Development, http://www.ndrc.gov.cn/zcfb/zcfbtz/201612/W020161216659579206185.pdf.

intervene in cities to foster a low carbon transition. Sustainability transitions, particularly, can build upon learning about the experiences in cities and urban areas (Frantzeskaki, et al., 2016).

Studies of urban transitions have also generated an increasing interest on the spatial aspects of energy transitions. Several reviews of the field have argued that a more deliberate engagement with space will regenerate the field (Berkhout, et al., 2009; Coenen, et al., 2012; Truffer and Coenen, 2012; Bergek, et al., 2015; Hansen and Coenen, 2015). However, space concerns are not yet fully integrated into theoretical perspectives on transitions, and studies of urban sustainability transition continue to focus on governance processes, exploring particularly questions about political alliances and actor constellations (Binz, et al., 2012; De Laurentis, 2013; Gosens, et al., 2015).

Relational ideas about space have the potential to further enrich current thinking on the urban energy transitions. Ideas of relational spaces have already influenced debates about energy transitions (see Bridge et al., 2013, for example). Moreover, such ideas may have practical implications in relation to how to foster or accelerate urban energy transitions.

In this paper we seek to understand urban energy transitions in China, through an engagement with a salient example, the case of the popularization of solar hot water systems in Rizhao. Rather than looking solely into processes of energy governance, we seek to pay deliberate attention to the spatial dimensions of urban energy transitions. We do so by developing a framework grounded on notion of relational space, called Dimensions of Urban Energy Transitions (DUET) framework. Bringing together theories from both transitions studies and urban studies, this framework makes explicit how relational spaces influence such transitions alongside other known factors influencing transitions from industrial policy to governance processes. We apply this framework to study the case of Rizhao, a case study of an urban energy transition in the making, but also a case in which the popularization of solar hot water systems has been rapid.

The remainder of this article is organized as follows. Bringing together relevant theories, section 2 delineates the dimensions of DUET framework. This framework supports a change of view from transitions in cities to transitions of cities, that is, transitions which fundamentally shape the processes of change in the urban fabric, reconfiguring the urban fabric itself. Section 3 provides information on data collection and methods. The Rizhao case is then presented in section 4. Empirical materials illustrate the three dimensions of an energy transition of the city, as well as their dynamic interactions. The paper illustrates the multidimensional nature of energy transitions and the complex relations between processes of urban governance and territorial appropriation.

2. Theoretical framework: the Dimensions of Urban Energy Transitions (DUET) framework

2.1 Placing socio-technical innovation within the urban context: three dimensions of urban energy transitions

Sustainability transitions are driven by innovation of emerging technologies, along with changes of socio-technical configurations. Current perspectives on socio-technical innovation, such as approaches of the Technological Innovation Systems (TIS) and the Multi-Level Perspective (MLP), tend to overlook the spatial dimensions of energy transitions (Negro, et al., 2012; Turnheim and Geels, 2012). For example, Turnheim and Geels (2012) reviewed the evolutionary process of transitions from coal dominance to the four-fuel economy (1913-1967), as well as the destabilisation of coal in the electricity sector (1967-1997) in Britain. This socio-technical analysis is primarily concerned with national-level transitions. The diversity of sub-national contexts is rarely taken into account. Nevertheless, socio-technical innovations can hardly be separated from place-specific contexts, since the formation of socio-technical niches depends on socio-technical experimentation in specific places by a range of local actors (Castán Broto and Bulkeley, 2013). This is particularly true of urban sustainability transitions, in which socio-technical innovations depend on wider urban contexts where multiple processes of simultaneous reconfiguration take place (Hodson and Marvin, 2010).

The Technological Innovation Systems (TIS) approach defines innovation as a collective activity. Innovations are developed and deployed through the complex interactions among actors and organizations; physical artifacts and the institutions that pose 'the rules of the game' enable and constraint innovation possibilities (Carlsson and Stankiewicz, 1991; Hekkert et al., 2007; Bergek et al., 2008). Following Bergek et al. (2008) and Hekkert et al. (2007), the emergence and diffusion of *socio-technical experimentation* relate to a combination of the following six key processes: entrepreneurial experimentation, knowledge development and diffusion, guidance of the search, (niche) market formation, resources mobilization, and creation of legitimacy (Negro, et al., 2007). Entrepreneurial experimentation provides impetus for continuous innovation. Studies of business models for innovation have highlighted the mediating role of firms in the translation of technical potential into economic value, driven primarily by a 'crave' for business opportunities (Chesbrough and Rosenbloom, 2002; Chesbrough, 2010). Successful socio-technical experimentation follows pioneering entrepreneurial activities to translate newly-emerging technology into concrete business opportunities. Processes of guidance development, exchanging knowledge (cross-boundary interactions and technology transfers), mobilizing resources (finance, labor, know-how) and establishing legitimacy all contribute to opening up and maintaining an operative local market.

New socio-technical configurations take place alongside *urban political processes*. The emergence and diffusion of experimentation in the city entail close involvement of a wide array of actors. Actors are involved in multiple processes of collaboration, contestation and conflict. The six elements of socio-technical experimentation become highly politicized within place-specific contexts, whether this is in relation to the transformation of urban institutions, the confrontation of different interests, or the encounters between multiple material agencies (Rutherford and Coutard, 2014; Bulkeley et al., 2016). Related to this are three key processes of urban politics: urban material politics, processes of contestation, and the reproduction of urban regimes. Politics around radical physical alterations of urban environment also constitute energy transitions (Bulkeley et al., 2016; Hodson et al., 2016). Rutherford (2014) showed how urban materialities of energy transition are engaged with continuous everyday conflicts. Conflicts between different actors evolve with changing local discourses around possibilities for action and energy futures (McFarlane and Rutherford, 2008; Späth and Rohracher, 2010; Hodson and Marvin, 2012; Castán Broto and Bulkeley, 2013; Moss, 2014). Existing urban institutions may hinder or adapt transitions. For example, in Shenzhen (China), the municipality took on the task of electric vehicle deployment, providing one-time subsidy of 120,000 CNY for E-taxi (nearly half the cost of purchasing at a price of around 300,000 CNY) and a twelve-year free commercial operation license (Li et al., 2016). In this case, urban governance played a key role in the reproduction of dominant regimes. The Shenzhen case, for example, shows how local governments can influence directly in the selection of competing technologies. More broadly, cities are situated within relational multi-scalar networks (Macleod and Jones, 2007), and thus activities that take place in cities are also influenced by trans-urban dynamics. For instance, urban policies are often closely related to political agenda at national and supranational levels (Rutherford and Coutard, 2014).

A socio-spatial dimension, *socio-spatial reconfigurations*, adds additional dimensions to the two explained above. Spatial entanglements of energy systems are both pre-conditions and outcomes of transitional processes. On the one hand, specific places are always attached by or embedded within pre-existing socio-spatial configurations. Such conditions may promote or inhibit the emergence and diffusion of socio-technical experimentation (Castán Broto and Bulkeley, 2013). On the other hand, place-based socio-spatial arrangements are continuously (re)shaped by emerging socio-technical transitions. In this sense, territorial socio-spatial arrangements play the role both as the medium (contextual enabling/disenabling factors) and as the consequences (socio-spatial manifestations) of socio-technical experimentation that interact closely with dynamic urban processes.

Socio-spatial arrangements reflect the multi-dimensional territorial proximities, technological relatedness and spatial clustering, and social and cultural embeddedness of urban experiences and practices around certain energy. Territorial proximity indicates the intense relation of proximity dimensions and local niche experimentation and innovations (Boschma, 2005; Coenen, et al., 2010). Proximity can either be the physical distance between city and resources (locational proximity), the shared expectations of or mutual trust between various local actors (cognitive proximity), or the similarity of norms and values between the emerging niches and the incumbent local institutions (institutional proximity). Technological relatedness refers to the relatedness between the preexisting industries in a region and a new industry that enters from outside or emerges through local entrepreneurial activities. The relatedness of industries is an important factor in the attraction and formulation of technologically related experimentation and innovations, since related industries have a higher probability of entering the region (Neffke, et al., 2011). The high degree of technological cohesion is often associated with geographical agglomerations of emergent industries in a long run (Ter Wal and Boschma, 2011). Socio-spatial embeddedness and path dependency, as a sub-dimension of socio-spatial configurations, depicts the degree to which existing energy technologies are embedded into the urban physical environments or the daily social practices of energy use (Bridge et al., 2013). Besides urban infrastructure, this sub-dimension recognizes the role played by social practices in transitions. The everyday engagement of social practices in energy transitions has been highlighted in many studies (Jalas et al., 2014; Shove and Walker, 2010). As noted by Jalas et al. (2016), energy transitions necessitate the integration of technologies into the "rhythmic mixes in everyday life". As Bridge et al. (2013) explain this embeddedness as "both 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).

Bringing together the three dimensions of urban energy transitions, the DUET framework (Fig. 1) recognizes that pre-existing socio-spatial arrangements shape socio-energetic relations and influence the opportunities for experimentation. Such opportunities for experimentation are also reconfigured by the dynamics between socio-technical experimentation and processes of urban politics. Moving away from conventional understandings of cities acting as static and passive containers for incubating energy-related innovation (as criticized in Bulkeley, et al., 2010; Coenen and Truffer, 2012; Hodson et al., 2016), the DUET framework looks at cities as processes under continuous change, whose transformation is accelerated during a transition.

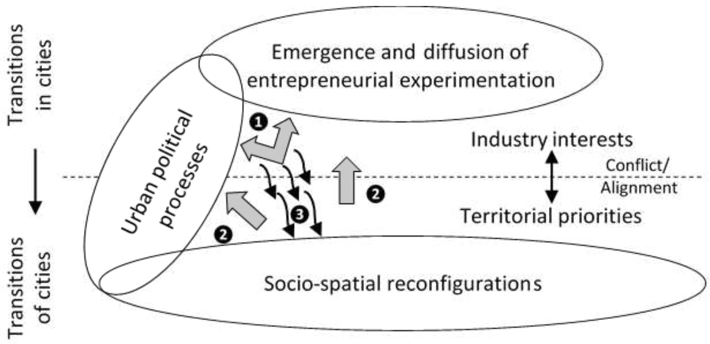

Fig. 1. The Dimensions of Urban Energy Transitions (DUET) framework

2.2 Moving away from "transitions in cities" towards "transitions of cities"

In the DUET framework, energy transitions combine socio-technical change and socio-spatial transformations with a particular focus on the dynamics of conflict or alignment between industry interests and territorial priorities. Hodson and Marvin (2010) highlight the mutual constitution of socio-technical regimes interests and urban territorial priorities. They argue for a need for an increasing understanding of how urban governance shapes future priorities. Despite varied renewable energy technologies and energy-efficient technologies that are technically and economically feasible, the exclusive nature of existing urban infrastructures that are embedded in urban technologies inevitably inhibits the diffusion of alternatives. In other words, tensions exist between capturing the complexity of the urban milieu in urban infrastructure regimes (Monstadt, 2009) and following the trajectory of a specific technology, to look into the competing or even incompatible relations between alternative technologies that emerge and evolve at the scale of city.

Conflict and alignment of industry interests and urban priorities co-emerge in urban transitions towards sustainability. For instance, there are cases of conflicts related to large-scale on-shore wind farm and land use (Felber and Stoeglehner 2014), and alignments between the installation of photovoltaic systems and agricultural practices (Sacchelli, et al., 2016). These conflicts or alignments at the city scale reveal the interdependence between practices of industry actors in cities and urban governance priorities. Transition possibilities will depend on a variety of factors such as the development of mutual relationships, the possibility of technical, spatial, or economic contiguity, and the establishment of competing future visions, in which conflicts need to be resolved and alignments achieved.

Following the work of Truffer and Coenen (2012), the DUET framework (Fig. 1) aims to deliver a context-sensitive understanding of energy transition processes. It depicts the overlapping dimensions of socio-technical experimentation, socio-spatial reconfigurations and urban political processes, considering that urban actors might represent both industry interests and urban priorities in some cases. There is an underexplored relationship between the generation of innovation within and alongside specific socio-spatial patterns. However, by mapping the dimensions of urban energy transitions, the framework reveals less-understood dimensions which deserve more attention in the transitions literature.

The role of cities in energy transitions is dynamic. There is a need to move away from understandings of cities as containers for transitions, a perspective of "transitions in cities". Instead, in 'transitions of cities', urban priorities play a key role in the strategic actions of dominant actors such as governmental or business organisations. Urban actors act as intermediaries who resolve conflicts or facilitate the alignment between industry interests and territorial priorities (Moss, 2012). In "transitions of cities", three types of interactions emerge. In the beginning of energy transitions in cities, socio-technical experimentation emerges along with the entry of a new technology, inducing a series of interactions with urban political processes (see ❶ in Fig. 1). During this process, pre-existing socio-spatial arrangements act as contextual factors that shape both urban political process and different processes of experimentation, as well as their interactions (see ❷ in Fig. 1). Socio-spatial arrangements are transformed through continuous, sustained and in many cases long-lasting interactions between experimentation and urban processes (see ❸ in Fig. 1). Table 1 provides an overview of how the different dimensions of the framework have been referred to in the literature.

Table 1 Description and indicators for urban process and energy transitions

Framework components	Aspects (coding)	Description of indicators
Emergence and diffusion of socio-technical experimentation (Bergek, et al., 2008; Hekkert, et al., 2007; Huang, et al., 2016; Negro, et al., 2007) (Dimension 1, D1)	Entrepreneurial experimentation (D11)	Project started with new technology; New entrants
	Knowledge development and diffusion (D12)	R&D projects, investment in R&D; Workshops and conferences; Joint research projects.
	Guidance of the search (D13)	Regulations, goals and targets; Establishment of funding programs.
	Niche market formation (D14)	Niche markets formed; Drivers of market formation (e.g. specific favorable tax regimes)
	Resources mobilization (D15)	General local resources (e.g. capital and human resources); External resources inflow
	Creation of legitimacy (D16)	Attitudes towards the technology among different stakeholders; Rise and extent of interest groups and their activities

Reproduction of urban political processes (Bulkeley, et al., 2014; Burgalassi and Luzzati, 2015; de Vries, et al., 2012; Rutherford and Coutard, 2014) (Dimension 2, D2)	Urban material politics (D21)	Politics of change of urban spatial structure or physical landscape
	Processes of contestation (D22)	Local political discourse; Contesting and conflicting power relations across city
	Reproduction of urban regimes (D23)	Practices of a range of urban actors (e.g. everyday practices of residents; government interventions); Multi-level governance
Socio-spatial reconfigurations (Boschma, 2005; Bridge, et al., 2013; Coenen, et al., 2010; Neffke, et al., 2011; Ter Wal and Boschma, 2011; Truffer and Coenen, 2012) (Dimension 3, D3)	Territorial proximity (D31)	Locational proximity; Cognitive proximity; Institutional proximity
	Industry relatedness and spatial clustering (D32)	The relatedness between the preexisting industries (regional industrial base) and a new industry; Geographical agglomeration of the industry
	Socio-spatial embeddedness and path dependency (D33)	Volume of sunk costs of capital investment; Place-based cultures of consumption and practices

3. Study area, material and methods

Solar hot water systems have been popularized in urban China in general, and in Rizhao in particular. Their development has been different from the development of solar photovoltaic (PV) and wind power in China that are primarily triggered by either foreign market demand or government guidance. Instead, Rizhao's SWH market demonstrates a bottom-up pattern driven by local demands. This bottom-up mechanism makes it easier to observe the interactions between experimentation and local political processes. Moreover, SWHs, as household consumption goods, are deeply intertwined with urban residents' everyday life. This enables us to look deeper into the reconfigurations of urban experiences and social practices that often result in path dependencies in energy production and consumption processes. SWHs exemplify urban energy transitions.

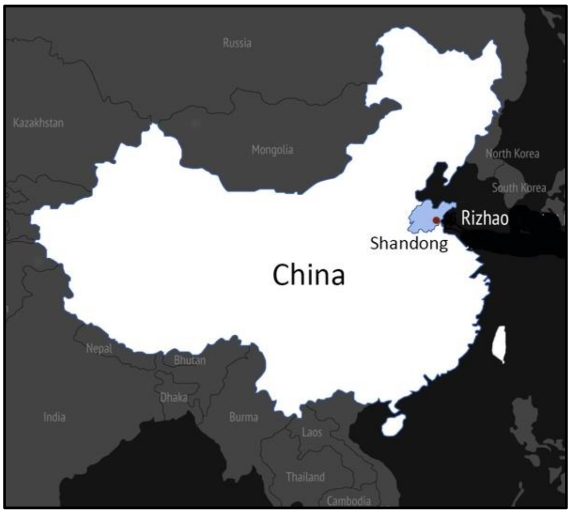

Fig. 2. Location of Shandong province and Rizhao city

In the empirical study, we apply the DUET framework to the case of SWHs popularization in Rizhao, through examining different dimensions of the transitions and the dynamic interactions between them. Rizhao City is located in the eastern coast of Shandong Province in China (Fig. 2), with an area of 5,358.57 km^2 and an urban population of 1.36 million[5]. The average annual insolation duration is more than 2540 hours, with approximately 330 days of sunshine a year. Abundant solar resources act as a natural advantage for development of solar hot water systems in this city. The case illustrates the

[5] Rizhao Statistical Yearbook, 2016

analytical dimensions of the DUET framework. Following Negro et al. (2007) and Huang et al.'s (2016) process analysis method, we apply a combination of both event history analysis and semi-structured interviews.

Event history analysis entails to compile a rich account of historical events that are related to technological development, based on data sources such as professional journals, newspapers and websites of specific relevance to the case study. This approach can also be used to observe the change of urban processes. The events were then stored in a database, classified, and systematically analyzed in relation to each dimension of the DUET framework. In the event analysis we follow the DUET framework to focus on the interactions between experimentation, urban political processes, and socio-spatial reconfigurations. Therein, the event history analysis mainly answers the 'what'-type questions: what are the manifestations of each dimension and what kind of interactions they exhibit? However, event analysis method cannot provide enough information on why and how these interactions occur. Semi-structured interviews were analyzed to shed light on the causal links between the three components. To sum up, event history analysis answers the 'what'-type questions, and semi-structured interviews address the 'why' and 'how'-type questions.

For the event history analysis, we selected three types of data sources, including a professional journal that specializes in solar industry ("Solar Vision"), a national press publication that reports on general events related to SWH development ("Solar Energy"), and three local presses that focus on provincial and urban events ("Jinan Daily", "Jinan Times" and "www.rzw.com.cn"). The multi-level sources cover SWH related events that occur within the city as well as in the broader region. We also reviewed SWH related events that occur in Shandong Province, since the external forces, especially industry development and local governance of neighbouring cities in Shandong, might play an important role. "Solar Vision" is the only professional journal specializing in the solar thermal industry in China. It was established by a previous Himin staff in Dezhou, Shandong, and thus pays detailed attention to events taking place in Shandong. Through a review of every issue of "Solar Vision" published from 2009 to 2016, we extracted more than 500 reports. We also reviewed 253 articles on solar energy in Shandong published in "Solar Energy" from 1991 to 2016. We also reviewed 1788 news (2007-2016) from "Jinan Daily" and "Jinan Times" and 155 news (2013-Feb.2017) from "www.rzw.com.cn" that report on both provincial-level and urban-level events related to SWH development in Rizhao. These materials were analyzed to extract key events that are related to the diffusion of solar hot water systems in Rizhao, which we present in section 4.

The qualitative study included 27 interviews with varied stakeholders (Table 2). The interviews lasted from 10 minutes (with an end-user) to over two hours (with a government official), with an average duration of 46 minutes.

Table 2 Overview of the interview materials

Actor type	Number of Interviewees	Affiliation of interviewees
Government	4	Bureau of Development and Reform in Ju county, Rizhao; Bureau of Housing and Urban-Rural Development in Ju county and Rizhao
Manufacturer	7	Kehao; Muyang; Himin
Real estate developer	2	Jinrun; Rizhao Cheng Tou
Industry organization	1	Rizhao Solar Energy Industry Association
NGO	3	Rizhao Solar Culture Association; Solar Vision
End-user	10	-
Total	27	

4. The sun shines on Rizhao: a case study of the popularization of solar hot water systems

4.1 The emergence and diffusion of socio-technical experimentation

The commercialization of SWH technology started after the breakthrough of research on evacuated tube collectors by Tsinghua University in the 1980s (D12) (Hu et al., 2012). Three key pioneering enterprises were founded in Shandong province: Sang Le in 1987, Himin in 1995, and Linuo Paradigma in 2001 (D11) (Goess et al., 2015). Back then, the idea of using solar energy for water heating was new in the Chinese context, and a niche market for this new product was not yet formed. Therefore, entrepreneurial experimentation was conducted by these pioneering enterprises, so as to open up the market for SWH products (Interview, NGO). Fig. 3 shows pictures of the advertising activities of Himin in the 1990s. The company used various tactics to attract people’s attention (D11). Entertainment performances, for example, sought to create on-site opportunities to disseminate SWH related knowledge, to establish the legitimacy of this product (D16), and to develop niche audiences. Through these marketing activities in the early stage of development, a niche market for SWH products was gradually opened up. This helped to develop local markets in Rizhao and some residents started to embrace the new technology. Fig. 4 is a photo of Rizhao in 1998 that shows roof-mounted SWHs being installed in residential buildings. The figure demonstrates that as early as 1998, there were already a substantial proportion of residents using SWHs in Rizhao, indicating the successful formation of an early niche market in this city (D14).

Fig. 3. Advertising activities organized by Himin in the 1990s. (Photo provided by Hongzhi Cheng, chief editor of Solar Vision)


Fig. 4. A bird's eye view of the roof-mounted SWHs in Ju county, Rizhao. (Photo taken by Chengjun Ma, 1998)

In Rizhao, a promising market attracted new enterprises into the industry. Muyang, a local SWH manufacturer in Ju county in Rizhao, was founded in 2003 (D11). Following the experience of pioneering enterprises such as Himin[6] (D12), Muyang devoted substantial resources to technology innovation, especially in the technology of wall-mounted SWHs. Muyang was looking to seize the opportunity of what they saw as an unprecedented expansion of the so-called “construction project market” (D14), in which contracts are often directly signed between real estate developers and SWH manufacturers to install SWH products for whole newly-built neighborhoods [7] (Interview, Manufacturer). Muyang invested RMB 0.36 billion (D15) in the introduction of an advanced production line of solar hot water systems from Germany (D12). Then it became the largest flat plate SWH manufacturer in China with an annual output of more than 300,000 wall-mounted SWHs[8]. Presented as an outstanding local SWH enterprise, Muyang became an important player in the popularization of SWH in Rizhao[9]. In 2013, it completed the installation of wall-mounted SWHs in more than 8,000 apartments, and roof-mounted SWHs in more than 3,000 apartments in Rizhao (D14).

The case of Muyang, shows that in Rizhao socio-technical experimentation translated the newly-emerging SWH technology into concrete business opportunities. Processes of entrepreneurial experimentation, knowledge exchange, resources mobilization and legitimacy building contributed to opening up and maintaining a local market for energy technologies.

4.2 Reproduction of urban political processes around SWH development

Along with the anchoring of a new energy technology into the local contexts, various urban political processes that involve multi-stakeholders were triggered by emergent entrepreneurial experimentation.

Since 2001, when a new mayor was appointed in Rizhao, the development of clean energy was listed as one of the municipal government’s strategic plans[10] (D13, D23). However, there were hardly any governmental guidance or industry standards specifying the development of SWH industry until 2004. With the growing popularity of SWH products among local people, several issues emerged that the local government found increasingly hard to ignore (Interview, Government). For instance, under the absence of proper product and industry standards, SWHs were often installed individually on the roof of residential buildings in an unregulated fashion (see Fig. 5) (D14 -> D33). From local governments’ point of view, these unregulated SWHs not only were detrimental for the general image of the city (D21), but also posed potential safety risks for citizens (for instance old roof-mounted SWHs might fall off) (D22) (Interview, Government). On the other hand, the discourse around the use of SWH was mixed among residents in Rizhao (D22). For instance, in many newly-built commercial neighborhoods developers themselves did not allow the installation of SWHs (Interview, Government). In other cases, complaints from other residents or neighbors were enough to stop attempts to install SWHs (Interview, End-user).

[6] “Solar Vision”, issue 52, 68.
[7] “Solar Vision”, issue 53, 20-21.
[8] “Solar Vision”, issue 52, 70-71.
[9] http://www.muyangtyn.com/case_detail/newsId=92.html
[10] http://inhabitat.com/rizhao-the-sunshine-city/

Fig. 5. Individually installed SWHs on the roof of residential buildings in Rizhao. (Photo taken by the first author, 2016)

In 2004, seeking a solution for unregulated installation of SWHs, a government official in the Bureau of Housing and Urban-Rural Development of Ju County went to Himin's production base in Dezhou city, where he saw for the first time the building-integrated SWH installed in dormitory buildings (D11 -> D23). Inspired by Himin's own self-regulation, this official issued a proposal for integrating SWHs into the design and construction of residential buildings in Ju county, which was later documented in their regular conference summary as "the mandatory installation regulation of building-integrated SWH in newly-built residential buildings" (D23) (Interview, Real estate developer). Although an official regulation was not issued in Ju county, the mandatory installation of SWH was implemented quite strictly (Interview, Government), which helped the maintenance of SWH related socio-technical experimentation in Rizhao in terms of market expansion and legitimacy building (D23 -> D14 and D16).

In 2007, encouraged by the UN Award and borrowing from successful practices in Ju county in its smooth enforcement of the mandatory installation of SWH system, the Rizhao municipal government issued the regulation for the mandatory installation of SWHs in newly-built low-rise and multi-storey residential buildings[11] (D23). The mandatory installation of building-integrated SWHs in Rizhao has greatly accelerated resource mobilization (D23 -> D15) (Interview, Government). It also opened up a new market segment for SWH products (D23 -> D14): the aforementioned "construction project market" (Interview, Manufacturer). Nevertheless, the mandatory regulation also caused substantial conflicts between different urban actors who, to a certain extent, jeopardized the established legitimacy of this industry (D22 -> D16). For instance, to save costs, some developers chose to install very cheap products without the consent of residents (Interview, Manufacturer). As a result, there were some cases where the installed SWHs were soon after dismantled and sold as waste by users or even by the real estate developers themselves (Interview, Industry organization). Newly emergent problems further shaped the pathways of socio-technical transitions of Rizhao.

4.3 The territorial socio-spatial (re)configurations as both medium and outcome of energy transitions

SWH development in Rizhao has happened within a particular socio-spatial context and enabled specific socio-spatial (re)configurations.

Territorial proximity was an important facilitator of SWHs development. For instance, being close to core enterprises such as Himin (Dezhou city) and Linuo Paradigma (Jinan city), Rizhao was influenced by the marketing activities conducted by these pioneering enterprises (D31 -> D14). On the other hand, close interactions between entrepreneurial experimentation and urban governance are likely to occur (see for instance the formulation of Ju county's mandatory regulation policies inspired by Himin's experimentation on building-integrated SWH) (D31 -> D23).

[11] http://www.rz.gov.cn/wszf/zxwj/20070927090452.htm

Moreover, the penetration of SWH technology into local people's everyday life originated from institutional proximity, namely of the alignment of this technology with the place-based norms, tradition and culture (D31). 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"). Rizhao has a long history of the 'Sun Worship Culture', and is one of the world's five sun worship culture origins[12]. Moreover, citizens in Rizhao have a long-standing tradition of using solar power to heat water for shower, normally in the summer, by simply putting the water outside for a whole day. They vividly call this tradition as "Shai Shui" (offering the water a sunbath) (Interview, Government and End-user). These examples show that significant proximity exists between SWH technology and local pre-existing institutions.

In the case of Rizhao, socio-spatial reconfigurations mainly manifest in the formation of industry clusters and the changes in urban infrastructures, consumption culture and social practices. In 2011, there were more than 150 SWH-related enterprises in Rizhao, providing more than 30,000 jobs[13]. In particular, in Ju county, many small SWH-related enterprises cluster around the production base of Muyang (D32). The urban built environment is reconfigured around SWH popularization. Fig. 6 illustrates the embeddedness of SWH in the urban landscape in Rizhao (D33). Residents' daily practices are also reshaped around new energy technologies. For instance, the interviews revealed that in relatively under-developed areas in Rizhao, the possession of a SWH is regarded as a symbol of social status, and it is even listed as one of the "must-have items" for a marriage, just as color TV and washing machines[14] (D33) (Interview, End-user). This is a typical case of the reconfiguration process of residents' consumption culture and the embeddedness of solar energy into the local contexts.

Fig. 6. The embeddedness of SWH in the urban landscape in Rizhao. (Photo taken by the first author, 2016)

4.4 Evolving conflicts and alignments between industry interests and urban priorities

The DUET framework can be read also chronologically, in terms of the different interactions between dimensions. In the case of Rizhao, SWHs depended on interactions between industry interests and urban priorities. This analysis reveals conflicts and alignments between industry interests and urban priorities in Rizhao's transitions towards sustainability.

During the early phase of SWH industry development, the industry's priority was to translate the new technology into business opportunities and open up the local market. This phase witnessed active entrepreneurial experimentation by pioneering enterprises. Back then, this newly-emerging industry had not yet attracted the attention of local policy makers. Urban priorities of Rizhao did not target the

[12] http://talk.rzw.com.cn/wenhua/2013/0121/107582.shtml
[13] http://newenergy.in-en.com/html/newenergy-1170477.shtml
[14] http://www.gov.cn/jrzg/2008-09/20/content_1100765.htm

deployment of renewable energies in the 1990s. There was a lack of alignment between industry interests and urban priorities.

The tide seemed to turn when a new mayor Zhaoqian Li was appointed in 2001. Scholars have highlighted the role of a new mayor who foresaw the importance of developing renewable energies (Ye, 2009). Shortly after his appointment, the municipal government published the "*Eco-city Construction Plan of Rizhao*". At the time the new mayor was appointed, both the industry and the potential consumers had started to incorporate SWHs in their daily practices. However, until 2004, the SWH industry had hardly any governmental guidance or industry standards for its development. Under the absence of governmental guidelines, the growing popularity of SWH products among local residents unexpectedly posed substantial challenges to urban governance. Conflicts thus emerged between industry interests of expanding the market and urban governance priorities such as the promotion of a particular urban image.

In 2007, the UN Clean Energy Award gave international recognition for Rizhao (Schroeder and Chapman, 2014). The popularization of SWHs was an important component mentioned in the Award of the UN Prize. Since winning of the UN award, urban policy-makers in Rizhao showed strong interest in the development of SWH and the municipal government's role evolved from passive regulation to active implementation. In this sense, if the appointment of the new mayor signaled a turn of urban development strategy to clean energy, the UN award acted as a catalyst for the shift of government attitude from indifference to engagement and the formation of specific alignment between urban priorities and SWH industry interests, which helped to resolve the previous conflicts between industry interests and urban priorities. A series of favorable policies were enacted, represented typically by the mandatory installation regulation of SWHs in residential buildings. The SWH industry then witnessed a new wave of prosperity, owing to the opening-up of the "construction project market", explained above. The rise of Muyang is a typical example of a company seizing the opportunity of unprecedented expansion of a new market segment.

However, the growth of markets and popularization of SWHs did not go uncontested. In China, urban governance priorities are closely related to strategic plans of higher-level (provincial or national) governments. In 2009, the Shandong provincial government enacted a document "*The Mission Decomposition Scheme for Accelerating the Application of Solar-thermal Systems*", which detailed specific goals in the implementation of SWHs. A target is set every year for all the cities in the Shandong province and municipal governments resort to all means so as to achieve the required target annual installation area of solar collectors. Responding to this provincial level strategy, the Rizhao municipal government extended the mandatory installation regulation of SWHs from low-rise and multi-storey residential buildings to high-rise buildings in 2010. Although this indicated the alignment between governance priorities and industry development, it also generated fierce price competition between enterprises and the phenomenon of "bad money drives out good" (Interview, Manufacturer). Many unqualified products entered the market, which engendered the legitimacy of this technology established by pioneer enterprises during the previous phase of development. As such, the intensified mandatory installation of SWHs induced many problems which jeopardized the development of SWH industry. Urban priorities to implement SWHs have in a sense conflicted with industry interests of legitimacy-building and market-maintenance.

5. Conclusion

Urban energy transitions consist of sustained and continuous processes. Socio-technical approaches (such as TIS) have been used to look at urban energy transitions (Negro, et al., 2012; Turnheim and Geels, 2012). In relation to the DUET framework, they mainly emphasize observations of innovation processes and socio-technical experimentation in the city. They struggle to recognize the city as a process in-the-making. Moreover, slick representations of urban energy transitions may overlook the messy interactions between active processes of experimentation and the dynamics that emerge in the local contexts. Many situated processes of urban change play a role in urban energy transitions regardless of whether they are deliberate or not.

In this paper we propose the DUET framework as a means to place socio-technical innovations within an urban context. The DUET framework both acknowledges and makes explicit the mutual dependence of urban political processes and socio-technical innovations. Territorial socio-spatial arrangements are regarded as both contextual enabling factors and socio-spatial manifestations of energy transitions.

The case of Rizhao illustrates the dimensions of the DUET framework. Socio-technical experimentation and urban political processes co-evolve in a highly dynamic transitional trajectory in Rizhao. Socio-technical changes reinforce and transform existing urban institutional and governance arrangements. With its increasing popularity, the SWH technology was embedded in the urban built environment. This fostered a simultaneous process of learning and adaptation among local institutions and contestation among different urban actors. Pathways towards the urban energy transition are simultaneously influenced by three-dimensional processes. The key question is if industry interests conflict or align with territory priorities, which are also subject to changes along with the reproduction of urban political process.

Overall, through the Rizhao case, the DUET framework has proved to be a systematic analytical tool to reveal the multiple dimensions of an energy transition of the city. This multi-dimensional perspective reveals the intricate relations between transformations of energy systems and urban change. The framework also highlights salient elements in the transition process, such as the alignment of industry and territorial priorities in the Rizhao case. Future research will explore the full possibilities of the DUET framework. One limitation of our approach in this case is the focus on a single technology. However, the successful implementation of one technology does not guarantee an overall low-carbon transition of the whole city.

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