Experimentation and Transition toward Low-carbon Cities: Shanghai as a Case Study

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Declaration

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university. To the best of the author's knowledge, it contains no material previously published or written by another person, except where due reference is made in the text.



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This PhD journey is more than academic training, exploration of knowledge, and pursuing a degree for me; instead, it is a self-transformation process like a cocoon rebirth. I have become a better self in a comprehensive way, intellectually and emotionally. More importantly, I have gained a lot of love and friendship and also reshaped my values and understandings of life from this PhD experience.

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Statement of Contribution

This thesis is submitted as a Thesis by Compilation in accordance with https://policies.anu.edu.au/ppl/document/ANUP_003405

I declare that the research presented in this Thesis represents original work that I carried out during my candidature at the Australian National University, except for contributions to multi-author papers incorporated in the Thesis where my contributions are specified in this Statement of Contribution.

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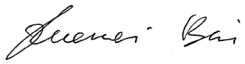
Senior author or collaborating authors endorsement: 

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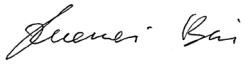
Senior author or collaborating authors endorsement: 

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Abstract

Cities are central to climate mitigation, as they are the largest carbon emitter at a global scale and also a hotbed for initiating and testing low-carbon innovations. Worldwide, transition toward a low-carbon pathway in cities has been practiced by many frontrunners, with different levels of commitment and capacity. There is a substantial body of literature studying the cities' multi-dimensional transformation process, demonstrating a variety of transition pathways and varying degrees of success in practice. There is, however, a limited understanding in terms of the internal mechanisms that enable cities' low-carbon transition processes, especially in rapidly developing regions. In recent decades, sustainability experiments, which embody an innovative social-technical configuration central to a novel solution for sustainability, have gained growing attention in urban sustainability transition research and practice, as they can be used as instruments by local governments for sustainable development. Investigation into how cities can enable and upscale sustainability experiments for low-carbon goals is helpful to unravel the underlying transition mechanisms.

This thesis aims to address the above research gap by exploring two main questions: How cities initiate and enable sustainability experiments for their low-carbon initiatives and what institutional settings and mechanisms are needed to support urban low-carbon transition. This research adopts a case-study approach. Shanghai is used as a case-study city because it has been undergoing rapid economic growth and transition, has initiated many innovative practices toward low-carbon transition, and is a designated Pilot Low-Carbon City in China. In this sense, Shanghai can be a suitable case for addressing these two research questions – 1) how have diverse actors in Shanghai initiated and facilitated sustainability experimentation, and 2) what institutional settings and mechanisms were adopted for low-carbon transition.

Four main chapters collectively address the research questions by examining the local and national policy context and the governance structure for Shanghai's low-carbon initiatives, as well as the institutional and financial mechanisms for enabling incubation of home-grown innovations and the adoption of externally introduced practices, and further upscaling of successful ones for transition. Chapter 2 examines the policy evolution process of Shanghai's low-carbon initiatives and the governance structure that may nurture sustainability experiments for policy learning. Chapter 3 investigates how cities have adopted sustainability experiments in order to understand the innovative processes in contextualizing the experiments to facilitate adoption. Chapter 4 inspects direct and indirect effects of a city-level direct-funding scheme on urban low-carbon transition, with weighted focus on its catalytic effects on institutions and local capacity building. Chapter 5 analyzes the policy schemes for enabling business sectors to engage in urban low-carbon initiatives and seeks to understand the roles and degrees of involvement of the business sectors. The findings and arguments are summarized below.

Chapter 2 reveals that Shanghai's low-carbon initiatives are well embedded and integrated into its existing policy frameworks, but with new low-carbon policy targets and measures. A strong vertical linkage between the central and local governments is identified., More importantly, a nested structure for innovative policy practices is presented, where a top-down design is met with bottom-up innovation and proactive adoption of enabling mechanisms. The structure includes two layers of experiments that facilitate learning through policy

experiments across scales, which enables a pool of experiments for testing a number of innovations in a variety of policy fields, to screen the effective ones from many and to upscale.

Chapter 3 demonstrates that post-experiment adoption and contextualization is an innovation in itself by presenting a conceptual framework illustrated by the EPC (energy performance contracting) adoption case in Shanghai. The findings indicate that contextualizing innovations in a new environment requires mobilization and realignments of actors, resources, and institutional arrangements within the process of learning, which involves much more than simple duplication and often has distinctive outcomes. The "horizontal linkages" with the original experiment play an essential role in innovative practices in post-experiment adoption, facilitating information/knowledge transfer and learning via actor interactions across experiments.

Chapter 4 discusses the multiple roles of direct funding in cities' low-carbon transition, taking Shanghai's special fund on low-carbon initiatives as the example. This fund addressed crosscutting policy issues on climate mitigation, with a direct carbon-reduction effect. Over the 11 years of its implementation, the fund plays a role in enabling coordination and collaboration across different governmental departments. Importantly, this direct-funding scheme created avenues for the engagement of business stakeholders and raising public awareness on low-carbon and sustainability issues, through subsidization for technology adoption and low-carbon-themed campaigns, which collectively have improved the city's capacity for achieving the transition. The findings also show that a well-designed city-level direct fund scheme can fill an "implementation" gap between the policy intentions and the policy outcomes.

Chapter 5 shows the interactions between business sectors and their host city's low-carbon policy setting, by exploring several policy schemes implemented in Shanghai. Shanghai has developed policy strategies on firms over time – from mandatory emission reduction to employing market mechanisms. Under this policy setting, a business transformation in some local companies is identified – from carbon emitters to solution providers to other firms – by means of expanding their business to newly emerging low-carbon markets. The policy schemes, either directly supporting a specific low-carbon industry or enabling their growth by providing incentives to create market demand, may play a role in triggering local low-carbon industries' development. In addition, market factors and policies that enable businesses to engage in the transition might collectively have built a platform for driving technology innovation and adoption in the city.

This PhD research has advanced knowledge in urban sustainability transition literature and provided policy implications by addressing two puzzles in the transition research. First, it inquiries into supporting mechanisms and structures that foster innovations for sustainability changes in cities. It adds new insights into the multi-level governance literature, by presenting Shanghai's governance structure, which has a strong vertical linkage with the national government and new enabling mechanisms for urban low-carbon initiatives. This favoring intuitional set-up opens an experimenting platform for novel practices in various urban sectors to fuel the transition. Importantly, this PhD research unravels the interconnections between policy measures, institutional arrangements, local capacity building, and financial mechanisms, presenting co-developing processes in above multiple dimensions in the matters

of mutually supporting, reinforcing, and facilitating each other's establishment and functioning in implementation. The above insights have filled a significant gap in unveiling hidden mechanisms by cities for sustainability transition in the literature. Second, it investigates the internal processes of experiments to understand its innovative nature. The finding – that post-experiment adoption requires realignments of various resources, with a new social-institutional-economic configuration as the outcome – offers a better understanding of diffusion, embeddedness, and scaling of sustainability experiments to achieve sustainability outcome. Empirically, the conceptualization of contextualization can be used as an analytical approach to inspecting other adoption case studies. As a whole, the novel findings and evidence-based arguments from this PhD research have empirical implications for policy learning, in terms of involving policies to foster innovations to drive sustainability changes in a synergic manner in cities.

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Chapter 1: Introduction

1. Research background

Cities are central to climate mitigation (Amir Bazaz et al., 2018; Bai et al., 2018). On one hand, they are the largest carbon emitter on a global scale, which might be aggravated due to an unprecedented rise in urbanization (UN, 2018). On the other hand, cities are a hotbed for initiating and innovating low-carbon innovations (Amir Bazaz et al., 2018), which may provide sustainability solutions for the global transition.

Cities' transition toward a low-carbon pathway has been practiced by many frontrunners worldwide (Allman et al., 2004; Bai et al., 2018; Granberg and Elander, 2007; Irvine and Bai, 2019; Rosenzweig et al., 2010; Zimmerman and Faris, 2011). In practice, cities have different levels of commitment to their low-carbon initiatives, contingent on their carbon endowments and local capacity (Broto and Bulkeley, 2013; Bulkeley et al., 2010). For example, numerous cities have declared they will aim for 100% renewable energy or zero-carbon emissions in the following decade or so (ACT, 2016; Melbourne, 2014; REN21, 2019); while rapidly developing cities might be less ambitious as they may be confronted with greater challenges like economic development and technology adoption (Gouldson et al., 2016; REN21, 2019). There is a substantial body of literature studying cities' multi-dimensional transformation processes (Betsill and Bulkeley, 2006; Bulkeley et al., 2012; Corfee-Morlot et al., 2009; McCormick et al., 2013; Van der Heijden, 2016), indicating a variety of transition pathways and degrees of success in practice (Bai et al., 2010; Coenen et al., 2010; Newton and Bai, 2008). In recent years, exploring the underlying mechanisms that supports cities' transition has drawn a growing research attention (Evans et al., 2016; Frantzeskaki et al., 2017b). Notwithstanding some initial understanding, the internal mechanisms of urban low-carbon transition need to be further investigated, especially in the developing regions.

Cities can be considered as an arena where stakeholders can collectively design, test, and learn from low-carbon practices (Evans, 2016; Fuenfschilling et al., 2018; Irvine and Bai, 2019) as they may provide protective shelters for innovations (Bai et al., 2010). Urban sustainability experiments, which embody an innovative social-technical configuration central to a novel solution for sustainability (Berkhout et al., 2010), can be a useful leverage adopted by the local government for enabling the transition. Adopting a portfolio of related transition experiments – that complement and strengthen each other – can make a contribution toward achieving the sustainability objective (Loorbach, 2010). In addition, sustainability experiments can be used for policy learning. For example, urban living laboratories (ULL) are localities devised to learn from the experiments, with evaluation of interventions in order to gain real-time knowledge and monitor ongoing improvement (Bulkeley et al., 2016; Bulkeley et al., 2019).

According to Bai et al. (2010), sustainability experiments may follow four different pathways: a) the experiment might fail and die out; b) it might stay as an individual experiment without being diffused; c) it might be "multiplied" and adopted in other contexts, or d) it might be "upscaled" with systems change, e.g., policy change at a higher government level. The "multiplication" can be considered a process of upscaling if this is done on a large scale and if the focus of concern is the aggregated effect of these experiments.

In the latter two pathways of experimenting toward sustainability transition, there are some factors that may enable or impede the processes (Figure 1). For example, cities' climate governance – which is embedded in the vertical and horizontal linkages with other authorities across levels and jurisdictions – may facilitate or hinder city-level practices (Betsill and Bulkeley, 2006; Bulkeley et al., 2012; Corfee-Morlot et al., 2009; McCormick et al., 2013; Van der Heijden, 2016). Moreover, coordinating other non-government actors' commitments and engagements, such as the business sector, may assist in the integration of different interests and resources in urban mitigation (Chu et al., 2018; Ryan, 2015). In addition, adopting sustainable financial mechanisms for urban low-carbon initiatives is a primary challenge faced by local authorities to enable on-the-ground actions (Barnard, 2015; Homsy, 2016; McLean and Borén, 2015). Understanding these enablers and barriers will provide the evidence-based insights to facilitate transformative changes at a large scale.

2. Research aims and questions

This PhD research aims to fill the knowledge gaps in understanding the internal mechanisms of the urban low-carbon transition, in terms of **how cities initiate and enable sustainability experiments for their low-carbon initiatives and what institutional settings and mechanisms are needed to support the urban low-carbon transition**. This dissertation adopts a case study approach to investigate these research questions, taking Shanghai as a case study. Shanghai is a city that has been undergoing rapid economic growth and transition; it has initiated many innovative practices toward low-carbon transition and is a designated Pilot Low-Carbon City in China. Specifically, this PhD dissertation examines the Shanghai case by answering the below sub-questions.

- How do Shanghai's low-carbon initiatives emerge and evolve in the local and national policy context?
- What mechanisms can enable sustainability experiments to steer the low-carbon transition in cities?
- How do sustainability experiments travel across contexts? And what does this contextualization process entail? Taking EPC adoption in Shanghai as a case study.
- How does a city-level direct-funding mechanism play a role in enabling institutional coordination and local capacity building?
- How do the Shanghai government enable the engagement of the business sectors in urban low-carbon initiatives? How do the corporate sectors interact with their host city's policy setting?

The components of this research and their placement in the broader research background are presented in Figure 1.

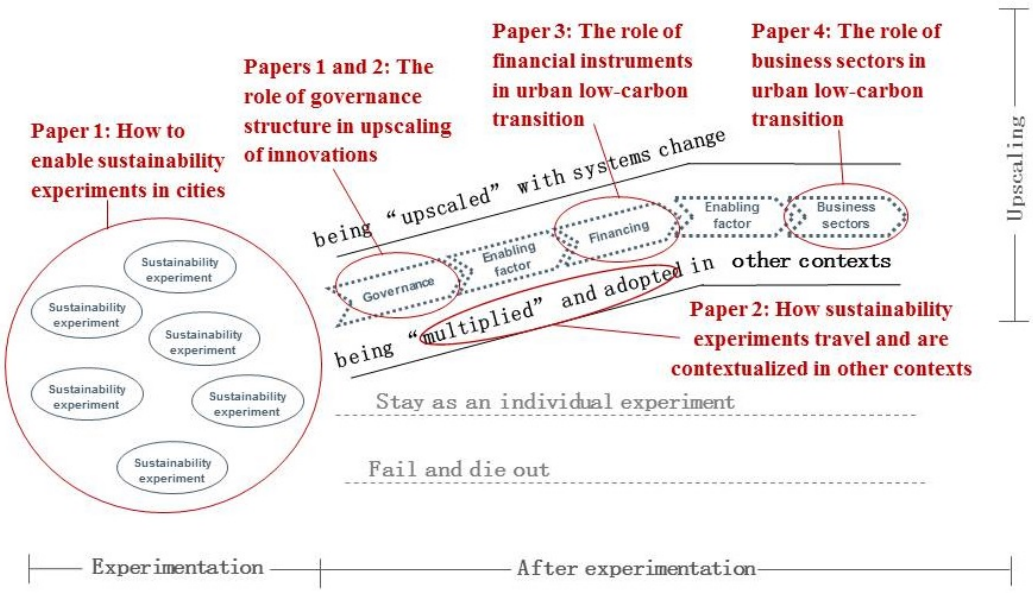

Figure 1. Research components of this thesis and their placement in urban sustainability transition research

There are two stages in the process of sustainability experiment and transition. The left part of Figure 1 shows the experimentation period where numerous sustainability experiments are incubated in cities. The first research focus is on how cities nurture sustainability experiments to fuel the transition. In the next stage, tested experiments may follow different pathways (Bai et al., 2010). The second research focus is therefore on the enabling factors in this process. This thesis mainly examines three factors: The multi-level governance structure, business sectors' role, and financing mechanisms. In addition, the post-experiment adoption process of sustainability experiments (that are tested elsewhere) in the recipient city was inspected, to unravel the mechanisms that facilitate the contextualization of innovations for transition.

3. Key concepts and perspectives

3.1 Sustainability experiments in cities

Transition toward low-carbon pathways may present a policy challenge to local governments. To tackle this new challenge, cities might be open to various sustainability experiments for innovating, testing, and learning to steer the transition (Loorbach, 2010; Rotmans and Loorbach, 2008).

Sustainability experiments in cities are widely reported in the literature (Bai et al., 2010; Broto and Bulkeley, 2013), and are defined as planned initiatives that embody a highly novel socio-technical configuration and are likely to lead to substantial sustainability (environmental) gains (Berkhout et al., 2010). Experiments are designed to be the practice ground for innovations in terms of building actor networks, stimulating learning processes, and promoting them to develop into a stable social-technical configuration (Bai et al., 2010; Kemp et al., 1998; Loorbach, 2010; Loorbach and Rotmans, 2010).

Sustainability experiments can be adopted at two different layers – on the one hand, the city as a whole can be considered a sustainability experiment when examining its role in informing national low-carbon policymaking. On the other hand, the city can be seen as a locus for numerous sustainability experiments implemented by the city. The policy-learning process is happening along with low-carbon experimentation in cities.

In systems innovation theory, upscaling of niche experiments may lead to a regime change, resulting from linkages between processes at these multiple levels (Geels, 2002; Geels et al., 2016; Smith et al., 2010): 1) Niche innovations build up internal momentum, 2) exogenous developments create pressure on the incumbent regime (dominant practices and associated rules) and, 3) tensions in the regime create windows of opportunity for the expansion of niche innovations. The above theoretical analysis from system innovation theory is conducive to understanding the role of sustainability experiments in urban low-carbon transition.

Specifically, "multiplying sustainability experiments" may bring changes in the incumbent regime, which is regarded as an "upscaling" pathway of experiments. This multiplication process can happen within one city (that may enable the change of a regime in a city), or beyond the scope of an individual city. Cities may learn from each other. For example, a successful sustainability experiment tested in one city may travel and be translated across other cities to facilitate their transitions. Therefore, the scaling-up of successful local innovations is not only critical in achieving transformation toward low-carbon resilient cities (Bai et al., 2018), but also benefits advances in sustainability at a national or global scale.

In urban sustainability research, the co-evolution of institutions and technologies are emphasized. Understanding the mechanisms that supports the synchronized development of technical innovations and associated social elements is critical for enabling urban sustainability transition. Albeit with some initial research efforts on understanding the transition mechanisms, this topic needs to be further investigated (Frantzeskaki et al., 2017a). From an experimental perspective, some experiments entails attempts in arrangements within and between institutions to produce new ways of governing (institutional experiment); while some others involves novel practical actions (practical experiment) (McGuirk et al., 2014). These two types of experiments may influence and reinforce one another in practice to bring about a broader change. The knowledge about institutional arrangements and enabling mechanisms in cities for incubating a variety of sustainability experiments needs to be further explored in the literature.

Moreover, understanding the horizontal linkages across cities - which might contribute to the broadening of experiments - is imperative to unravel the transition mechanisms (Bai et al., 2009; Wieczorek et al., 2015). For example, urban sustainability transitions engage active local actors who seek solutions outside their city and proactively create connections and foster networks to translate and embed these new sustainability experiments to city's policy, practice and infrastructure (Frantzeskaki et al., 2017a). Along with actor networking, other linkages might be created as well, including knowledge, capital, institutions and technologies (Sengers and Raven, 2015; Wieczorek et al., 2015). These linkages may collectively facilitate the diffusion of innovations. Thus, more research endeavors are needed to add new understanding regarding how successful experiments travel across contexts via these linkages and to be embedded in new environments.

3.2 The role of urban low-carbon governance in the transition

The climate governance structure of cities – featured in the roles of stakeholders and their interactions, institutions, and governance mechanisms – plays a critical role in facilitating transition (Amir Bazaz et al., 2018; Arup, 2015). Broadly, this local governance structure is embedded in a multi-level governance framework of global climate change (Betsill and Bulkeley, 2006; Bulkeley et al., 2009), which consists of two types of linkages – vertical and horizontal (Bai et al., 2009). Vertical coordination refers to the interactions between different levels of government, while in horizontal coordination, multiple actors, both within and outside of the government, interact with each other to facilitate climate actions, forming overlapping networks and partnerships in different political and non-political spheres (Arup, 2015; Fuhr et al., 2018).

In the above complex governance framework, inertias and institutional barriers exist, which may barricade the transition. Within a city, there is a mismatch between the nature of urban low-carbon transition as an inter-sectoral and multi-actor process (Bai, 2007; Romero-Lankao et al., 2018) and there is the issue-based governance of – and overlapping jurisdictions between – individual governmental sectors. Thus, establishing inter-departmental cooperation may support local climate actions (Allman et al., 2004). In addition, fragmentation also exists among different urban actors (Nagorny-Koring and Nochta, 2018; Romero-Lankao et al., 2018).

To address the institutional limits in local governance, experiments can be used to forge and encourage new institutional innovation in cities (Broto, 2017; Bulkeley and Castán Broto, 2013; Smeds and Acuto, 2018), regarded as “governance experiments” among many other types. For example, the experimental approach may create new opportunities for public and private actors to realign their authority and force in practices (Bulkeley and Castán Broto, 2013; Gómez-Álvarez et al., 2017; McGuirk et al., 2015), and probably benefits the formation of new institutional arrangements. Or, cities may adopt temporal and experimental mechanisms through which multiple government departments can collaborate on mitigation policy issues, with the institutional benefit of addressing the fragmentation in regulation and jurisdiction.

Exploring experimental cases initiated and tested in and beyond cities may enrich the knowledge and learning from this topic and identify novel ways and mechanisms to build this new governance.

3.3 The business sector’s role in urban mitigation

Actors in sustainability experiments bring various resources and are active in learning, both of which are vital to forming an actor network in a new social-technical configuration (Hoogma, 2002; Kemp et al., 1998; Schot and Geels, 2008). The business sector is an important actor in urban sustainability experiments, as it is active in innovating and adopting low-carbon technologies and solutions. Also, it plays a role in the city’s low-carbon governance structure.

For example, corporations can decarbonize the urban system by both delivering decarbonization projects in cities and modulating their own business activities.

The existing literature on business response to climate change mainly focuses on international and regional levels, indicating that business sectors may face both challenges and opportunities. They produce greenhouse gas (GHG) emissions from energy use and production processes (Fischedick et al., 2014), and therefore may face regulatory risks like carbon-control policies and carbon-pricing mechanisms. At the same time, they are victims of climate disaster, enduring severe consequences like property damage and business interruption (Pauw, 2015; Tang and Yeoh, 2007).

In global climate mitigation, both cities and business sectors are essential players. There is a large and growing body of literature on urban mitigation and adaptation as discussed above, as well as another body on the response of the business sector to climate change (Eberlein and Matten, 2009; Kolk and Pinkse, 2005). However, there is little research that explores the interactions of these two actors (Bradford and Fraser, 2008; Whiteman et al., 2011). Cities are an aggregated area of diversified businesses. Corporate climate actions could be constrained or enabled by their host cities' policies and market environments. Thus, knowledge gaps exist in understanding the corporate sector's degree of engagement and various roles according to their business scope in a city's low-carbon transition.

3.4 Financing low-carbon transition in cities

Conducting sustainability experiments and enabling the upscaling of successful ones require city governments' financial capacity to do so (Chang and Price, 2016; Floater et al., 2017). Climate change creates new challenges for urban finance: it necessitates a greening of existing financial instruments, and puts additional pressure on city budgets (Kamal-Chaoui and Robert, 2009). In general, there could be financial constraints for cities, and they might be reluctant to commit to significant expenditures on low-carbon agendas at a point when local authority budgets are not generous or other services are prioritized (Sullivan et al., 2012).

However, some frontrunner cities have demonstrated the potential to finance climate actions (C40 and ARUP, 2015). A report by C40 and ARUP reveals that C40 cities have funded 64% of reported climate actions using their budget and savings. For those actions taken at a large (city-wide) scale, this proportion increases to 70%. In another report by carbonn® Climate Registry (which included 608 cities across 62 countries), 81% of finance sources for the completed and in-progress actions come from local governments (Deng-Beck and van Staden, 2015). Also, OECD's findings indicate that cities and regions were responsible for 55% of spending and 64% of investment in selected infrastructure sectors that have a direct implication for climate change, based on the available data over 2000–2016 in 30 OECD countries (OECD, 2018). Yet, on a global scale, cities' financial competence for mitigation as a whole is inadequate, especially in developing regions (Barnard, 2015; Homsy, 2016; McLean and Borén, 2015).

When using city-level public funds for mitigation, there are two ways – direct investment into infrastructure projects, e.g., government procurement and public investment in carbon-efficient infrastructure (C40 and ARUP, 2015; Deng-Beck and van Staden, 2015; REN21, 2017),

or using the money as financial leverage to encourage private-sector investment or to reduce the upfront cost for new technology adopters, often in the form of subsidies (Fuller et al., 2009; Roy et al., 2013; Zhan and de Jong, 2018). For example, frontrunner cities have applied subsidies in a variety of urban sectors, e.g., improving energy efficiency in buildings (Di Pilla et al., 2016; Hou et al., 2016; Krarti, 2015; Lihtmaa et al., 2018), promoting electric vehicles in the transport sector (Masiero et al., 2016; Thorne and Hughes, 2019), and encouraging rooftop solar photovoltaic (PV) installation in households and businesses (Asano and Aoshima, 2017; Frey and Mojtahedi, 2018; Fuller et al., 2009; Mah et al., 2018; Rodrigues et al., 2017).

In addition, market mechanisms such as carbon pricing are adopted for financing mitigation actions. In the literature, a few city-level cases have been reported (Jiang et al., 2014; OECD, 2010; Wu et al., 2014), but the application and effectiveness of carbon pricing are mostly examined and reported at a regional or national level (Lee et al., 2008; Price et al., 2005; Schneider and Goulder, 1997; Shinkuma and Sugeta, 2016). Carbon pricing might not be a feasible financial instrument for cities because they might have greater negative impacts at a small scale (e.g., in cities) than at a larger scale (e.g., in a national level). Using this instrument could raise the price of carbon-intensive products, thus distorting competition between regions (Elkins and Baker, 2001; Hoel, 1996; Ismer and Neuhoff, 2007; Scrimgeour et al., 2005). In addition, the design of this market mechanism could be complex (Ash et al., 2002; Poterba, 1991; Ulph and Ulph, 1994), so it might be difficult for a city-level government to achieve independently.

There is a research gap in terms of examining the financial mechanisms in cities in a comprehensive way, i.e., not only the cost-effectiveness and emission-reduction outcome but also the impacts on other aspects of urban low-carbon transition. The research to fill this gap may provide evidenced-based understanding that could potentially encourage more investments into low-carbon initiatives in cities.

4. Research methodology and analytical approaches

Methodologically, this dissertation adopts a case-study approach (Yin, 2017), taking Shanghai as a case study city. Shanghai is a pilot city in a national policy scheme for low carbon transition in China. For policy learning and to achieve its transition goals, Shanghai has financially and institutionally supported a variety of sustainability experiments, with initial positive transition outcomes. Moreover, Shanghai has been undergoing economic and social transitions driven by its rapid development and urbanization, for example, from a manufacturing-oriented industrial structure to the service industries dominated one. These multiple on-going transition processes may provide opportunities for the city actors to innovate, and also present the possibility of achieving some synergetic changes. In this regard, Shanghai could be a suitable case for investigating the proposed research questions, to understand how Shanghai could nurture and scale sustainability experiments for its low-carbon initiatives and what supporting mechanisms are adopted and tested during this process.

This work mainly draws on system innovation theory, urban sustainability experiments and transition, and urban low-carbon governance. These theoretical concepts and perspectives are applied to collectively inspect 1) institutional arrangements and enabling mechanisms for incubating sustainability experiments in cities, 2) innovative processes in post-experiment

adoption, 3) the horizontal linkages between experiments for facilitating innovation transfer, 4) the roles of coordination mechanism and direct-funding mechanisms in urban low-carbon transition from a systems perspective, and 5) policy schemes and institutions for addressing fragmentation across urban actors.

The data collection is guided by the research questions and proposed theoretical lenses. Two-month fieldwork was carried out in Shanghai in 2016, including semi-structured interviews and collection of archival data sources and government documents. The data collection is supplemented by following-up online/phone interviews with relevant stakeholders and deskwork of collecting and reviewing policies, government reports, corporate reports, and news in the media. This multi-source data collection approach is employed 1) to understand the case study in a comprehensive way and 2) to make evidence-based arguments from complementary data sources.

The interviews with the government officials aim to understand the government's perspectives on Shanghai's low-carbon transition, their endeavors and strategies, and the policymaking processes and supporting institutions. Guided by the information from these interviews, further information searching and document review were conducted to gain relevant evidence. The interviews with other stakeholders such as business sectors were to understand their perspectives on Shanghai's low-carbon initiatives and related policies, and their adaptive strategies and mitigation actions under the host city's policy environment.

Different analytical frameworks are adopted for different papers, serving the specific research questions of each paper. Data-analysis methods include qualitative and quantitative approaches. For example, an analytical approach of organizing policies in chronological order is specifically devised to scrutinize the low-carbon policy evolution process in Shanghai (Chapter 2). A conceptualization approach is adopted in Chapter 3 to analyze the innovative processes in contextualization, drawn on system innovation theory and sustainability experiment concept and evidenced by EPC adoption case in Shanghai. Linkage analysis is designed in a quantitative way to visualize the institutional formation for cross-sector coordination on urban mitigation (Chapter 4). The detailed methodologies will be articulated in each chapter, and data sources are presented in supplementary materials after the chapters.

5. Thesis structure and research components

To address several niche gaps in urban sustainability transition research, this thesis consists of four main chapters, as shown in Figure 1. The thesis structure and the research questions of each chapter are presented in Table 1. This research is in the format of a thesis by compilation, including three published papers (Chapters 2, 3, and 4) and one paper in preparation to submit (Chapter 5). The candidate Yuan Peng is the first author of the four papers, and Xuemei Bai and Yujian Wei are the coauthors (authorship details are included in Statement of Contribution).

Table 1. Thesis structure and research questions

	Chapter title	Research questions
Chapter 1	Introduction	
Chapter 2 (Paper 1)	Experimenting toward a low-carbon city: Policy evolution and nested structure of innovation	• How do low-carbon policies emerge and evolve within the local and national policy contexts? • What are the supporting structures and enabling mechanisms of innovative policy practices, both in terms of institutional and financial aspects, for implementing urban low-carbon policies?
Chapter 3 (Paper 2)	Scaling urban sustainability experiments: Contextualization as an innovation	• How are sustainability experiments (innovative practices) adopted elsewhere? What does this contextualization process entail? Is it a simple duplication or something more? • How are the practices in different contexts linked? How does the adopted experiment contribute to sustainable development in the recipient context?
Chapter 4 (Paper 3)	Financing urban low-carbon transition: The catalytic role of a city-level special fund	• What are the direct and indirect impacts of direct-funding mechanisms (e.g., subsidy policies) in urban low-carbon transition?
Chapter 5 (Paper 4)	Enabling business-sector engagement in urban low-carbon initiatives: Emission constraint and new market opportunities	• What policy schemes can cities adopt to engage the corporate sector in the city's low-carbon initiatives? • How do business sectors respond to their host cities' mitigation policy environments? • How do business sectors interact with other actors in urban low-carbon transition? • How do business sectors play their role in sustainability experiments for transition?
Conclusion		

Paper 1 (Chapter 2): This chapter aims to answer the question of how cities enable sustainability experiments to fuel their transition. This research starts by exploring how a city's low-carbon initiatives are developed under the existing national and local policy frameworks, and then further investigates the governance structure that underpins that city's low-carbon initiatives, especially inspecting the roles of different government entities in different levels and sectors. The findings show that the city's low-carbon initiatives are embedded and integrated into its existing policy frameworks, but with new low-carbon policy goal measures. There is strong vertical linkage between central and local governments. More importantly, a nested structure for innovative policy practices was identified, including the top-down design of pilot projects for policy learning and locally invented enabling mechanisms for policy experiments. This structure consists of two layers of experiments that facilitate learning through policy experiments across scales. Theoretically, the Shanghai case study provides an

important addition to multi-level governance, where the current regime is actively involved in and enabling the niche experiments with the purpose of extracting learning. In practice, the Shanghai case demonstrates that the combination of an active and enabling role from the national government along with the capacity and vision of local government is essential for low-carbon initiatives to be successful.

Paper 2 (Chapter 3): This paper mainly addresses the question of how a tested innovation can transfer and be adopted in other contexts to facilitate urban sustainability transition. First, the study identifies the critical components that characterize the innovative processes in experimentation based on the system innovation literature. Then, this framework is applied to examine the embeddedness of energy performance contracting (EPC) in Shanghai. This chapter also identifies and compares the innovative elements that emerged during the contextualization with those in the original contexts from which Shanghai learned. The findings reveal that adopting sustainability experiments (that have been tested somewhere else) requires mobilization and realignments of local actors, resources, and institutional arrangements within the process of learning. Contextualization involves much more than simple duplication and often with distinctive outcomes, thus in many ways is an innovation in itself. In addition, innovation in post-experiment contextualization is supported by various "horizontal linkages" with the original experiment, which include information/knowledge transfer and learning via actor interactions across experiments. However, the focus of learning shifts from external (i.e., from the original context) to internal (i.e., within the new context) during the contextualization process. This chapter contributes to an in-depth understanding of how innovations travel and are translated to new contexts, which is a significant gap in the systems innovation literature. Empirically, this new understanding may inform policymaking in terms of facilitating adoption of innovations learned from other cities.

Paper 3 (Chapter 4): the paper examines the direct and indirect effects of a city-level direct-funding scheme on urban low-carbon transition. This chapter inspects a special fund on urban mitigation in Shanghai, paying special attention to its flow-on effects on institutional arrangements and local capacity building. The findings show that, besides a direct carbon-reduction effect, the fund became a catalyst for a series of institutional changes in the city over the 11 years of its implementation, by enabling and enhancing cooperation across numerous governmental units in Shanghai. In addition, the fund facilitated the improvement of the city's capacity for achieving low-carbon transition, by covering the administrative expenses on carbon management, subsidization for technology adoption, and low-carbon themed campaigns. Moreover, the study shows that a well-designed city-level direct-funding scheme can fill the "implementation" gap between the policy intention and the policy outcomes, and may nurture and enable a pool of policy experiments and innovations for effective policy learning. Theoretically, these new insights reveals the relationship between two enabling mechanisms – financial supporting scheme and institutional coordination mechanism. Empirically, the findings justify that a city-level direct fund could be a more attractive option in managing low-carbon transition, evidenced by its multiple roles.

Paper 4 (Chapter 5): This preliminary research examines how the city government can enable engagement of different business sectors in the city's low-carbon initiatives. Drawing on the literature on business-sector responses to the existing regulatory schemes at a global/regional scale, this research identified three types of corporations according to their roles in climate

mitigation – emitters, providers, and investors. Based on this understanding of business types, this chapter investigates several policy schemes that Shanghai's government adopted to engage the business sector, as well as the firms' attitudes and actions in responding to these policies. The primary findings show that Shanghai has developed its policy strategies on firms over time from mandating carbon reduction to employing market mechanisms. From this policy setting, a business transformation in some local companies is identified – from carbon emitters to solution providers to other firms – by means of expanding their business to newly emerging low-carbon markets. The multiple policy schemes implemented in Shanghai, either directly supporting a specific low-carbon industry or enabling their growth by providing incentives to create the market demand, may play a role in triggering local low-carbon industries' development. The findings in Shanghai will have empirical implications for other cities, especially for those where the industries are still the major emission source, in terms of involving policy efforts to encourage business contribution for transition. In addition, it might also provide new understanding into urban climate governance literature by presenting policy strategies that may address the fragmentation across urban actors.

Each chapter is innovative and original in its own way, but the thesis in its entirety makes a contribution to knowledge and policy by unraveling two types of internal mechanisms – 1) the enabling mechanisms by cities that underpin their low-carbon commitments and actions, and 2) the facilitating mechanisms in sustainability experiments that drive innovations. First, the supporting structure and institutional set-up – that uphold cities' experimentation role – are unfolded. Specifically, the strong relations between active government at different levels, together with the institutional coordination and financial supports by the city's government, creates a platform for numerous sustainability experiments to take place for extracting learning, upscaling of successful ones, for the city's transition objectives. More importantly, the research reveals the inter-links between different enabling mechanisms in policy, institutional, and financial dimensions. These enabling mechanisms are governance experiments in nature, which are mutually supporting, reinforcing, and facilitating each other's establishment and functioning in real-world practices. The elucidation of the underlying patterns in the above interactions – makes a significant contribution to both climate governance and sustainability experiment literature. Second, this dissertation involves theoretical efforts to disclose the internal courses in post experiment adoption, revealing the innovation nature of contextualization in adopting sustainability experiments in recipient environments. The insights, explaining how successful experiments and innovations travel across contexts and how they are transferred elsewhere, sheds light on the internal mechanisms of sustainability experiments and the communication patterns between experiments. Moreover, this conceptual framework can also be used as an analytical tool to scrutinize the innovation adoption process in other cases. Empirically, the thesis in its entirety can provide policy learning for other cities, especially those in transition economies, in terms of sharing tested policy measures that can enable the incubation and adoption of innovations in cities for transitioning to a low-carbon path.

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Chapter 2: Experimenting towards A Low-carbon City: Policy Evolution and Nested Structure of Innovation

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Experimenting towards a low-carbon city: Policy evolution and nested structure of innovation

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Nested structure of innovation

ABSTRACT

Cities can play a key role in the low-carbon transition, with an increasing number of cities engaging in carbon mitigation actions. The literature on urban low-carbon transition shows that low-carbon urban development is an inevitable trend of urban sustainable future; there is a great potential albeit with some limitations for cities to reduce its carbon footprints, and there are diverse pathways for cities to achieve low-carbon development. There is, however, a limited understanding in terms of the internal mechanism of urban low-carbon transition, especially in rapidly developing economies. This paper attempts to address this gap. We examine how low-carbon policies emerge and evolve, and what are the enabling mechanisms, taking Shanghai as a case study. We developed an analytical framework drawing on system innovation theory and sustainability experiments for this purpose. A total of 186 relevant policies were selected and analyzed, which is supplemented by the interviews with stakeholders in the government to gain a deeper insight into the policy contexts in Shanghai. We found that the city's low-carbon initiatives are embedded and integrated into its existing policy frameworks. A strong vertical linkage between the central and the local governments, and more importantly, a nested structure for innovative policy practices were identified, where a top-down design is met with bottom-up innovation and proactive adoption of enabling mechanism. The structure includes two layers of experiments that facilitate learning through policy experiments across scales. The uniqueness, effectiveness, applicability and limitations of these efforts are discussed. The findings provide new theoretical and empirical insights into the multilevel governance of low-carbon transition in cities.

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1. Introduction

Cities can play a key role in climate change mitigation, not only because they are the major carbon emitter accounting for up to 75% CO2 emissions (IPCC, 2014), which is expected to grow with increasing urbanization (UN, 2014), but also because of their capacity, flexibility, and willingness to actively engage in climate change debate and action as demonstrated by many front-runners among them (Allman et al., 2004; Granberg and Elander, 2007; Rosenzweig et al., 2010; Zimmerman and Faris, 2011). Many cities have either committed or already made substantial efforts to reduce their carbon emissions, with various levels of ambitions and capacities (Broto and Bulkeley, 2013; Bulkeley et al., 2010). More recently, numerous cities have declared to aim for 100% renewable energy or zero carbon emission in the following decade or so (ACT, 2016; Melbourne, 2014). Collectively, such city level initiatives and efforts may have the potentials to shift the carbon trajectories towards a more sustainable end.

There is a substantial body of literature on urban low-carbon transition, with various focuses such as the overall trend, challenges and features of urban response to climate change at international scale (Betsill and Bulkeley, 2006; Bulkeley et al., 2012; Corfee-Morlot et al., 2009; McCormick et al., 2013); various case studies of local government practices for low-carbon transition, focusing on local climate change policy, financial programs, investment benefits for low-carbon development, low-carbon transition in sectors (Bulkeley and Kern, 2006; Fuller et al., 2009; Gouldson et al., 2014; Newman, 2004); scenario modelling and carbon emissions calculation to inform urban policy making (Fong et al., 2009; Gomi et al., 2010; Li et al., 2010; Phdungsilp, 2010); and the effectiveness of urban level low-carbon practices (Allman et al., 2004; Nakamura and Hayashi, 2013; Van der Heijden, 2016). Collectively, these research show that the concept of low-carbon urban development has been increasingly adopted in cities

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worldwide; cities have a great potential for global Greenhouse Gas (GHG) reduction by reshaping their carbon trajectories; and there may be diverse pathways and degree of success in achieving this target (Bai et al., 2010; Coenen et al., 2010; Newton and Bai, 2008). However, there is limited understanding in terms of the internal mechanism of urban low-carbon transition, with some critical questions left to be further explored, e.g. how low-carbon policies emerge and evolve in the local and national policy context, how innovative policies emerge and play a part in urban low-carbon transition, and what institutional setting and mechanisms are needed to support policy implementation and novelty practices. Such knowledge gaps are more significant in rapidly developing cities, where a more rapid increase in carbon emission is projected (Ru et al., 2010; U.S.EIA, 2013), and where integrating global concerns into local management can be more challenging compared to cities in developed countries (Bai, 2007).

We aim to address some of these knowledge gaps taking Shanghai as a case study. Shanghai is a city that has been undergoing rapid economic growth and transition, initiated many innovative practices towards low-carbon transition, and is a designated Pilot Low-Carbon City in China. To better understand the internal mechanisms of a major metropolitan government in a transition economy in tackling low-carbon development, we ask two questions: a) How low-carbon policies emerge and evolve within the local and national policy context; b) What are the supporting structure and enabling mechanisms of innovative policy practices, both in terms of institutional and financial, for implementing the urban low-carbon policies.

We employ the concepts of system innovation and sustainability experiment for analysis. Sustainability experiment is defined as planned initiatives that embody a highly novel socio-technical configuration likely to lead to substantial (environmental) sustainability gains (Berkhout et al., 2010). The experiments are designed to be the practicing ground for innovations in terms of building actor-network, stimulating learning processes, and promoting them to develop into a stable social-technical configuration (Bai et al., 2010; Kemp et al., 1998; Loorbach, 2010; Loorbach and Rotmans, 2010). The “innovations” can be “knowledge-based innovations”, e.g., technical innovations – relying on knowledge and expertise; or “relations-based innovations”, e.g. governance innovations that aim to alter the relationships between people in an organization; and “mixed innovations” that include attributes and aims of both types (David cited in Daniell et al., 2014).[1] In addition to these typologies, there are different ways of doing things, which we define as the “process-based innovations”. Much of the novelties discussed in this paper will be about “relations-based”, “mixed” or “process-based” innovations, as will be detailed in later sections. To enable a fine-tuned analysis of the role of main actors, various vertical and horizontal linkages, and the enabling mechanism supporting the experiments at different levels, the concept of experiment is used at two different layers—on the one hand, the city as a whole can be considered as sustainability experiment when examining its role in informing national low-carbon policy-making. On the other hand, the city can be seen as a locus for numerous sustainability experiments (e.g. policy practices and pilot projects) implemented by the city. The structural relationship between these two layers is discussed.

Hooking low-carbon issues to existing local policy scheme has proven to be effective in addressing climate change related issues at city level (Bai, 2007; Betsill, 2001). In this regard, a better understanding of the structure and trajectory of existing policy framework of a city, in particular, those with low-carbon implications is important. A set of criteria is developed for the selection of relevant local policies with low-carbon implication. A total of 186 policies are selected, categorized, put in time sequence and analyzed in relation to development stages of the city. Further, based on a thorough analysis of governmental documents and interviews with government officials, the institutional setup to facilitate cooperation between government sectors, and financial mechanism for policy implementation are discussed. To evaluate the effectiveness of these policies and governance, we discussed trends in energy consumption, air quality and CO_2 emission in Shanghai from 1998 to 2015. Finally, the limitations and broader applicability of Shanghai case are discussed.

There are six sections in this paper. The following section presents a brief review of current understanding of low-carbon city initiatives, as a context for examining Shanghai's low-carbon transition. In Section 3, we present the analytical framework of this paper and the methodology of data collection and analysis. Section 4 presents the relative positioning of low-carbon policies in the existing broader policy framework and its evolution; Section 5 presents enabling mechanisms for policy implementation, where we present a nested structure for innovative policy practices. Section 6 discusses the characteristics of low-carbon governance, evaluates their effectiveness using quantitative data, and discusses the applicability and limitation of Shanghai experience in a broader context. Section 7 presents the conclusion.

2. Understanding low-carbon city initiatives

Low-carbon cities can be interpreted from different perspectives and analytical lenses, e.g. emphasis on controlling GHG emissions without compromising city' economic development and livability by World Bank (Baeumler et al., 2012) and World Wildlife Fund (WWF, 2008), emphasis on renewable energy substitution and decoupling economic growth from fossil energy by The Climate Group (Stephens, 2010), emphasis on setting a quantitative CO2 emissions reduction target and a concrete low-carbon developing plan by Asia-Pacific Economic Cooperation (Rufo et al., 2012). Cities worldwide may be at different economic development stages, varying in carbon endowments and local government capacity. Especially for rapidly developing cities, they are confronted with more challenges of balancing the economic development and carbon emission control.

The low-carbon city concepts have been discussed in China as well. Many Chinese scholars argue that low-carbon cities will be an inevitable developing choice and an essential approach for cities in China to achieve urban sustainability in the future, with an increasing focus on decoupling economic development from GHG emissions (Chen and Zhu, 2009, 2013), or developing low-carbon industries (Gu et al., 2009; Liu and Wang, 2010; Yang and Li, 2013); while others highlight a societal transition approach beyond the economic sector, including low-carbon infrastructure, culture, lifestyle, consumption behavior and so on, aiming at achieving synergies between low-carbon transition and the quality of life transition (Dai, 2009; Liu et al., 2009; Yuan and Zhong, 2010).

The literature on low-carbon cities in China largely falls into the following three categories:

1) Quantitative modelling to analyze emission sources, baselines as well as future emission scenarios at city and national level, aiming at identifying priority action areas and informing policy development (Chen et al., 2009; Li et al., 2010; Lin et al., 2013; Wang et al., 2011; Xu Guoquan and Zhaohua, 2006 ; Zhang et al., 2011), or identifying co-benefits between different GHG emission reduction strategies and local environmental

[1] David, A., 1996. Structure et dynamique des innovations managériales, Cinquième conférence de l'AIMS, Lille. (In French).

protection measures (Dolf and Chen, 2001; Lin et al., 2010; Yang et al., 2013). Findings from these research show that GHG emissions can be controlled if appropriate policies are in place, and integrated solutions may be needed.

2) Developing indicator systems for assessing "low-carbon city" (Price et al., 2013; Shao and Ju, 2010); and evaluating existing policies, programs, and instruments (Lo, 2014; Price et al., 2011; Wang and Chang, 2014). These studies indicate that an appropriate evaluation system needs to fit in China's economic and social context, also have identified challenges in implementation.
3) The growing body of literature on Emission Trading Scheme (ETS) in China and its pilot program shows that the implementation of ETS in China faces a few problems (Zhang et al., 2014), such as a national carbon intensity target creating difficulties for making a cap, and ETS implementation interacting with regulation in the energy sector (Jotzo and Löschel, 2014). At current stage, ETS programs in pilot cities and provinces differ from one another in many aspects, e.g., sectoral coverage, cap setting, allowance allocation (Jiang et al., 2014; Qi et al., 2014; Wu et al., 2014).

While providing valuable insights regarding low-carbon initiatives and their performance, there is a gap in above literature-a lack of systematic research on internal mechanisms of urban low-carbon transition, especially from the perspective of local governments' proactive role and its institutional setup.

In practice, a national policy scheme of pilot low-carbon cities/provinces in China was launched in 2010. The central government aims to stimulate policy learning from this program to inform national-level policymaking. As a new policy in implementation only for a few years, there are a limited number of papers on it. These papers mainly discuss barriers in implementation, for example, the lack of a clear definition or specific guidance and methods on how to design a low-carbon initiatives for pilot cities (Khanna et al., 2014); the lack of more ambitious mitigation targets set by local authorities than the allocated ones from the up-level (Khanna et al., 2014; Zhang, 2015); less involvements of public and other stakeholders (Khanna et al., 2014; Zhang, 2015); the need for a management system and a platform for exchanging experience, evaluating performance, etc. (Wang et al., 2015). However, in relation to the current study on this pilot policy scheme, there is an absence of empirical evidence regarding how these pilot cities formulated low-carbon initiatives within their existing policy frameworks and institutional settings, and how these policies have been implemented in practices.

3. Analytical approach and data

3.1. Theoretical perspective and analytical framework

The analytical framework of this study encompasses three elements: the system innovation and sustainability experiments concepts, the context and evolutionary process of relevant policies, and key implementation mechanisms.

3.1.1. Experimentation and transition

Experiment is an important concept and analytical element in system innovation theory (Elzen et al., 2004). Experiments represent small initiatives in which the earliest stages of a process of socio-technical learning takes place. Experiments typically bring together new networks of actors with knowledge, capabilities, and resources, cooperating in the process of learning (Berkhout et al., 2010). In the early stage of innovation study, the experiment is always technical-central (Geels, 2005a, b; Twomey and Gaziulusoy, 2014), however, in fact, many experiments are in the field of policy and institutional reform and implementation processes (Bai et al., 2009).

The concept of experiment in system innovation theory emerges from the concept of niche, in multilevel perspectives (MLP) (Geels, 2005a). Niche is "protected spaces", which shields the experiments from a mainstream market selection. Niches are important because they provide locations for learning processes (Geels, 2005a). Regimes are the meso-level concept, and usually, are characterized by a stable set of institutions that govern the behavior of actors; in this regard, in niches, by contrast, rules are more fluid and emergent (Berkhout et al., 2010). The macro-level is landscape, which refers to aspects of the wider exogenous environment. It contains a set of heterogeneous, slow-changing factors, but it also contains shocks and surprises, such as wars, rapidly rising oil prices, which are beyond the direct influence of actors and cannot be changed at will (Elzen et al., 2004; Geels, 2005a). System innovations come about through the interplay and alignments between dynamics at multiple levels (Geels, 2005a): (1) niche innovations build up internal momentum, (2) exogenous developments create pressure on the regime and (3) tensions in the regime create windows of opportunity for the expansion of niche innovations (Geels, 2002; Geels et al., 2016; Smith et al., 2010).

The role of experiment in the system innovation theory shows that experimentation is an essential learning process. No matter what results the experiment ends with, it may offer feedbacks or accumulate experiences, which may contribute to positive change. Focusing in the urban context, Bai et al. (2010) note that individual innovative practices can be considered "experiments" when they harbor the potential to bring about regime change towards a sustainable end. Also, experimenting can be an essential process in transition management that has the potential to overcome the tension between the open-ended and uncertain process of sustainability transitions and the ambition for governing such a process (Frantzeskaki et al., 2012). Laakso et al. (2017) identify four key functions of experimentation, i.e. testing, creating profound influence, multiplying influence, and promoting systemic change. This categorization clarifies what can be expected from an experiment, thus may help actors to evaluate and adopt experimental approaches in practice.

Two layers of experiments are identified in this study. The national government can designate larger scale experiments at city level, with the aim to inform, test, and modify a particular policy before a broader introduction of it. Also, within city, a low-carbon policy practice/project implemented can be seen as an experiment if the project contains highly novel components, designed to test out first with the plan to be introduced in other parts of the city if successful.

3.1.2. Low-carbon policy evolution process

The nature of curbing CO2 emission lies in reducing fossil energy consumption. By recognizing this, the city managers may rethink the global concerns of tackling climate change. That is, it may not be a remote concern, but can be associated with some existing policy schemes. The CCP[2] experience in US cities suggests that climate change is most likely to be reframed as a local issue when the preferred policy response (controlling GHG emissions) can be linked to issues (e.g., air quality) already on the local agenda (Betsill, 2001). Bai (2007) argued that linking up with local issues (e.g., environment protection, energy security) can be even more important for cities in developing countries, where more severe

[2] CCP: Cities for Climate Protection (CCP) campaign sponsored by the International Council for Local Environmental Initiatives.

local issues often top the policy agenda. In China, even though urban low-carbon schemes have only emerged in recent years; existing studies show that policies for energy efficiency improvement, environmental protection have been in place for a long time (Andrews-Speed, 2012; Price et al., 2011). We assume that Shanghai' low-carbon initiatives might be rooted in existing policy framework, rather than a completely new thing. To verify this hypothesis, low-carbon policy evolution process is inspected, with the purpose of understanding the trajectory of policy development in the past and at present.

3.1.3. Enabling mechanisms for implementing urban low-carbon initiatives

Cities are complex systems, and many urban challenges require a systems approach to tackle (Bai et al., 2016). Climate protection is a complicated challenge and only can be achieved if there is inter-departmental cooperation (Allman et al., 2004). Institutional mechanisms can either facilitate policy execution, if the mechanisms and the specific requirements for policy implementation match one another, or set the scene for implementing a policy. Generally, the scope of institution needs to be defined for a specific context (Connor and Dovers, 2004). In this research, we refer institutions to the government structures and the cooperation between government units.

In addition, efficient financing is an essential requirement for empowered governance. Climate change creates new challenges for urban finance: it necessitates a greening of existing financial instruments and put additional pressure on city budgets, which creates the need for additional resources (Kamal-Chaoui and Robert, 2009). In practice, deficient financing tools and budget constraints at local levels of government appear to hamper the success with efforts to confront climate change challenges in cities in many places of the world (Collier, 1997; Kamal-Chaoui and Robert, 2009). In this research, we examine a financial mechanism for implementing low-carbon policies in Shanghai and how it operates in practice.

3.1.4. Analytical framework

As shown in Fig. 1, Shanghai case study will be examined from three analytical perspectives: 1) low-carbon experiments in two layers to understand how vertical linkage enables policy experiments; 2) low-carbon policy evolution process to examine how urban low-carbon initiatives relates to the city existing policy framework; 3) enabling mechanisms to analyze how urban low-carbon initiatives are implemented. This framework is supposed to address the research questions raised in Section 1, and it is designed for a combined analysis of policy evolution from time sequence, and an enabling institutional structure based on vertical linkage and horizontal linkage.

3.2. Data collection and analysis

Data on a total of 186 policies are collected and analyzed. They are mainly collected from websites of Shanghai governments, public policy reports, codes of policies, as well as internal government reports. These desktop sources are complemented by interviews with former and current government officials.

Some policies, e.g., environmental policies, energy policies, have co-benefits of controlling GHG, even though they are originally formulated to tackle environmental or energy issues (Dolf and Chen, 2001; He et al., 2010). Thus, the low-carbon policy scope we define in this paper includes energy saving, environmental protection, and low-carbon. The policies selected in this study are those issued after 1998 because the Chinese government began to make more substantial efforts into energy conservation and emissions reductions since 10th five year plan period (i.e. after 2000). In order to identify specific policy measures and instruments, these policies are further divided into 13 subcategories. The number of the policy within each sub-category is calculated and put into a chronological order of introduction. The detailed criteria for policy selection and classification are clarified in Supplementary materials.

In order to examine the effectiveness of policies, we examined several indicators including: annual energy consumption, energy

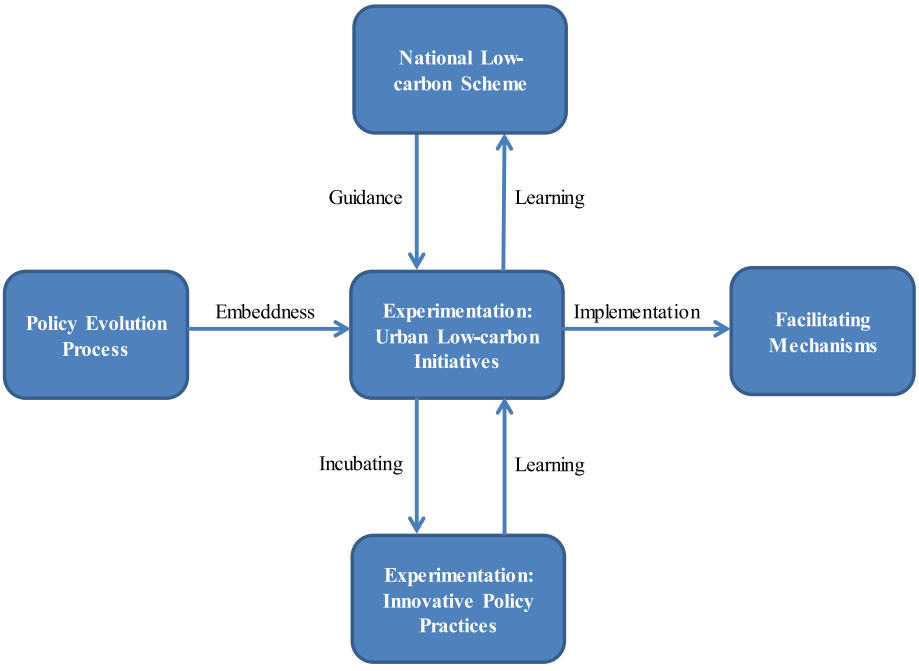

Fig. 1. Analytical framework integrating policy evolution process and linkages between different governmental units.

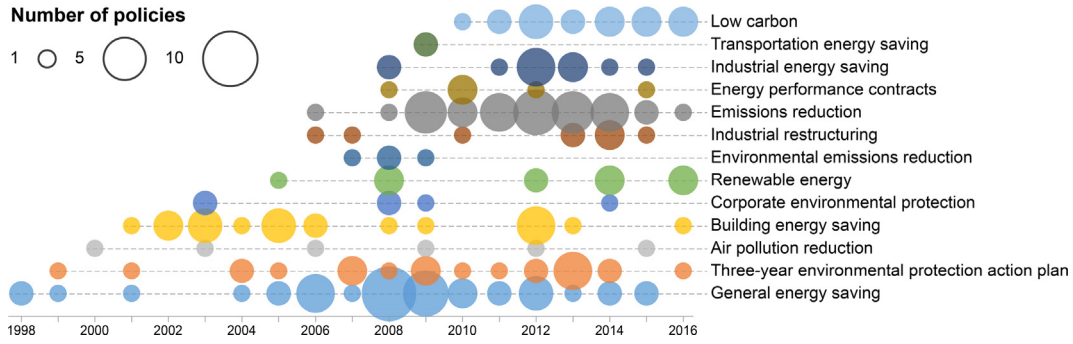

Fig. 2. The evolution of low-carbon related policies in Shanghai.

intensity and energy consumption per capita, annual CO_2 emission, CO_2 emission intensity and CO_2 emission per capita. Some primary data are collected from Shanghai Statistical Yearbook. The data regarding CO2 emission in Shanghai are calculated based on city's energy consumptions from 1998 to 2015. The total carbon emission includes two parts: annual CO_2 emission calculated from 1) local fossil energy combustion, and 2) from imported electricity that is generated in other areas but consumed in Shanghai. The accounting method is stated in Supplementary materials in details.

4. The evolution and drivers of low-carbon policies in Shanghai

4.1. Low-carbon policies evolution process

Selected policies are further sorted into 13 sub-categories (see Supplementary materials) according to their purposes or policy measures, e.g., air pollution reduction, building energy saving, etc. The policy number of a sub-category and its emergence time can reflect local governmental efforts into management areas of energy, environment, and low-carbon (detailed explanation in Supplementary materials). The numbers of policy measures introduced over time within these 13 sub-categories are shown in Fig. 2.

Three insights can be drawn from Fig. 2: 1) Most of the policy measures are continuous, which means once a policy measure has been adopted, it will be further supported by follow-up policies in following years until the initial target is achieved. 2) The policy focuses seem to vary in different years. This is because some policies are task-oriented. Once a policy program (with a specific task) is accomplished, the local government will move on to another task; then policy focuses change accordingly. 3) Both the number of policies and the number of sub-categories are growing over time, which shows an increasing and substantial endeavor undertook by Shanghai government.

A milestone during this evolution process is the introduction of city's low-carbon initiatives in 2012, i.e., *Shanghai 12th five-year plan for energy conservation and addressing climate change*. GHG management, environmental emissions control, and energy conservation are supposed to be synergistically addressed in this policy scheme. Before that, no explicit objective for GHG control was officially announced. Moreover, it is also the first time that Shanghai government incorporated climate protection target into city's five-year plan policy system, which is the most important policy scheme in China. In principle, if clear targets and detailed policy measures are proposed in the five-year plan, local government will achieve the objectives in the following five years.

Base on above analysis, we conclude that Shanghai's low-carbon initiatives have rooted to city's existing policy framework. *Shanghai 12th five-year plan for energy conservation and addressing climate change* covers a broad range of policy areas, including energy conservation and environmental protection, both of which had been introduced and implemented before city's low-carbon initiatives launching (shown in Fig. 2). In other words, although explicit low-carbon policies are new, relevant policies with low-carbon implications have been in place before it. Thus the whole evolution process can be divided into two distinctive stages: implicit stage (GHG controling embedded in energy policies and environmental protection policies) and explicit stage (low-carbon initiatives and explicit low-carbon policies being introduced).

4.2. The drivers of low-carbon policies evolution

The economic development of Shanghai, especially the growth of GDP and the industrial restructuring, has a significant impact on local energy consumption and GHG emissions. Shanghai was a traditional heavy industrial city since New China establishment (Tu and Shi, 2006) with a high rate of fossil energy consumption in the industry sector. Then, after the reform and opening-up in China, city's industrial structure began to change, due to a new economic strategy to encourage service sector development. Although the proportion of service sector in Shanghai is increasing (accounting for 64.8% of Shanghai's GDP in 2014)[3], the secondary industry is still the largest consumer of end-use energy (55.2% in 2014).[3] Also, total energy consumption of Shanghai is continuously growing because of rapid economic development and living standard improvement. To control the energy use, on the national scale, the central government regularly designated energy controlling targets to Shanghai according to national energy policy schemes. The growth of energy consumption and the energy saving targets from the central government are drivers for Shanghai government to enact a serial of energy policies as shown in Fig. 2.

Addressing air pollution is another driving factor. Heavy industries have caused serious environmental problems in Shanghai partly because of coal combustion. Meanwhile, air pollution from transportation gradually became severe as well, due to a growing number of motor vehicles. A senior official from Shanghai government said that "The truth is, battling against air pollution has become the most primary task in Shanghai nowadays".

As analyzed above, there were three main policy measures with low-carbon implication: 1) industrial restructuring driven by economic development; 2) energy saving target set by the central government; 3) addressing local environmental pollution and resource constraints.

In 2009, the Chinese government committed controlling China's carbon emissions to the international world. To fulfill this promise,

[3] Data from the Shanghai Statistics Bureau.

a national carbon-control target had been made, and translated down to local governments, which became a local performance indicator for evaluating local government officials' works. The external pressure from the international society on GHG mitigation had converted to internal pressures for local authorities, and marked the beginning of the explicit stage for urban low-carbon transition. During this stage, greater efforts were made by the Shanghai Government than before by enacting several explicit low-carbon policies, such as designating the pilot low-carbon areas at district level, introducing local standards of carbon labeling, and setting up a special fund for energy conservation and emissions reduction.

5. Innovative policy practices and enabling structures

5.1. Policy experimentation and innovative elements in policy practices in Shanghai

In Shanghai case, innovative elements can be observed in low-carbon policy experiments. This fact can be explained as a result of the relation between the central and the city governments. New national policy is often introduced without detailed guidance, thus leaving plenty of rooms for local governments to explore and experiment with innovative policy approaches. Below are several of such examples in relation to low carbon policy.

5.1.1. Going beyond top-down target

Shanghai government has set more ambitious targets than national targets, with actions going beyond what is required by the central government. Two examples illustrate this well. Although the central government requires local authorities to make a local GHG inventory every five years, Shanghai government updates their inventory every year in order to accurately monitor the city's GHG emissions. The government believes this is necessary because Shanghai is experiencing ongoing rapid economic development. Another is the example of carbon labeling. The central government has issued policies and standards on carbon labeling at the national level since 2010. To support these policies, Shanghai government developed and issued two local standards of carbon labelling since 2013, which are the first local policies of this kind in China.

5.1.2. Pilot programs at sub-city level

Shanghai government carries out pilot programs at the sub-city level based on, or in a similar way to, national programs to stimulate policy learning and gain local experience. A case in point is a pilot program for encouraging sub-city areas to transition to low-carbon districts. Shanghai is a megacity with various industries and businesses, e.g., a harbor area, a central business district, an export processing zone, etc. Diverse pathways are needed to assist these various areas and industries with low-carbon transition. In 2011, eight areas at the sub-city level were designated as pilots to explore innovative policy practices and administrative mechanisms, as well as to trial advanced technological applications.

5.1.3. Introducing regular planning cycle at local level

Local plans are regularly updated to achieve local policy targets, e.g., *three-year environmental protection action plan* is an innovative policy mechanism to address local environmental problems, which has been implemented in Shanghai since 2000. The target and countermeasures for controlling air pollution are included. By now, six rounds of plans have been enacted, which demonstrates that constant efforts are being undertaken for environmental protection.

5.1.4. Innovative institutional arrangements

Shanghai government introduced a new way of allocating duties to government units to supervise energy consumers in the city. Under this new arrangement, the municipal-level departments are responsible for large state-owned companies, while district-level governments are in charge of the others within their jurisdiction. This mechanism assures that supervisor can have real authority to manage corresponding energy users. This institutional arrangement was initiated in Shanghai as an innovative practice to achieve the energy conservation target.

5.2. Enabling mechanisms

Two major enabling mechanisms are identified in Shanghai case, i.e. an institutional mechanism that fosters inter-departmental coordination, and a financial mechanism consists of the special fund program.

5.2.1. The coordination mechanism

Shanghai Municipal Commission of Economic and Information (SHEIC) was the main authority for the city's energy control because SHEIC is in charge of the secondary industry that is the largest energy consumer. With rapid urban and economic development, the energy consumption in transportation and building sectors have grown substantially, which is out of SHEIC's administrative scope. This resulted in a scattered energy consumption management function across several departments. In addition, tackling issues like air pollution requires cooperation between energy management sectors and the environmental protection bureau (SHEPB). A coordination mechanism across government sectors was called for.

In 2008, a leadership team for energy conservation and emissions reduction was set up, members of which are key city leaders and department heads. The executive office was established in Shanghai Municipal Development & Reform Commission (SHDRC). In 2009, *Shanghai energy saving regulation* was revised. In the newly revised regulation, SHDRC was appointed to coordinate city's overall energy management. “SHDRC is responsible for coordination, supervision, and administration of Shanghai's energy conservation. More specifically, SHDRC is supposed to draw up the city's energy saving plans and policy measures, and is responsible for coordinating policies implementation”. This newly revised regulation officially confirms SHDRC's coordination duty across different government sectors, thus ensures a more effective policy implementation.

5.2.2. The financial mechanism

In order to finance the variety of innovative practices outlined above, Shanghai government established a special fund for energy conservation and emissions reduction. The guiding policy includes the funding sources, supporting scope, responsible departments, assessment procedure, etc. Policy areas listed in city's low-carbon initiatives are included in the supporting scope.

The leadership team and Shanghai Finance Bureau (SHFB) are jointly responsible for the fund's management. In practice, it is the execution office set up in SHDRC who coordinates the fund's operation. Therefore, SHDRC is not only a sector coordinator but also a fund manager; the special role of SHDRC connects the coordination mechanism and the financial mechanism working together.

The fund allocation is task/project-oriented, and requires a well-planned specific project before the application, which is in form of formulating a detailed policy for implementation Table 1 presents some examples of the projects supported by the special fund. The implementation policy can be jointly or separately issued by

Table 1
Examples of policy projects supported by the special fund.

Time	Policy project	Policy number	Project partners
2008	Special subsidies to promote distributed energy supply systems and gas air-conditioners	[2008] No. 48	SHDRC,SHCTC, SHEIC, SHSTC, SHFB
2008	Special subsidies to develop renewable energy	[2008] No. 96	SHDRC, SHFB
2009	Subsidies as incentive to eliminate and renew old or used vehicles	[2009] No. 17	SHCC, SHDRC, SHEPB, SHPSB, SHFB
2009	Special subsidies for projects of building energy conservation	[2009] No. 816	SHCTC, SHDRC, SHFB
2009	Special subsidies for energy saving and emission reduction in transportation	[2009] No. 1640	SHCTC, SHDRC, SHFB
2011	Special subsidies for ground works and capacity building regarding energy saving and climate change	[2011] No.073	SHDRC
2012	Special subsidies for clean energy substitution of coal/mahout consumption boiler	[2012] No.36	SHDRC, SHEIC, SHEPB, SHFB SHCTC, SHQTSB
2014	Encouraging purchase and use of new energy vehicles[a]	[2014] No.21	SHDRC, SHEIC, SHSTC, SHCTC, SHPSB

Note:
Abbreviations for Shanghai government sectors.
Shanghai Municipal Urban Construction and Transportation Commission (SHCTC).
Shanghai Municipal Commission of Science and Technology (SHSTC).
Shanghai Environmental Protection Bureau (SHEPB).
Shanghai Public Security Bureau (SHPSB).
Shanghai Municipal Commission of Commerce (SHCC).
Shanghai Municipal Bureau of Quality and Technical Supervision (SHQTSB).
[a] "New energy vehicles" refers to electric vehicles, hybrid vehicles and fuel cell vehicles in the policy.

government sectors, including subsidy range, selection criteria, subsidy standards, etc.

This financial mechanism has three features: 1) it financially supports policy implementation of city's low-carbon initiatives; 2) SHDRC has overarching authority of making the city-level plan, coordinating government sectors, and managing the special fund, which ensures the financial resource to support city's key projects and the low-carbon strategy; and 3) all implementation details have been elaborated before a policy project is approved, which could guarantee the execution efficiency in practice.

5.3. Nested structure of innovative policy practices

The vertical linkages between the central and the city governments encourage low-carbon policy experiments. Shanghai is designated to be a low-carbon pilot city by the central government, with the aim of gaining hands-on experience to inform future policy-making nationwide. The central government plays a role as a target setter and performance evaluator; while the Shanghai government plays a role as a local entity who has much leeway to innovative trial approaches to achieve upper-set targets. The extent to which local governments respond to the central government depends on their motivations, capacity, and constraints (Qi et al., 2008).

As discussed above, the Shanghai government established two enabling mechanisms for implementing city's low-carbon initiatives. The coordination mechanism joins policy fragments from various government sectors in charge of economy, energy, and environment. Financial mechanism ensures resources are available to sponsor low-carbon policy projects. With these two enabling mechanisms, various policy experiments are emerging, to the benefit of policy learning.

Through in-depth analysis of Shanghai case, we identify an emergence of a nested structure, which encourages innovative policy practices for urban low-carbon transition (Fig. 3). The structure encompasses two layers of experiments, one instigated by the national government through the low-carbon pilot cities and provinces program where each city or province is an experiment, and the other instigated by individual cities where various experiments on policy measures, financial mechanisms, and institutional designs are conducted within the city. This is similar to the multi-level perspectives presented in system innovation literature (see for example Geels, 2002), but with a different role of the upper level government where it is actively involved in designing and enabling the experiments with a clear goal to achieve policy learning.

6. Discussion

6.1. A Shanghai model

There are several characteristics of Shanghai's low-carbon approach, as summarized below. City's low-carbon initiatives are embedded and integrated into existing policy framework, instead of a completely new strategy. Low-carbon policies evolution process in Shanghai can be divided into two stages: the implicit stage and the explicit stage. Before 2009, which is implicit stage, Shanghai has been on its way of adjusting industrial structure, improving energy efficiency and controlling air pollution, etc., the co-benefits of which contribute to GHG control. In explicit stage, Shanghai low-carbon initiatives were introduced, which is an integrated policy strategy tackling multiple challenges. The low-carbon initiatives root in the city's existing policy framework. The strategy of hooking "low-carbon" onto other local policies schemes is common and not necessarily initiated in Shanghai. However, Shanghai's low-carbon initiatives are more than re-interpreting traditional policy schemes with low-carbon implication, but with new low-carbon policy measures such as local pilot low-carbon developing districts, carbon labeling.

The strong vertical linkage between central government and local government provides favorable institutional setting for low-carbon policy experiments. In China, municipal authorities are required to achieve targets set by the central government, although the actual input may vary greatly depending on their level of motivation and capacity. Such an institutional setting leaves much room for local governments to conduct policy experiments aiming at policy learning while fulfilling the task. Shanghai is designated as a Pilot Low-carbon City, which opened opportunities for various policy experiments to incubate innovations. With the city's efforts, a number of creative policy practices emerged in Shanghai, e.g., introducing regular planning cycle at a local level, and going beyond the top-down target. In this sense, the vertical cooperation of governments across levels presented in Shanghai case is facilitated by the institutional setting in China.

Coordination mechanism and financial mechanism enable low-

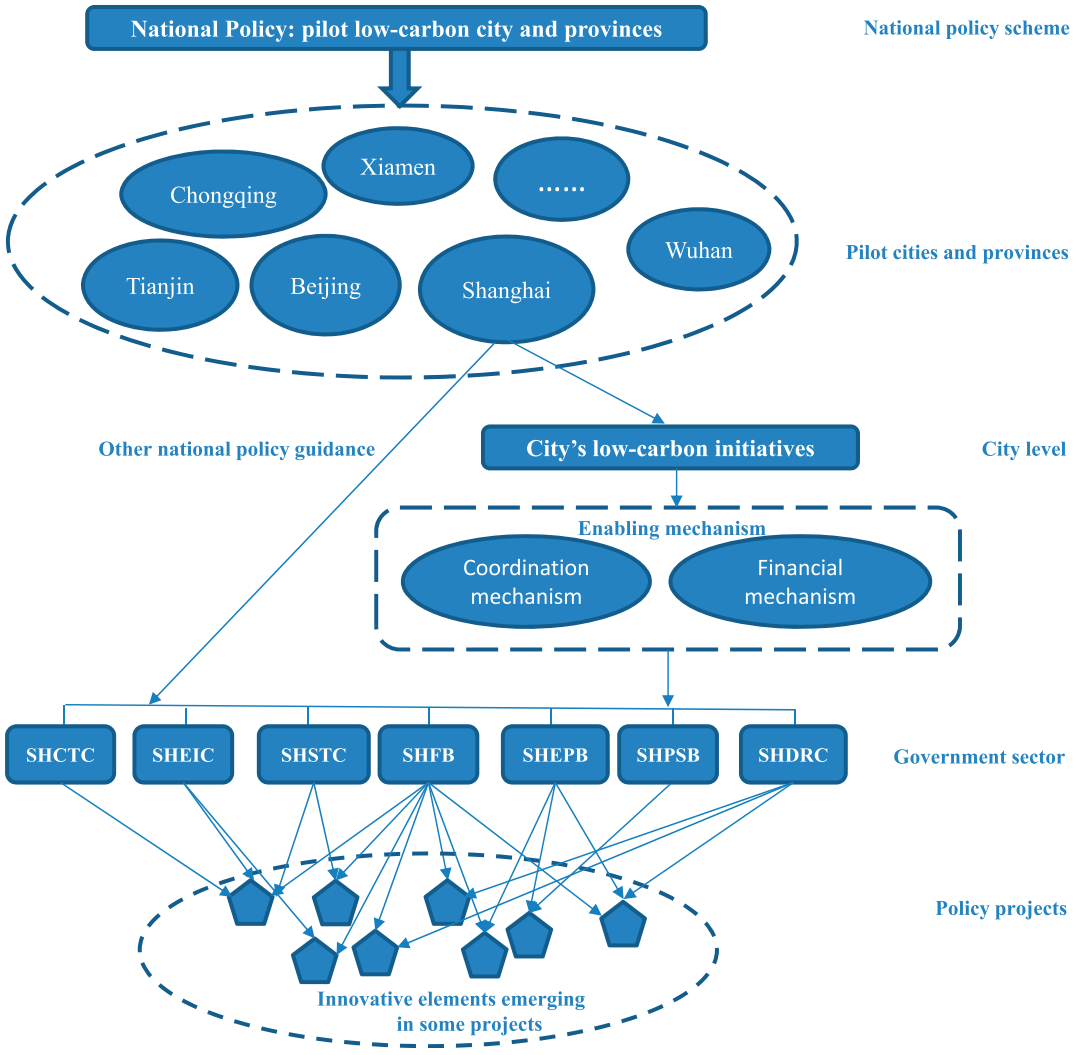

Fig. 3. Nested structure of policy innovation and experimentation

carbon initiatives implementation, and also are innovative practices initiated by the local government. SHDRC is responsible for both coordinating sectors and managing fund. Its role avoids overlapping or shifting duties between government departments, and also ensures the financial supports in synergy with policy implementation. This institutional setting and funding mechanism are instrumental in local low-carbon actions.

A nested structure for innovative policy practices can be identified through Shanghai case study. This nested structure consists of the institutional arrangement between different levels of government (vertical linkages), coordination across government sectors (horizontal linkage) and a financial mechanism. It presents a favorable setting for low-carbon policy experiments aiming at policy learning, developed under a clear leadership role of central government and giving more governing leeway for local authorities. Importantly, this policy framework reveals the importance of local capability in urban low-carbon transition in terms of institutional arrangements and financial resources.

6.2. The effectiveness of Shanghai model

Demonstrating the effectiveness of Shanghai's various initiatives quantitatively is challenging, because the low-carbon policies has been in place relatively a short time ago and some of the effects need more time to appear, and more importantly, the city is under a rapid development. Nevertheless, here we examine the energy consumption, and CO2 emission in Shanghai over a period from 1998 to 2015 as shown in Figs. 4–6, to see whether the effectiveness is manifested by these trends.

The total energy consumption (Fig. 4) kept increasing due to the fact that Shanghai has experienced a rapid economic growth. This increasing trend slowed down during 2010–2015, which overlaps with the period where more explicit low-carbon and other policies were implemented (see Fig. 2 on the policy evolution process). The energy intensity kept decreasing, showing a decoupling of economic growth from energy consumption. The energy consumption per capita grew from 1998 to 2008, and, after 2008, fluctuated within a narrow range (Fig. 6). These trends may present positive outcomes of the various policies discussed above. Several issues remain, e.g. the fossil energy use still accounts for a large part of total energy consumption, while the proportion of local non-fossil fuels in primary energy consumption is low (0.7% in 2015) (according to *Shanghai 13th five-year plan for energy development*). This fact may imply a structure challenge of primary energy use in Shanghai.

We estimate annual CO_2 emission of Shanghai based on fossil energy consumption and imported electricity from State Grid (which means this part of CO2 emitted outside of the city). Fig. 5

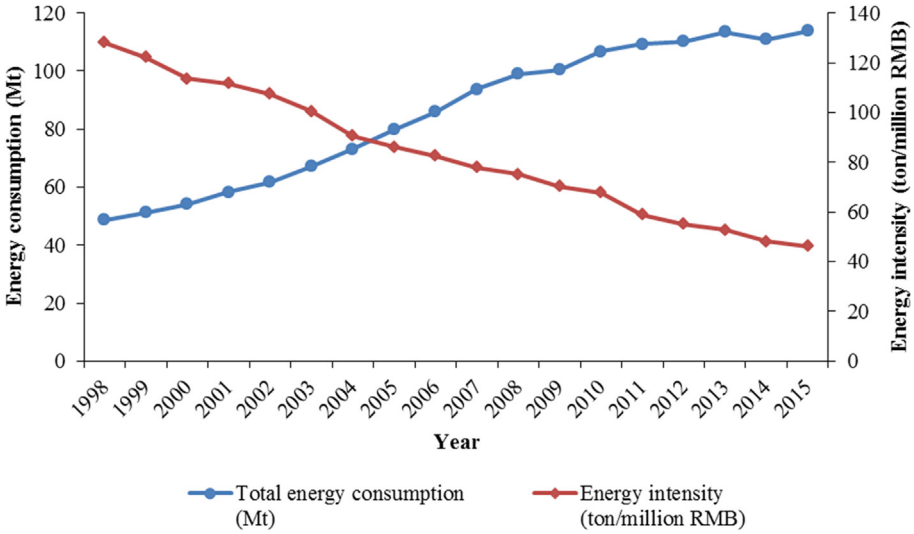

Fig. 4. The trends of total energy consumption and energy intensity in Shanghai from 1998 to 2015.
Data source: Shanghai statistical yearbook

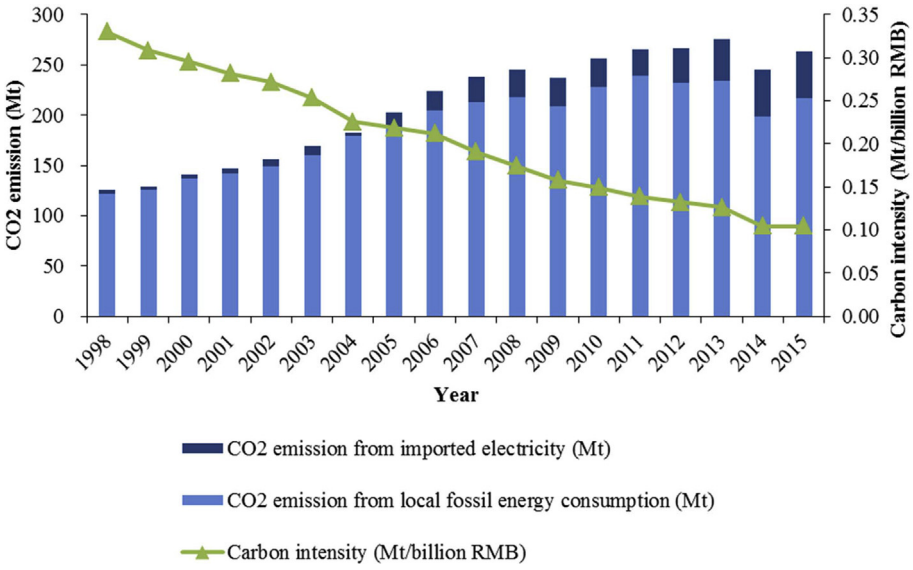

Fig. 5. The trends of CO_2 emission and carbon intensity from 1998 to 2015 in Shanghai.
Data source: calculated by the authors

shows the trends of CO2 emission and carbon intensity, and Fig. 6 shows the trends of CO2 emission per capita from 1998 to 2015 in Shanghai. It can be seen that the total emission was growing over time, but since 2010, the growth seems to slow down and fluctuates. The peak emission appeared in 2013. According to *Shanghai 13th five-year plan for energy conservation and addressing climate change*, the annual CO_2 emission is targeted to be less than 250 Mt by 2020, which is less than in 2013. The carbon intensity had been following a decreasing trend, showing a reduction of 67.9% in 2015 compared to 1998. The trend of per capita CO_2 emission had increased until 2006, followed by a period of fluctuation; and then it started to decrease after 2013 (Fig. 6). The share of CO_2 emission from imported electricity was growing. This tendency is more prominent during 12th five-year plan period, accompanied by a decreasing trend in the share of the direct emission from fossil fuel use within Shanghai administrative boundary.

While it is not possible to accurately attribute these trends to specific policies, it is reasonable to assume that these are positive outcomes of the various efforts made by Shanghai city in reducing energy consumption and CO_2 emission. In particular, a possible inflection point implies that the policy framework and nested structure of low-carbon governance identified in this study may enable a sustainability transition in Shanghai. However, this transition has only just begun. The increasing share of the CO_2 from transboundary electricity suggests the need to pay closer attention to the externality in achieving Shanghai's low-carbon target.

6.3. The applicability and limitation of Shanghai model

The strong vertical linkages and the nested structure identified in Shanghai case study may be enabled by the institutional environment in China where a central government always plays a powerful role. Thus, the application of Shanghai Mode might be confronted by the fact that institutional settings could be different

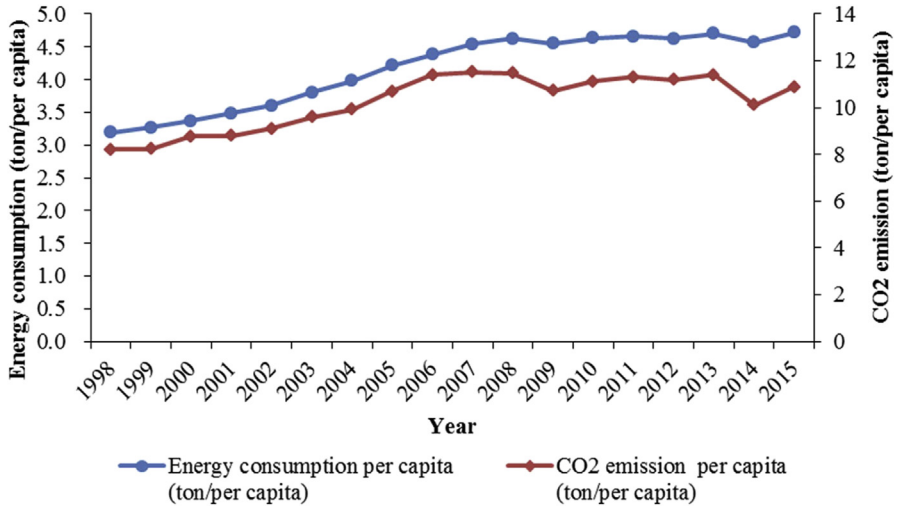

Fig. 6. The trends of energy consumption and CO_2 emission per capita from 1998 to 2015 in Shanghai. Data source: calculated by the authors

in other municipality contexts worldwide. However, we argue that the governance model demonstrated by Shanghai case may not be limited to China's context due to the nature of climate governance. Previous research on multi-level governance found that the relations between local, regional, and national state authorities have been critical in local response and competence to climate actions (Bai et al., 2009; Bulkeley, 2010; Corfee-Morlot et al., 2009; Deangelo and Harvey, 1998). A study in several OECD countries argues that local action and experience can inform national policy; national governments can work hand-in-hand with local governments to require and encourage the development of locally tailored policy and voluntary action (Corfee-Morlot et al., 2009). However, in reality, the role of municipalities in key sectors related to GHG emissions is usually defined by central or regional governments and is delegated to local authorities, so local governments may have limited powers and resources to achieve a transition (Bulkeley, 2010; Corfee-Morlot et al., 2009; Jones, 2012). Moreover, active supports from upper-level government vary from case to case: some supports are based on specific programs (Corfee-Morlot et al., 2009), or there is an absence of national leadership on the issue of climate change (Gore et al., 2009). In this sense, we could understand that the nature of cities' climate strategies and actions requires integrated efforts that involve multiple levels, and there is no reason why a stronger and more enabling vertical linkages, or a similar nested structure of innovation cannot be formed in other institutional settings.

The Shanghai case demonstrates a rather successful approach of the multi-level governance, which may be needed as a possible sustainable solution to drive a profound societal transformation towards a sustainable and low-carbon future (McCormick et al., 2016). From theoretical perspective, Shanghai case provides important addition to multilevel governance, where the current regime is actively involved in and enabling the niche experiments with the purpose to extract learning. In practice, the Shanghai case demonstrates the combination of an active and enabling role of the national government with the capacity and vision of the local governments is essential for low carbon initiatives to be successful.

There are several important limitations and remaining tasks in Shanghai's low carbon initiatives. Even though the nested structure is well designed and engenders positive results at implementation stage as quantitatively proved in Section 6.2, the full impacts and effectiveness are still to be seen as the transition has just started and the total CO_2 emission is still large. Moreover, while the focuses of this paper are policy experiments, policy innovations, competence of municipality, and relations between government units/levels, there is a broader structural context such as the high dependency on fossil fuel and relatively low renewable energy share. Improving energy efficiency is important but with limitations. Furthermore, the growth of imported electricity may signify a growing externality during Shanghai's low carbon transition. Last but not the least, these policies are mainly targeted at big firms. As a government officer admitted during an interview, the financial and policy supports, and monitoring for small firms are inefficient. Future study may need to include the roles of non-government stakeholders, as well as the pathways of upscaling the successful experiments.

7. Conclusion

This research investigates the internal mechanisms of urban low-carbon transition in rapidly developing economies, taking Shanghai as a case study city, with a particular focus on low-carbon policies evolution process and enabling mechanisms for policy experiments. The findings show that Shanghai's low-carbon initiatives root in its existing policy framework, which is complemented by new policy instruments with explicit target at carbon emissions reduction. Shanghai's low-carbon initiatives demonstrate a strong vertical linkage between central and local governments. We identified a nested structure for innovative policy practices, which is a combination of top-down design and bottom-up, proactive adoption of enabling mechanism, and multiple layers of experiments. Such a structure provides a favorable institutional setting for capturing learning from policy practices and experiments at different levels. The effectiveness of low-carbon initiatives in Shanghai is demonstrated by energy consumption and carbon emissions trends. The Shanghai case may offer new insights to study the multi-level governance of low-carbon cities, where the current regime is actively involved in and enabling the niche experiments with the purpose to extract learning. In practice, Shanghai case may demonstrates the importance of combining an active and enabling role of the national government with the capacity and vision of the local governments for a successful low carbon transition in cities.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.jclepro.2017.10.116.

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Supplementary Material 1

The criteria for policy selection and classification

The scope of policies selected in this research can be concluded into three groups: energy conservation, environmental protection and low-carbon. The selection criteria in regard to the policy scope are:

- Energy policies include those policies directing at building energy saving, transportation energy saving, industry energy saving, or renewable energy development. Besides energy policies aiming at specific sectors as above, there are some energy policies that are not targeted at particular areas, but are the overall plans/strategies, or some policy measures applied in a broad range of areas, here, defined as "general energy saving."
- Environmental policies are polices aiming at reducing air pollution; or policies aiming at multiple targets, including air pollution; or policies aiming at improving the city's environmental quality through the means of energy management or industrial restructuring.
- Explicit low-carbon policies refer to any policy measures specifically related to greenhouse gas management or control, e.g., making city's GHG inventory, controlling GHG emissions in industries, or implementing the carbon emission trading scheme, etc.

But this classification is general and is inefficient to reflect detailed policy measures. Thus, we further sort them into 13 sub-categories (Table 1). The policy number of a sub-group and its emergence time can reflect the time when the local government began to adopt a certain kind of policy measure, how many policies regarding this policy measure are enacted in each year, and whether this policy measure is continuously employed by the government or not. From above analysis, we can understand the local government's efforts into low-carbon governance. If the number and types of policies are increasing, more efforts could be made, vice versa.

Moreover, locally-issued policies can be divided into two categories based on their scopes and purposes: master policy and implementation policy. Master policies include policy strategy, plans, measures, and instruments, etc., all of which outlines a policy framework. Implementation policies only stipulate detailed implementation procedures regarding how to make master policies into practice; for example, they can be some government documents to inform the firms about how to apply for financial incentives or tax references or guide them to report their energy consumption or CO2 emissions. In this research, only master policies are selected for the analysis of the positioning and linkages of low carbon policy. As the number of implementation policy may only reflect that the procedure of carrying out a policy plan requires simple or complicated steps, but not the new inputs, new plans or substantial efforts by the local government.

Table2. Sub-categories of low-carbon policies

Sub-category	Description
Three-year environmental protection action plan:	Three-year guiding plan for local environmental protection, including clear goals and concrete implementation step.
Air pollution reduction	Policy measures for curbing air pollution and improving air quality
Environmental emissions reduction	Combined policies (including water pollution control, air pollution control and others)
Emissions reduction	Combined policies (including carbon emissions control and other environmental emissions control)
Corporate environmental protection	Policies for encouraging industries to take actions for environmental protection.
General energy saving	Policies for improving energy efficiency, or reducing energy consumption, or monitoring, reporting and verifying energy consumption, etc. (in general but not confined to specific areas)
Building energy saving	Policies for improving energy efficiency systems in buildings, or energy efficiency standard for buildings or monitoring, reporting and verifying energy consumption of buildings.
Industry energy saving	Policies for improving energy efficiency, reducing energy consumption, or monitoring, reporting and verifying energy consumption, etc. in industries.
Transportation energy saving	Policies for improving energy efficiency in the transportation system, e.g., replacing old and high energy-consumption vehicles.
Industrial restructuring	Policies for adjusting industrial structure, e.g., replacing energy-intensive industries with the service industry. Industrial adjustment policies cover a wide range of areas, and only those beneficial for energy consumption control are selected in this research.
Energy performance contracts	Policies for facilitating adoption process of energy service industry.
Renewable energy	Policies for encouraging technology development of renewable energy and its application, as well as management of renewable energy projects, etc.
Low carbon	Explicit policies for Greenhouse Gas management and control, e.g., making city's GHG inventory, pilot ETS, etc.

Supplementary Material 2

The methods of calculating CO2 emission related data and energy consumption per capita

We estimated CO_2 emission in Shanghai from 1998 to 2015. To simplify the calculation, we only calculated the emission from energy consumption. There are two parts: the first part is CO_2 emission from fossil energy combustion; the second part is CO_2 emission calculated based on imported electricity consumption (this part of electricity generated outside the city but consumed in the city). In this way, we could understand how CO_2 emission transfers across regions along with electricity transmission, as well as the externality of Shanghai low-carbon transition that might be caused by this transfer.

The CO2 emission from fossil energy combustion

We refer to the guidelines from the Intergovernmental Panel on Climate Change (IPCC) regarding the method of accounting CO2 emission from energy combustion (Eq.1).

$$\mathrm{CE_{energy}} = \sum_i \mathrm{CE_i} = \sum_i \mathrm{FC_i} \times \mathrm{NCV_i} \times \mathrm{EF_i} \times \mathrm{O_i} \qquad \text{(Eq.1)}$$

CEenergy: CO2 emission from fossil energy combustion

CEi: CO2 emissions from fossil fuel i combustion

FCi: Consumption of fossil i

NCVi: Net caloric value of fossil fuel i

EFi: Emission factor of fossil fuel i

Oi: Oxygenation efficiency of fossil fuel i (default value is 1 in this research)

The types of fossil fuels are selected from energy balance table1 (EBT) as shown in Table 1. These types are widely used in the Shanghai energy system. Emission factors for fossil fuels used in this research are referred to the research done by Shan et al. (2017) and from local policy guidance (Gu et al., 2012).

Table 3. Emissions parameters of fossil fuel combustion

	Fossil fuel	NCV(PJ/10^4 tonnes, 10^8 m3)	EF (tonne CO_2/TJ)	O
1	Raw coal (104 tonnes)	0.21	96.51	1
2	Cleaned coal	0.26	96.51	1
3	Other washed coal	0.15	96.51	1
4	Briquettes	0.18	96.51	1
5	Coke	0.28	115.07	1
6	Other coking products	0.28	100.64	1
7	Crude oil	0.43	73.63	1
8	Gasoline	0.44	69.3	1
9	Kerosene	0.44	71.87	1
10	Diesel oil	0.43	74.07	1
11	Fuel oil	0.43	77.37	1
12	Liquefied petroleum gas (LPG)	0.51	63.07	1
13	Refinery gas	0.47	73.33	1
14	LNG	0.42	63.64	1
15	Other petroleum products	0.43	74.07	1
16	Natural gas	3.89	56.17	1

The activity data are from energy balance table (EBT) of Shanghai from 1998 to 2015. Region EBTs are included in *China energy statistics yearbook (from 1999 to 2016).* The CO_2 emissions from fossil energy combustion during the period of 1998-2015 are shown in Table 2.

Table 4. CO_2 emission and carbon intensity in Shanghai from 1998 to 2015

Year	CO2 emission from local fossil energy consumption (Mt)	Percentage	CO2 emission from imported electricity (Mt)	Percentage	Carbon intensity (MT/Billion RMB)
1998	121.8	97.05%	3.7	2.95%	0.33
1999	125.4	97.07%	3.8	2.93%	0.31
2000	136.4	96.74%	4.6	3.26%	0.30
2001	141.5	96.40%	5.3	3.60%	0.28
2002	148.6	95.37%	7.2	4.63%	0.27
2003	160.4	94.66%	9.1	5.34%	0.25
2004	179.1	98.36%	3.0	1.64%	0.23
2005	187.8	92.85%	14.5	7.15%	0.22
2006	204.4	91.28%	19.5	8.72%	0.21
2007	213.0	89.53%	24.9	10.47%	0.19
2008	217.8	88.78%	27.5	11.22%	0.17
2009	209.0	88.19%	28.0	11.81%	0.16
2010	227.6	88.81%	28.7	11.19%	0.15
2011	238.9	89.94%	26.7	10.06%	0.14
2012	232.4	87.17%	34.2	12.83%	0.13
2013	233.7	84.91%	41.6	15.09%	0.13
2014	198.7	80.93%	46.8	19.07%	0.10
2015	216.5	82.32%	46.5	17.68%	0.10

The CO_2 emission from imported electricity

The calculation method is shown in Eq 2. The emission factors (EF) for regional power grids (2010) are released by National Development and Reform Commission (NDRC, 2010). We used the EF of Eastern China Power Grid as shown in Table 3. We used primary data from EBT as the activity data for calculation. The CO_2 emissions from imported electricity during the period of 1998-2015 present in Table 2**.**

$$\mathrm{CE_{ie}}=\mathrm{EC_{ie}}\times\mathrm{EF_{eg}} \qquad \text{(Eq.2)}$$

CE_{ie}: CO_2 emission from imported electricity

EC_{ie}: Electricity consumption (imported from other areas)

EF_{eg}: Emission factors of Eastern China regional power grid

Table 5. The emission factors (EF) for regional power grids

Region	EF (kgCO2/kWh)
Northern China regional power grid (ng)	0.8845
Northeastern China regional power grid (neg)	0.8045
Eastern China regional power grid (eg)	0.7182
Central China regional power grid (cg)	0.5676
Northwestern China regional power grid (nwg)	0.6958
Southern China regional power grid(sg)	0.5960

Carbon intensity

The carbon intensity of Shanghai from 1998 to 2005 is calculated with Eq.3. The GDP data can be obtained from Shanghai Statistical Yearbook. The result presents in Table 2.

$$CI = \frac{CE_{energy}+CE_{ie}}{GDP} \quad \text{(Eq.3)}$$

CI: Carbon intensity

CE_{energy}: CO_2 emission from fossil energy combustion

CE_{ie}: CO_2 emission from imported electricity

Energy consumption per capita and CO_2 emission per capita

Energy consumption per capita and CO2 emission per capita from 1998 to 2005 is calculated with Eq.4.and Eq.5. The data of total energy consumption and resident population can be obtained from Shanghai Statistical Yearbook. The result presents in Table 4.

$$EC_{pc} = \frac{Ec_{total}}{RP} \quad \text{(Eq.4)}$$

EC_{pc}: Energy consumption per capita

CE_{total}: Total energy consumption

RP: Resident population

$$CE_{pc} = \frac{CE_{energy}+CE_{ie}}{RP} \quad \text{(Eq.5)}$$

CE_{pc}: CO_2 emission per capita

CE_{energy}: CO_2 emission from fossil energy combustion

CE_{ie}: CO_2 emission from imported electricity

RP: Resident population

Table 6: Energy consumption per capita and CO_2 emission per capita in Shanghai from 1998 to 2015

Year	Energy consumption per capita (ton/per capita)	CO_2 emission per capita (ton/per capita)
1998	3.19	8.22
1999	3.27	8.24
2000	3.37	8.76
2001	3.49	8.80
2002	3.60	9.10
2003	3.81	9.59
2004	3.98	9.92
2005	4.22	10.70
2006	4.38	11.40
2007	4.54	11.53
2008	4.62	11.46
2009	4.55	10.72
2010	4.63	11.13
2011	4.66	11.32
2012	4.63	11.20
2013	4.70	11.40
2014	4.57	10.12
2015	4.71	10.89

Note:

1. The Energy Balance Table (EBT) is an aggregate summary of energy production, transformation and final consumption in one area, which could reveal the energy flow of one region (Shan et al., 2017).

Reference:

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Chapter 3: Scaling urban sustainability experiments: Contextualization as an innovation

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Scaling urban sustainability experiments: Contextualization as an innovation

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ABSTRACT

Research shows urban sustainability experiments are critical for sustainability transition in cities and beyond, especially when they are multiplied in other contexts and upscaled. Even with a growing body of literature on sustainability experiments, little is known on how these experiments travel to and are contextualized in other contexts. Here we attempt to fill this gap, taking the adoption and proliferation of Energy Performance Contracting (EPC) in Shanghai as a case study. First, based on the system innovation literature, we identify the critical components that characterize the innovative practices. We then examine the contextualization process of EPC in Shanghai using this characterization. Finally, we identify and compare some innovative elements that emerged during the contextualization with those in the original contexts from which Shanghai learned. We argue that post experiment adoption and contextualization requires mobilization and realignments of actors, resources, and institutional arrangements within the process of learning, which involves much more than simple duplication and often with distinctive outcomes, thus in many ways is an innovation in itself. Innovation in post experiment contextualization is supported by various "horizontal linkages" with the original experiment, which include information/knowledge transfer and learning via actor interactions across experiments, but the focus of learning shifts from external (i.e. from the original context) to internal (i.e. within the new context) during the contextualization process. These findings contribute to an in-depth understanding of how innovation can transfer across cases, which is a significant gap in current system innovation literature, and may inform practice in terms of how to facilitate the scaling of experiments to achieve sustainability transitions.

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1. Introduction

Sustainability transitions are conceptualized as long-term, multi-dimensional, and fundamental transformation processes through which established socio-technical systems shift to more sustainable modes of production and consumption (Markard et al., 2012; Smith et al., 2005). This shift might be induced by sustainability-oriented innovations, which may provide solutions for persistent problems and alternative ways to achieve sustainable development (Loorbach, 2010; Vollenbroek, 2002).

Innovations with sustainability implications may emerge and be nurtured in sustainability experiments at their early stage. Experimentation is an important analytical concept in system innovation study, and an effective policy instrument (Kemp et al., 1998; Rotmans and Loorbach, 2008; Schot and Geels, 2008). Berkhout et al. (2010) define sustainability experiments as planned initiatives that embody a highly novel socio-technical configuration and that are likely to lead to substantial (environmental) sustainability gains. These experiments are the testing grounds for novelties: building actor networks, encouraging various learning processes and eventually forming stable social-technical configurations (Berkhout et al., 2010; Kemp et al., 1998; Loorbach, 2010; Loorbach and Rotmans, 2010).

Cities have received much attention recently as fertile grounds for innovation and experimentation, and the profusion of urban sustainability experiments in practice has been studied and reported in various regions worldwide (Bai et al., 2010; Broto and Bulkeley, 2013; Bulkeley and Castán Broto, 2013; Laakso et al., 2017; Williams, 2016). The widespread innovative practices and experiments in cities are increasingly shaping the urban-

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environmental linkages, with profound sustainability implications in cities and beyond (Bai et al., 2017).

Scaling up successful local innovations is critical in achieving transformation towards low carbon resilient cities (Bai et al., 2018), and sustainability at large. To enable scaling, it is important to examine what happens after the initial, successful experiments. According to Bai et al. (2010), sustainability experiments may follow four different pathways: a) the experiment may fail and die out; b) it may stay as an individual experiment without being diffused; c) it may be "multiplied" and adopted in other contexts, and d) it may be "upscaled" with systems change, e.g., policy change at a higher government level. The "multiplication" can be considered as a process of upscaling, if this is done on a large scale and if the focus of concern is the aggregated effect of these experiments. In practice, much effort is put into enabling multiplication of successful experiments, as demonstrated by the many cross-city exchange platforms such as C40 and ICLEI, etc.

However, little is known about to how successful experiments and innovations travel across contexts or about how they are transferred to elsewhere (Williams, 2017), although the investigation of these processes is conducive to understanding the internal mechanisms of experiments, "broadening and upscaling" (Rotmans and Loorbach, 2008; Sengers et al., 2016) in transition. In addition, the linkages and interactions across experiments are often underexplored (Raven, 2007; Raven and Verbong, 2007). Yet, understanding such "horizontal linkages" may reveal conditions within which "translation" between experiments takes place (Bai et al., 2009). More importantly, the nature of the contextualization process and what it entails in the new context remain underexplored.

In this article, we attempt to fill these gaps by exploring the following questions: How are sustainability experiments (innovative practices) adopted elsewhere? What does this contextualization process entail? Is it a simple duplication or something more? How are the practices in different contexts linked? And, how does the adopted experiment contribute to sustainable development in the recipient context? To answer these questions, we start by identifying the elements that characterize a sustainability experiment based on system innovation literature. We then use this conceptualization to analyze the case study – the adoption and proliferation of Energy Performance Contracting (EPC) in Shanghai. EPC is a market mechanism to improve energy efficiency, which has been widely practiced in many regions (Hansen et al., 2009) and was introduced in Shanghai in 2002. Similarities and differences between the practices in the original experiments and the new context are examined. We end by conceptualizing the contextualization process, and arguing that post-experiment contextualization is an innovation in itself.

2. Research methodology

The research includes a case study based on fieldwork and a conceptual analysis based on system innovation and sustainability transition literature.

2.1. Data collection in fieldwork

We collected first-hand data from a two-month-long fieldwork project in Shanghai in 2016, which included extensive semi-structured interviews with stakeholders including government officials, the chair of Energy Service Companies (ESCOs) association, and ESCOs of different types. Other materials collected on site, e.g. government internal reports, public-accessible government documents, and other grey literature, complement the interview results.

2.2. Analytical approaches

We begin with a brief literature review of the role of sustainability experiments in sustainability transition. We then characterize the key elements of experiments based on system innovation literature. The perspective of "horizontal linkages" across experiments as identified in Bai et al. (2009) is employed as an analytical tool to examine how sustainability experiments to be translated across contexts.

2.2.1. Experimentation in sustainability transition

The multi-level perspective (MLP) from system innovation theory reveals how a social-technical innovation formed in experimentation contributes to sustainability transition (Elzen et al., 2004; Geels, 2005a). The core concept of MLP is the socio-technical regime - a complex configuration of three interlinked dimensions: a network of actors and social groups, formal, normative and cognitive rules that guide the activities of actors, and material and technical elements (Geels, 2004). The institutional stability of the regime is dynamic, i.e. innovation still occurs but is of an incremental nature, leading to technical trajectories and path dependencies (Berkhout et al., 2010; Geels, 2005a). There are two other levels: the lower level is niches where novelties are developed; while the higher level is socio-technical landscapes, comprising a range of exogenous developments that influence regimes and niches (Elzen et al., 2004; Geels, 2005a). Socio-technical transition is considered resulting from linkages between processes at these multiple levels (Geels, 2002; Geels et al., 2016; Smith et al., 2010): 1) niche innovations build up internal momentum, 2) exogenous developments create pressure on the regime and, 3) tensions in the regime create windows of opportunity for the expansion of niche innovations.

In the transition process, experiments play an important role in testing the innovations that typically occur in a niche level (Evans et al., 2016). According to Berkhout et al. (2010), there are two characteristics of these experiments: 1) the experiments represent small initiatives in which the earliest stages of a process of socio-technical learning takes place; 2) the experiments typically bring together new networks of actors with knowledge, capabilities, and resources, cooperating in the process of learning.

Various types of experiments in transition study are designed, mobilized and evaluated for different purposes (Berkhout et al., 2010; Nevens et al., 2013; Sengers et al., 2016; Vergragt and Brown, 2007; Weber et al., 1999). At an early stage of innovation study, more emphasis was put on the technological elements of the experiments (Geels, 2005a, b; Twomey and Gaziulusoy, 2014). However, Raven et al. (2010) point out that social innovation also plays a crucial role in transition research and practice. Technological and social innovations co-evolve in the case of transitions towards sustainability (Evans et al., 2016). Technological innovations induce social innovations and vice versa. In addition to the social innovations co-evolving with technologies, some kinds of social innovations aim at minimizing the negative social effects and improving the way of meeting people's social needs, like those in bounded socio-technical experiments and grassroots experiments (Sengers et al., 2016). Moreover, some innovations are in the field of policy formation and implementation and are associated with institutional reforms (Bai et al., 2009). The EPC examined in this paper is a new market mechanism for improving energy efficiency and thus a social innovation.

2.2.2. Characterizing key elements of sustainability experiments

As a niche in MLP is the loci where experiments are developed, examining niche experiments may provide insights into understanding sustainability experiments. Typically, the following three

internal processes occur in niche experiments (Hoogma, 2002; Kemp et al., 1998; Schot and Geels, 2008):

a) *The articulation of expectations and visions.* Expectations are considered crucial for niche development because they provide direction to learning processes, attract attention, and legitimize (continuing) protection and nurturing.
b) *The building of social networks.* This process is important to create a constituency behind the new technology, facilitate interactions between relevant stakeholders, and provide the necessary resources (money, people, and expertise).
c) *Learning processes at multiple dimensions*: This includes technical aspects and design specifications, market and user preferences, cultural and symbolic meaning, infrastructure and maintenance networks, industry and production networks, regulations and government policy, societal and environmental effects.

Building on and extending above characteristics of experiments, we conceptualize the internal dynamics that characterize an experiment as presented in Fig. 1. This framework consists of three key components, including 1) the novelty and vision 2) actors' interaction in practices and the processes of learning, and 3) three realignments, namely a realignment of actors, a realignment of resources, and a realignment of institutional arrangements. The dynamic processes of the three realignments are of particular importance, as they illustrate how a social-technical configuration emerges in a specific context.

Novelty and vision: This part includes the novelty, which could be new products/technologies/social practices; the various resources that might be required to enable this innovation; and the vision/expectation on the possible outcomes of the innovation. As a whole, they provide an object to be tested in sustainability experiments, an initial expectation to attract the attention of potential stakeholders, and a direction that guides the learning processes.

Actors' interaction in practices and the processes of learning: The embedding of the novelty in a new context can occur through the actors' interaction with one another and the various learning that occurs in the process. New connections between actors and a new network can be formed, and learning activities typically take place in multiple dimensions. "Learning-by-doing" or "reflective learnings" are considered critical to forming a new social, economic and institutional configuration in experimentation.

Realignments: The system innovation literature has not specifically clarified the original attributes of the participating stakeholders before they are involved in the experiment. Although not paid specific attention in the literature, the origin and the inherent characteristics of the participating stakeholders (agents in the existing regime, newly established entities, or external agents such as international organizations) may influence their new roles in the experiment, e.g. how they interact with each other, what kind of resources they can mobilize, and what kind of political/institutional relations they form. In practice, these realignment processes are often inter-linked. The outcome of these realignments is a new social-technical configuration that facilitates the experiment.

This conceptualization shows the processes through which a novelty can be embedded in the social and institutional context; in other words, the essential components and processes of a social-technical innovation. This conceptualization can be used to inspect and compare experiments. We apply this analytical framework to examine what happens in the destination (as opposed to the original site where innovation took place) city and how the process of contextualization and its outcome compare to the original experiments.

2.2.3. Horizontal linkages between experiments

If our focus is on understanding how sustainability experiments are transferred to other contexts, the MLP might not be sufficient, as it mainly addresses "vertical" relations between niches, regimes, and landscapes. Shove and Walker (2010) extend the scope of debate, introducing the aspect of social practice theory to scrutinize the transition process. Their study focuses on social practice - how the patterns and practices of numerous social practices interrelate, erode and reinforce each other. This new perspective implies that relations between sustainability practices may play an inevitable role in the transition, which is not adequately discussed in the literature.

Such connections across regimes are conceptualized as "horizontal linkages". Bai et al. (2009) argue that linkages between different levels in socio-technical systems (vertical linkages) as well as between the same levels across different socio-technical systems (horizontal linkages) are critical to explaining the emergence of sustainable development pathways. A three-dimensional analytical framework is proposed in their research as demonstrated in Fig. 2. The first dimension emphasizes the need for vertical linkages between various levels (e.g., local, national, international). The second dimension consists of horizontal linkages, e.g., linkages within levels, i.e., between experiments and between regimes. The third dimension is time, i.e., how the vertical and horizontal linkages change over time, or with economic development, and how

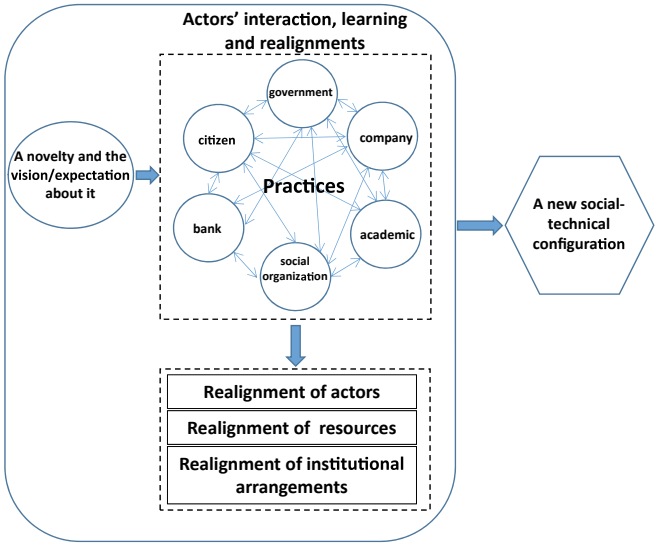

Fig. 1. Conceptualizing the formation of an innovative socio-technical configuration in experimentation.

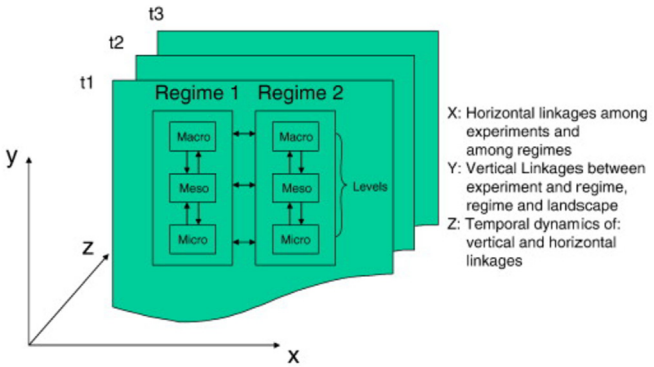

Fig. 2. A three-dimensional analytical framework of the linkages (Bai et al., 2009).

changes, in turn, affect the transition. All three dimensions play a role in the diffusion of innovative practices - facilitating or inhibiting. This conceptualization, in particular, the horizontal linkages, is used to examine the linkages of experiments translated across contexts.

3. Case study: the adoption of EPC in shanghai

We apply the above frameworks – conceptualization of key characteristics of experimentation presented in Fig. 1 and horizontal linkages conceptualized in Fig. 2 – to analyze the process of the adoption and proliferation of EPC in Shanghai. Moreover, similarities and differences between contextualization and experimentation are drawn by comparing the Shanghai case to the original experiments elsewhere.

3.1. The background of EPC development in shanghai

Shanghai City has been confronted with multiple challenges of rapid development, industrial restructuring, energy security, climate mitigation, and air pollution (Peng and Bai, 2018). Improving energy efficiency could be a multi-effect solution for tackling these problems (Gillingham et al., 2009). In 2002, EPC was introduced to Shanghai for this purpose. This mechanism is market-based and involves a package of both the technical aid and necessary funding for energy cost saving investments by an outside company (i.e. other than the energy user), using the energy cost savings themselves to pay for that investment (Brown, 1988).

Energy Service Companies (ESCOs) provide EPC services. The first ESCOs originated in France around 100 years ago. Since the 1970s, EPC has been widely practiced in the U.S., some European countries, and other regions (Brown, 1988; Davies and Chan, 2001; Geiβler and Waldmann, 2006; Hansen et al., 2009; Li and Nie, 2010; Seefeldt, 2003; Vine, 2005; Yan and Yan, 2009). The U.S. has led ESCO industry development in recent decades (Bertoldi et al., 2006; Kiss et al., 2007).

In the 1990s, ESCOs were introduced into Asia. The potential EPC market in this region is estimated to be large (Nakagami and Murakoshi, 2009). As a first step, many Asian countries examined the U.S. experience. In some cases, governmental supports were provided. Meanwhile, cooperation with international organizations for funding and logistical support was also an important resort to some countries (Nakagami and Murakoshi, 2009).

EPC was brought into China in 1998 (Shen, 2007). Since then, China has seen excellent growth of the ESCO industry (Limaye, 2013). Shanghai's government adopted EPC for energy conservation as a local strategy, learning from U.S. and German experience. To facilitate this adoption, Shanghai established two new organizations: *Shanghai Energy Performance Contracting Management Committee* (SEPCMC), which is a special government agency as an enabler (Xie, 2007); and *Shanghai Energy Conservation Technologies and Service Corporation* (SECTSC), which is the first ESCO in Shanghai (a government-owned company) to implement EPC demonstration projects (Lin et al., 2004). Both SEPCMC and SECTSC played a crucial role in the initial stage of adoption.

The quick development of the ESCO industry in Shanghai has been supported by a series of policies issued by the local government to promote the EPC market. Between 2002 and 2009, more than 600 EPC projects were implemented in Shanghai, with over 60 ESCOs registered with SEPCMC (SHDRC, 2011). By 2017, there were more than 480 ESCOs in Shanghai. The EPC mechanism has become a dominant practice for improving energy efficiency in Shanghai, the number of projects accounting for approximately 50% of total energy-efficiency retrofit projects. During the period from 2011 to 2015, the amount of 0.148 million ton standard coals, equivalent to 0.33 million-ton CO_2 emission, was reduced via EPC projects in Shanghai.

3.2. The Shanghai EPC practice as a sustainability experiment

Shanghai is a megacity still growing, with a large stock of existing infrastructure as well as a rapid expansion of the newly-built urban area. As such, the city's strategy for energy conservation and carbon emission control may consist of two parts: retrofitting the existing systems and integrating low-carbon technologies into new infrastructure. Thus, achieving the energy efficiency gains in existing urban stocks (buildings, industries) is one of the steps made by Shanghai towards the carbon efficient future, together with other long-term and short-term policy schemes like adjusting the city's energy mix, enabling renewables production, promoting low-carbon technologies application and Shifting the mode in public transport infrastructure. Some of these urban retrofitting efforts might create a negative carbon lock-in to the future (Ürge-Vorsatz et al., 2018). However, these efforts could still bring about a sustainability benefit to the city and are an essential part of, and a primary step for, achieving the city's strategic low carbon transition. The adoption of this multi-focus strategy and the step-by-step plan might be due to the fact that the renewables replacement in urban energy mix might take a longer time as a complex and contingent process for cities to accomplish. In this regard, the EPC mechanism holds the potential to change energy efficiency improvement practices in Shanghai, and can be regarded as a sustainability experiment that provides an innovative solution to achieve energy-efficiency and cost-effectiveness outcomes for existing urban infrastructure, where the traditional approach (i.e., relying solely on the investment from the government or the owner of the urban stock) was proven to be ineffective and insufficient.

The vertical linkages between Shanghai's municipal government and other stakeholders play a critical role in the protection and proliferation of the EPC experiment. There are two supportive actions from the municipal government in a top-down direction. One is setting-up SEPCMC as a service-oriented government agency participating in the experiment; the other is enacting policies and offering subsidies. Meanwhile, SEPCMC, as a coordinator, collects and analyzes first-hand information from experimentation and hands-on experience from local practices; then gives feedback to the upper-level government for policy making in a bottom-up direction. In this way, bi-directional linkages, consisting of top-down policy and financial support and bottom-up practice feedbacks, have formed to nurture EPC experiments, as well as facilitate its proliferation throughout the city.

Twelve years after introducing the EPC mechanism, there has been a regime change in the energy efficiency improvement practice in Shanghai: from energy consumers' self-investment or government-sponsored investment for single equipment/technology replacement to EPC which provides a package solution to customers with diagnosis consultancy service, market-based financing and technical aid for a systematic improvement. The proliferating practices in Shanghai have shifted from the traditional mode to EPC as one dominant mode.

3.3. The articulation of the vision

Shanghai's government has an explicit vision regarding adopting EPC. “Even at an early stage, Shanghai's government has a clear strategy in terms of how to adopt EPC. They are not planning on just copying existing examples from other regions, but are trying to contextualize them by integrating them into local conditions (social, economic, and institutional)” (Xie, 2004). This “contextualized”

adoption strategy may imply a divergence between Shanghai and other predecessors in the very beginning of this adoption experiment. The Shanghai ESCO industry might be co-shaped by the existing EPC models and Shanghai local circumstances.

The unique local circumstances of adopting EPC include the following. Firstly, energy-conservation technology updating in industries was required by the local authority, but the investment was insufficient. For private sectors, they lacked motivation and funds. For state-owned companies, they had financial support from the government, but this government-sponsored approach was unsustainable. Secondly, Shanghai had been undergoing a transition from a planned economy to a market-oriented economy. Under these circumstances, EPC as a market mechanism is welcomed. In addition, industrial restructuring is an essential economic strategy in Shanghai, which encourages the development of local service industries, like ESCOs.

A localized vision towards adopting EPC was articulated in the Shanghai case, which is to improve the city's energy efficiency and to encourage ESCO industry for the purpose of facilitating the industrial restructuring. This vision is important for attracting attention and resources from potential stakeholders, and also for providing direction to learning processes and technology development (Geels and Raven, 2006).

3.4. Shifting learning modes

A clear shift in terms of the learning process can be observed in Shanghai's case: from across-case learning mobilized by a horizontal linkage with previous experiments, to internal reflexive learning facilitated by a variety of contextualization processes. This shifting process is accomplished over three stages of adoption: preparation, pilot-projects practices, and large-scale implementation.

In the preparation stage (from 2000 to 2002), Shanghai's government devoted to learning experiences from other cases for relevant knowledge and experience, by means of desk-studying, organizing workshops and field surveys. The learning outcome of this stage is the recognition of the importance of governmental support during the early adoption phase, which drives the establishment of SEPCMC as a coordinator and facilitator.

Pilot projects were the focal point at the second stage (from 2002 to 2004). The learning activities were also government-led, but more actors were engaged (e.g., ESCOs, customers). SEPCMC explored some demonstration projects. Then, SECTSC, as the first ESCO in Shanghai, carried out the pilot projects, demonstrating how ESCOs run business and make profits. The outcomes of this period are 1) more than 100 demonstration projects were conducted, and 2) an initial scale of the ESCO industry appeared with the establishment of 20 plus ESCOs. 3) The connections across local actors were gradually built-up. At this stage, the stakeholders still needed to learn experiences from other cases; but meanwhile, reflexive learnings on pilot projects were emerging, which signifies the beginning of a learning-mode shift.

The third phase featured scale application of EPC after pilots. The actor-network expanded on the scale and became more complex than before. More ESCOs were established, and customers' backgrounds became more diverse (from various industries). Other types of stakeholders, e.g., banks, audit institutions, and social communities, started to engage as well. Internal reflexive learning dominated at this stage.

3.5. Three realignments in contextualization

During the adoption of EPC, stakeholders and resources, and some institutional elements were reorganized and reassembled to form a new configuration, as illustrated below.

3.5.1. Realignment of actors

Table 1 shows the types of stakeholders in Shanghai EPC market and how their roles have shifted and realigned in the new practice.

The energy users have adapted to their new role as EPC customers. Firstly, most firms in Shanghai were reluctant to invest in technology-updating projects for energy conservation, and this passive attitude began to change to some extent after EPC was introduced, because the technology upgrading projects can be financed by other stakeholders. Secondly, the mindset of the firms had changed from that of the planned economy. The paid-service of energy management consultancy was difficult to be accepted for the firms, because “those products” were considered “intangible” and such business model did not exist in the traditional economy (Xie, 2007). Last but not least, the customer firms had to modulate their financial system to adopt EPC, as the existing financial procedure in energy-user firms did not match the business model of EPC. The customers need to pay ESCOs on an agreed rate made before project installation, instead of actual energy bills at the operation stage, whereas their previous financial process only supported the payment based on the actual cost.

The ESCO is a relatively new industry in Shanghai, and the service provider companies originated from a diversity of backgrounds (Li and Wei, 2011). Some are new start-ups with small-scale and weak financial capacity, while others are subsidiaries of large corporations from various business backgrounds. For example, some large manufacturers became the parent companies, founding ESCOs to extend their business scope into the service industry, or to explore new marketing channels for their products. Such ESCOs may have different strengths and motivations associated with their holding companies.

The Shanghai government assumed a new role as a facilitator

Table 1
Roles of stakeholders in the EPC adoption experiment in Shanghai.

Actors	Old role	New role
Energy users	Mainly referring to various firms in Shanghai, e.g., state-owned companies and private sectors that need to improve their energy efficiency	Customers in the EPC market
ESCO (newly-established firms; or a branch company of an existing large corporation)	Some ESCOs were separated from large corporations; they were before an energy management department of a large corporation; Some ESCOs were newly established, founded by manufacturers and retailers offering energy-saving products	Offering energy management services, e.g., EPC
The government	A regulator and policymaker	A facilitator, enabler, and policymaker
Local banks	Being inclined to invest in less risky businesses	A financier, designing new financial products for ESCOs
Audit institutions	From various backgrounds, e.g., research institutes, policy advisory bodies, business sectors	Verifying saved energy from EPC project

and coordinator. Before, the local government was a regulator, supervising energy-users and employing conventional instruments like making standards, assigning tasks, and offering grants. In the EPC market, the government utilized and facilitated this market mechanism. The new role can be illustrated by SEPCMC's duties: 1) exploring demonstration projects and supporting their implementation; 2) promoting EPC market; 3) policy consultancy; 4) organizing training; 5) learning experiences from other cases; 5) coordinating stakeholders. SEPCMC is a crucial stakeholder at every stage of contextualization, by gluing, assisting and cooperating with other stakeholders (SHDRC, 2011; Xie, 2007). In addition, a systematic policy framework for promoting the EPC market and encouraging the ESCOs industry also demonstrates an enabling effort by the local authority.

Some local banks started to invest in EPC projects by adjusting their business strategies and creating new loan products. In principle, banks are reluctant to lend money to newly-founded companies without long-term credit records like ESCOs. However, these banks were also experiencing a transition in the market-oriented economy, by experimenting with more diverse investment products than before. With this backdrop, some local banks proactively came up tailored loan products for ESCOs.

Audit institutions started to join, playing a role as a third party to verify the outcome of EPC projects since 2010 when a relevant policy was enacted. Eight organizations have acquired the qualifications as the first batch. These organizations came from diverse backgrounds, business scope, and roles, e.g., research institute, policy advisory bodies, business sectors, but in the EPC market, they run a new business of examining saved energy.

This realignment process of actors has been a complex one often involving intensive learning activities and role transformation on the actors' ends.

3.5.2. Realignment of resources

Along with the actors' realignment, various resources, including capital, human, and technology, were realigned as well. Fig. 3 presents the comparison of financial sources into energy conservation projects before and after the introduction of the EPC mechanism. There are two main differences: the government's financial support changed from fixed-asset investments (especially state-owned) to subsidies, and the sources of funding increased, from two investors —the government and energy users to a number of diverse stakeholders —ESCOs, banks, and other market investors. In Shanghai's case, the major financiers have shifted from the government to market investors. According to *the development report of the ESCO industry in Shanghai (2016)*, from 2011 to 2015, the market investment in EPC projects was 8.5 billion, while the government grant was 0.3 billion. This shift in investors' types can be seen as an outcome of resource realignments.

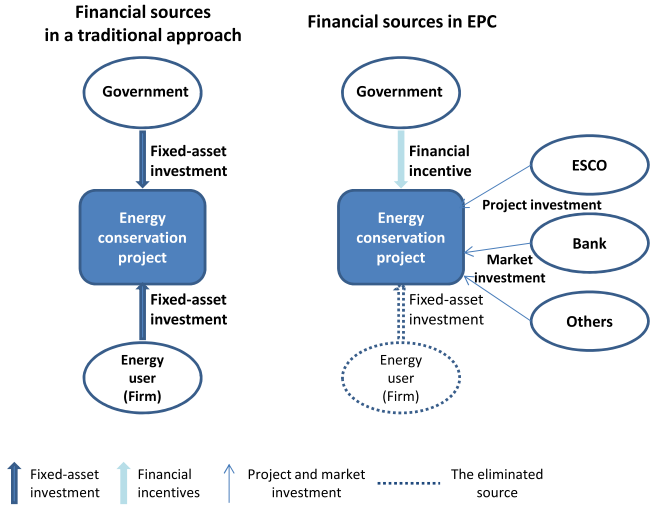

Fig. 3. The comparison of financial sources for technology upgrading projects between in a traditional approach and EPC.

The human resource required in the EPC market has been gradually assembled and trained, with adjusted job assignments for relevant staff, or new job posts, especially for the technical personnel in ESCOs. According to *the development report of the ESCO industry in Shanghai (2018),* the number of people employed in Shanghai's ESCO industry reached 48,600 by 2017. Most of these employees acquired the knowledge, skills, and expertise for their jobs by means of self-learning, training and practicing via projects. The outcome of human resource realignment is a qualified workforce with expected expertise and professional skills.

The implementation of EPC projects has brought about a realignment of technologies and products as well. EPC projects helped fast adoption of some new products/technologies, in particular at their initial stage of entering the market. The popularization process of the energy-saving bulb is an example. The energy-saving bulbs were expensive for users at its early stage, but since being widely used in EPC projects, they gradually became known and accepted by customers. This, along with the declining price, greatly helped the energy-saving bulbs to eventually take a large share in the market, which is a positive byproduct of the EPC projects.

3.5.3. Realignment of institutional arrangements

The introduction of EPC into Shanghai was intertwined with multiple transitions occurring in the city, in particular, the economic transition from planned economy to market-oriented economy, and the government institutional reform towards a service-oriented government. The institutional rearrangements developed in adopting EPC assisted the economic restructuring by nurturing the ESCO industry (service industry) and the government institutional reform by experimenting with their new role as an enabler. A series of policies for adopting EPC has been enacted (Table 2), covering a broad range. This policy framework may indicate a new institutional element emerging in adopting EPC in Shanghai.

The institutional realignment is closely linked to the changing stakeholder roles and actor realignment. For example, the state-owned companies, as energy users, perform as an independent market entity in the EPC market, instead of an affiliate to the government. The government takes the role of an enabler, instead of a regulator and an investor.

Moreover, the popularity of EPC may imply a change in terms of social cognition. People started to acknowledge and understand how market mechanisms, like EPC, work and function, as well as how the service-oriented government may work.

These changes of policies, stakeholders' roles and their internal institutions, and social cognition are all part of the realignment of institutional settings. This realignment to some extent facilitated the economic transition and the transformation of government role as well, which means the influence of post experiment adoption, as illustrated by the Shanghai case, might go beyond the scope of the experiment.

3.6. Endogenous innovation in adoption and contextualization

Shanghai's case shows that the adoption process involves various innovative initiatives and creative solutions, which might be largely driven by the unique challenges and opportunities in a

Table 2
Policies for facilitating the adoption of EPC in Shanghai.

Year	Policy	Government sector
2008	The implementation measures of specific support for EPC projects in Shanghai	SHEIC, SHFB
2008	Shanghai EPC project operational guidance	SHEIC
2010	The administrative measures for energy audit institutions	SHDRC, SHFB, SHEIC, SHCTC, SHQTSB
2010	The administrative measures for ESCOs registration	SHEIC, SHDRC, SHFB, SHCTC
2010	The financial-incentive measures for EPC projects in Shanghai	SHEIC, SHDRC, SHFB, SHCTC
2012	The preferential-tax policy for energy-consumption companies of applying EPC	SHEIC, SHFB, SHLTB
2015	The interim administrative measures for public institutions of implementing EPC projects	SHGAB

Acronym of government sectors: Shanghai Municipal Finance Bureau (**SHFB**), Shanghai Construction and Traffic Committee (**SHCTC**), Shanghai Municipal Bureau of Local Tax (**SHLTB**), Shanghai Municipal Bureau of Government Affairs (**SHGAB**), Shanghai Municipal Development and Reform Commission (**SHDRC**), Shanghai Municipal Commission of Economy and Informatization (**SHEIC**), Shanghai Municipal Bureau of Quality and Technical Supervision (**SHQTSB**).

new context. These innovative initiatives and creative solutions can be considered as *endogenous innovations* during the process of contextualization. Four endogenous innovations can be identified from the Shanghai case, as illustrated below.

Firstly, Shanghai had to find its own ways through learning-by-doing to implement EPC in secondary industries, as there was limited implementation in secondary industries in predecessor cases. For example, some ESCOs have originated their own technical solutions or services to win the market.

Secondly, a new and tailored loan product for EPC projects, named “receivables pledge”, is co-developed by SEPCMC and local banks. ESCOs could use receivables as security for loans, instead of tangible assets in a traditional way, which overcomes the disadvantage of EPC projects as a “new” unproven business. This solution is especially helpful for small-scale ESCOs.

Thirdly, the Shanghai case presents an innovative governmental approach for adoption, including the role of SEPCMC in supporting and coordinating other actors, a set of enabling policies, and a special fund in place for subsidizing EPC projects. This comprehensive and concerted effort by the Shanghai government significantly differs from those reported in other regions, where the government plays a much less prominent role.

Fourthly, some new knowledge - especially the know-how based on local practice was produced in the contextualization process. For example, TERR[1] framework for energy efficiency diagnosis is one of the local research outputs (Wei, 2015; Wei et al., 2015). TERR is acronyms of timing sequence control (T), energy efficiency grade (E), requirement analysis (R), and recycle waste energy (R). This framework was widely used by local ESCOs and energy users in practice. Such new knowledge produced in post experiment adoption might be transferable to other contexts.

3.7. Comparison with the U.S. and German cases

How does Shanghai's case compare with the EPC practices in other contexts, in particular with those in the U.S. and Germany from whom the city had learned? Answering this question is important in helping to understand the nature of post experiment adoption, as the similarities may indicate the linkages across experiments, and the disparities may imply innovative characteristics of contextualization. We compare the three cases in several aspects, e.g., drivers, demanding markets, actor roles, and outcomes of realignments.

As shown in Table 3, there are some similarities. For example, energy security and price factor are two primary drivers for promoting EPC; the building sector is the major demand market; government support is available at the initial stage; some ESCOs are subsidiaries of large companies. These similarities might be due to the characteristics of the EPC mechanism itself, in terms of drivers and demanding markets, or they might be the result of experience sharing and knowledge translating across cases. Importantly, they may reveal some horizontal linkages, such as learning through actors’ interactions.

But there are notable differences in many ways as well, such as the original backgrounds of ESCOs, the nature and scope of government's role, and the policy instruments they employ. These differences are strongly characterized by local contexts. Firstly, the demand sector is different, and in the case of Shanghai, it was mainly the secondary industry. As shown in Table 4, the share of the industrial sector was the largest in the annual revenue of the ESCO industry from 2013 to 2017. Comparatively, the industrial penetration in the U.S. is low, with the public and institutional buildings as the primary market (Satchwell, 2010). In Germany, ESCOs are

Table 3
Comparison of the ESCO industries in Shanghai, the U.S., and Germany.

	Main driving forces	Main market	Main policy leverages	Types of ESCO
Shanghai	Energy security pressure; Energy conservation targets allocated by the upper-level government; A transition from the planned economy to the market economy	Manufacturing industries; Buildings	Demonstration projects; Government agency as a facilitator and coordinator; A supporting policy framework	Subsidiaries of large companies, e.g., manufacturers; Newly-established and small-sized companies
The U.S.	Energy security awareness arose from the oil shocks of the 1970s	Public and institutional markets; Commercial building projects	Establishing and creating an initial demand for ESCO services by policy support and market development programs	Subsidiaries of large companies, e.g., equipment manufacturers, large utilities; Independent ESCOs
Germany	Energy price increase	The supply side of the market, e.g., tertiary and industrial sector if including Energy Supply Contracting; Private sectors buildings; Public sectors buildings	Making standard procedures and documents; Supporting schemes, e.g., Energy Saving Partnership; Government support to ESCOs association	Former municipal utilities; Multinational companies; Large energy companies; Others, e.g., equipment suppliers, construction companies, engineering and consulting firms

The references for this table include: Goldman et al. (2005), Bertoldi et al. (2006), Seefeldt (2003), Hansen et al. (2009), Kiss et al. (2007).

Table 4
Annual revenues of the ESCO industry in different sectors in Shanghai (unit of revenue: billion RMB).

Year Sectors	2013		2014		2015		2016		2017	
	Revenue	Share	Revenue	Share	Revenue	Share	Revenue	Share	Revenue	Share
industry	1.413	46.8%	1.993	43%	2.503	49.5%	1.696	41%	1.575	37.6%
construction	1.057	35%	1.459	31.5%	1.591	31.4%	1.588	39%	1.441	34.4%
transportation	0.074	2.4%	0.110	2.4%	0.118	2.3%	0.057	1.4%	0.328	7.8%
others	0.476	15.8%	1.072	23.1%	0.848	16.8%	0.735	18%	0.843	20.2%

Sources: The development report of the ESCO industry in Shanghai Municipal Government (2015, 2016, 2018).

more active in the supply-side market, e.g., boiler house retrofits; and improved hot water and steam distribution systems (Hansen et al., 2009). This difference in demand markets across cases may indicate EPC project experiences are not necessarily compatible across contexts, which means Shanghai's ESCOs needed to learn more from their own local projects.

Secondly, the business scopes of ESCOs' parent companies are different. In the U.S. and Germany, parent companies are large utilities, energy companies, and equipment suppliers, whereas, in Shanghai, some ESCOs originated from large manufacturing companies. This difference may indicate different business motivations and business models of ESCOs across different contexts.

Thirdly, the degree of governments' involvements is different. The Shanghai government is more proactively involved in establishing the local EPC market, while in the U.S. and Germany, the government was less involved. In Berlin, for example, the ESCO industry was promoted by an energy agency consisting of multiple stakeholders, including the local government, banks, and energy companies. The government subsidized some projects at the initial stage but drew back later, and then the agency operated independently (Singh et al., 2009). In contrast, the enabling/coordinating agency in Shanghai case is an affiliate to the government, with stable and continuous policy and financial support.

4. Discussion: post experiment adoption and contextualization as an innovation

Our analysis above shows that a new social-technical configuration could emerge in contextualization, albeit supported by the linkages with other similar experiments somewhere else. In order to articulate the dynamics and characteristics in this course, we present a conceptual framework illustrating the post experiment adoption and contextualization, as shown in Fig. 4.

The left part in Fig. 4 shows three key components of the sustainability experiments, from whom the adopters learn from, including the innovation (it could be products/technologies/social practices), the proven outcomes (the vision), and the established social networks and other components that enable the innovation in the original contexts. The knowledge from the existing examples provides learners a vision, prospective, and initial understanding of the innovation before adoption, which may enable the formation of a collective credible expectation by actors towards innovation, and further encourage them to develop strategies to make systemic efforts for transition (Bakker et al., 2012; Berkhout, 2006; Budde et al., 2012; Farla et al., 2012).

There are some apparent advantages of being an adopter, e.g. the existence of the proven outcome and available knowledge/experience. However, the new context is often different from those where original experiments were implemented. Such disparities imply possible barriers or favorable factors while embedding the introduced innovation.

Although the success in the original context can attract/encourage potential stakeholders to participate in the new context,

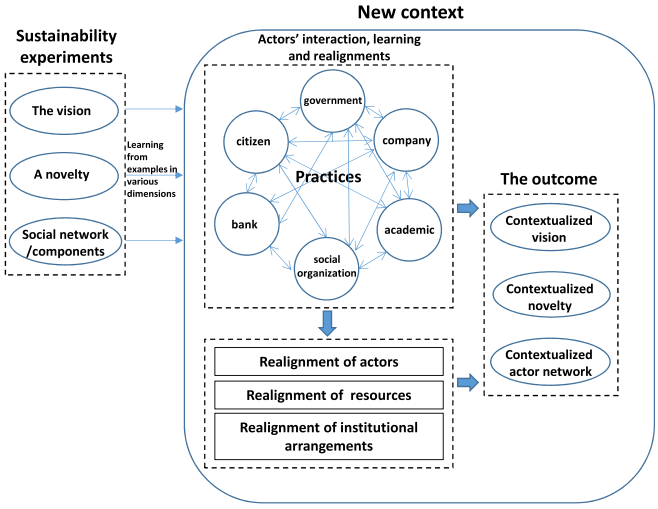

Fig. 4. Horizontal linkages and the innovative processes in post-experiment adoption.

the vision may need to be fine-tuned according to the local circumstances as a "contextualized vision", as illustrated in the Shanghai case. There might be a "facilitator" from the learner side (e.g., the local government) or from the outside (e.g., international organizations) to initiate the adoption. The facilitator' role is critical in contextualization, especially when they possess the required resources or power (Farla et al., 2012).

Various learning processes occur in practices through actors' interaction, with two characteristics. Firstly, there is a clear shift from across-cases learning to internal reflective learning (illustrated in section 3.3). Secondly, "social learning" (as opposed to "technical learning") is dominant in contextualization, with the aim to establish the institutional configuration within the new context. This is because the technical aspects are relatively stable once it has been tested in the original experiment and context-free.

The three realignments taking place in post experiment adoption (shown in Fig. 4), i.e., a realignment of actors, a realignment of resources, and a realignment of institutional arrangements, are interlinked and central to the contextualization. The stakeholders have access to various resources (Wieczorek et al., 2015), and the extent to which they can mobilize those resources might affect their role and performance in the new network, as well as influence the dynamic processes of resource mobilization and institutional restructuring (Farla et al., 2012; Musiolik et al., 2012).

As a result, a new socio-technical configuration, with contextualized vision, contextualized novelty, and contextualized social network/components, has emerged in the new context. Here, we emphasize that the outcome of this contextualization is distinctive from those of predecessors from whom learners drew experience. What can be observed from the case study is that contextualization might be a process of establishing a variety of connections between the introduced innovation and the social context in a recipient side,

achieving the institutional embeddedness of an introduced innovation. In addition, one characteristic of contextualization can be recognized as "endogenous innovation", which are original and inventive elements emerged during the contextualization process.

Understanding contextualization offers an opportunity to investigate horizontal linkages between a similar type of experiments across time and space. The linkages shown in Shanghai's case include an information/knowledge flow across cases and interactive activities between stakeholders from different contexts. Particularly, peer learning and replication of "good practices" enabled by these horizontal linkages may be of critical importance to the adoption process. For example, in the case of South-South transfer of experiences of village-level solar power supply models from India to Kenya, the role of horizontal linkage provides important inspiration and knowledge for the development of new socio-technical designs in a new socio-spatial context, based on local needs (Ulsrud et al., 2018). This study emphasizes that similar problem situations between countries may enhance the effectiveness of learning processes, which illustrates the importance of the horizontal linkages between relatively homogenous contexts; while our research further inspects the role of the horizontal linkages in innovative processes across divergent environments.

Post experiment adoption is critical for "upscaling" and "broadening" innovations. The scaling up and out processes are possible pathways for sustainability experiments to change regional, national and global policy, and to spread at a larger scale (Smeds and Acuto, 2018).

The new social, economic and institutional configuration that emerged in contextualization might imply that contextualization could be a new source of innovations. Berkhout et al. (2010) emphasize that in developing regions, new technologies or innovative practices may be learned from industrialized countries, but locally interacting processes of social, institutional and technological learnings and practices are crucial for innovations. The innovation from contextualization might become a "seed for transition (Elzen et al., 2004)", bringing a sustainability gain to the learners' side. In Shanghai case, after the EPC adoption experiment was successfully conducted in pilot projects, the learning was integrated into the municipal government's policy-making process for proliferating EPC in the city, culminating with a regime change in the practice of improving energy efficiency in Shanghai.

Innovation in contextualization is crucial for the diffusion of a successful sustainability experiment. The establishment of an EPC market in Shanghai is a successful case; while a failed case can be found in Williams (2016)'s study. A low-carbon experiment initiated in Sweden encountered difficulties while being translated into China, failing to engender a contextualization outcome, because "the core Swedish principles underpinning the model (e.g., major public investment, city-wide infrastructural systems) are incompatible with the Chinese development regime." In addition, Kirchherr and Urban (2018)' research also recognizes institutional factors in the recipient country as key determinants in the successful adoption of low carbon energy technology. Based on the perspective developed in our paper, the failure in the above cases is due to the lack of innovation in the contextualization process. As we contended in this study, contextualization requires a great amount of innovative efforts from various actors in the new context, in addition to horizontal linkages with the original experiment.

5. Conclusion

How successful sustainability experiments travel across contexts is not well understood in the socio-technical system innovation and transition literature. To fill this gap, this paper aims to explore the characteristics and internal mechanisms of the translation and contextualization of innovative practices proven effective in other contexts, taking the adoption of EPC in Shanghai as an example. We begin with the conceptualization of key elements of innovation, which includes the articulation of vision, the processes of learning, and the realignment of actors, resources, and institutional arrangements. We then use this characterization to examine the contextualization process of EPC in Shanghai. To better understand the nature of contextualization, we extract and compare the process and outcome of the contextualization to those in the original contexts. Finally, we examine the role of horizontal linkages across similar cases.

Our analysis shows that a new social, economic and institutional configuration that emerged from the realignment process is the key for an innovation to be embedded in the new context. This process of contextualization goes far beyond learning and copying from previous successful examples. The initial stage can be facilitated through various "horizontal linkages", which include information/knowledge transfer and learning via actor interactions across experiments. But, subsequently, there is a clear shift in terms of dominant learning mode – from external cross-cases learning to internal reflective learning. These social, economic and institutional outcomes of contextualization are also distinct from those of the predecessors, with many home-grown innovative elements. Thus, even though a post experiment adoption clearly benefits from having predecessors, e.g., established visions, proven outcomes, and available information/knowledge to learn from, it involves much more than simple duplication, and in many ways can be considered to be an innovation itself.

The conceptual recognition of innovation during the contextualization process, supported by horizontal linkages but emerging during the learning and realignment processes in the new context, may shed some light on why many proven innovations and successful experiments are not swiftly translated and duplicated elsewhere in practice. Theoretically, it may contribute to a better understanding of diffusion, embeddedness, and scaling of sustainability experiments to achieve sustainability transition. Contextualization could be a new source of innovations. Renewed attention needs to be paid to identifying, extracting, and integrating/translating the learnings from these new innovations into the transferable knowledge.

Note

1. An energy technician/consultant can use this framework when diagnosing the energy saving potential for a energy user from four perspectives: 1) whether the operation time of an equipment is necessary, any energy is wasted because of inappropriate time management; 2) Whether there are products with better energy-efficient performance that can replace current equipment; 3) whether the operation of current equipment is beyond the actual demand, which indicates the energy-saving potential; 4) whether wasted energy can be recycled.

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Chapter 4: Financing urban low-carbon transition: The catalytic role of a city-level special fund

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Financing urban low-carbon transition: The catalytic role of a city-level special fund in shanghai

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ABSTRACT

Financing mitigation actions in cities is critical to achieving 1.5 °C emissions pathways. Direct funding, such as grants and subsidies, is a feasible financial instrument to enable local authorities to conduct climate mitigation projects. Current literature has largely focused on the cost-effectiveness of direct-funding instruments on carbon reduction, but little on how these instruments influence other aspects of the urban low-carbon transition. A comprehensive understanding of the role of direct funding in low-carbon transition is important, as this new understanding may potentially encourage more direct investments by cities into their low-carbon initiatives. Here we examine the direct and flow-on effects of a city-level direct-funding scheme on urban low-carbon initiatives, taking Shanghai as a case study. Our findings show that the direct results of Shanghai's fund scheme include carbon reduction outcomes and a variety of policy outputs, such as a range of subsidy policies, data reporting systems, and demonstration projects. More importantly, over the 11 years of its implementation, the fund has become a catalyst for a series of institutional changes – by enabling and enhancing cooperation across numerous government departments in Shanghai. In addition, the funding scheme created avenues for the engagement of business stakeholders and raising public awareness on low-carbon and sustainability issues, through subsidizing technology adoption and low-carbon-themed campaigns. Collectively, these processes have improved the city's capacity for achieving low-carbon transition. Our study shows that a well-designed, city-level direct-funding scheme can fill the "implementation" gap between the policy intentions (i.e., the low-carbon initiatives and implementation framework) and the policy outcomes (e.g., carbon reduction and the institutional formation in the transition). Such a scheme may also nurture and enable a pool of policy experiments and innovations for effective policy learning, identification of successful experiments, and upscaling. With these broader catalytic effects, a city-level direct fund could be a justifiable and attractive option in managing low-carbon transition.

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1. Introduction

Low-carbon transitions in cities are critical to ensuring a climate-safe future (Bai et al., 2018b; Bazaz et al., 2018; Broto and Bulkeley, 2013; Mi et al., 2019), but how to finance low-carbon transition cost-effectively is a primary challenge faced by local authorities (Colenbrander et al., 2018; Stern, 2007). Against this backdrop, some frontrunner cities are actively practicing a variety of approaches with commonly used policy instruments, as well as experimenting with innovative financial mechanisms (Bodnar et al., 2018; Environment, 2018; Irvine and Bai, 2019).

Some frontrunner cities have demonstrated their willingness and competence in financing urban low-carbon transition (C40 and Arup, 2015; Deng-Beck and van Staden, 2015; Environment, 2018). For example, more than 50% of reported urban climate actions within C40, the carbonn® Climate Registry, and the Organisation for Economic Co-operation and Development (OECD) were funded by the city budget or their savings (C40 and Arup, 2015; Deng-Beck and van Staden, 2015; OECD, 2018). In terms of investing in energy efficiency and renewable energy technologies, some cities move even faster than their national governments, driven by the energy-consumption growth due to urbanization (REN21, 2017). Yet, on a global scale, cities' financial competence for mitigation as a whole is inadequate, especially in developing regions (Barnard, 2015; Homsy, 2016; McLean and Borén, 2015). Thus, to mobilize more financial resources, a stronger justification for direct investment

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Abbreviations

AB	Audit Bureau
AC	Agriculture Commission
CAB	Civil Affairs Bureau
CC	Commerce Commission
CTB	Culture and Tourism Bureau
CTC	Construction and Transportation Commission
DRC	Development and Reform Commission
EC	Education Commission
EIC	Economy and Informatization Commission
EPB	Environmental Protection Bureau
FB	Finance Bureau
FDSB	Food and Drug Supervision Bureau
GAB	Government Administration Bureau
HC	Health Commission
HMC	Housing Management Commission
HRSSB	Human Resources and Social Security Bureau
IO	Information Office
LCAB	Landscaping and City Appearance Bureau
MSB	Market Supervision Bureau
PLRB	Plan and Land Resources Bureau
PSB	Public Security Bureau
QTSB	Quality and Technical Supervision Bureau
RTB	Radio and Television Bureau
SB	Statistics Bureau
SC	Supervision Bureau
SOAC	State-owned Assets Supervision and Administration Commission
STC	Science and Technology Commission
TPMB	Transport and Port Management Bureau
WMB	Water Management Bureau
WMO	Waste Management Office

into urban low-carbon transition is required (Coalition for Urban Transitions, 2019; Gouldson et al., 2018).

Public funding can be vital for urban low-carbon transition, as it can be used as financial leverage to encourage private sector investment or to reduce the upfront cost for new technology adopters, often in the form of subsidies (Fuller et al., 2009; Roy et al., 2013; Zhan and de Jong, 2018). Subsidization is considered a feasible option for promoting climate action because subsidy providers do not seek a financial return on investment (Price et al., 2008). In this sense, there will be less difficulty for relevant stakeholders to accept and implement. In practice, subsidies and grants are the second most commonly used mechanism among C40 cities (C40 and Arup, 2015). There is a compelling economic case for stakeholders in cities to make an investment at scale into cost-effective low-carbon measures (Gouldson et al., 2015). However, in reality, a higher upfront investment in carbon-efficient measures than in conventional alternatives (Schmidt, 2014) may become a barrier for adoption. In the short term, subsidies by governments can remove this price barrier to encourage the initial uptakes.

In practice, subsidies have been applied in various urban sectors to facilitate the adoption of new technologies, to encourage private sector investment, or to reduce the upfront cost for adopters (Fuller et al., 2009; Roy et al., 2013; Zhan and de Jong, 2018). Examples include improving energy efficiency in buildings (Di Pilla et al., 2016; Hou et al., 2016; Krarti, 2015; Lihtmaa et al., 2018), promoting electric vehicles in the transport sector (Masiero et al., 2016; Thorne and Hughes, 2019), and encouraging rooftop solar photovoltaic (PV) installation in households and businesses (Asano and Aoshima, 2017; Frey and Mojtahedi, 2018; Fuller et al., 2009; Mah et al., 2018; Rodrigues et al., 2017), etc. Moreover, subsidies can be flexibly designed in diverse ways to fit different circumstances and policy needs. There are many examples of this, including rebates, municipal green bonds, revolving green funds, energy efficiency mortgages, and tax abatement (C40 and Arup, 2015; Thorne and Hughes, 2019; Van der Heijden, 2017).

Subsidies as policy instruments are not without limits. The subsidy scheme may attract criticism for its market-distortion effect (Burniaux and Chateau, 2014; Owen, 2004). For example, global fossil-fuel subsidies remain large, amounting to 6.5% of global GDP in 2015 (Coady et al., 2017), which in itself creates obstacles for renewables deployment and energy-efficiency improvement (Assmann et al., 2006; REN21, 2017). In addition, subsidies can be expensive; thus, they are often constrained by the limits of governments' financial and administrative budgets (de Groot et al., 2001; Houde and Aldy, 2014; Price et al., 2008; Rosenow and Galvin, 2013), and also might be challenged by opportunity costs in terms of how to optimize the allocation of limited public budget.

More importantly, the price barrier is not the only obstacle to enable low-carbon actions in cities. Studies (Colenbrander et al., 2017; Gouldson et al., 2015) indicate that building local capacity, enhancing provision of information, and developing favorable institutional and policy environments are essential to enable the long-term low-carbon transition. This is because even if there is a possibility of allocating an extra budget for subsidizing urban mitigation actions, cities might face difficulties in their institutional capacity to design and implement the subsidy scheme in order to achieve desirable outcomes. In some cities, for example, there might be a lack of coordination power across key urban elements to stimulate and facilitate the transformative change, which may be caused by path dependency and lock-in in institutional behavior (Bai et al., 2016). The nature of urban low-carbon transition as an inter-sectoral, multi-level, and multi-actor process (Runhaar et al., 2018; Webb et al., 2018) calls for a re-assemblage of institutions at a city level to tackle the inherent temporal, spatial, and institutional mismatches in urban low-carbon governance (Bai, 2007; Bulkeley and Luque-Ayala, 2017; Dowling et al., 2014). In this regard, the design and implementation of subsidies in low-carbon transition require institutional collaboration, and thus also have the potential to change the status quo. However, there are few insights in the existing literature on the interlinks between city-level subsidies and institutional collaboration. Most existing literature focuses on the cost-effectiveness of subsidy policies and the direct carbon-reduction result, without taking into account the more comprehensive, flow-on effects of such policy measure (Dowling et al., 2014; Kalkuhl et al., 2013; Sarkar and Singh, 2010).

Moreover, from the urban sustainability transition perspective, cities' low-carbon transition requires changes in many urban sectors in a systematic matter (Bai et al., 2016), which require many trial and error. Low-carbon innovations can be tested through urban sustainability experiments (Bai et al., 2010; Berkhout et al., 2010). Policy interventions and financial support play an enabling role in initiating and adopting these low-carbon experiments (Peng and Bai, 2018), but it remains unclear how city-level financial mechanisms can stimulate and nurture such experiments.

To fill the gaps, this paper examines the direct and indirect impacts of a city-level direct-funding scheme, taking Shanghai's special fund aiming at energy conservation and emissions reduction as a case study. We focus on the design, implementation,

effectiveness, and direct and flow-on impacts of a city-level funding scheme to achieve their low-carbon policy targets. The following section presents a literature review on the role of direct-funding instruments in urban climate mitigation. Section 3 presents the methodology for case analysis. Section 4 analyzes the fund design, size, distribution, and implementation. Section 5 evaluates the outcomes of the special fund, in terms of direct carbon reduction, spillover effects on institutions, and on enabling sustainability experiments for the transition. In Section 6, we discuss the implications and limitations of the direct-funding scheme illustrated by the Shanghai case, grounded in the relevant literature. Section 7 presents our conclusions.

2. Literature review: the role of direct-funding instruments in urban climate mitigation

To enable the transition towards sustainability, subsidization is a widely used policy instrument for enabling energy efficiency and deployment of renewables (Assmann et al., 2006; The World Bank, 2010; Owen, 2006), with the benefit of emissions control (Dowling et al., 2014; Fischer and Newell, 2008; Kalkuhl et al., 2013; Menanteau et al., 2003; Sarkar and Singh, 2010; Tanaka, 2011). Subsidies for energy efficiency improvement are one of the most widespread fiscal incentives applied in energy-saving projects (Price et al., 2008; Tanaka, 2011), since they began in the 1970s. Subsidies as capital incentives encourage energy users to adopt energy-efficient technologies (de Groot et al., 2001; Kemp, 2000; Tanaka, 2011). In addition, subsidized projects may also play a demonstrative role in disseminating information about the existence and user experience of these new technologies (de Groot et al., 2001). Moreover, from the government's standpoint, subsidies could be viewed – as a temporary measure – as a lever or stimulus to prepare for new regulations relating to an emerging social-technological practice. Eventually, a larger market might be created than otherwise exists, demonstrated in the popularity and social acceptance of the subsidized energy-efficient technologies (WEC, 2004). Similarly, subsidy schemes for promoting the deployment of renewable energies are expected to facilitate the establishment of a sustainable renewable energy market (Fischer and Preonas, 2010). The most commonly used subsidy for this purpose – feed-in tariffs (FIT) – has been proven effective in promoting renewable electricity in some places (Butler and Neuhoff, 2008; Fischer and Preonas, 2010; Menanteau et al., 2003; Mir-Artigues and Del Río, 2014; Nicolini and Tavoni, 2017; Zhao et al., 2013).

On the other hand, there is a long history of subsidizing fossil-fuel energies, which continues to grow in recent years (Burniaux and Chateau, 2014; Gerasimchuk, 2015; Merrill et al., 2015; Ochs et al., 2013). This large amount of government expenditure has encouraged massive carbon emissions on a global scale and also blocks the deployment of renewable energies (Stefanski, 2017). Hereof, removing fossil-fuel subsidies may alternatively benefit climate mitigation (Burniaux and Chateau, 2014) and also save the public budget. A recent study shows that if this released budget can be wisely reinvested in other sectors, such as transportation, positive outcomes on economic growth and income distribution can be expected (Kim and Samudro, 2019). In this sense, globally, the financial gap for sustainability transition (IPCC, 2018) might be not only about the insufficient government budgets, but more a matter of the misplaced financial resources in the energy market.

At the same time, cities, as central players in global climate mitigation, may face the challenge of lacking sufficient fiscal capacity, if they need to adopt direct-funding instruments to enable their low-carbon transition (Homsy, 2016; McLean and Borén, 2015). In practice, subsidies are used as an instrument to facilitate the adoption of carbon-efficient technologies in many urban sectors. For example, subsidies are provided to retrofit buildings to decarbonize existing buildings stock. The relevant research found that the design of a subsidy is key to maximizing carbon reduction and achieving distribution equality (Di Pilla et al., 2016; Hou et al., 2016; Krarti, 2015; Lihtmaa et al., 2018). In some cities where electric vehicles (EV) adoption is being promoted, it is found that the EV price is one significant barrier to adoption (Adepetu and Keshav, 2017); therefore, subsidies on EV purchases can be a useful mechanism. The subsidy design varies according to differentiated local conditions and integrates manifold considerations such as the equity of EV subsidies and the alternative policy options in long-term policymaking (Breetz and Salon, 2018; Masiero et al., 2016; Thorne and Hughes, 2019). Another example is direct funding of rooftop solar PV, proven effective at increasing the number of installations (Asano and Aoshima, 2017; Fuller et al., 2009). The literature on this topic emphasizes the need to consider local natural, economic, and social conditions in policymaking for the cost-effectiveness of policies, such as solar radiation level, subsidization level, and cost saving for self-consumption (Frey and Mojtahedi, 2018; Mah et al., 2018; Rodrigues et al., 2017). The sector-focused subsidy schemes discussed above primarily aim at promoting a specific carbon-efficient technology or project in a particular policy domain, with diverse policy designs contingent on the technology type and varied local conditions, and also in different forms (e.g., post-purchase rebate, tax reduction, or FIT) (Mah et al., 2018; Rogge et al., 2017).

Although the subsidy design is critical to increasing the uptake of new technologies, some practical problems in implementation may affect the effectiveness of this policy instrument. For example, the free-rider problem may hamper the cost-effectiveness of policies (Houde and Aldy, 2014; Malm, 1996; Rosenow and Galvin, 2013; Thollander and Dotzauer, 2010). Also, policy administrative issues may restrict the implementation effects, causing some problems like high transaction costs and complex and long application procedures (de Groot et al., 2001; Price et al., 2008). Moreover, there might be some unintended consequences of subsidy policy design – for instance, some research (Holland et al., 2015) points out that there are land-use costs and habitat loss resulting from subsidizing bio-energy sources.

3. Research methodology

We investigated the Shanghai special fund for energy conservation and emission reduction in a comprehensive way, including the design elements (e.g., policy goals and principles, and the scope and distribution), three implementation stages, and the direct and indirect outcomes. Data were collected through two-month fieldwork in Shanghai, including interviewing government officials and collecting policy documents, which was supplemented by deskwork, including online search. Detailed information on the interviews is presented in the supplementary document 1.

A total of 12 policy domains, consisting of 41 subsidy policies, were identified and relevant data were collected. Collected data were analyzed to first understand the trend of annual fund expenditure and its distribution, and then to estimate carbon reduction from a variety of subsidized policy domains. To understand the role of the special fund in supporting local capacity building, an in-depth analysis of 167 subsidized projects under the subsidy policy for enabling capacity building was conducted. Finally, to understand the effectiveness of the fund in enabling institutional collaborations, linkage analysis was performed on all 41 subsidy policies, identifying all institutions involved in each policy and visualizing their interaction, which also reveals the evolving focus and complexity of institutional collaborations

enabled by the fund. Data collection and analysis of subsidy policies are presented in detail in the supplementary document 2.

4. Case study: the design and implementation of the Shanghai special fund

4.1 The fund design, size, and distribution.

The Shanghai special fund for energy conservation and emission reduction was enacted in 2008, providing financial support to urban sustainability projects and capacity building activities (Peng and Bai, 2015 (Peng and Bai, 2018),). This financial mechanism plays multiple roles in Shanghai's low-carbon transition. Specifically, this policy scheme widely covers 12 policy domains, as shown in Fig. 1, which may enable the city's transitions in a comprehensive way. The fund distribution indicates that air pollution reduction and industrial restructuring are the two primary policy focuses in Shanghai, due to the city's fossil fuel energy consumption status (Liu et al., 2012). In addition, Shanghai is a pilot low-carbon city of China in a national policy-learning scheme (Ohshita et al., 2015; Wang et al., 2015). To perform the city's experimenting role, the special fund also contributes by sponsoring various transition experiments. Moreover, the fund also covers the extra-governmental expenditure on carbon management, such as outsourcing consultancy, staff training, and data collection and reporting, which might improve the carbon administration in the local government.

(Data source: calculated by authors based on the Shanghai government documents, details in the supplementary document 2).

Before this fund scheme, there were already some sector-based subsidy policies, with carbon reduction effects (Peng and Bai, 2018). Comparatively, this new scheme covers cross-cutting mitigation issues, with the possibility of triggering cross-jurisdiction policy coordination, by means of financially mobilizing different government departments to collaborate.

The special fund policy explicitly indicates that the sources of the special fund are from the municipal fiscal budget, price-discrimination charge for electricity use, and other sources of public funds allocated by the municipal government. How the local government manages their municipal finance to allocate budget is beyond the scope of the paper - the focus of this research is how allocated fund are used to enable low carbon transition.

Subsidies in this special fund scheme come in two forms. The first is direct financial incentives to engage other stakeholders, including the business sector and citizens. For example, the firms are rewarded with capital incentives based on their reduction performance. This rewarding design may drive the firms to try to achieve their best carbon reduction outcome (Wang, 2014; Zhang, 2014). The second subsidization form is to invest in policy research/consulting and in the building-up of reporting and monitoring systems, or to cover the extra cost of administration.

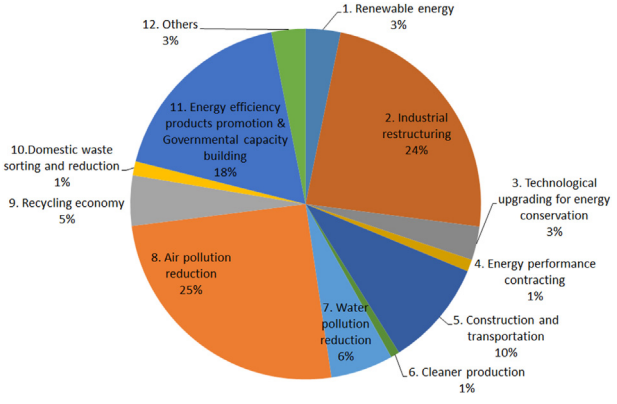

Fig. 1. The fund distribution in different policy areas based on the total expenditure from 2009 to 2018.

There is a consistent budget input in this fund scheme (Fig. 2). Its share in annual GDP was fluctuating between 0.05 and 0.14% from 2009 to 2018, and the percentage in annual fiscal expenditure was between 0.19 and 0.51% during the same period. This public fund investment may indicate the Shanghai government's willingness and financial capacity for its low-carbon initiatives.

(Data source: calculated by authors based on Shanghai government documents, details in the supplementary document 2).

4.1. Fund implementation

This fund and the coordination mechanism across institutions are two pillars in Shanghai's low-carbon governmental structure (Peng and Bai, 2018). In reality, the fund mechanism operates within the structural framework of the coordination mechanism. Specifically, Shanghai's Municipal Development and Reform Commission (DRC) plays a joint role in connecting these two mechanisms, through the integrated duty of coordinating inter-sector collaboration and managing the fund. The DRC is responsible for making an annual reduction plan, convening institutions to collaborate, and allocating and monitoring the fund use.

The fund scheme includes two levels of policies. The master policy defines the overall purpose, principles, scope, and operating procedures. Under these guidelines, each subsidy policymaking and policy implementation follow three steps – policy design, budget allocation, and policy implementation, with the first two steps primarily involving coordination within the governmental agencies, and the third step engaging more types of stakeholders.

We take one subsidy policy as an illustrative example: Promoting the adoption of electric vehicles (EV). This policy project engages seven governmental units: the DRC, the Finance Bureau (FB), the Economic and Informatization Commission (EIC), the Commerce Commission (CC), the Science and Technology Commission (STC), the Construction and Transportation Commission (CTC), and the Public Security Bureau (PSB). Each sector has its specific role in policymaking and implementation, in accordance with its jurisdiction and administrative duties.

The policymaking process for an individual subsidy policy has a "gluing effect" on governmental agencies, where these agencies are collectively working on a multi-target policy proposal. There is a lead department in policymaking, and other department co-operates. All the participant departments jointly issue the policy after it is approved. This policy proposal consists of both policy goals and operation details, and can be adjusted at the operation stage, integrating practical feedback and changing conditions. Following the EV adoption example, the policy details were revised twice after its initial design in 2016 and 2017, respectively.

The second step of budget allocation comes after the approval of the policy plan by the DRC, including a few rounds of interactions between the DRC (the coordinator) and other institutions, as illustrated in Fig. 3. The cooperating sectors are required to report the fund demand to the DRC for annual budget planning. Then, the DRC and FB evaluate the budget request before allocating the money to this subsidy policy (Fig. 4).

At the operational stage, other stakeholders, including individuals, businesses, or research/consultancy institutes, are engaged as subsidy recipients. Fig. 5 exemplifies the policy implementation of EV promotion, collectively operated by five governmental sectors under the coordination of the DRC. There are two types of subsidies in this subsidy policy: One is the purchase rebate and the other is a free license plate to the EV buyers. Purchase rebate is covered by the fund

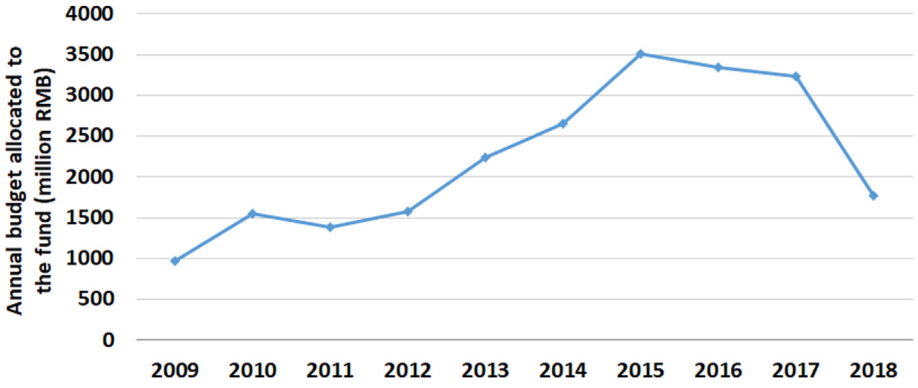

Fig. 2. Annual budget allocated to the special fund.

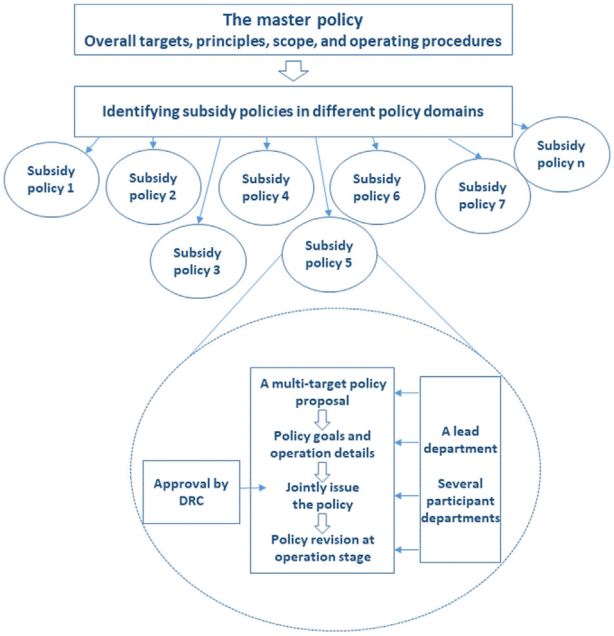

Fig. 3. Policy design: the policymaking process for an individual subsidy policy. Note: DRC: Development and Reform Commission.

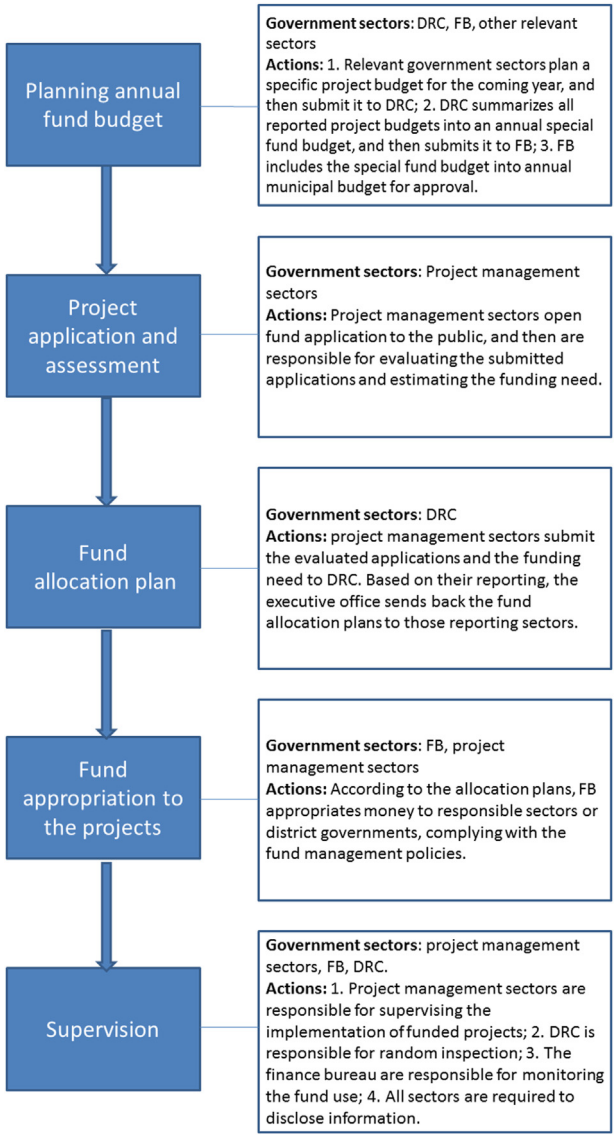

Fig. 4. Budget allocation: the process of budget allocation for an individual subsidy policy. Note: DRC: Development and Reform, FB: Finance Bureau.

scheme. After purchase, the fee for the plate is waived by the government as well. In Shanghai, an auction-based mechanism for a new number plate is implemented, with an average cost of around US$13,000 per plate in 2018. Required by the policy, the automobile companies apply for certification for a certain vehicle model in order to qualify for the purchase rebate. After the sale, the buyers are obliged to provide the vehicle registration documents to the sellers for them to claim the rebate. The CTC and PSB are collectively in charge of issuing the plates, and also provide registration documents to the new EV owners for the rebate-claiming procedure. The CC is also a participant department, who is responsible for setting regulations for the second-hand EV market (Fig. 6).

The case of promoting EV adoption unveils various institutional cooperation under the special fund scheme. Over 11 years, a total of 41 subsidy policies in 12 policy domains have been enacted. The detailed analysis of how these policies have collectively enabled the institutional changes in the city's low-carbon governance will be discussed in the next section.

DRC: Development and Reform Commission, FB: Finance Bureau, EIC: Economy and Informatization Commission, PSB: Public Security Bureau, CTC: Construction and Transportation Commission, STC: Science and Technology Commission.

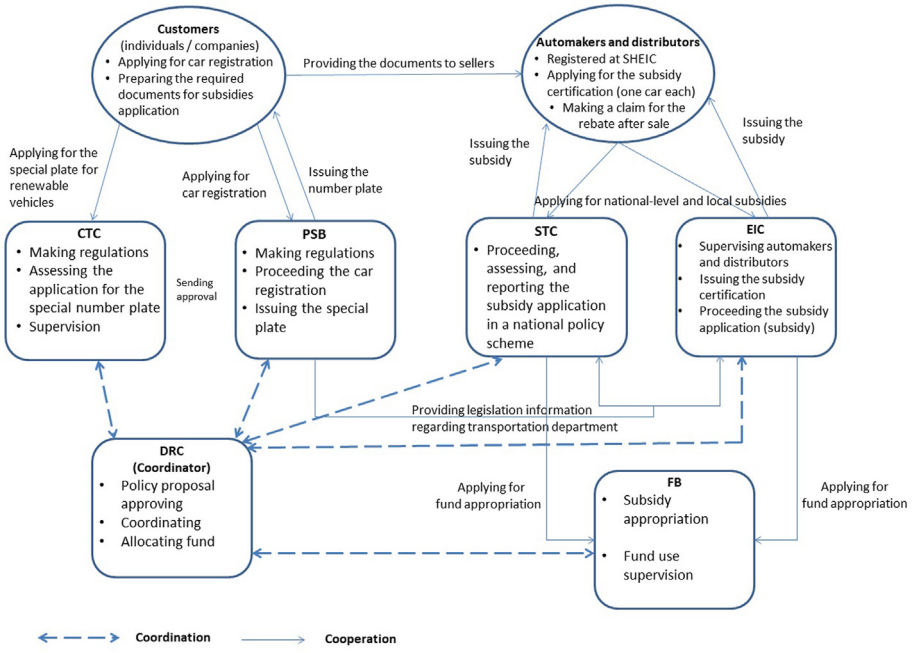

Fig. 5. Policy implementation: the stakeholders' roles and interactions at the implementation stage. Note: Here coordination refers to organizing and intermediating participating departments in the projects, but not directly participating; and cooperation refers to directly working on the projects.

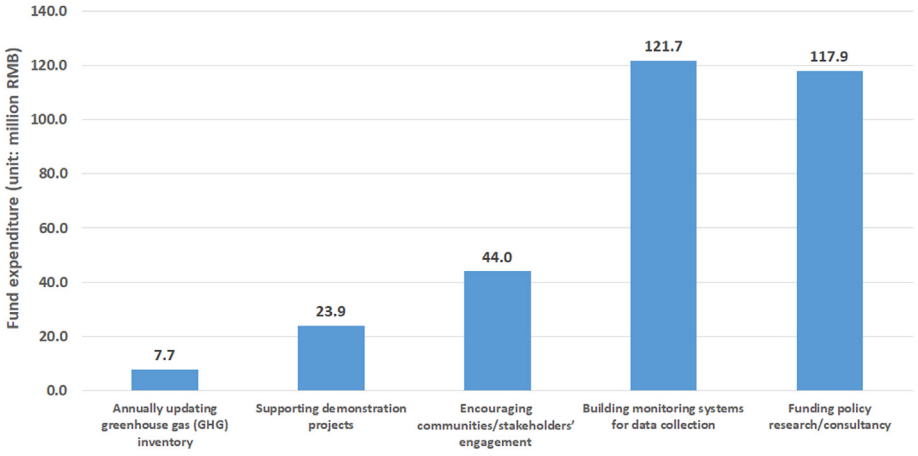

Fig. 6. The categories of funded capacity-building programs and their scale from 2009 to 2017.

5. Case study: direct and spillover effects

5.1. Direct policy results

Two types of direct policy results can be identified, including carbon reduction outcomes and a series of capacity building initiatives. Based on government-released data, we estimate carbon reduction in eight policy domains from 2011 to 2015, where 85% of the total fund is spent, as shown in Table 1. The carbon reduction of this scheme is equivalent to 1.6% of Shanghai's energy-based carbon emissions[1] during the same period. The share of 1.6% may only represent a fraction of an aggregated outcome of all carbon-control policies in Shanghai. Besides the special fund scheme, there are other sector-based schemes with a carbon reduction effect, for example, in the policy domains of energy conservation, environment protection, industrial restructuring, and technologies promotion (Peng and Bai, 2018). Comparatively, this special fund focuses more on cross-cutting policy issues, playing a role in further reducing the emissions in addition to other existing policies. As shown in Table 1, the cost-effectiveness of different subsidy policies under this special fund scheme on carbon reduction is calculated as million RMB/million tons, which is ranging from 55.15 to 6034.48 million RMB/million tons. The subsidization of technical improvement for energy conservation in industries is the most efficient one.

The CO2 emission factor for standard oil adopted in this table is 3.19 ton CO2/ton standard oil, calculated based on the default values from the policy of the accounting and reporting guidance for greenhouse gas emissions in Shanghai.

To understand what kinds of capacity-building actions are supported and their scales, a total of 167 projects are identified in the policy category of "local capacity building" (category 11 in Fig. 1) between 2009 and 2018. The projects are classified into five groups, as shown in Fig. 5 (the detailed information on data collection and classification is included in the supplementary material 2). They are

Table 1
The direct carbon reduction and the cost-effectiveness of the fund projects.

Supporting areas	The number of subsidized projects	Fund cost (million RMB)	Outcome	CO_2 Emission reduction (million tons)	million RMB/ million tons
Industrial restructuring	4208	2570	Saving 4.35 million tons standard coal	9.70	264.95
Replacing fossil fuels with clean energy for boilers and furnaces	5153	560	Saving 1 million tons standard coal	2.23	251.12
Renewable energy	Wind power project: 0.473 million kilowatts Solar energy project: 0.1 million kilowatts Annual energy production: 1.2 billion kilowatt-hours	190	Saving 0.36 million tons standard coal	0.95	200
Transportation	The number of energy-saving projects in the transportation system: 153 Replacing fuel oil with clean energy for 1243 vehicles	430	Saving 0.21 million tons standard oil	0.70	642.75
Energy performance contracting	311	90	Saving 0.148 million tons standard coal Stimulating non-government investment 516 million RMB	0.33	272.73
Promoting distributed energy systems and gas-fired air conditioning	The number of distributed energy systems: 11 The number of gas-fired air conditioning: 28	70	Saving 5210 tons standard coal	0.01	6034.48
Circular economy	46	120	Saving 500,000 tons standard coal	1.12	107.62
Technical improvement projects in energy conservation in industries	935	300	Saving 2.44 million tons standard coal	5.44	55.15
Energy-saving projects and the building-up of energy monitoring systems in buildings	The number of green building projects: 297 The number of energy-monitoring buildings: 1288	430			
Promoting EV and building charging points	The number of subsidized EV: 54,000 The number of charging points: 21,700	1130			
Promoting energy-efficient air-conditioners and lighting	The number of subsidized air-conditioners: 1.72 million The number of subsidized light bulbs: 7.96 million	210			

* The CO2 emission factor for standard coal adopted in this table is 2.23 ton CO2/ton standard coal, from the policy of the quota allocation and management plan for the Emissions Trading Scheme in Shanghai from 2013 to 2015.

1) annually updating greenhouse gas (GHG) inventory to monitor urban carbon footprint, 2) supporting demonstration projects for policy/technical learning, 3) encouraging engagement with communities and stakeholders, 4) building monitoring systems for data collection in urban sectors, and 5) funding policy research/ consulting to inform policymaking. These subsidized activities are the direct policy outputs of the fund, which may play an enabling role in developing local government's carbon management capacity and engaging other urban actors.

5.2. Spillover impacts on institutions

Inertia in the urban institutional setting is considered as one of the main barricades to mitigation actions in cities (Betsill, 2001; Webb et al., 2018). In this section, we explore whether this funding scheme may have an impact on the institutional dimension in Shanghai.

5.2.1. Enabling a collaboration institution on cross-cutting mitigation policy issues

A subsidy policy framework enabled by this funding scheme is gradually established, with an increasing number of subsidy policies (shown in Fig. 7) and dynamic policy focuses (shown in Fig. 8) over time. Some policies are task-oriented. Once the specific goal of a subsidy policy is achieved, the local government will move on to new tasks (Peng and Bai, 2018). In each year, the local government introduces new policies, and also removes some old ones. For example, the subsidy policy for promoting energy-efficient air conditioners and light bulbs was cancelled after these promoted products became popular enough in their own right. The policy for promoting industrial waste recycling was phased out when the waste recycling capacity in those industries had been established. But some new policy programs, such as subsidies for green buildings and comprehensive utilization of crop straw resources, were introduced in later years. Thus, the total number of policies may vary year to year.

Along with a growing number of subsidy policies, cooperation across governmental institutions has gradually built up. To understand this institutional process, we adopt the chord chart in Fig. 8, to visualize the collaborative links across institutions involved in policy implementation. We count the connection between two institutions as one link. For example, if four institutions work together in a subsidy policy, the total links of this policy is 6 (the detailed explanation about the development of the chord charts is included in the supplementary document 2). In the beginning, the links between different government departments were only within a small group of institutions; then, the interactions increased across more governmental units over the years. There is a growth in the number of subsidy policies, which may potentially bring more government agencies to join. Moreover, the trend presented by the chord charts may also indicate a growing diversity in subsidy projects, where a variety of government sectors have opportunities

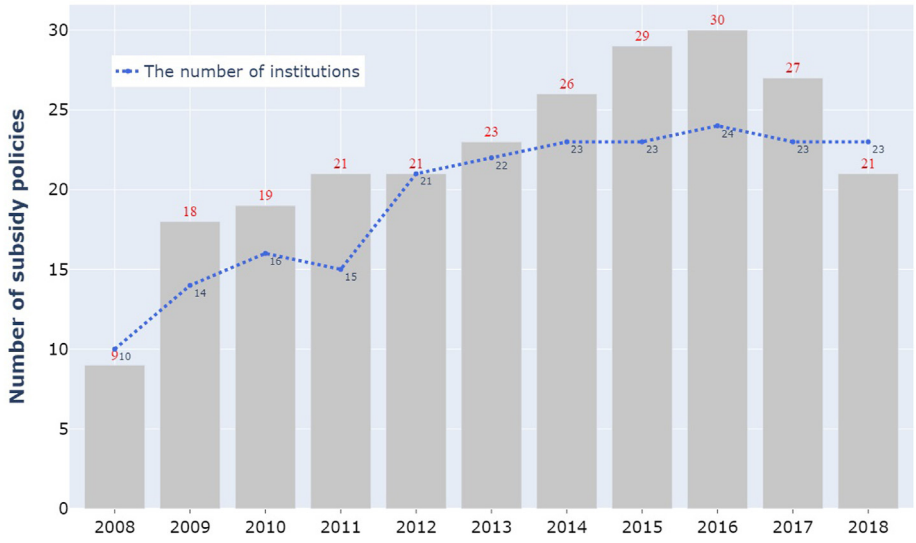

Fig. 7. The total number of subsidy policies and participant governmental sectors in each year from 2008 to 2018.

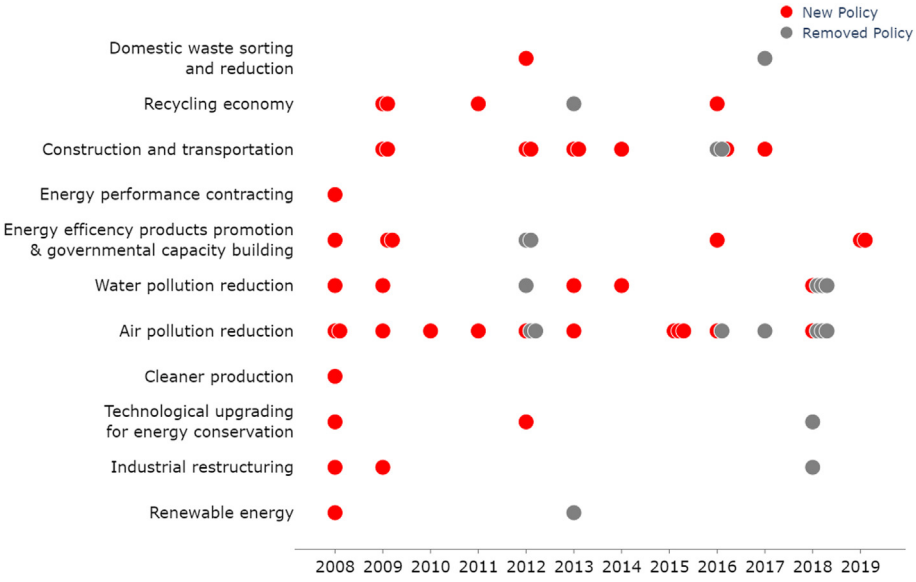

Fig. 8. The changing policy focus - the types of policies funded by the special fund scheme during 2008–2019.

to engage in urban sustainability development. An institution may have connections with many other different institutions, or have intensive links with one single institution but on different subsidy policies. On average, each subsidy policy involves four or five participant institutions. The 11 chord charts unravel an institutional formation process enabled by the funding scheme through a process-oriented approach. This process-analysis method is a novel perspective in the literature for understanding the institutional development for accommodating climate policy issues (Patterson et al., 2019).

To identify which government units are more actively collaborating under this fund scheme, we analyze the participation level of each institution over the years 2008–2018. The participation level of an individual department is the percentage of the number of the policies this department is involved in the total number of subsidy policies over 11 years (the data and calculation process for participation level are detailed in the supplementary document 2). As shown in Fig. 9, the participation level of the majority of the institutions is lower than 20%. Comparatively, five institutions are more involved (above 20%). They are the Development and Reform Commission (DRC), Finance Bureau (FB), Economy and Informatization Commission (EIC), Construction and Transportation Commission (CTC), and Environmental Protection Bureau (EPB). The DRC and FB engage in all subsidy projects due to their roles as coordinator and budget manager, respectively. The participation level of the EIC is also high, between 45 and 80% over 11 years, albeit with a decreasing trend from 77.8% in 2008 to 52.38% in 2018, which indicates that the mitigation activities may concentrate on the economic sector in Shanghai. In contrast, the participation level of the CTC is notably increased from 11.11% in 2008 to 52.38% in 2018. The opposite trends of those two sectors may imply a shift in policy focuses from emissions reduction in the economic domain to urban buildings and transport along with the city's ongoing transition over a decade. Moreover, the participation level of the EPB is

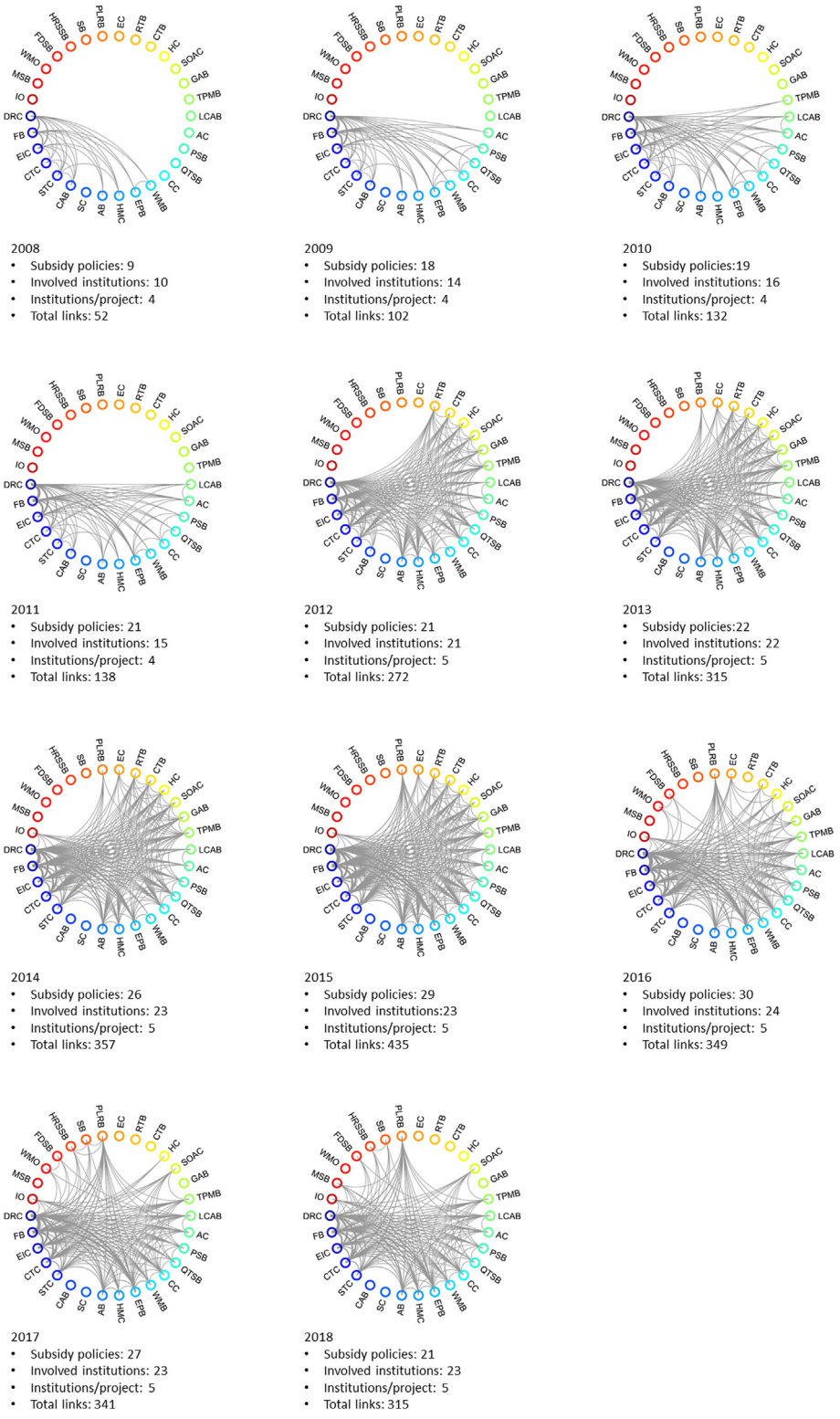

Fig. 9. The cooperation links across institutions under the special fund scheme from 2008 to 2018. Note: See the abbreviation list for the details of the full names of government departments in the figure.

comparatively high and stable between 20 and 50%. The active role of the EPB in collaborating may suggest that the cross-cutting policy issues (i.e., how to achieve synergy effects of a policy on both pollution reduction and carbon reduction) is one major policy concern for the local government, which is tackled under this scheme. This participation-level analysis reveals a degree of coherence in this collaborative network, where a few agencies might be central to conducting mitigation actions in Shanghai (Fig. 10).

Note: See the abbreviation list for the details of the full names of government departments in the figure.

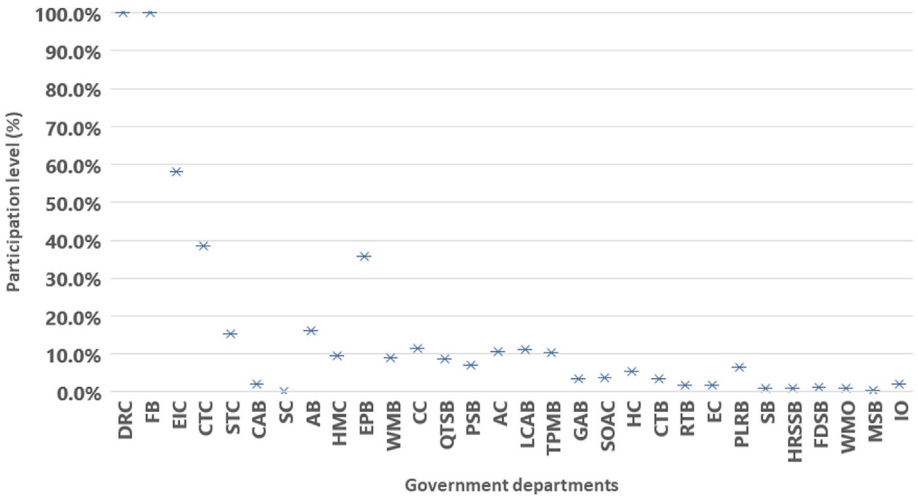

Fig. 10. The participation level of an individual government department over 11 years from 2008 to 2018.

5.2.2. The enabling role in addressing the implementation gap

An "implementation" gap may exist between policy outputs and policy outcomes in urban mitigation. In other words, climate policy outputs may be difficult to translate into concrete actions on the ground. There might be two causes for this gap – a lack of financial resources and a lack of coordination across policy domains (Runhaar et al., 2018). In this regard, the special fund may play an enabling role in closing the gap, through directly subsidizing a variety of mitigation projects, enabling the policy plans to convert into actions, as well as catalyzing an institutional process for cross-sector cooperation. In addition, the fund mechanism is operating within the structural framework of the coordination mechanism designed by Shanghai's government. Therefore, to some degree, this fund scheme may have empowered the coordination mechanism, preventing it from existing only as an "empty frame" without financial resources to support its function in practice.

5.2.3. Capacity building in local actors

The special fund may have also enabled local actors' capacity building, in terms of carbon management and technological updating. The funded training and other assistance to the corporate sectors have helped them to build up their carbon management capacity. In addition, governmental incentives have encouraged local firms to replace their high-emission facilities or to adopt clean energy. For example, the fund has financially supported Shanghai's institutional building-up for Emission Trading Scheme (ETS), where a variety of local actors are engaged in this framework. The scheme has funded several fronts: 1) the policy research for making local monitoring, reporting, and verification (MRV) guidances and trading rules, 2) the carbon-accounting training for the firms, 3) the capacity development of audit institutes to verify corporate emissions, and 4) the establishment of a trading platform. Through these processes, the influence of this special fund goes beyond the public sector, playing a role in enabling the coordination across different actors in low-carbon governance. In our interview, staff members from state-owned large energy consumer industries who were assigned to carbon management duty in some local companies have acknowledged the enabling role of the fund in their internal capacity building on carbon management.

5.2.4. Raising public awareness

The funding scheme has sponsored a variety of awareness-raising campaigns and community activities themed on low-carbon lifestyles. It is hard to quantitatively estimate the impact of those campaigns, but they may play a role in fostering public awareness toward sustainability, by means of spreading knowledge among citizens and encouraging behavior changes. Fostering social cognition – which is regarded as part of informal institutions in society – might benefit the transition (Munir, 2002; Zucker, 1987).

5.3. Generating a pool of experiments

The Shanghai government is open to low-carbon experiments due to its policy-learning role in a national scheme. The special fund plays a role in financially supporting the testing of innovations in policies, technologies, and social practices. For example, under the wide scope of the scheme, it financially enabled a variety of demonstration/pilot projects in technology fields such as carbon/energy efficiency, low emission transport, circular economy, clean production, and in the policy and social practice fields such as pilot Emission Trading Scheme (ETS) and pilot low-carbon communities. These multiple trial-and-error processes create a platform to explore solutions for the transition, although not all experiments can succeed or be popularized on a larger scale.

One case of upscaling is the impacts of Shanghai's pilot ETS in a national scheme. This pilot program provides policy-learning feedback for upper-level ETS policymaking. Moreover, in a forthcoming national market, Shanghai plays an influential role by operating a national trading platform and exporting experiences to other non-pilot provinces.

6. Discussion: the catalytic role of the special fund in urban sustainability transition

Shanghai's experience shows that, to some degree, the city-level direct-funding mechanism can play a role in reducing emissions by subsidizing mitigation actions. This finding echoes the prevailing discussion in the literature, in terms of the emission reduction effect of the subsidy instrument (Dowling et al., 2014; Fischer and Newell, 2008; Kalkuhl et al., 2013; Menanteau et al., 2003; Sarkar and Singh, 2010; Tanaka, 2011).

Shanghai's case also indicates that direct funding can play an enabling role in the city's institutional processes for mitigation. Specifically, its design for tackling inter-jurisdictional policy issues may potentially trigger cross-sector collaborations. Its actual effectiveness in implementation, in terms of establishing a

cooperation institution, is evidenced by the linkage analysis. We identified that the joint role of the DRC as a coordinator and fund manager is the key to the operation process. This is because the DRC can exploit its joint role to run the subsidy policies on the structural framework of the coordination mechanism, and, at the same time, the fund scheme has financially empowered the coordination framework. This coordination institution enabled by the fund is essential for the city's low-carbon initiatives because the transformative change needs a "whole of government" approach, avoiding policy coordination failure (Schot and Steinmueller, 2018). In addition, the special fund might play a role in addressing an implementation gap between policy outputs and policy outcomes (Runhaar et al., 2018), in terms of funding on-the-ground actions and enabling institutional changes.

Comparing Shanghai's case with other cities, the approaches adopted by many municipal governments for urban mitigation have an explicit aim to establish a coordinated institution (Anguelovski and Carmin, 2011; Betsill, 2001; Burch, 2010; Hölscher et al., 2019; Kern et al., 2017), while the primary policy goals of Shanghai's direct-funding scheme are to reduce carbon and to enable policy learning. In this regard, the institutional outcome in Shanghai's case can be regarded as a spillover effect. This finding may bring a new perspective toward the multiple impacts of a subsidy instrument on cities' transition. In the literature, the flow-on impacts of a specific urban initiative on sustainability beyond its initial goals is still underexplored, although there are a few reported cases. For example, taking the city of Durban in South Africa as a case study, Diederichs and Roberts (2016) highlighted the significant opportunities that mega-event greening initiatives offer to promote investments in resource-efficient local infrastructure and to establish local climate protection projects for long-term social and ecological co-benefits. The positive spillover effects of low-carbon policy programs, demonstrated by Shanghai's special fund and Durban's mega-event greening initiatives, may provide encouraging policy lessons - low-carbon policies, if designed well, can harness significant synergies and social-economic co-benefits across different aspects of an urban system and over a long run, which in turn underscores the importance of a systems approach in cities (Bai et al., 2016, 2018a).

Moreover, the fund may catalyze the building up of local mitigative capacity. Some research (Winkler et al., 2007; Yohe, 2001) indicates that the mitigative capacity includes a range of diverse resources, such as financial availability, regulatory effectiveness of government, public attitudes and awareness, technological factors, etc. To mobilize and transfer these resources into effective actions, adequate city-level climate governance – characterized by horizontal cooperation among sectors and stakeholders and vertical connections across levels – is needed (Amir Bazaz et al., 2018; Arup, 2015; Sudmant et al., 2017). In this regard, Shanghai's fund mechanism may not only leverage a variety of local resources but also mobilize them into actions. For example, it supports the adoption of carbon-efficient technologies in many urban sectors, widely engaging a variety of stakeholders from businesses and communities, which might potentially benefit the city's transformative competence in the long run. It also covers the extra-governmental expenditure on carbon management issues, and mobilizes the administrative resources of different government departments on mitigation actions, to enable institutional changes.

The enabling role of Shanghai's direct-funding scheme in local capacity building may have empirical implications in urban sustainability transition. For example, this mitigation competence might be "local-tailored" in Shanghai, considering the contextualized features of the local endowment and mitigation challenges. Some research contends that the local capacity needs could be place-based across diverse geographic, political, and cultural contexts (Dennis Tänzler et al., 2017; Raven et al., 2019). In innovation transfer study, the bespoke local capacity is a critical enabling factor in embedding introduced innovations in the cities to facilitate their transition (Peng et al., 2019; Winkler et al., 2007). In this sense, the Shanghai case might be a useful reference in terms of how to enable local capacity building to assist the contextualization of innovations in sustainability transition research.

Importantly, the fund mechanism may financially facilitate a platform for numerous sustainability experiments to exist concurrently. Those sustainability experiments – embodying a highly novel configuration – are likely to lead to substantial environmental sustainability (Bai et al., 2010; Berkhout et al., 2010), which can be purposely employed for transition management (Loorbach, 2007; Rotmans and Loorbach, 2008). Thus, to some degree, the enabling role of the special fund in nurturing sustainability experiments might be helpful in steering the urban transition. Notably, the probability of landing on a "successful experiment" could be increased by simultaneously conducting a large number of experiments. In this way, a policy-learning process stimulated by the fund might help to test and discriminate between the effective experiments (that need to be scaled up) from the inefficient ones (that need to be abandoned). If only focusing on one or a small number of experiments, there might be a risk of no gain or limited outcome.

Even if the direct-funding mechanisms can be an achievable option for cities, it may require a stable and sufficient financial capacity of a municipal government to adopt it (Winkler et al., 2007). The complexity in China's fiscal policy and institutions may have significant implications for fiscal sustainability in cities if they plan to allocate an expanded municipal budget for a low-carbon special fund (Ahmad and Colenbrander, 2020). Especially, many sustainability projects may require continuous support for years, with a consistent investment before reaping benefits, making reliable revenue streams particularly critical for policy success (Hawkins et al., 2016). Shanghai is capable of self-funding from its own budget, running the special fund over 11 years. This consistency ensures that some subsidy policies may last for years to achieve the policy goals, and also give enough time for the formation of a coordination mechanism in implementation. However, for some other cities, especially cities in rapidly developing regions, other development priorities may challenge the local governments, leading to a tight budget for sustainability (Colenbrander et al., 2018; Löffler, 2016). Setting up an overarching direct-funding scheme might go beyond their financial competence.

International financial aid may play a role in alleviating the funding-source constraints in developing cities (Acuto, 2016; Bank, 2010; Kameyama et al., 2016). Most climate funds have explicit lending criteria for a preference for investments in "hard" infrastructure (infrastructure projects built on sites), rather than "soft" infrastructure (local capacity and institutional settings for climate issues) (Fankhauser and Burton, 2011). However, this "soft" competence is particularly desirable in developing worlds for self-sustainable transition (Romero Lankao, 2007; Shemdoe et al., 2015; White and Wahba, 2019). Hypothetically, if a small amount of international aid could be re-directed into developing the soft competence in these developing cities, then the ways of how to efficiently use the freed resources for this purpose might need to be explored. On this subject, the Shanghai case may provide some experiential insights.

7. Conclusion

The impacts of direct-funding instruments on social, economic, and institutional dimensions for urban sustainability are not well established in the literature. This paper examines the influence of

subsidy instruments on urban sustainability transition from a systems perspective, taking Shanghai as a case study. We examine Shanghai's special fund for energy conservation and emission reduction, looking at the policy design and implementation, and its direct and flow-on effects on the city's low-carbon transition. A linkage analysis is applied to understand the effectiveness of this scheme in enabling collaboration between institutions. The direct results of Shanghai's special fund scheme include carbon reduction outcome and a variety of tangible capacity building activities, such as data reporting systems and demonstration projects. The fund plays a catalytic role in enabling coordination and collaboration across different government departments on cross-cutting policy domains. In addition, we also identified the flow-on impacts on capacity development in other non-government actors. Collectively, the special fund may have enabled local capacity building in multiple ways, through financing the governmental capacity building, incentivizing engagement from other stakeholders, and raising public awareness. The study also shows that a well-designed, city-level direct fund scheme can fill an implementation gap between the policy outputs and the policy outcomes and may nurture and enable a pool of policy experiments and innovations for effective policy learning, identification of successful experiments, and upscaling.

Adopting the direct-funding mechanism for enabling local capacity and institutions on climate mitigation may put extra pressure on the city's budget, especially difficult for cities in developing regions. Given the many benefits such a mechanism may render, some redirection of international aid funds to developing regions could be helpful to establish a direct-funding scheme – like in Shanghai – to facilitate local competence. The new perspectives of understanding direct and spillover impacts of the subsidy instrument in urban sustainability transition, illustrated by the Shanghai case, may encourage further investigation on its synergic outcomes in other aspects of an urban system, such as in economy or in society. This may provide evidence-based information to encourage more direct investment into cities' low-carbon initiatives.

Notes:

1. The data of Shanghai's total CO2 emissions (energy consumption based) is calculated by the author in the paper *Experimenting towards a low-carbon city: Policy evolution and nested structure of innovation* (2018).

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2020.124514.

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Supplementary material 1: About interviews

Two groups of interviewees are included – government staff (six people) and corporate staff (12 people). Interviewees of the first group are from government departments that are responsible for Shanghai's carbon management or energy conservation management. Interviewees of the second group are from a variety of industries, including renewable energy, energy service companies, chemical industry, power stations, motor companies. We adopted the snowball approach to identify and contact the interviewees.

We conducted semi-structured interviews with government staff, discussing three types of questions based on their positions and serviced organizations.

1. The background and development of low-carbon policies in Shanghai
2. The scope of responsibility of the government agencies where they serve and the role of this government agency in Shanghai's low-carbon coordination mechanism and special fund scheme.
3. The outcomes of subsidy policies.

We conducted semi-structured interviews with corporate staff, guided by questions from a survey form. But the discussion is not limited by the survey questions. The survey questions are used as prompts, but not for quantitative analysis. The contents of the conversions with interviewees from different companies vary, depending on the degree of their involvement in subsidy policies.

Business Profile	
1. Company name	
2. Ownership	a. State-owned enterprise b. Enterprise under collective ownership c. Associated enterprises d. Foreign-invested enterprises e. Private enterprise f. Others_____
3. Business scope	
4. Core businesses	
5. Is Shanghai market/location important for company's core businesses?	a. Very important b. Somewhat important c. Not important d. Others_____
If "no", why?	
6. Where are the major markets for these businesses? (Please identify some areas/cities.)	
The official stand on climate change	
7. Does the company have an official stand on climate change? (e.g., public statement, plan, strategy, etc.)	

8. Is climate protection regarded as a risk or an opportunity to the company?	
9. Environmental report **a. Does the company prepare and submit an environmental report regularly?** **b. What report?** **c. How often do you submit?** **d. To what agency(ies) do you submit?**	
10. Is climate protection included in the environmental report?	
Perceptions of cities' low-carbon initiatives and market	
11. Has the company ever heard about or paid close attention to a city's low-carbon initiatives?	
12. Has the company ever considered the city's low-carbon initiatives in business? And how?	
13. Does the company have any businesses offering energy-saving services/solutions, or carbon-reduction services/solutions?	
Current involvement and implementation	
14. Has the company currently been involved in any low-carbon related policy schemes led by the Shanghai government?	
15. Does the company proactively/passively get involved in these policy schemes?	
16. Climate strategy **a. Does the company have its own specific strategy for climate protection?** **b. Or has the climate protection been integrated into the company's overall strategy as an important element?**	
17. Does the company have any carbon-reduction/energy-conservation projects led by you currently or planned to be implemented?	
18. What are the concrete approaches/methods employed by the company to save energy consumption/cut carbon emissions?	
Ambitiousness for future involvement	
19. Is the company willing to play a more important role in Shanghai low-carbon transition?	
20. Why is/is not the company prepared to play a more important role?	
21. What are the company's purposes for	

doing so?	
22. What are the barriers of playing a more important role?	
23. What policy tools do you think are more effective regarding urban low-carbon transition?	a. Command-and-control (e.g., banning activities and practices, or requiring the use of a particular technology); b. Economic incentives or market-based mechanisms (e.g., emissions taxes and trading); c. Direct government action and involvement (e.g., subsidies or investment); d. Education and information; e. Others_____

Supplementary material 2: Policy data collection and analysis

The data collection and analysis for each figure and table in the manuscript are explained below.

Figure 1. The fund distribution in different policy areas based on the total cost from 2009–2018

Shanghai's government regularly releases public announcements on the details of the fund expenditure, several times a year. We collected the data from these accessible public documents, and then sorted and calculated them. Figure 1 presents the distribution of the fund in different policy domains over the years.

Table 2. Fund expenditure in different policy areas
(unit: million RMB)

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Total
Renewable energy	58	57	70	75	27	13	6	109	81	218	714
Industrial restructuring	423	544	474	549	537	406	606	615	684	465	5303
Technological upgrading for energy conservation	160	123	144	85	40	14	24	10	85	4	689
Energy performance contracting	15	2	11	48	19	18	0	63	16	52	244
Construction and transportation	110	232	131	127	72	256	252	189	98	715	2182
Cleaner production	13	20	28	32	20	15	13	20	0	20	181
Water pollution reduction	43	85	80	127	148	225	257	239	79	0	1283
Air pollution reduction	15	75	124	255	965	1291	874	1271	624	145	5639
Recycling economy	58	40	127	110	110	94	120	157	96	120	1032
Domestic waste sorting and reduction	0	0	0	65	73	0	129	20	0	0	287
Energy efficiency products promotion & governmental capacity building	74	168	176	108	71	164	1067	650	1475	36	3989
Others	0	197	21	0	160	160	160	0	0	0	698
Total	968	1544	1387	1583	2243	2655	3509	3343	3238	1775	

Figure 2. Annual cost of the special fund

The data of Shanghai's GDP and fiscal expenditure are collected from accessible public government documents.

Table 3. Cost of the special fund and its share in GDP and the fiscal expenditure over the years
(unit: million RMB)

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Annual cost of the special fund	968.3	1544.2	1387.3	1583.3	2242.6	2655.3	3508.7	3343.3	3238.2	1775.2
GDP	1528558	1743321	1953384	2053352	2225766	2406087	2564347	2817865	3013386	3267987
Fund cost/GDP	0.06%	0.09%	0.07%	0.08%	0.10%	0.11%	0.14%	0.12%	0.11%	0.05%
Annual fiscal expenditure	298970	330290	391490	418400	452860	516570	800360	888870	867700	942680
Fund cost/annual fiscal expenditure	0.32%	0.47%	0.35%	0.38%	0.50%	0.51%	0.44%	0.38%	0.37%	0.19%

Figure 3. Policy design: the policymaking process for an individual subsidy policy

This diagram is designed and made by the authors based on the information from the interviews with government officers and the understanding of relevant policy documents.

Figure 4. Budget allocation: the process of budget allocation for an individual subsidy policy

This diagram is made based on a policy document illustrating the implementation of subsidy policies, complemented by the information from the interviews with government officers.

Figure 5. Policy implementation: the stakeholders' roles and interactions at the implementation stage
This diagram is designed and made by the authors based on the subsidy policy documents on promoting EV uptake in Shanghai.

Table 1. The direct carbon reduction from the fund projects
The data of fund-project outcome is from a government report on the special fund implementation from 2011 to 2015. The carbon emission avoided in table 1 is calculated based on the saved energy released by the report. However, the energy saved by the last three projects in table 1 is not reported, maybe because these projects are related with the capacity building (e.g., the building-up of energy monitoring systems in buildings) or infrastructure construction (e.g., promoting EV and building charging points). The outcomes of these projects are not quantifiable; instead, the fund played an enabling role in promoting these actions. With our best efforts, we did not collect other outcomes of these three categories in our fieldwork and neither any available public-access information online.

Figure 6. The categories of funded capacity-building programs and their scale from 2009–2017
There is a category of "energy efficiency products promotion & governmental capacity building", which shares 18% in total, as shown in Figure 1. The purpose of this figure is to explore how the money is spent to support "capacity building" activities. The data is collected from regularly-released public announcements on fund expenditure by the Shanghai government. In these policy documents, the names of supported projects and the expenditures on these projects are listed. Based on our understanding of document reviews and interviews, we made a classification for these capacity-building projects. They are 1) annually updating greenhouse gas (GHG) inventory to monitor urban carbon footprint, 2) supporting demonstration projects for policy/technical learning, 3) encouraging engagement with communities and stakeholders, 4) building monitoring systems for data collection in urban sectors, and 5) funding policy research/consultancy to inform policymaking. Guided by this classification, we collected 167 projects from the government documents and then classified them into the five categories.

Figure 7. The total number of subsidy policies and participant governmental sectors in each year
All the subsidy policy documents are public-accessible online. In some policies, there is explicitly-stated expiration date (in one year or a few years). Some policies are updated before expiration, and some subsidy projects are terminated. At the same time, new policies are being introduced each year. We tracked the changes of policies and their participant sectors over the year, and summarized the findings in Figure 7.

Figure 8. The dynamics of new policies and removed policies in each year from 2008–2018
We categorized subsidy policies into twelve policy domains, and then tracked their enactment years and termination years. Figure 8 shows the dynamic changes of these subsidy policies in different domains over the years.

Figure 9. The cooperation links across institutions under the special fund scheme from 2008–2018

There are 41 subsidy policies that have been gradually developed over 11 years. For each policy, there are several government agencies involved. The list of participant departments is included in the public-accessible policy document. As described in the paper, these government departments have different roles in policymaking, budget application and appropriation, and policy implementation. For example, if four institutions work together in a subsidy policy, we count the connection between two institutions as one link. The total links of this policy is $\binom{4}{2} = 6$. The visualization of these links is shown in Figure 11.

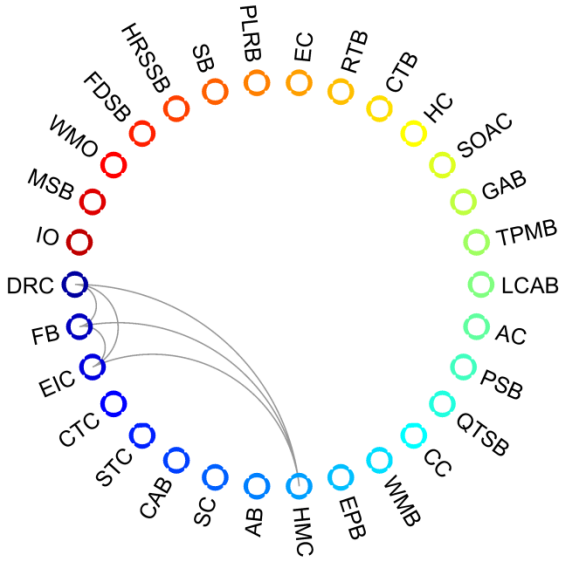

Figure 11. Cooperation links of a subsidy policy with four engaged institutions

Next, we superpose all implemented policies in one specific year in one diagram. For example, there are nine policies in operation in 2008, as shown in Table 4. The total links from nine policies are visualized, as shown in Figure 12.

Table 4. The subsidy policies in 2008

Policy domain	Subsidy policy (Subsidized activities)	Number of involved institutions	Number of links
Renewable energy	Development and deployment of renewable energies	6	15
Industrial restructuring	Relocation of direct emissions activities	3	3
Technological upgrading for energy conservation	Technological upgrading projects for energy conservation	3	3
Cleaner production	Encouraging the firms to adopt cleaner production processes or technologies	3	3
Air pollution reduction	Subsidies for distributed energy generation and gas air conditioners	5	10
Air pollution reduction	Desulphurization in coal-fired power plants	3	3
Water pollution reduction	COD reduction in sewage treatment plants	4	6
Energy efficiency products promotion & governmental capacity building	Capacity building activities	4	6
Energy performance contracting	Subsidies for EPC projects	3	3

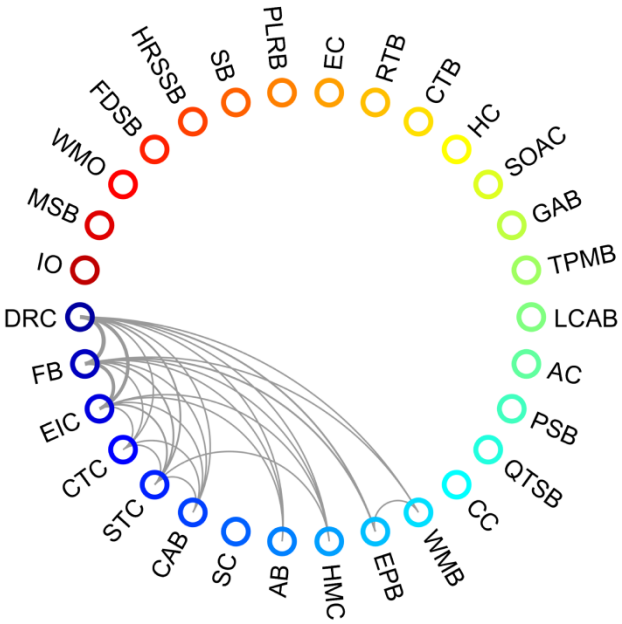

Figure 12. Cooperation links across institutions under the special fund scheme in 2008

In this way, we reviewed all subsidy policies under this scheme for 11 years. There are 11 chord charts in total (one chord chart representing one year), which can reveal the institutional development over time.

Figure 10. The participation level of an individual institution over 11 years

We calculate the participation level (p) of an individual department in each year – the percentage of the number of policies in which one specific department is involved in the total number of policies in each year, as shown in Table 4.

$$p = \frac{m}{n} \times 100\%$$

where m is the number of policies in which one department participated in a single year and n is the number of policies that year.

Then, we further calculate the participation level (P) of an individual department over 11 years, using a weight calculated as follows.

$$P = \sum_{i=1}^{11} p_i \cdot w_i = \frac{\sum_{i=1}^{11} p_i \cdot n_i}{\sum_{i=1}^{11} n_i}$$

where p_i is the participation level of an individual institution in year i and w_i is the corresponding weight calculated as the ratio between the number of policies in year i (n_i) and the sum number of policies over 11 years.

Table 5. Participation rates of the institutions over 11 years

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	The weighted participation rate
DRC	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
FB	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
EIC	77.8%	61.1%	68.4%	61.9%	71.4%	65.2%	57.7%	51.7%	46.7%	48.1%	58.2%
CTC	11.1%	22.2%	31.6%	28.6%	38.1%	39.1%	46.2%	48.3%	40.0%	40.7%	38.5%
STC	22.2%	11.1%	10.5%	9.5%	19.0%	17.4%	15.4%	17.2%	13.3%	14.8%	15.2%
CAB	11.1%	5.6%	5.3%	4.8%	4.8%	0.0%	0.0%	0.0%	0.0%	0.0%	2.0%
SC	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
AB	11.1%	11.1%	5.3%	4.8%	19.0%	17.4%	19.2%	20.7%	16.7%	18.5%	16.0%
HMC	11.1%	5.6%	5.3%	4.8%	14.3%	8.7%	7.7%	6.9%	6.7%	11.1%	9.4%
EPB	22.2%	22.2%	31.6%	38.1%	23.8%	30.4%	34.6%	44.8%	40.0%	48.1%	35.7%
WMB	11.1%	11.1%	10.5%	9.5%	4.8%	4.3%	7.7%	10.3%	10.0%	11.1%	9.0%
CC	0.0%	11.1%	10.5%	9.5%	9.5%	13.0%	11.5%	13.8%	13.3%	11.1%	11.5%
QTSB	0.0%	5.6%	5.3%	4.8%	9.5%	8.7%	11.5%	10.3%	10.0%	11.1%	8.6%
PSB	0.0%	5.6%	5.3%	4.8%	9.5%	8.7%	7.7%	6.9%	6.7%	7.4%	7.0%
AC	0.0%	5.6%	10.5%	14.3%	14.3%	13.0%	11.5%	10.3%	10.0%	11.1%	10.7%
LCAB	0.0%	0.0%	5.3%	4.8%	14.3%	13.0%	11.5%	10.3%	16.7%	14.8%	11.1%
TPMB	0.0%	0.0%	5.3%	0.0%	14.3%	21.7%	15.4%	13.8%	10.0%	11.1%	10.2%
GAB	0.0%	0.0%	0.0%	0.0%	4.8%	8.7%	7.7%	6.9%	3.3%	0.0%	3.3%
SOAC	0.0%	0.0%	0.0%	0.0%	4.8%	4.3%	7.7%	6.9%	3.3%	3.7%	3.7%
HC	0.0%	0.0%	0.0%	0.0%	4.8%	13.0%	11.5%	10.3%	6.7%	3.7%	5.3%
CTB	0.0%	0.0%	0.0%	0.0%	4.8%	8.7%	7.7%	6.9%	3.3%	0.0%	3.3%
RTB	0.0%	0.0%	0.0%	0.0%	4.8%	4.3%	3.8%	3.4%	0.0%	0.0%	1.6%
EC	0.0%	0.0%	0.0%	0.0%	0.0%	4.3%	3.8%	3.4%	3.3%	0.0%	1.6%
PLRB	0.0%	0.0%	0.0%	0.0%	0.0%	4.3%	3.8%	10.3%	10.0%	14.8%	6.6%
SB	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	3.7%	0.8%
HRSSB	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	3.7%	0.8%
FDSB	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	3.3%	3.7%	1.2%
WMO	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	3.3%	3.7%	0.8%
MSB	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%
IO	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	3.8%	3.4%	3.3%	3.7%	2.0%

Chapter 5: Enabling business-sector engagement in urban low-carbon initiatives: Emission constraint and new market opportunities

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Enabling business-sector engagement in urban low-carbon initiatives: Emission constraint and new market opportunities

Abstract

In the global sustainability transition, cities and business sectors are two important players. To achieve low-carbon initiatives in cities, local governments may need to actively enable engagement and contributions from business sectors. The existing literature mainly examines corporate responses to climate change and the existing regulatory schemes at a national and international level. However, the business sector's degree of engagement and their role in the urban transition process remains unclear. This paper aims to fill this gap, taking Shanghai as a case study. We investigate how Shanghai's government regulates local firms to achieve the city's transition target, through inspecting a series of local low-carbon policy schemes and corporate-sector attitudes and actions in response to these schemes. Multiple analytical perspectives are applied, using the concepts of sustainability experiments, urban sustainability transition, and network governance as theoretical lenses, and employing a systems approach. In Shanghai's case, there is a transformation in policy strategies for engaging business sectors for carbon reduction, from mandate only to resorting to market-based policy schemes. Under this policy setting, we identified a transformation in some local companies –from carbon emitters to solution providers to other firms –by means of expanding their business to newly-emerging low-carbon markets. Several enabling policy schemes implemented in Shanghai – either directly supporting a specific low-carbon industry or facilitating their growth by providing incentives to create the market demand – may play a role in triggering development of local low-carbon industries. In addition, policies and market factors might have collectively built a platform for driving technology adoption and innovation in the city. The insights from the Shanghai case study may have empirical implications for other cities, especially for those where industries are still the major emissions source, in terms of suggesting a policy strategy of simultaneously reducing industrial emissions and enabling local low-carbon industries. The research will also provide a theoretical understanding of how to address the fragmentation across urban stakeholders in urban low-carbon governance.

1. Introduction

Cities and the business sector are therefore two important players when it comes to stabilizing climate between 1.5°C and 2.0°C rise (Amir Bazaz et al., 2018; Kolk and Pinkse, 2008). The city's local government may need to facilitate the engagement of corporations in urban mitigation because achieving low-carbon initiatives in cities requires the integration of different interests and authorities (Chu et al., 2018; Ryan, 2015). But, in reality, fragmentation between these two actors exists (Romero-Lankao et al., 2018). In this sense, the investigation into how to coordinate business engagement may provide useful insights into the urban sustainability transition study.

The business sector is a key actor in the functioning of an urban system. They provide goods and services in urban systems, and broadly engage in urban infrastructure construction. Importantly, the business sector is active in innovating technologies and solutions for urban development. In recent years, the voice and action of corporate actors on urban climate issues has increased (Broto, 2017; Bulkeley and Castán Broto, 2013). However, the degree of

engagement and role of businesses in this transformative process in cities remains unclear (Baranova and Paterson, 2017; Bradford and Fraser, 2008; Cadez et al., 2019; Uyarra et al., 2016; Whiteman et al., 2011).

At a global or regional scale, there is a growing research interest in business-sector attitudes and actions in response to climate change. The existing literature indicates that business sectors may face both challenges and opportunities. They produce greenhouse gas (GHG) emissions from energy use and production processes (Fischedick et al., 2014), and therefore may face regulatory risks like carbon-control policies and carbon-pricing mechanisms. At the same time, they are victims of climate disaster, enduring severe consequences like property damage and business interruption (Pauw, 2015; Tang and Yeoh, 2007).

In reality, corporate strategies for climate issues are dynamically changing over time and are context specific. When global warming issues were initially raised, some companies, especially U.S.-based firms, proactively resisted prospective regulatory changes by challenging climate science and lobbying governments at various levels (Hoffman, 2005a; Leggett, 1999; Levy and Egan, 2003). This is because most businesses have operated in a self-interested way, disregarding social and environmental aspects while pursuing economic gains (Elkington, 2013). But such resistance did not last long. Comparatively, firms from Europe responded slower but were more receptive to climate issues (Kolk et al., 2008; Sullivan and Gouldson, 2013). Eventually, at the global scale, corporate sectors, especially big businesses, started to take mitigation actions through joining some voluntary/regulatory schemes such as the carbon-trading scheme (Damert et al., 2017; Pinkse and Kolk, 2007). Individual company strategies might depend on each firm's perceptions toward climate change, their particular industry regulations, and national policies set by the countries they operate in (Eberlein and Matten, 2009; Kolk and Pinkse, 2005).

Meanwhile, climate change could bring a market shift (Hoffman, 2006). New market opportunities are largely related to renewable energy and climate-friendly technology (Kolk and Pinkse, 2004; Okereke, 2007). For example, renewable energy business opportunities may attract investments and promote related technological development (Aslani and Mohaghar, 2013; REN21, 2019). The influence of new business opportunities might be broader if considering supply-chain companies (Cormier et al., 2005; Kolk and Pinkse, 2004). In this regard, business sectors play a role in innovating and delivering mitigation solutions driven by market factors.

The existing literature indicates that business sectors may engage in global mitigation in multiple ways, depending on the regulatory settings where they are embedded and their position in the market. Based on this understanding, we aim to fill a research gap in terms of understanding engagement from business sectors in city-level mitigation actions, through investigating city-level mitigation policy schemes and corporate responses, attitudes, and actions to these schemes. We take Shanghai as a case study.

Moreover, from sustainability experiments and transition perspectives, the business sector can be one actor in a niche social-technical experiment. They are active in the learning processes of innovating and adopting new technologies and forming a new social network central to the new technologies (Peng et al., 2019; Raven et al., 2007). From a systems

innovation perspective, the niche experiment plays a role as a transition seed, which can build up momentum for transforming the regime when a window of opportunity appears (Geels, 2002; Smith et al., 2010). In this regard, investigating the Shanghai case may also present a chance to understand what policy interventions can enable the specific role of business sectors in experimentation and further enable the regime shift.

The research questions of the present article are: What policy schemes can cities adopt to engage the corporate sector in the city's low-carbon initiatives? How do business sectors respond to their host cities' mitigation policy environment? How do business sectors interact with other actors in urban low-carbon transition? How do business sectors play their role in sustainability experiments for transition?

In the next section, we review the literature to understand the impacts of carbon-control regulations and market environments on corporate strategies and actions. In section 3, we present the research methodology of this paper, using the scholarship on sustainability experiment and transition, urban low-carbon governance, and systems approach as analytical lenses. In section 4, we investigate and analyze the case study. Section 5 presents the discussion and conclusion.

2. Literature review: Understanding the business sector's role in climate mitigation

The goal of this literature review section is to identify the roles of business sectors in global mitigation, and then, based on this acquired understanding, to further investigate corporate reactions to Shanghai's low-carbon policies and corporate involvement in local mitigation actions in an urban context (Shanghai), in the next section.

The reasons for the corporate response to climate change can be attributed to three major challenges – the impacts of climate change, changes in the regulatory environment, and new business opportunities emerging in a shifting market. We reviewed the literature to understand how businesses respond to these three factors, including their strategies and actions.

Impacts of climate change on business sectors

Natural disasters can affect businesses in terms of destroying or reducing their production. Some industries face risks and suffer losses from the changing climate (Pauw, 2015; Tang and Yeoh, 2007), which may raise adaptation issues for them. For example, the agriculture, fishery, and forestry industries are in a vulnerable position as they are endangered by the direct impacts of climate change, and their business losses may further expand to downstream industries (Ficke et al., 2007; Kirilenko and Sedjo, 2007; Stokes and Howden, 2010; Trabacchi and Stadelmann, 2013). In addition, manufacturing plants are not immune from encountering similar issues. A flood disaster in Thailand halted hard-disk and car production in one local area in 2011, with global-scale consequences including product shortages and price hikes (Surminski, 2013). Moreover, those financial losses have a knock-on effect on insurance companies and endanger their business. Assumptions about possible catastrophic weather events can no longer be made based on past experience, thus insurance companies can no longer calculate risks based on historical data but have to rely more heavily on both

mainstream science and customer feedback (IISD, 2000; Mills, 2009). Finally, businesses that are not directly endangered by climate instability may have other concerns associated with climate impact, such as cost-saving, reputation, regulatory changes, financial impacts, and their perception of future market shifts (Hoffman, 2006; Okereke, 2007).

In terms of climate adaption, companies who suffer physical damage from climate hazards may need to develop and implement adaptation strategies. As for climate mitigation, corporate political attitudes, in general, vary from being offended and reactive to being cooperative and proactive (Bui and De Villiers, 2017; Levy and Kolk, 2002). The climate actions they adopt may also vary widely. For example, they may join in carbon-disclosure projects and emission trading schemes, improve energy efficiency, and promote product and technology innovation and direct corporate activities for mitigation (Kolk et al., 2008; Okereke et al., 2012; Sullivan and Gouldson, 2013). Instead of direct reduction, they may also use some compensatory approaches such as the Clean Development Mechanism (CDM) as part of their mitigation efforts (Lütken and Michaelowa, 2008; Sutter and Parreño, 2007). In addition, they can influence and interact with other stakeholders, such as companies in the supply chain or industry, NGOs or (local) governments (Kolk and Pinkse, 2005). The above actions are essential to control carbon emission in the Anthropocene, as industrial activities are one main cause of GHG emissions (Fischedick et al., 2014).

Climate policies on business sectors and their responses

Policy interventions can play a role in raising corporate awareness of climate issues. According to Begum and Pereira (2015) research in Malaysia, there is a lack of clear understanding regarding the impacts of climate change among local companies, due to the absence of government guidance and intervention. These companies held a view that Malaysia has not encountered a severe threat from climate change and natural disasters, though Malaysia has experienced frequent floods. The local companies did not realize the possible relationship between their business activities and climate issues. This case may indicate the role of policy interventions, such as legislation and regulations, in raising business awareness. Also, as pointed out in Stern's review (Stern, 2007), "Greenhouse gas (GHG) emissions are externalities and represent the biggest market failure the world has seen," thus, the role of governments in climate protection is expected.

There are several policy schemes in practice for controlling industrial GHG emissions, for example, emission trading schemes, carbon taxes, and the CDM (Gasbarro et al., 2017; Kolk et al., 2008; Kolk and Pinkse, 2008; Martin et al., 2014; Michaelowa and Jotzo, 2005). They play a role in facilitating carbon control in firms. The research by Luo and Tang (2016) on large companies that participate in the Carbon Disclosure Project indicates that the quality of corporate carbon management systems is associated with the presence of the emission trading scheme, to some degree. Regulations and regulatory enforcement can exist as coercive and normative pressures on firms' environmental management practices (Delmas and Toffel, 2004). Some of these carbon-control schemes are voluntary in nature; and the participant companies might also be driven by many other factors associated with social norms, like enhancing a corporation's reputation, showing its social responsibility, or improving its financial evaluation by investors (Kolk et al., 2008; Rezessy and Bertoldi, 2011). In general, business sectors may perceive climate policies as regulatory risks. They are therefore being cautious and may take reactive approaches. For example, in research by Bui

and De Villiers (2017), companies revert to a passive strategy (from a proactive one) toward climate change when policy pressure reduces. Particularly, policy uncertainty might be one major consideration that barricades firms' sizable investments (Bui and De Villiers, 2017; Paul et al., 2017).

Some existing research indicates that a national government's political stance and policy schemes construct a regulatory setting for corporate sectors. Kolk and Pinkse (2008) identify that when multinational companies take climate action in different countries, they have to deal with distinctive national patterns, adopting a multi-domestic, frequently home-country-focused approach. For example, a case study by Okereke (2007) among the UK FTSE 100 companies (The Financial Times Stock Exchange 100 Index) reveals that all of those companies that report on their carbon-management program admit on their website to the importance of present and future national regulations as a key driver of corporate climate strategies. The UK government has been promoting ambitious actions on climate change as it is a signatory to the Kyoto Protocol and a former member of the EU. Comparatively, during the same period, in the case of Canada, an underdeveloped regulatory framework was viewed as an obstacle for integrating climate change into a strategic plan for businesses. There was business resistance against regulatory carbon constraints for a time. But, later, some business leaders considered that the existing regulatory gap might be an opportunity to shape future regulation and actively lobbied for a national climate plan (Eberlein and Matten, 2009). However, there is little research discussing the impact of low-carbon initiatives and policy environment on companies at a city level, as well as their interplay with local governments.

A market shift and business sector responses

Tackling climate change may also indicate a market shift (Hoffman, 2006). A radical adjustment in business sectors might be required. Hoffman (2005b) points out that, when understanding corporate climate change strategies, the analytical angle needs to be changed from a strictly environmental issue driven by regulatory or social pressures to a strategic issue driven by market pressures. Companies face new competitive environments in a carbon-control world, where some businesses will decline while others may rise. Corporate sectors may take actions to adapt to this changing market. For example, emitters with carbon-intensive products may take this chance to improve products or optimize processes to reduce costs, or to capitalize on the emission-trading market; and some businesses may identify and seize emerging opportunities by developing low-carbon solutions for the new markets (Ayoub and Abdullah, 2012; wbcsd, 2018; Wright, 2015).

New market opportunities are largely related to renewable energy and climate-friendly technology (Kolk and Pinkse, 2004; Okereke, 2007). A large flow of investment may be redirected from high-carbon to low-carbon technologies to meet the mitigation needs (Schmidt, 2014). For example, in the case of Europe, corporate research and development (R&D) investments in low-carbon technologies account for a larger share than investments made with public funds, highlighting the importance of substantive corporate actions and industrial research activities (Wiesenthal et al., 2012). An analysis report by the World Business Council for Sustainable Development states that the business sector may also play a major role in channeling investment toward a low-carbon economy (wbcsd, 2015). This growing investment may drive other related markets beyond the direct investment projects, such as companies in the supply chains, and may also have other social impacts like changes

in employment structure (Cucchiella and D'Adamo, 2013; Lehr et al., 2008; wbcsd, 2015; Wee et al., 2012).

Interactions across market actors may influence corporate climate behaviors. For example, investors' awareness and pressure on corporate sustainability performance may encourage firms to report and manage their carbon emissions (Hawn et al., 2018). The pressure from competitor companies or requirements from supply-chain companies may compel firms to control their carbon emissions to fit into new business environments (Cormier et al., 2005; Kolk and Pinkse, 2004). In addition, reputation (as perceived by consumers) may become a nonnegligible consideration for businesses in a world where climate issues are receiving increasing attention (Hoffman, 2005b; Tang and Yeoh, 2007).

Interplay of policy and market environments

The extant literature indicates the importance of both policy and market environments on corporate attitudes and actions toward climate change. On top of that, the interaction of these two environments might also play a collective role. Greenhouse gas control represents a market transition, but this transition is different from those that have happened in the past, which have been triggered by the changes of consumer demands or technology developments (Hoffman, 2005b). Instead, government mitigation policies are reshaping the market environment, with mandatory management on emitters and incentive measures for emerging low-carbon industries. Responding to this policy environment, the market and business activities may provide feedback for policymaking (Schmidt, 2014; Uyarra et al., 2016; Wiesenthal et al., 2012). This two-way communication might form a positive loop to engage the business sector in climate actions.

Different roles of businesses in climate mitigation

From the above literature we have identified three types of businesses in climate mitigation according to their roles, as illustrated in Figure 1. The emitters may enhance their carbon management to cut emissions in response to regulatory pressure, and also, they value their environmental performance due to their corporate reputation among investors and the public. To reduce carbon, emitters may seek carbon-efficient technologies, solutions, or services from the market, which, to some degree, may drive new market demands for an emerging low-carbon industry. The provider companies (of low-carbon technologies, solutions, and services) are responsive to both market and policy signals. They gain business benefits from climate protection, but they are also risk-takers due to the policy uncertainty and the immaturity of the market. Investors are the third type, as they finance technological innovation, low-carbon infrastructure, and application of technologies. They could motivate the other two types of companies but also take risks from regulatory and market uncertainties. Under some circumstances, the three types may not have clear boundaries. For example, some companies may self-invest in some carbon-efficient technologies.

To the best of our knowledge, there is little research on business behaviors according to their different roles in climate change. Some knowledge gaps associated with the above classification, such as the dynamic interactions across different types and with other stakeholders and their interplays with policy/market environments, are underexplored. Research to address the above gap is important because it will provide new understanding that can be helpful to 1) identify different business strategies according to corporate positions

in mitigation in order to develop their organizations to be fit for future, 2) identify diverse ways in which different businesses can contribute to sustainability transitions, 3) identify the synergistic effects from interactions of different business types, which may facilitate the transition, 4) inform policymaking to collectively and concertedly engage different business types in order to maximize their contribution.

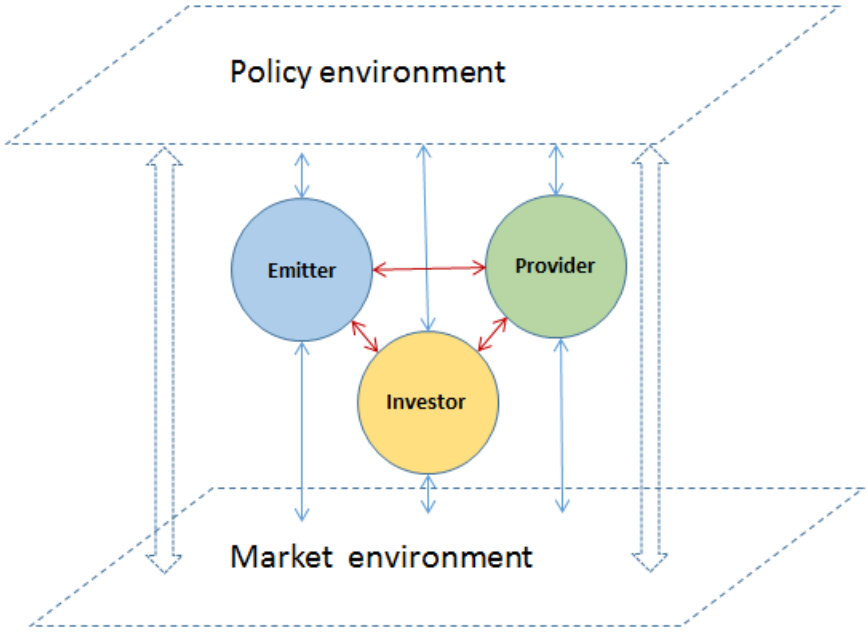

Figure 1. The roles of different businesses in climate mitigation and their interactions with one another and with the policy and market environments

3. Research methodology

3.1 Analytical method and data collection

We investigate the interplays between the policy setting of Shanghai's low-carbon initiatives and the business actors (mainly focusing on carbon emitters and solution providers, as shown in Figure 1). First, we review two types of policy schemes that may have impacts on emitters and solution providers, respectively. The first type includes three mitigation schemes (including energy-saving regulation, energy-performance contracting, emission trading scheme) and the second type includes two policy schemes for stimulating market demand and enabling two industries, i.e., the energy Service Company (ESCO) industry and electric vehicle (EV) industry. From the policy review, we can discern the policy intentions and policy instruments used by the government. Second, we examine the firms' attitudes and reactions to these schemes. Moreover, to understand market factors that influence the policy outcome, we investigate the market and industry development of three examples: ESCO industry, EV industry, and carbon asset management industry. In addition, we explore whether there are new forms of actor interplays under these policy schemes and the impacts of these actor networks.

We collected the data in three ways, as illustrated below.

First, we conducted semi-structured interviews with some key stakeholders, including government officers, representatives from business associations, experienced experts, and businesspeople. Key informant interview is often the most effective way to obtain information about the decision-making process when the respondent is an expert in the topic (Burnham et al., 2008).

Second, to understand Shanghai's low-carbon policy environment for corporate sectors, we performed deskwork on collecting, reviewing, and analyzing policy documents. We developed criteria to screen the policies, including 1) policies that directly target emission control in industries, 2) policies that target other policy domains but have a carbon-reduction effect on firms, such as energy policies and air pollution policies, 3) facilitating policies for developing new industries that provide carbon-efficient products/solutions/services for urban decarbonization, 4) other relevant documents, including government reports, gray literature, academic papers, and media reports.

Third, to understand corporate attitudes and actions toward the policies, we collected company-related information in the following steps, 1) making a targeted company list, e.g., high-emission companies, or the companies in a certain industry, 2) reviewing company websites, 3) searching and reviewing social responsibility reports to collect firms' carbon-management information, and 4) reviewing other online resources such as business association websites.

3.2 Analytical perspectives

We examine the Shanghai case from three theoretical lenses as articulated below.

Urban sustainability experiments

The low-carbon policy schemes in Shanghai's case may promote pilot projects and niche practices that engage business sectors. We employ the conceptual framework of sustainability experiments to analyze these niche activities. Sustainability experiments are defined as planned initiatives that embody a highly novel socio-technical configuration and that are likely to lead to substantial sustainability (environmental) gains (Berkhout et al., 2010). The experiments are designed to be the practicing ground for innovations in terms of building actor networks, stimulating learning processes, and promoting them to develop into a stable social-technical configuration (Bai et al., 2010b; Kemp et al., 1998; Loorbach, 2010; Loorbach and Rotmans, 2010). In real-world practice, the business sector is on the frontline of inventing and promoting new technologies. In this sense, they might be a critical actor in sustainability experiments. In some cases, the business sector may even be proactive in taking a leading role in conducting urban sustainability experiments (Broto and Bulkeley, 2013).

Urban low-carbon governance

Urban climate governance is embedded in a vertical setting linked with national- or international-level management (Bai et al., 2010a; Betsill and Bulkeley, 2006; Corfee-Morlot et al., 2009; Kemmerzell, 2018; Peng and Bai, 2018; Reckien et al., 2018). Moreover, within a city, there is fragmentation among urban actors and across urban sectors (Romero-Lankao et

al., 2018), leading to uncoordinated climate actions. In general, municipal governments take a leading role in local climate governance, with varying degrees of participation and financial input. There are several governance modes they may adopt, e.g., self-governing, governing through enabling, governing by provision, governing by authority, and partnerships (Bulkeley et al., 2009; Kern et al., 2008).

However, realizing the potential of cities in global sustainability requires integration of different interests and authorities (Chu et al., 2018; Ryan, 2015); thus, there is a need to expand the research attention from the local government role to other stakeholders' roles. In particular, the voices and actions of business actors and civil society are growing (Broto, 2017; Bulkeley and Castán Broto, 2013), indicating the emergence of new political players and their plea for reshaping the existing institutions.

To understand the interactions between the city's government and the business sectors, we resort to the scholarship of network governance, which emphasizes materializing the results of policy intentions (Khan, 2013). Conventionally, regulation is based on a top-down way of command, while the market is a self-organizing governance form based on free transactions between social actors. Comparatively, the networks depend on "links between public and private actors, which may integrate or tradeoff some traits and characteristics of these two parties" (Khan, 2013). This is likely to lead to an unconventional/innovative governance method with benefits for local climate actions. Lee and Painter (2015) contend that comprehensive local climate change policies could be generated and sustained through networks and associations of a variety of actors, instead of only on government initiatives and resources. In addition, network governance is also useful in the implementation of climate policy measures (Caniëls and Romijn, 2008). In reality, if there are potential business interests for corporate organizations, they could be more proactive in climate governance networks in cities (Ryan, 2015).

Systems approach in urban sustainability transition

A city is a complex system, consisting of ecological, economic, social, and cultural components interacting with one another in multi-dimensions (Bai et al., 2016), thus, a comprehensive perspective is needed when dealing with urban issues. The systems approach was introduced to urban and regional planning in the late 1960s, to put an emphasis on social and economic processes in urban planning, which is traditionally based on the physical design (McLoughlin, 1969). Later, along with increasing urban environmental problems and other issues of modern society, a knowledge base on systematically understanding and tackling those multiple challenges began to emerge in the literature (Pincetl et al., 2012). In the face of urban climate issues, the systems approach is used to analyze the compound effect generated by climate change, arriving at the suggestion that responding actions must be taken to simultaneously address multiple challenges at multiple levels (Da Silva et al., 2012). In reality, some local governments commenced climate actions by hooking global concerns onto existing policy frameworks such as energy and environmental policies (Bai, 2007; Peng and Bai, 2018). In recent years, advancing the systems approach for sustainable cities has gradually gained more attention from researchers (Bai et al., 2016).

In this research, we attempt to inspect the impacts of low-carbon policy schemes on business sectors from the systems perspective, including both direct outcomes of policy intentions and unintended consequences.

4. Case study

4.1 The background for low-carbon transition in Shanghai

Shanghai is one pilot low-carbon city in a national scheme. The central government aims to stimulate policy learning from this program to inform national-level low-carbon policymaking. This pilot program encourages Shanghai's government to experiment with many innovative policy practices. The municipal government established two enabling mechanisms for facilitating low-carbon policy projects – a coordination mechanism and financial mechanism (Peng and Bai, 2018). These two mechanisms have facilitated the implementation of low-carbon policies, many of which engage the business sector.

Along with low-carbon transition, there are other multiple transitions occurring in Shanghai – the economic transition from a planned economy to a market-oriented economy and the government institutional reform toward a service-oriented government. These social-economic transitions may provide the possibility that corporations can have more freedom in the market and may play a bigger role in urban development. In addition, the city has been going through industrial restructuring from secondary industry to service industry, due to the city's economic strategy, local environmental problems (pollutant emissions), and the limited land and other resources (leading to a cost increase for some low-output companies). Against this backdrop, the low-carbon industry is favored and promoted by the local government. A senior government official from the interview illustrated that Shanghai has a development strategy of achieving the integrated transitions – which targets not only emissions reduction but also low-carbon industry development.

Shanghai has a diversified industrial structure, with various types of business actors. Moreover, some companies in Shanghai may have an awareness of climate issues. For example, there are branch offices of multi-national corporations located in Shanghai, and their parent companies may have responsive strategies to climate change. Also, some local companies might be influenced by their supply-chain partners that place emission-control requirements on them.

4.2 Interplays between Shanghai's mitigation policy setting and business sectors

Policies for energy conservation and carbon reduction

The local government issued several policy schemes to curb carbon emissions from the industrial emitters – energy-saving obligation, energy performance contracting (EPC), and a carbon-trading scheme (ETS). Accordingly, Shanghai's government set up two specialized institutes for two of the above schemes. One is Shanghai Energy Conservation Supervision Center (SECSC) – a law enforcement agency for supervising corporate energy conservation (obligation policy enforcement); the other is Shanghai Energy Performance Contracting Management Committee (SEPCMC) – a service agency for facilitating EPC adoption (the

market mechanism). Table 1 lists the policy schemes and the roles of Shanghai's government and business sectors, as well as their interactions.

Table 1. Policy schemes for energy conservation and carbon reduction and the response of business sectors

Policy schemes	Policy approach	Government role	Business sector role	Impacts of the policy	Corporate feedback on policymaking / adjustments
Energy-saving obligation	Mandate	Making and enforcing the law; providing training and energy-saving consultancy;	Establishing internal energy management system; conducting energy-saving projects; adopting energy-efficient technologies	Achieving Shanghai's energy-saving goals	Practical challenges/barriers; detailed technical difficulty, institutional restraints and other needs for policy support
Energy performance contracting	Market mechanisms	Facilitator; intermediary; providing subsidies	ESCOs providing EPC services; emitters adopt EPC or other options, depending on their situations and needs	Development of ESCO industry; EPC becomes one proliferating practice in the regime	Local practices for policymaking to contextualize EPC; market and technology information to adjust the level of subsidies
Emission Trading Scheme	Carbon pricing	Setting up the institutions, setting rules and standards	Participating in EPC; fulfilling their compliance; improving carbon management	Tapping the energy-saving potentials across local companies	Practical experience for policymaking and adjustment

The main responsibility of SECSC is enforcing the energy conservation laws in Shanghai. However, in practice, it does more than its defined duty. For example, it provides a variety of services to corporate emitters, helping them improve their energy-saving performance, e.g., training, energy efficiency diagnosis services, and policy interpretation. This agency also collects and monitors energy consumption data from local emitters, as well as tracking the firms' energy efficiency modifications. A database built on the above first-hand information can inform the policymaking.

There is a process of attitude change in local firms toward SECSC. When SECSC started to perform its duty in 1998, local firms were reluctant to cooperate and held a defensive position. After some years, they were gradually familiar with SECSC's responsibility and functions and found the free supportive service helpful. Importantly, companies have benefited from reduced energy costs by adopting energy-efficient equipment and technologies. Their attitudes have increasingly become more cooperative and they have established their internal energy management.

Shanghai's government also adopted EPC – the market mechanism for energy-efficiency improvements in urban infrastructure. SEPCMC was set up to facilitate the adoption and to nurture/support ESCOs. Facilitated by a set of policies and subsidies, the EPC market keeps growing and the EPC mechanism becomes one proliferating practice in implementing energy efficiency projects in Shanghai (Peng et al., 2018).

Attitudes towards EPC and acceptance of it by businesses are varied, according to their different situations and needs. For example, some large companies' energy costs account for a significant share of their total cost. Also, their energy-management teams are experienced, with adequate technical capacity. Thus, those companies may conduct energy-efficiency projects by themselves. In contrast, some medium- and small-sized companies – that lack funds and technical competence – may prefer EPC.

In a national policy scheme, Shanghai is designated as a pilot ETS market. Shanghai's government has established the local institutions for the ETS. Shanghai's ETS plays a role in tapping the energy-saving potentials in local corporate emitters and balancing their reduction contributions. Individual companies may have different energy-saving costs, due to their uneven technical and financial capacities and divergent energy systems. For large firms, the "low-hanging fruits" might already have been harvested; thus, they may need to invest more if they want to further reduce emissions. Some firms of this type are willing to do so to demonstrate their social responsibility. Meanwhile, some firms with poor energy performance may still have room to increase efficiency at a lower cost. Thus, they are willing to sell the allowance in the market. There is an increasing trend in the number of participant companies, from 197 in 2013 to 368 in 2016.

Policies for stimulating market demand and enabling low-carbon industries

Shanghai's government issued enabling policies for adopting carbon-efficient technologies, solutions, or practices, as well as providing direct support for nurturing local low-carbon industries. Table 2 presents two examples.

Table 2. Policy schemes for enabling low-carbon industries and the respective corporate responses

Industry	Policy measures	Development of industry	Policy impacts	Corporate feedback on policymaking / adjustments
ESCO	A specialized agency; demonstration projects; technical support; subsidies; networking	Local ESCO industry is growing in terms of the number of companies and annual industrial revenue; ESCO industry has expanded its business in other provinces	Stimulating and catalyzing market demand in the initial phase; supporting capacity building of local ESCOs; regulating the industry	Local practices and experience; technology and market information; barriers to industrial development; adjustment of subsidy levels
Electric Vehicle	Exemption of registration fee; purchase subsidies; subsidizing and regulating the building of a charging infrastructure	Growth of industrial revenue	Shanghai became one frontrunner city that holds a large number of new energy vehicles on a world stage; deployment of charging infrastructure	Technology and market information; phasing out of purchase subsidies along with industry growth; EV/used-EV market regulations

Along with the adoption of EPC in Shanghai, the local government also issued specific policies to enable development of ESCOs, drawing on feedback from local ESCO business practices. SEPCMC plays a role in collecting and analyzing the feedback from its interactions with ESCOs and other stakeholders (Peng et al., 2019). A policy framework has gradually been established, starting from simply subsidizing EPC projects and progressively expanding to regulating the market and stakeholders. This is because, after the initial scale of the market enabled by subsidization, more policies are needed to sustainably support the industry's development. However, from the government's standpoint, the main purpose of incubating this industry is to encourage it to deliver local energy-saving projects. After low-hanging fruits in efficiency projects have been reduced, the project cost increases because more advanced technologies are needed. To further decarbonize the urban infrastructure, the subsidy level is adjusted regularly. For example, in 2017, the subsidy was 800 RMB/standard coal (saved), increased from 500 RMB/standard coal (saved) in 2016.

Before adoption, there was no ESCO in Shanghai; however, after 12 years, there were around 430 ESCOs established, and the annual revenue of the ESCO industry was 4.634 billion RMB in 2014. The establishment of the ESCO industry may indicate a business engagement strategy that Shanghai government adopts – stimulating a market demand to grow local ESCO industry in order to deliver the projects for urban decarbonization. This strategy is also used for the adoption of EV in Shanghai. Since 2014, a set of policy measures are employed to promote EV adoption, including exemption of registration fee, purchase subsidies, and enabling deployment of a charging infrastructure.

The rapid increase in the vehicle population might reflect the effectiveness of those policies. By 2017, 199,700 EVs had been sold in Shanghai. The growing market may have prompted a growth in the local motor industry. In 2016, the industrial output value was 13.26 billion RMB, up 29.5% from the previous year; in 2017, the revenue grew to 23.24 billion RMB with an annual increase rate of 42.6%. In 2018, the revenue reached 25.93 billion RMB.

The surveys conducted by the local government may evidence the positive relation between the subsidy instrument and the local motor industry growth. The survey results show that 52% of buyers (from the survey sample) have purchased or are willing to choose EVs because of the purchase rebate. The survey also indicates that more than half of the respondents prefer Shanghai-made EVs if they plan to buy. In 2015, the number of locally made EVs was 39,099; while the registration number of new EVs in the same year was 37,604 units. The production and sales volumes in Shanghai are basically equal.

4.3 Influence of market factors

In this section, we investigate how market factors have influenced the outcome of these policy schemes.

Market growth as a key driver for industry independence

The enabling policies have nurtured new industries (such as ESCO and EV) by stimulating market demand and providing financial support. After the initial markets had been formed, the resulting market might act as a driving factor to enable those new industries to grow out of the policy support. We continue to use the cases of ESCO and EV industries as examples.

The share of the subsidized EPC projects in total is decreasing over the years. At the initial stage, all the demonstration projects were subsidized by the government. However, after a 12-year market development, in 2014, the number of subsidized projects only accounts for 45.5% of the total number of local EPC projects, which indicates that more than half of EPC projects are independent of the government's financial support. The market demand has become one major driver in growing this industry.

Similarly, along with the EV market growth, a phasing-out policy of the rebate has been introduced since 2016. Taking passenger vehicles as an example, the rebate had been reduced from 40,000 RMB per vehicle in 2015 to between 10,000 RMB and 30,000 RMB (according to different vehicle models) in 2016. In 2017, the rebate further decreased to less than 22,000 RMB. In 2018, eligibility criteria became more rigorous, and some vehicle models were excluded from the subsidies list. In comparison to the decreasing trend of subsidies, the EV

market scale and industry revenue are increasing, which may imply independence of the local EV market from the rebate policy. The survey conducted by the local government indicates that there is a high rate of acceptability (81.2%) among potential buyers in Shanghai, which might be one factor underpinning market demand.

Market competition as an enabling factor for low-carbon industries' capacity building

Competition between companies might be another factor in the development of local low-carbon industries. In the case of ESCOs, some low-capacity companies are gradually being eliminated from the market (SECESA, 2018). As a result, along with the industry maturing, overall industry capabilities have improved, as evidenced by the indicators in Table 3. Competition has urged individual companies to grow their technical strength. By 2018, 32 local ESCOs hold patents for a variety of low-carbon technologies, e.g., energy-efficient air conditioning and illumination, heat utilization, and monitoring systems. From the interview, the manager of Shanghai Kingcheng HV&AC Company acknowledged that the initial market demand driven by subsidization had spurred its business growth. However, the market has become more competitive as more ESCOs join the industry. To compete with other firms, the company started to invest in R&D for new products and solutions. This overall industrial capacity could be important for delivering decarbonization projects in Shanghai. As the low-hanging fruits are picked, the local EPC market requires advanced technologies and services.

Table 3. The industrial capacity of ESCOs in Shanghai

	Scale		**Human resource**		**Registered capital (million RMB)**		
	Under 50 employees	Above 50 employees	Technician	Other staff	Above 100	Between 10 and 100	Below 10
2014	68.0%	32.0%	39.1%	60.9%	6.2%	49.4%	44.4%
2017	62.3%	37.7%	49.0%	51.0%	9.4%	63.7%	26.9%

(Source: Shanghai ESCO development report of 2015, 2018)

New business opportunities may stimulate an emerging supply-chain market

There could be various new business opportunities emerging from the enabling environment in Shanghai. A supply-chain market might appear in response to these new business needs. For example, as the Shanghai ETS market is developing, there is a demand for the carbon-asset management service. Some existing companies or start-ups launched this new business, indicating the sprout of a new industry.

We collected the information on these companies in Shanghai from the website of China Carbon Trading (CCT), which is a national emission-trading information website, supervised by the national government. There are 12 carbon asset management companies based in Shanghai and registered on this website. After reviewing and analyzing their business scopes, we conclude that they have four major businesses: 1) Corporate carbon footprint verification and carbon asset management services, 2) emission reduction consultancy, financing, technological, and training services for corporate emitters, 3) developing carbon financial instruments for the financial market, and 4) conducting research and policy consultancy for the government. These new businesses meet the need of the maturing carbon market. For example, some trading companies may want to outsource their carbon accounting and transaction management, and the potential opportunities of carbon financial instruments might have attracted local financial institutes.

These carbon asset management companies have different backgrounds, e.g., research institutes, subsidiaries of large companies, and branch offices of foreign firms. Individual companies only cover some of the above four types. There is an obvious relevance between the business focuses of these companies and the business scope of their parent companies. In addition, after reviewing the reported business cases on CCT, we found that at this initial stage, these companies have little experience, and thus they are experimenting with various ways of carrying out the new businesses and competing in this emerging market.

This emerging supply-chain market is not directly supported by the government's policies; instead, it is growing in response to the business needs in the ETS market. Nevertheless, policy interventions are required to regulate the market (Cui, 2018).

4.4 Transformative changes in local actor interplays

Relationship transformation between the government and business sectors (from regulation to stimulating new market opportunities for reducing carbon)

The relationship between Shanghai's government and business sectors has been changing, from the regulator and being regulated to stimulating new market demands to attract corporations' interests for reducing carbon. This transformation can be observed from the government's relations with two types of business actors. One relationship is between Shanghai's government and corporate emitters. Initially, the local government relied on "hard" measures such as energy-saving obligations to curb energy use in industries. Then, the government employed "soft" measures, to stimulate the corporate sectors' interests in the new markets, such as EPC (reducing the energy cost) and the ETS. The other relationship is between the government and the firms of low-carbon industries. The government supported the development of those industries by stimulating the market needs and expected that they could play a role in delivering the decarbonization projects.

Business transformation from "emitters" to "providers"

In Shanghai, some existing companies may adjust their business scope, changing their role in urban mitigation. For example, there are 200 ESCOs registered at Shanghai Energy Conservation & Environmental Service Association; we analyzed the business scope of those companies and their shareholders by reviewing their company websites. We identified that 25 ESCOs from 200 firms have their parent companies or at least one corporate shareholder from manufacturing industries. These controlling companies are emitters under the carbon-control policies, but they might have financial capacity and the technical strength of emissions management. Gaining experience from the companies' internal energy/emissions management, their energy teams are professional and competitive accomplished in the emerging ESCOs industry if they become independent subsidiary companies. To some degree, these companies may contribute to the city's transition in two ways – not only reducing their emissions but also exploiting their existing technical and financial resources to service other emitters.

Another example is the carbon asset management industry. To some degree, this emerging industry might evolve from existing companies in Shanghai, who expand their businesses into new business areas. Some of these parent companies are from the manufacturing industry.

Growth of a new actor network to enable innovation diffusion

The new networks forming in the transition consist of incumbent stakeholders with their new roles (e.g., the local government and some existing companies) and new stakeholders (e.g., recently developed low-carbon industries). The growing linkages across actors may play a role in enabling innovative activities and innovation diffusion.

For example, under Shanghai's carbon-trading market, some carbon asset management companies, corporate emitters, and financial organizations worked together to explore new business models and carbon financial instruments. Those linkages built during their tentative cooperation activities might stimulate experiments with business innovations in carbon management services and finance (Lu and Tang, 2016).

Importantly, the growth of networks might play an enabling role in the proliferation of business innovations. A case in point is the upscaling of EPC experiments in Shanghai. A simple network was configured during the demonstration period. Later, enabled by the policies, more stakeholders were engaged, such as banks, audit institutes, new ESCOs, and emitters, which created more inter-actor linkages. For example, the linkages across banks, the government, and ESCOs mobilized more financial resources to EPC markets; and the linkages across emitters, ESCOs, audit institutes, and the government benefited the standardization of project implementation. With an increasing number of involved stakeholders, more EPC projects were being practiced. EPC became one proliferating practice in the regime (Peng et al., 2019).

4.5 Initial policy outcomes

We present two initial outcomes of Shanghai's low-carbon policy schemes, where the business sectors behave as a critical actor in these transformative changes. As shown in Figure 2, there are two opposite trends – the increasing trend of annual industry value added and the decreasing trend of industrial energy intensity, indicating that the growth of Shanghai's industrial sector might become less dependent on energy consumption, and carbon emissions from their business activities might be constrained. There could be many driving factors for this outcome, and the mitigation policy schemes analyzed in this paper might be included.

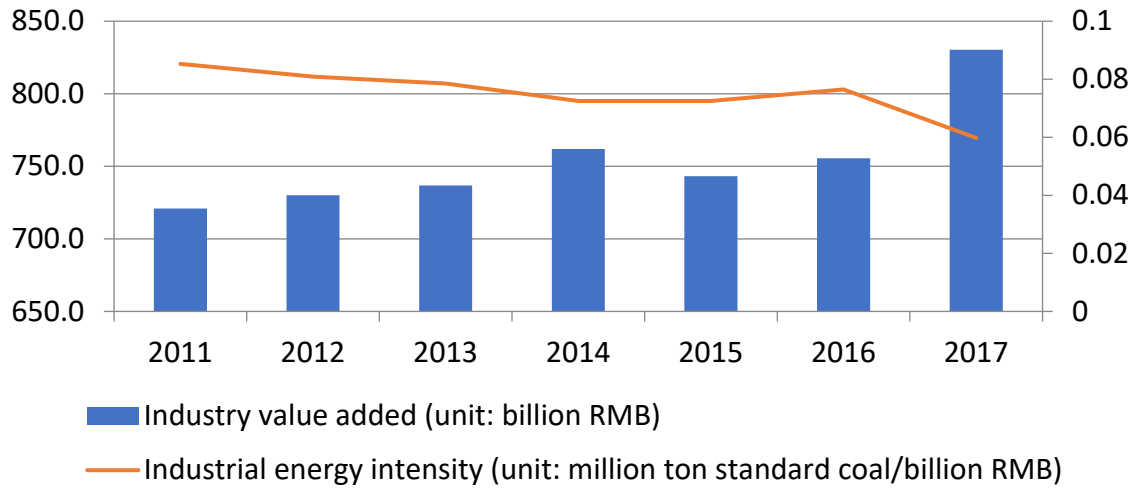

Figure 2. The opposite trends of annual industrial value added and industrial energy intensity in Shanghai

As shown in Figure 3, since 2010, the annual revenue of industries associated with energy conservation and environmental protection has been growing. This trend might be driven by the local enabling policies, including policy schemes discussed in this paper.

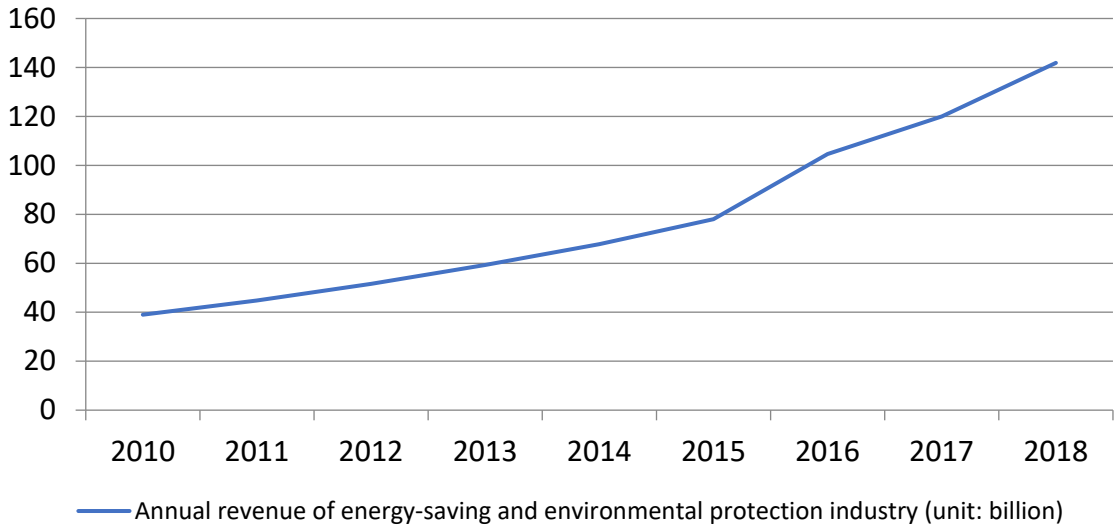

Figure 3. The trend of annual revenue of energy-saving and environmental protection industry in Shanghai (unit: billion RMB)

Note: The data were collected using a variety of approaches. The 2010 data were released by the government; the 2013 data were forecast in the research (Dongxu and Wenqiao, 2014); the 2011 and 2012 data were calculated by the author based on the values of 2010 and 2013; and the data from 2014–2018 were released by Shanghai's government.

5. Discussion and conclusion

There is a transformation in policy strategies for engaging business sectors in carbon reduction, from mandated carbon reduction to resorting to market-based policy schemes. Industrial emissions are the largest carbon source in Shanghai; thus, the Shanghai government implemented mandatory emission reduction for firms at the initial stage. For mitigation purposes, stringent policies in energy-demand sectors (industries especially) are needed in the short term (Méjean et al., 2019). However, previous experience in industrialized countries shows that, in most cases, mitigation policies have exempted or had limited influence on the industrial sectors owing to economic factors, or have only addressed the low-hanging fruit (Michaelowa et al., 2018). Moreover, in the beginning, the Shanghai government faced the challenge of local industries having lack of competence in terms of delivering energy-saving projects.

To address the above challenges, at a later stage, the Shanghai government adopted a market-mechanism strategy, issuing various policy schemes to stimulate firms' interests in the new market. These policy schemes gave incentives to both emitters and solution/technology providers. For example, the emitters can reduce energy costs by conducting EPC or can obtain carbon assets under the ETS. Low-carbon solution/technology providers can have business opportunities in the growing markets. Market actors are viewed as the best providers of environmental solutions if they are given the right incentives (Khan, 2013; Rogner, 2012). Shanghai's case shows that the policy incentives are crucial to stimulate initial market demand; however, market factors may play a role at a later stage in terms of facilitating firms' independence from policy support.

In contrast to national or provincial governments, the city government might have direct administrative influence on and be able to provide direct support to firms for emission reduction. This direct relationship might bring some convenience for the close interactions of these two actors. For example, SEPCMC collaborates with local ESCOs to develop the local market; and during this process, SEPCMC may identify the firms' policy needs and then provide further support. Another example is that SECSC worked closely with high-emission firms to supervise their energy consumption and also to assist in their capacity building.

The multiple policy schemes may play a role in triggering development of local low-carbon industries

We identified that the multiple policy schemes implemented in Shanghai may play a role in triggering the emergence and growth of several low-carbon industries, but with different levels of policy influence on different industries. The government can provide both direct support for industry development and the incentives for stimulating market demand, such as EPC adoption. Or, it can focus only on the incentives for creating a market demand, and then indirectly promote industry growth, such as EV adoption. In addition, some policy schemes may have a flow-on effect on supply-chain markets. For example, along with the EPC market maturing, new business opportunities from this market induced the appearance of local carbon-asset management industry.

Co-benefits of mitigation policies are recognized in the literature (He et al., 2010; Rashidi et al., 2017). Embedding energy/mitigation strategies in local business as well as encouraging economic development is recommended in policymaking (Aslani and Mohaghar, 2013). In this sense, Shanghai's case may present a good approach in terms of how the government coordinates with the corporate sector on urban mitigation actions, with co-benefits for local businesses.

Multiple policy schemes might play a role in catalyzing business transition in some existing local firms

In general, manufacturing firms with high emissions are regarded as barriers or inertial factors in the low-carbon transition. However, in Shanghai's case, some existing firms experienced a business transition – expanding their business to a new market, building on their technical and financial strengths. Shanghai's experience indicates that if there are enabling policies or market incentives these local emitters may adapt to the carbon-control environment in a proactive way – not only cutting their emissions but also exploiting their experience to provide services to other emitters. To some degree, their role in the transition is changing from "carbon emitter" to "solution provider", probably driven by the "pushing" factor of the stringent emission-control policies and the "pulling" factor of opportunities in the new markets.

Multiple policy schemes and market factors might have built a platform for driving technology adoption and business innovation

Shanghai's low-carbon strategy might play a role in driving technology innovations and adoption. In energy-intensive industries, the decarbonization of industries requires the adoption of carbon-efficient technologies (Masson-Delmotte et al., 2018), and policy support is critical for doing so (Bataille et al., 2018).

In Shanghai's case, both the pushing policies (stringent carbon-control policies) and the pulling policies (enabling policies for energy service/carbon market) may facilitate the adoption of energy-efficient technologies. For example, in the initial stage of EPC, applied technologies may only have addressed the low-hanging fruit. After a decade, the adoption of more advanced technologies for decarbonization is needed and is enabled by increased subsidies. In addition, local policy and the market environment may also have collectively stimulated innovations from corporate sectors such as locally designed EVs, patents by ESCOs, and some experimental financial instruments.

Although we exhaustively explored how to engage the commitments and contributions of business sectors to the city's low-carbon initiatives by analyzing the Shanghai case, we acknowledge the limitations of this research. We only identified and analyzed a few cases representing some intriguing phenomena happening under Shanghai's low-carbon transition. We did not inspect the overall trend of local industrial transition; nor did we evaluate the emission-reduction effects of the policy schemes in a quantitative way. We regard this paper as preliminary research. This research field requires more attention and investigation and we expect our research can provide some primary understanding of the future in-depth study on business roles in urban low-carbon transition.

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Supplementary Material 1

Table 1. The annual industrial value added and industrial energy intensity in Shanghai

Year	Industry value added (unit: billion RMB)	Industrial energy intensity (unit: million ton standard coal/billion RMB)
2011	720.9	0.0853
2012	730.1	0.0809
2013	736.8	0.0785
2014	762.0	0.0725
2015	743.1	0.0725
2016	755.5	0.0765
2017	830.4	0.0598

Data source: Shanghai Statistical Yearbook

Table 2: The annual revenue of energy-saving and environmental protection industry in Shanghai

Year	Annual revenue of energy-saving and environmental protection industry (unit: billion RMB)
2010	39
2011	44.8
2012	51.6
2013	59.3
2014	67.8
2015	78
2016	104.6
2017	120
2018	141.87

Conclusion

Cities are key players in achieving the global mitigation target of limiting global warming to 1.5˚C, which can be demonstrated by their ambitions and low-carbon actions. There is a growing body of literature reporting forerunner cities' low-carbon transition, mainly focusing on their endeavors to translate policy targets to policy outputs, and sometimes, discussing the policy efforts that might bear fruitful outcomes in the end. Yet, knowledge gaps exist in both empirical and theoretical dimensions in terms of what are the underlying mechanisms and general patterns that drive cities' low-carbon transition.

The concept of sustainability experiments, empirically, is employed as an instrument by municipal governments for incubating innovations targeted at low-carbon goals; and, academically, can be used as a theoretical lens to understand the enabling mechanisms for the urban sustainability transition. Even with a growth of knowledge on the role of sustainability experiments in this transition, the internal mechanisms – that enable innovative processes in experimentation – needs to be further investigated.

This thesis takes Shanghai as the case study city, advancing the knowledge in the literature by filling the above gaps. The main research questions are:

- How has Shanghai nurtured and scaled sustainability experiments to align with its low-carbon initiatives and
- What supporting mechanisms are needed for the city's low-carbon transition, and how do these mechanisms work in Shanghai's case?
- How do the insights from the Shanghai case study advance the urban sustainability transition study theoretically and empirically?

Four main chapters collectively addressed the research questions with different foci. The main findings are summarized below.

Over time, there is an evolutionary process of low-carbon policies in Shanghai, indicating that Shanghai's low-carbon initiatives are embedded in its existing policy framework, instead of being a completely new strategy. Specifically, policy measures with low-carbon implications – e.g., industrial restructuring, energy-saving, and addressing environmental pollution – were implemented in the city long before the city's low-carbon initiatives were introduced. These measures were employed to tackle local economic and environmental challenges. Later, explicit low-carbon policies were integrated into the city's overall transition plan, which is more than simply re-interpreting traditional policy schemes with low-carbon implications, instead, incorporating new policy goals, projects, and instruments.

The national and local policy context for initiating and implementing Shanghai's low-carbon initiatives is unfolded in this study. A nested structure, with strong vertical linkages between central and local governments for innovative policy practices, is identified. There is a top-down design from the central government for policy learning, joined by bottom-up policy innovations enabled by the proactive local government. Such a structure provides a favorable institutional setting for stimulating two levels of policy experiments – city experiments taken

as a whole to inform national low-carbon policymaking, and sustainability experiments within a city as trial approaches to achieve the transition target. For example, the pilot ETS program in Shanghai provides policy-learning feedback for upper-level ETS policymaking. The findings illustrate the role of multi-level governance structure in the city's experimentation process toward sustainability transition.

Along a horizontal dimension across cities, Shanghai is open to learning and adopting good practices (such as sustainability experiments) tested in other places, to achieve its low-carbon targets. By investigating the case of EPC adoption in Shanghai, this thesis illustrates how innovations travel across contexts. The findings show that experiment transfer is supported by horizontal linkages between cases, such as learning through actor interactions. There is a shift in learning observed in Shanghai's case: from across-case learning to internal reflexive learning facilitated by a variety of contextualization processes. The adoption process has mobilized and realigned various actors, resources, and institutional arrangements facilitated by external and internal learning. As a result, the contextualization of EPC in Shanghai forms a new social, economic, and institutional configuration, for example, new actor networks, new job opportunities, new institutions, etc. The new configuration is distinctive from its predecessors in many ways with endogenous innovations, such as an innovative governmental approach for the adoption and a tailored loan product for EPC projects. The research concludes that contextualization is an innovation in itself and can be a new source of innovation.

The enabling mechanisms for low-carbon transition, especially in the financial and institutional dimensions, are a focus of this thesis. From a systems perspective, the research identified that Shanghai's special fund scheme has spillover effects in facilitating a series of institutional changes and supporting local capacity building, by enabling and enhancing cooperation across numerous governmental departments in Shanghai, over its 11-year implementation. Specifically, along with a growing number of subsidy policies on cross-cutting mitigation issues, cooperation across governmental institutions has gradually built up. Moreover, the fund may catalyze the building up of local mitigative capacity, such as financial availability, low-carbon technologies, and public awareness; and also mobilize them into actions by widely engaging a variety of stakeholders from business and communities and by supporting the adoption of carbon-efficient technologies. Collectively, the direct-funding mechanism, collaboration institutions, and local capacity building play a role in opening up a pool of sustainability experiments to identify the successful one to upscale for transition, including both locally-nurtured innovations and the adoption and contextualization of experiments from outside (e.g., EPC adoption).

The thesis offers a preliminary discussion on how Shanghai can encourage business sectors' contributions in its low-carbon initiatives by investigating several policy schemes implemented in Shanghai for this purpose. The findings show that there is a transformation in policy strategies for engaging corporate sectors in carbon reduction, from mandatory emissions reduction to employing market-based policy measures. Multiple enabling policy schemes – either directly supporting a specific low-carbon industry or enabling growth by providing incentives to create market demand – may play a role in triggering local low-carbon industries' development. Importantly, the policies and market factors might collectively have built a platform for driving low-carbon technology adoption and innovation in the city.

Weaving the findings of four papers together, this PhD research makes a significant and original contribution to knowledge on urban sustainability transition and provides evidence-based policy-learning cases.

Theoretically, this PhD study looks into the enabling mechanisms for sustainability experiments in cities and the underlying mechanisms inside experiments for incubating innovations. First, cities are widely regarded as fertile grounds for sustainability innovation, but the internal structures and patterns are unclear. This research looks into this black box, by decomposing supporting structures, institutional settings, and policy frameworks that underpin cities' capacity of nurturing sustainability experiments to stir the transition. The findings add new insights into the multi-level governance literature by illustrating the importance and outcome of combining the active and enabling role of the national government with the capacity and vision of local governments for stimulating low-carbon transition in cities. Importantly, the policies, institutional arrangements, and financial mechanisms investigated in Shanghai's case are relations-based and process-based innovations in themselves, which are in formation and testing processes. Another significant contribution of this research is to investigate the complex co-evolving processes of the above governance experiments, revealing their interlinkages – i.e., the enabling mechanisms in policy, institutional, and financial dimensions are mutually supporting, reinforcing, and facilitating each other' establishment and functioning in implementation. Second, this PhD dissertation fills an important gap in system innovation theory and urban transition study – where the adoption and duplication processes of tested experiments in new contexts are underexplored – by conceptualizing the creative courses in contextualizing a learned sustainability experiment in recipient cities. This theoretical conceptualization unravels that the nature of contextualization is an innovation in itself. The new insights not only provide a tool to analyze adoption processes in other cases, but also shed light on the underlying mechanisms in broadening and scaling sustainability experiments through innovation multiplication.

Empirically, the research illustrates the policy efforts involved in Shanghai's low-carbon transition, including the emergence of low-carbon initiatives, the policy outputs driven by target-oriented governmental efforts, and the policy outcomes enabled by supporting resources and active stakeholders. This empirical case can attract the attention of learner cities for extracting useful policy learning, from policy practices by a major metropolitan government in a transition economy in tackling low-carbon development. Especially, the strategy and policy schemes – that Shanghai's government adopted to stimulate business sectors' contribution with co-benefits of emission reduction and local economic development – may give inspiration for other cities in developing economies, where industrial carbon emission is one major source, compared to developed cities.

Although making contributions to urban sustainability transition literature, this PhD research has several limits. For example, the transferability of policy innovations identified in this research is discussed at a theoretical level, and operational recommendations in detail for policy learning in practices are not included. This is because 1) ready-to-use suggestions need the consideration of the specific conditions in learner cities and to be tailored to their pragmatic needs, and 2) systematic quantitative analysis was not conducted in this research,

but is required if the findings are supposed to support the practical use of policy innovations. For example, the evaluation of the input and output of a policy scheme in a quantitative way is essential to inform the learners to plan their own policies. The study on the business sector's role in urban low-carbon transition is preliminary research based on document analysis, and the conclusions are drawn from a few representative policy schemes, as opposed to a comprehensive analysis of the city's low-carbon policy environment to businesses.

Future investigations are necessary to further explore the supporting mechanisms for transition in cities. For example, more empirical examinations of the contextualization framework (Chapter 3) are desirable, to unravel how to efficiently adopt the innovations in new localities, and to extend the current understanding of the role of contextualized innovations in transition. Moreover, in-depth research is needed on understanding the business sectors' contributions to low carbon transition at a city level, e.g., the overall trend of industrial transition under urban sustainability transition and the evaluation of emission-reduction effects of policy schemes on industries in a quantitative way. This new knowledge would benefit policymakers to better engage the business in the city's low-carbon initiatives, and may also theoretically extend the knowledge in urban climate governance by scrutinizing the private sector's role. Last but not least, further work is certainly required on cross-case research to reveal the patterns of urban transitions under diverse geopolitical contexts, to unfold the intercity and extralocal interactions, and how these interactive dynamics play a role in incubating and scaling innovations. Especially, It will be important that future studies could pay a renewed attention to developing cities facing multiple challenges, as such new knowledge on their innovative ways to deal with these pressing issues simultaneously (e.g., resolving poverty and tackling environmental degradation) could be shared for learning among their peers, which might potentially benefit the transition.

Appendix 1. Interviewee list and interview questions

Appendix 1.1 – Round 1 interviewee list (June 2016–September 2016, fieldwork in Shanghai)

Name	Position	Organization	Interview Summary
Anonymous	Office head of environment and resources	Shanghai Municipal Development and Reform Commission	Overview introduction of Shanghai economic development, energy management, environmental protection, and climate protection
Anonymous	Senior officer	Shanghai Municipal Development and Reform Commission	Overview introduction of Shanghai-specific low-carbon policies
Anonymous	Retired officer	Shanghai Municipal Commission of Economy and Informatization	Overview introduction of Shanghai Energy Conservation Supervision Center
Anonymous	Senior officer	Shanghai Municipal Energy Conservation Supervision Center	Introduction of the responsibility and routine work of Shanghai Municipal Energy Conservation Supervision Center
Anonymous	Director	Shanghai Energy Conservation Association	Introduction of the responsibility and routine work of Shanghai Energy Conservation Association, ESCO industry in Shanghai
Anonymous	Director	Shanghai Changning District Low-carbon Management and Development Center	Introduction of pilot low-carbon district program and the development of ESCO industry in Changning District
Anonymous	Staff	Shanghai Energy Conservation and Emissions Reduction Center	Introduction of pilot low-carbon practice area program in Shanghai
Yujian Wei	Director	Shanghai Energy Performance Contracting Management Committee	Introduction of ESCO industry in Shanghai
Di Wu	Director	ENVISION renewable energy company	Introduction of the company and its response to local policies
Hongjun Zhang	Manager	Shanghai Pudong Testing Technology Co., LTD	Setting up the energy-monitoring platform on local buildings for the government
Xiaoying Wang	Staff	Shanghai Zhixin Carbon Asset Management Co., Ltd	The company's business scope and its response to local policy and market environments
Anonymous	Staff	Shanghai Oriental Low-carbon System Integration Co., Ltd	ESCO, low-carbon solutions, and the company's response to local policy and market environments
Xuejun Shen	Senior vice president	Siemens	Low-carbon solutions and the company's response to local policy and market environments
Feng Chen	Manager	Shanghai KangCheng HV&AC Co., Ltd	ESCO, low-carbon solutions, and the company's response to local policy and market environments
Anonymous	Technical staff	Electric vehicle company	Electric vehicle design and manufacturing and the company's response to local policy and market environments
Anonymous	Energy manager	Chemical industry	Chemical products manufacturing and the company's response to local policy and market environments

Anonymous	Energy manager	Ford	Electric vehicle (no factory in Shanghai) and the company's response to local policy and market environments
Anonymous	Expert	Baosteel	Iron and steel production and energy service and the company's response to local policy and market environments
Anonymous	Technical staff	Electric vehicle company	Electric vehicle design and manufacturing and the company's response to local policy and market environments
Anonymous	Energy manager	Power station	Coal power generation and the company's response to local policy and market environments
Anonymous	Energy manager	Chemical industry	Chemical products manufacturing and the company's response to local policy and market environments
Hongyu Jiang	Manager	Isunopto	Energy technology (lightning) and the company's response to local policy and market environments
Charlie Cheng	Manager	Shanghai Haicheng Marine Equipment	Energy-saving product and the company's response to local policy and market environments
Honglin Zhang	Manager	Shanghai Chinllenge Gases Co., Ltd	The company's business scope and its response to local policy and market environments
Qingling Huang	Manager	Shanghai Bishen Electromechanism Co., Ltd	Natural gas generator and the company's response to local policy and market environments
Anonymous	Staff	John Cabot	Chemical products manufacturing and the company's response to local policy and market environments
Anonymous	Energy manager	Power station	Coal power generation and the company's response to local policy and market environments

Appendix 1.2 – Supplementary interviewee list (February 2017–August 2019, online interviews)

Name	Position	Organization	Interview Summary
Rumei Chen	Retired officer	Shanghai Municipal Commission of Economy and Informatization	Some specific discussions regarding the evolution process of energy-saving policies in Shanghai
Gengpo Ren	Senior officer	Shanghai Municipal Energy Conservation Supervision Center	Some specific discussions regarding the evolution process of energy-saving policies in Shanghai, business sectors' attitudes toward these policies, and policy outcomes
Yujian Wei	Director	Shanghai Energy Performance Contracting Management Committee	Some specific discussions regarding ESCO industry in Shanghai
Huan Ni	Director	Green Light-Year	The benefits for citizens from Shanghai's low-carbon policies

Appendix 1.3 – Interview questions

Questions for government staff

I discussed three groups of questions with interviewees based on their positions and organizations. The specific discussions varied due to the different topics.

1. The background and development of low-carbon policies in Shanghai

2. The government agency's responsibility scope

3. The outcomes of the government agency's work and policies

Questions for companies

The discussions with interviewees from business sectors are mainly based on the form below.

Business Profile	
1. Company name	
2. Ownership	a. State-owned enterprise b. Enterprise under collective ownership c. Associated enterprises d. Foreign-invested enterprises e. Private enterprise f. Others_____
3. Business scope	
4. Core businesses	
5. Is Shanghai market/location important for company's core businesses?	a. Very important b. Somewhat important c. Not important d. Others_____
If "no", why?	
6. Where are the major markets for these businesses? (Please identify some areas/cities.)	
The official stand on climate change	
7. Does the company have an official stand on climate change? (e.g., public statement, plan, strategy, etc.)	
8. Is climate protection regarded as a	

risk or an opportunity to the company?	
9. Environmental report **a. Does the company prepare and submit an environmental report regularly?** **b. What report?** **c. How often do you submit?** **d. To what agency(ies) do you submit?**	
10. Is climate protection included in the environmental report?	
Perceptions of cities' low-carbon initiatives and market	
11. Has the company ever heard about or paid close attention to a city's low-carbon initiatives?	
12. Has the company ever considered the city's low-carbon initiatives in business? And how?	
13. Does the company have any businesses offering energy-saving services/solutions, or carbon-reduction services/solutions?	
Current involvement and implementation	
14. Has the company currently been involved in any low-carbon related schemes led by the Shanghai government?	
15. Does the company proactively/passively get involved in these schemes?	
16. Climate strategy **a. Does the company have its own specific strategy for climate protection?** **b. Or has the climate protection been integrated into the company's overall strategy as an important element?**	
17. Does the company have any carbon-reduction/energy-conservation projects led by you currently or planned to be implemented?	
18. What are the concrete approaches/methods employed by the company to save energy consumption/cut carbon emissions?	
Ambitiousness for future involvement	
19. Is the company willing to play a more important role in Shanghai low-carbon transition?	

20. Why is/is not the company prepared to play a more important role?	
21. What are the company's purposes for doing so?	
22. What are the barriers of playing a more important role?	
23. What policy tools do you think are more effective regarding urban low-carbon transition?	a. Command-and-control (e.g., banning activities and practices, or requiring the use of a particular technology); b. Economic incentives or market-based mechanisms (e.g., emissions taxes and trading); c. Direct government action and involvement (e.g., subsidies or investment); d. Education and information; e. Others_____