Learning within local government to promote the scaling-up of low-carbon initiatives: A case study in the City of Copenhagen

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A B S T R A C T

Local governments are experimenting with low-carbon initiatives (LCIs) to learn how the transition to low-carbon cities can be advanced. However, little is known about how local governments can capitalize on what has been learned and use it to accelerate scaling-up processes. This paper explores the complex relationship between LCIs and learning processes at the level of local government. The issue is examined through an explorative embedded case study in the City of Copenhagen, a sustainability frontrunner. The paper makes three contributions that enrich literature and practice concerning climate governance for sustainability transitions. First, it offers an overview of two types of knowledge that can be derived from LCIs to accelerate scaling-up processes: instrumental and transformative knowledge. Second, the paper provides a concrete overview of learning practices for governing learning processes within local government. Local governments can learn from LCIs through four categories of practice: experience accumulation, knowledge articulation, knowledge codification, and knowledge distribution. Finally, the paper offers an overview of explanatory factors related to the motivation, resources, and skills that influence a local government's capacity to learn from LCIs. The findings particularly highlight the importance of setting a mandate for experimenting with and evaluating LCIs.

1. Introduction

Theory on urban climate governance and sustainability transitions highlights the importance of experimenting with low-carbon, socio-technical innovations in order to learn how low-carbon transitions can be advanced (e.g. Brown and Vergragt, 2008; Bulkeley, 2013; Castán Broto and Bulkeley, 2013; Geels and Deuten, 2006; Geels and Raven, 2006; Hoffman, 2011; Kivimaa et al., 2017; Schot and Geels, 2008; Sengers et al., 2016). Local governments in particular play a prominent role in experimentation for sustainability transitions, as cities represent a significant part of global GHG emissions and local governments have shown farsighted leadership in addressing climate change (Bulkeley, 2010; Castán Broto and Bulkeley, 2013; ICLEI, 2016; Mcguirk et al., 2015; Schreurs, 2008; Selman, 1998). In their endeavor to foster low-carbon urban development, local governments are increasingly initiating and enabling the implementation of low-carbon initiatives

(henceforth: LCIs or initiatives), such as the retrofitting of building districts or creation of eco-districts, in which they experiment with low-carbon, socio-technical innovations that have the potential to contribute to sustainable societal change (Bulkeley, 2013; Castán Broto and Bulkeley, 2013).

Theory on sustainability transitions suggests that all forms of experimentation with LCIs occur in protected spaces called 'niches', which provide resources and conditions (e.g. through public support structures or specific market segments) that shield the innovation from the selection pressures of the regime's dominant institutional structure and allow it to develop (Geels and Raven, 2006; Smith and Raven, 2012). However, to encourage scaling-up processes, it is important that the community of practitioners learns from LCIs that are being temporarily implemented in a particular space and at a certain scale (Castán Broto and Bulkeley, 2013; Hoffman, 2011; Kivimaa et al., 2017; Sengers et al., 2016). The scaling-up which may be horizontal, or vertical, or

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both - results in LCIs increasing their impact in terms of low-carbon development (van Doren et al., 2018). Horizontal scaling-up refers to the spatial growth of an initiative or its components as a result of internal growth, replication, or the uptake of similar initiatives. Vertical scaling-up occurs when the knowledge generated by LCIs leads to institutional change favorable to the low-carbon innovations implemented in LCIs (related to the concept of 'regime transformation', Smith and Raven, 2012).

While experimenting with LCIs and learning from them are considered important ways of conducting urban climate governance (Bulkeley, 2006; Castán Broto and Bulkeley, 2013; Kivimaa et al., 2017), the role of local government—a critical actor in low-carbon transitions—in governing the learning processes remains underexplored. Scholars have argued that knowledge and experiences from initiatives often remain trapped within the local project team, resulting in others having to 'reinvent the wheel' (Geels and Deuten, 2006). Knowledge loss at the end of LCIs can lead to higher costs, redundant work, and the same mistakes being made, thereby hampering the scaling-up of LCIs. Moreover, when local governments fail to learn from LCIs, the initiatives can be criticized for being isolated, fragmented, or stand-alone initiatives that do not contribute systematically to climate governance (Hoffman, 2011; Kivimaa et al., 2017; Mcguirk et al., 2015). Therefore, to be at the forefront of climate governance, local governments need to learn from previous experiences and embed relevant knowledge from LCIs into local decision-making structures so that it can be used for scaling-up processes.

This paper will explore the complex relationship between LCIs and learning processes at the level of local government. The question that is addressed through an exploratory research approach is: *How can local governments learn from LCIs so that they can scale them up?* To reflect on this question, insights from theory on urban climate governance and sustainability transitions are complemented with theory on organizational learning. The research question is empirically investigated through an exploratory embedded case study of six LCIs that focus on decarbonizing the building stock in the City of Copenhagen. Copenhagen is a relevant case, as it aspires to become the first carbon neutral city in the world and is implementing LCIs not only to reduce its carbon emissions but also to learn which approaches will enable it to achieve this aspiration (City of Copenhagen, 2009).

Section 2 begins by introducing the key concepts and analytical framework guiding this paper. Section 3 will elaborate on the research design, followed by an overview of the results in section four. The paper will conclude by reflecting on the policy implications of the findings.

2. Analytical framework

To reflect on the research question addressed in this paper, use has been made of theory on urban climate governance (Bulkeley, 2006, 2010; Bulkeley and Castán Broto, 2013; Bulkeley and Kern, 2006; Klein Woolthuis et al., 2013; Schreurs, 2008; Yohe, 2001), theory on sustainability transitions (Geels, 2004; Geels and Kemp, 2007; Schot and Geels, 2008; Smith and Raven, 2012), and theory on organizational learning (Hansen et al., 1999; Lam, 2010; Moorman and Miner, 1998; Prencipe and Tell, 2001; Vegt and Bunderson, 2005; Zollo and Winter

2002).[1] However, as these bodies of literature are large and as various comprehensive overviews of the literature exist (see Bennett and Howlett, 1992; Betsill and Bulkeley, 2007; Rashman et al., 2009; Schot and Geels, 2008; Wang and Ahmed, 2003), instead of replicating such work, we propose to synthesize the key findings regarding the following themes: learning outcome, learning output, learning practices, and explanatory factors for learning.

2.1. Learning outcome

Building on insights from organizational learning, we suggest that local government has learned from LCIs when inferences from previous LCIs are used to guide future conduct and decision-making on scaling-up processes (Levitt and March 1988; Scarbrough et al., 2004). It is important to emphasize that "*learning need not result in observable changes in behavior. An entity learns if, through its processing of information, the range of its potential behavior is changed*" (Huber, 1991, p. 89). Accordingly, we maintain that learning does not always result in observable scaling-up processes (i.e. 'impact') but can also occur when the knowledge from previous LCIs is used *as a reference* for future scaling-up processes, i.e. for the implementation of new initiatives (horizontal scaling-up) or for addressing restrictive institutional conditions (vertical scaling-up) (Huber, 1991; Mastop and Faludi, 1997).

2.2. Learning output

Based on theory on organizational learning and sustainability transitions, we maintain that LCIs generate tacit knowledge that tends to be applicable locally, i.e. in specific geographical places. Factors it can relate to include local problems, possibilities, needs, resource capacity, and skills. While local knowledge is highly context- and project-specific, the experiences of individual LCIs can, through learning practices (see section 5.2.3), be aggregated into abstract 'global' knowledge which has more formal and abstract characteristics (Rip, 1997).

Moreover, building on Argyris and Schon (1978) well-known framework on single-and double-loop learning in organizations, a distinction can be made between 'instrumental' and 'transformative' global knowledge. Instrumental knowledge refers to practical skills, strategies, and insights into cause-and-effect relationships between interventions and outcomes that are related to single-loop learning. This type of knowledge is practical in nature and is related to issues of effectiveness and goal-attainment (Argyris and Schon, 1978). It can lead to insights into the 'what works and why?' of LCIs. For instance, LCIs can generate knowledge relating to technical aspects, design specifications of innovations, and user preferences, and thereby can demonstrate the evidence base for innovations ('proof of concept'). In addition, LCIs offer insights into successful approaches or strategies contributing to project success. However, whereas instrumental knowledge can be used to strengthen the innovations being experimented with in LCIs and can contribute to horizontal scaling-up processes, the interpretation of the policy problem and dominant institutional structures remain intact.

Transformative knowledge, on the other hand, includes insights concerning the underlying assumptions, values, structures, problem perceptions, or goals underlying LCIs, which leads to double-loop

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[1] Within sustainability transitions theory, various studies reflecting on learning practices in the furtherance of niche development are helpful for understanding how local government can learn from LCIs. To our knowledge, theory on climate governance has not yet explicitly addressed the issue of learning, but we consider the insights it offers into factors that influence cities' ability to act on climate change are relevant for realizing initiatives and using lessons learned to promote scaling-up processes. Because processes of knowledge creation and knowledge transfer within organizations are central themes in theory on organizational learning, the theory offers valuable insights into how local governments can promote learning from LCIs.

learning (Argyris and Schon, 1978). It may comprise reflections on the institutional structures of the industry, market, policy, or socio-cultural context that need to be in place for large-scale application of the innovation to be possible. Double-loop learning is linked to institutional change because it deals with altering cognitive frames and perceptions on established, 'taken-for-granted' rules and systems related to a policy issue. Transformative knowledge can be used for vertical scaling-up processes directed at transforming the institutional environment in favor of the innovations experimented with in the LCIs.

In sum, learning occurs (there is a 'learning outcome') when instrumental and/or transformative knowledge ('learning output') are used as references for future scaling-up processes.

2.3. Learning practices

Theory on sustainability transitions maintains that the creation of explicit, global knowledge requires dedicated aggregation work, during which tacit, local knowledge is 'delocalized' and transformed into general rules (Geels and Deuten, 2006). Examples of such activities include model building, standardization, writing of handbooks, and the formulation of best practices. Through systemic knowledge aggregation from local projects, global knowledge becomes more articulated, stable, and specific (Schot and Geels, 2008).

Scholars in the field of organizational learning argue that the process of organizational learning occurs through various (not necessarily successive practices (Dixon, 1994; Hansen et al., 1999; Nonaka, 1994; Zollo and Winter 2002): knowledge accumulation, knowledge articulation, knowledge codification, and knowledge distribution. 'Knowledge accumulation' encompasses the relatively passive process of learning through experience. 'Knowledge articulation' involves a more deliberative process through which individuals and groups learn by reflecting on what works and what doesn't in the execution of projects or tasks (Zollo and Winter 2002). Knowledge articulation leads to an improved understanding of causal relationships and can promote double-loop learning through collective reflection (Argyris and Schon, 1978). After knowledge has been articulated, organizations can initiate a phase of 'knowledge codification', during which the articulated knowledge is codified in written tools, such as best practices or case study guides, and stored in databases or libraries where others can access it. Finally, knowledge can be distributed using a codification or personification strategy (Hansen et al., 1999). Whereas a codification strategy builds on the sharing of codified knowledge through impersonal tools, such as databases (whether or not online), a personification strategy encapsulates practices for sharing knowledge through direct person-to-person contact (Hansen et al., 1999).

2.4. Explanatory factors for learning

The different bodies of literature also offer insights into the factors conducive for learning from LCIs. From the literature analysis, three key groups of factors emerge: motivation, resources, and skills. 'Motivation' includes climate leadership and a willingness among politicians or persons in strategic positions to accelerate the low-carbon transition (Bulkeley, 2010; Bulkeley and Kern, 2006; Kingdon, 1995). Political leadership is expected to influence the resources available for experimentation with low-carbon innovations (Betsill, 2001; Granberg and Elander, 2007; Kasioumi, 2011; Romero-Lankao, 2012; Schreurs, 2008). Furthermore, commitment on behalf of employees (Senge, 1993), and 'a co-operative organizational culture' (Zollo and Winter, 2002) are expected to foster learning processes. In relation to 'resources', it is expected that a local government's resource capacity can influence its ability to learn from LCIs (Bulkeley and Kern, 2006; Geels and Deuten, 2006; Fichman et al., 1997; Holgate, 2007; Vegt and Bunderson, 2005; Yohe, 2001). Finally, it is suggested that a local government's capacity to learn from LCIs is influenced by the ability of project leaders and program coordinators to encourage discursive processes and critical

reflections, for which they draw on skills such as those relating to intermediation and cooperation.

2.5. A conceptual model to examine how local governments can learn from LCIs

Building on our findings from the literature review, we propose a conceptual model for studying how local governments can learn from LCIs so they can promote their scaling-up (see Fig. 1). We will use our empirical case study to explore and concretize both the practices related to the learning practices and the explanatory factors that drive or impede learning. It is important to note that the empirical analysis will be used to study how factors and learning processes influence learning *outcomes*, and will not focus on the *impact* of learning, i.e. scaling-up processes.

3. Research design

To explore how local government can learn from LCIs to promote scaling-up processes, we adopted an embedded case study design: we selected one city as a case study and studied various LCIs within that city as sub-units of analysis (Yin, 2014). A key advantage of a qualitative case study design is that it allows the researcher to deal with the subtleties and intricacies of complex social situations (Denscombe, 1988). This is particularly relevant given the exploratory nature of our research and the goal of identifying learning practices and factors not previously mentioned in the literature on urban climate governance. We chose the city of Copenhagen as our general case. This city is particularly interesting, as it has set itself the goal of becoming the first capital city in the world to have become carbon neutral by 2025 (City of Copenhagen, 2009, 2012) and actively supports the implementation of LCIs to learn how the transition to a low-carbon Copenhagen can be achieved. Through desk research and four informant interviews, we selected seven LCIs focusing on energy conservation in the existing building stock.

We opted to study LCIs on energy conservation because energy conservation in the urban building stock is a highly cost-effective measure for decarbonizing cities (Levine et al., 2007; UNEP, 2009). Aside from climate mitigation benefits, reducing the energy consumption of buildings also generates a variety of co-benefits, such as a reduction in energy costs, more local employment, and an improved indoor climate (Boardman, 2010; Levine et al., 2007). To allow for diversity in knowledge generated and actors involved, we selected LCIs representing different types of building stock. The cases were also selected for pragmatic reasons, such as the availability and willingness of the stakeholders involved in the LCIs to be interviewed. The overview of the key characteristics of the LCIs studied given in Table 2 reveals that the LCIs studied vary in size, scope, objectives, and type of building stock (see also Table 1). Four of the LCIs ('Ryesgade', 'Klimakarré', 'Sydhavnen', and 'Hedebygade') are sustainable urban renewal projects in residential buildings. Every year, various urban renewal projects are carried out in Copenhagen, and these present opportunities for deep retrofitting. These LCIs demonstrate how buildings of architectural value can be retrofitted and how building users can be involved in promoting the optimal use of the buildings. The objective of the LCI 'Carbon 20' was to reduce the GHG emissions of small and medium-sized enterprises in the City by 20% through improvements in energy efficiency. The LCI 'Energy Leap' ('Energispring') is a growing partnership program between the City of Copenhagen and major building owners, landlords, housing associations, and administrators committed to reducing energy consumption in their buildings. The final LCI relates to pilot projects with energy management and refurbishment of technical installations in the City's own building stock, such as municipal offices, libraries, sport arenas, and day-care centers.

There were four key steps in our research. The first was to identify the instrumental and transformative knowledge generated by the LCIs. The second step was to assess whether local government has learned
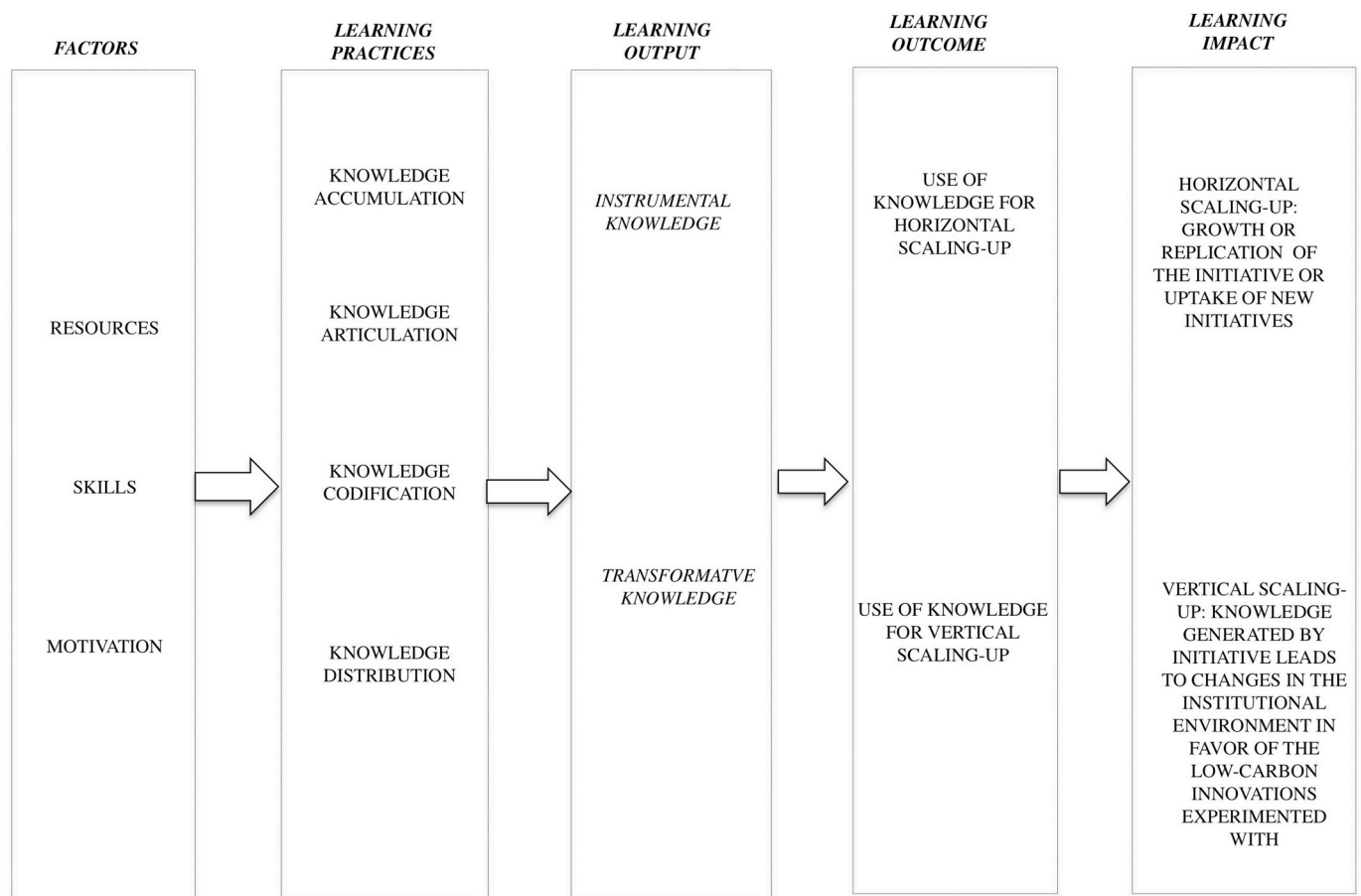
FACTORS	*LEARNING PRACTICES*	*LEARNING OUTPUT*	*LEARNING OUTCOME*	*LEARNING IMPACT*

Fig. 1. Ideal typical model representing the process of learning from LCIs.

from the LCIs, by examining to what extent the instrumental and transformative knowledge generated by LCIs has been used for respectively horizontal and scaling-up. In the third step, learning practices applied by the project team and department were identified. Finally, it was explored how the learning (or the lack of learning) could be explained by identifying the factors related to motivation, resources, or skills that enabled or hampered learning. Desk research and 19 semi-structured interviews were conducted to collect the necessary data. First, 13 semi-structured interviews (duration 60– 90 min) were held with key municipal stakeholders involved in the LCIs (such as project managers). An overview of the interviewees, who have been anonymized in order to maintain respondent confidentiality, can be found in Appendix A. During the interviews, which followed a basic script, respondents were asked to reflect on the following themes: the key instrumental and transformative knowledge derived from the LCI, the influence of the knowledge on scaling-up processes, and the learning practices and factors that had hampered or enabled learning. Appendix B provides an overview of the questionnaire and indicates how the data was coded. Semi-structured interviews were deemed suitable as they allowed us not only to systematically address all research themes, but also allowed for flexibility and for the exploration of learning practices and explanatory factors for learning that had not been previously discussed in the literature. Subsequently, six policy-makers were interviewed to reflect on the results and to discuss general learning practices within the organization. All interviews were audio-recorded, transcribed, and summarized.

Our conclusions concerning practices and factors explaining learning (or the lack of learning) are based on the inter-subjectivity of responses (Scheff, 2006). Empirical examples and quotes from the respondents are used to illustrate our findings. The results section will start with an

introduction to the case and LCIs. This is followed by an overview of the types of knowledge generated by the LCIs, an assessment of learning, and an overview of the practices and factors enabling or impeding learning. Due to space constraints, we have aggregated the results. It is important to note that the cases are illustrative rather than representative, as the key goal was to explore how local governments can learn from LCIs and thereby promote the scaling-up of LCIs.

4. Results

4.1. Introduction to the case

4.1.1. Toward a climate-neutral copenhagen

The City of Copenhagen has the political aspiration to be the first capital city in the world to have become carbon neutral by 2025. In 2009, the City Council adopted the Climate Plan for Copenhagen. This plan sets out the policy for achieving a 20% reduction in CO_2 emissions by 2015 and a vision for becoming carbon neutral by 2025. Copenhagen's Climate Plan reflects that the City's ambition to become carbon neutral is based on economic and normative rationales. "*Copenhagen as a Metropolis and capital must assume responsibility for the climate and show that it is possible to generate growth while also reducing CO_2 emissions*" (City of Copenhagen, 2012, p. 8). Because Denmark has traditionally been very energy-dependent (on other countries), it is considered to be financially rational to invest in energy conservation and renewable energy sources, particularly in light of the rising price of fossil fuels. Moreover, by acting as frontrunner in the field of low-carbon urban development, Copenhagen can attract pioneering companies with green ambitions, which will in turn leverage innovation, new jobs, and investments (ibid). The notion that becoming a climate-neutral city acts as

Table 1
Summary of characteristics of the LCIs studied.

Case	Ryesgade 30	Klimakarré	Sydhavnen urban renewal	Hedebygade	Carbon 20	Energy Leap	Energy pilot projects
Building type	Residential buildings	Residential buildings	Residential buildings	Residential buildings	Commercial building (SMEs)	Buildings owned by major investors in property, administrators, and housing associations	Municipal buildings
Goals	Deep retrofitting of a historical multistory building; 32 homes (built in 1896) and creation of penthouses	Urban renewal of building district to create a climate- resilient city district; Development of cost-effective solutions for energy conservation that have high technical and architectural value	Sustainable urban renewal project aiming to improve the quality of the district's buildings. Other goals include improving the quality of urban spaces and of neighborhood viability and cultural life	Sustainable urban renewal project in the Vesterbro district. In addition to urban renewal of 19 5-story blocks, 12 demonstration projects were carried out to demonstrate urban ecology solutions	Reducing energy consumption of SMEs by 20% through technical and behavioral measures		In-house pilot projects focusing on energy monitoring and energy management and BMS systems
Time period	2012	2013–2018	2014–2019	1995–2004	2011–2013	2015-present	2015–2018
Initiator and financer	Initiator: private developer (Drost Fonden). Co-financers: urban renewal department, City of Copenhagen; Krydsrum architects	Initiator and financer: urban renewal department of the City of Copenhagen; Henning Larsen Architects	Initiator and financer: urban renewal department, City of Copenhagen	Initiator: urban renewal department, City of Copenhagen; co-financer: Ministry of Housing and Urban Affairs	Initiator and financer: LIFE+; project manager: Gate21; partners: 7 municipalities; 2 universities (Aalborg University and Technical University of Denmark (DTU)	Initiator and financer: City of Copenhagen; co-financer and organizer: HOFOR	Initiator and financer: Copenhagen City Properties, City of Copenhagen
Low-carbon innovations applied (technical or social)	*Technical innovations*: Interior insulation; class A windows; centralized and decentralized partially solar-powered ventilation system; energy-saving facade with internal insulation; behavioral measures	*Technical innovations*: Facade that can be placed on the rear of the building and that can be developed in an industrialized fashion; new wall shafts for ventilation and new technical installations. *Social innovation*: innovation platform where market and industry actors can work together on developing integrated solutions	*Social innovations*: Community-based approach for developing energy conservation measures. Each household given customized advice and assistance in reducing their energy bill	*Technical innovations*: Urban renewal in accordance with Danish building regulations; urban ecology solutions included energy-efficient facades, sun walls with solar cells, heat exchangers, energy-saving facades. *Social innovations*: Low-tech solutions focusing on user involvement and behavior.	*Social innovations*: 100 Partnership agreements between the municipality and participating SMEs to reduce energy consumption. SMEs in the capital region were offered the opportunity to develop a green business model to enhance energy and resource efficiency. Companies were offered a structured process with potential analysis and support in order to develop green business models	*Technical innovations*: Data monitoring and benchmarking tool to identify opportunities for energy savings; *Social innovation*: Partnership agreement through which the partners commit to 7 principles, including participation in workshops, sharing of data and experience, and training for technical personnel	*Technical innovations*: Energy monitoring and management; surveillance and renovation of the BMS system (system to control ventilation, temperature and lighting)
Energy saving or carbon reduction (potential)	Primary energy consumption reduced by 73% from 162.5 to 43. kWh/m^2/year. The initiative received the Danish retrofitting award ('Renoverprisen') in 2013	50% reduction in energy consumption	Not quantified	20% reduction of energy consumption	Goal of the project was to reduce the footprint of at least 100 businesses. Reduce material consumption of 2,500 tons and annual CO_2 emissions by approximately 13,000 tons	CO_2 reduction of 6000 tons by 2025	Target of 15–20% reduction in energy consumption, to be attained through refurbishing technical installations and energy management

Table 2
Summary of instrumental knowledge derived from the LCIs.

	General themes related to the instrumental knowledge derived from the LCIs	LCIs
Innovation (what)	Having data on energy consumption and user behavior is critical for developing customized solutions and business models	Ryesgade, Klimakarré, Sydhavn; Carbon 20; Energy Leap; Energy pilot projects
	Need to continuously monitor applied technologies, also after project completion, to see how different technologies interact and to understand the influence of building use on energy performance	Ryesgade; Klimakarré; Energy Leap; Energy pilot projects
	Apply an integrative approach when developing solutions for reducing the energy consumption of buildings, businesses, and districts, and connect the goal of energy conservation to other goals (policy or otherwise), societal challenges, and urban development needs	Sydhavn; Carbon 20
	Novel approach for retrofitting heritage buildings; heritage buildings can be energy retrofitted without destroying their architectural value, by leaving intact the old street facade	Ryesgade; Hedebygade
	If low-tech solutions demanding user maintenance (e.g. green facade) are to perform optimally, ownership and commitment among users must be assured	Hedebygade
	Great potential for saving energy via energy management and surveillance and renovation of BMS systems (ventilation systems)	Carbon 20, Energy pilot projects
Strategies (how)	Create an open innovation platform to promote the continuous development of technologies and to develop integrated rather than stand-alone solutions	Klimakarré
	Create a platform where participants (with a common denominator) can share data and experiences and can benchmark their performance	Carbon 20; Energy Leap
	Promote user involvement and co-creation to ensure optimal use and ownership of the innovations applied	Ryesgade, Klimakarré, Sydhavn; Carbon 20; Energy Leap
	Assist households and businesses in implementing energy conservation measures from start to finish (one-stop shop)	Sydhavn; Carbon 20
	Work together with local actors whom building owners and users know and trust and who can tailor communication to their needs	Sydhavn; Energy Leap
	Communicate the co-benefits of energy saving to building owners and users	Sydhavn; Hedebygade, Carbon 20; Energy Leap

a leverage for green growth is illustrated by the following extract from the Climate Plan: "*The transition is one of the key elements to increasing increased economic growth in Copenhagen. The city must attract more foreign businesses within the green sector and must establish an innovation and entrepreneurial environment able to support the development of new solutions*" (ibid, p. 26). Climate neutrality implies a net zero carbon footprint and means that unavoidable carbon emissions may be compensated through carbon sequestration initiatives or investments in renewable energy. Climate neutrality is to be achieved through a variety of measures in different sectors. Most (74%) CO_2 reductions will be achieved in the area of energy production through an increase in renewable energy and by switching from coal to biomass in the CHP plants for district heating. The remaining reductions are to be achieved from initiatives in transport (11% reduction), energy consumption (7% reduction), city administration (2% reduction), and other areas (6% reduction) (City of Copenhagen, 2009).

4.1.2. Decarbonizing Copenhagen's building stock

Reducing the energy consumption of buildings is a great opportunity and challenge for decarbonizing Copenhagen. "*The building stock is responsible for the major part of the city's energy consumption*" (City of Copenhagen, 2016a,b, p. 29). As energy consumption requirements for new buildings are tightened regularly in accordance with the European Directive on the Energy Performance of Buildings, the greatest challenge lies in reducing the carbon footprint of existing buildings. Studies show that there is a great potential to make existing buildings more energy-efficient, as the great majority (70%) of buildings were built before the first building regulations were in place (ibid). Reducing the energy consumption of the existing building stock generates economic and social benefits; it is expected to lead to lower energy costs and an improved indoor climate, resulting in increased productivity and health for building users. Reducing energy consumption in buildings is also imperative for minimizing investments in renewable energy production. This is reflected by a quote of the Mayor of Technical and Environmental Affairs of the City of Copenhagen: "*We must develop methods to jump-start large-scale retrofitting of our buildings. Failure to do so will greatly increase the costs of our transition to a low-carbon future, as it will mean a greater need for energy production capacity*" (ibid). The City aims to systematically improve the energy performance of its buildings. Goals regarding energy consumption include a 20% reduction in heat consumption, a 20% reduction of electricity consumption in commercial and service

companies and a 10% reduction of electricity consumption in households compared to 2010 (ibid). Yet, practice shows that achieving these goals is challenging. "*The rate of retrofitting in Copenhagen remains slow, despite the enormous potential for energy savings*" (ibid, p. 22). Fortunately, various successful LCIs have been implemented that can offer valuable knowledge on how the City can accelerate the decarbonization of the building stock.

4.2. Learning from LCIS

4.2.1. Learning output

Tables 3 and 4 summarize the findings on knowledge derived from the LCIs.

4.2.1.1. Instrumental knowledge. Themes regarding instrumental knowledge—the what and how of LCIs—relate to the importance of taking user behavior into consideration and promoting user involvement for achieving predicted energy savings. As to the 'what' of LCIs: all respondents reflected on the importance of having reliable energy data and the need to take user behavior into consideration for the development of effective, building-specific solutions. Building users and caretakers play an important role in achieving predicted energy savings. LCIs such as Ryesgade demonstrate that it is not only very important but also a key challenge to ensure that building use is in accordance with innovation requirements. "*One of the reasons why the project did not accomplish the expected results is because of the way people use the building*" (R1). As people may have ingrained habits that hamper energy savings, they need to be informed about optimal building usage. As a result of the experiences with certain LCIs, such as Energyleap and pilot projects in municipal buildings, there is also awareness of the great potential (reductions of 15–20%) for energy savings through effective energy management and the refurbishment of technical installations. Energy management tools measure and visualize the heat consumption of buildings (from a distance) and link the data with weather forecasts and user behavior and needs (e.g. weekend or holiday; comfort level requirements per target group) in order to operate the installations optimally. As for the 'how' question: the LCIs also generated relevant knowledge on strategies contributing to the successful implementation of initiatives. Reducing the energy consumption of buildings is complex and technical; accordingly, building users need assistance with this process. Thus, important factors are personal advice and process

Table 3

Summary of the transformative knowledge derived from the LCIs. The lessons have been categorized in accordance with the four dimensions of the institutional context in which an LCI is implemented: policy, market, industry, and socio-cultural (see van Doren et al., 2018).

	General themes and lessons related to transformative knowledge derived from LCIs	LCIs from which the knowledge has been derived
Policy context	National energy pricing schemes/Low energy price discourages investments in energy efficiency	Ryesgade, Klimakarré, Urban renewal Sydhavn, Hedebygade, Carbon 20, Energy Leap
	Lack of statutory requirements for the energy performance of existing buildings makes it difficult to incentivize building owners to invest in energy efficiency; local government lacks statutory capacity to set regulatory requirements regarding the energy performance of buildings	Klimakarré
	Friction between energy retrofitting of buildings and local regulations regarding the aesthetics of buildings; complex permit procedures	Ryesgade, Sydhavn, Hedebygade
	No regulatory structures to address the split-incentives problem in shared buildings	Klimakarré, Sydhavn, Energy Leap
	Regulations regarding energy-labeling scheme need to be refined to make it possible to upgrade energy labels without additional costs and to address the performance gap of buildings	Ryesgade, Energy Leap
Market context	Difficulty of financing deep retrofits or small-scale energy retrofit projects ('creditworthiness'); creditors are skeptical of the potential of energy savings and long payback measures	Ryesgade, Klimakarré; Carbon 20
Industry context	Limited collaboration between supply-side actors; sector fragmentation and limited collaboration between market actors in developing integrated solutions	Ryesgade, Klimakarré
	Low level of expertise among building operators and technical personnel on how to optimize building operations through energy management and refurbishment of technical installations; many companies renovating or maintaining buildings are unaware of energy-saving possibilities or lack the expertise to carry them out	Energy Leap; Energy pilot projects
	High upfront and installment costs of deep retrofits	Ryesgade, Klimakarré; Urban renewal Sudhavn; Hedebygade,
Socio-cultural context	Lack of awareness among building owners and users about the benefits and opportunities of energy savings in buildings	Ryesgade, Klimakarré, Sydhavn, Hedebygade, Cabon 20; Energy Leap; Municial pilot projects
	Lack of sense of urgency among building owners and users to save energy and unwillingness to invest in energy efficiency, due to short-term investment horizons	Ryesgade, Sydhavnen; Klimakarré, Sydhavn, Carbon 20; Energy Leap

assistance by trusted, local actors who can tailor the communication to the specific needs of building users (e.g. costs or comfort). Moreover, co-creation and strong involvement of stakeholders can also enhance ownership and the behavioral change required for optimal use of the building.

4.2.1.2. Transformative knowledge. Transformative knowledge relates to critical reflections on the institutional structures of the prevailing regime and to ideas on how these structures need to be transformed in order to promote the large-scale application of the innovations applied in the LCIs.

As for policy-related lessons, the respondents' comments indicate a view that changes in national regulation can help the City achieve the goals set out in the 2025 Climate Plan such as energy taxation schemes, legislation to ensure district heatings operate efficienctly, and stricter regulations on energy companies so as to save energy in residential properties. Due to low energy prices there is currently no economic incentive for building owners to reduce energy consumption. Furthermore, the City of Copenhagen has no regulatory means for coercing building owners to reduce their energy consumption. Further developing the energy-labeling scheme and making it possible to upgrade energy-label ratings without high additional costs could incentivize homeowners to retrofit their building, thereby enhancing the significance of energy labels for property valuations. Another recurring challenge when retrofitting buildings is the friction between the energy performance of buildings and the aesthetics of the City's buildings. While there is general consensus among respondents that reducing the carbon footprint of Copenhagen's building stock should not be at the expense of its architectural heritage, local planning criteria or permit procedures could be optimized in order to streamline and fast-track energy retrofits in historical buildings. Finally, policy-related lessons relate to the fact that national regulation inhibits building owners from issuing an energy performance fee in order to address the split-incentive problem, which implies that building owners are often unwilling to invest in energy-saving measures, as the profits are experienced not by them but by the tenants.

The lessons learned in relation to the industry dimension of the regime relate to the fact that energy retrofits entail substantial capital investment and high installation costs. This is partly attributable to the fragmentation of industry and the lack of the collaboration needed in

order to develop integrated solutions. Another barrier relates to the 'performance gap' between building design and operation and the reluctance of supply-side actors to guarantee the performance of innovations. To close this gap, industry actors must take building usage into consideration when developing solutions, must coordinate the design and construction phases, and, when their innovaiton are up and running, must disclose data on the performance of buildings. Furthermore, there is a need for training and capacity building among contractors, constructing companies, and maintenance actors, as many lack knowledge on the technical options for reducing energy consumption. The energy pilot project and Energyleap project generated lessons on the great potential for energy savings (reductions of 15–20%) to be achieved through effective energy management and the refurbishment of technical installations. *"The mechanics of the building are just as important as the hardware. This is an overlooked point in the broader discourse on energy savings"* (R13). Within the scientific debate, there is currently much debate on zero energy (or near-zero energy) buildings. But unless a building's energy consumption is monitored and the mechanics of the building are adjusted accordingly, the building will not perform as promised.

A general theme related to the market dimension of the regime is the lack in financing opportunities and financing practices among creditors and financers, who may be skeptical about the performance of innovations and reluctant to finance energy retrofits. In addition, few market actors can assist households or companies to reduce their energy consumption, or can offer attractive 'one-stop-shop' packages.

An important socio-cultural barrier relates to lack of awareness and priority regarding energy conservation among building owners and tenants, making them reluctant to make long-term investments in energy conservation, regardless of the financial benefits in the long run. Moreover, two prerequisites for ensuring that the buildings are used in a way that will allow the predicted savings to be achieved are public environmental awareness and a willingness among building users to adapt their behavior accordingly.

4.2.2. Learning outcomes

4.2.2.1. Use made of instrumental knowledge for horizontal scaling-up processes. Respondents were generally positive about the local government's ability to use the instrumental knowledge generated by the LCIs

Table 4

Assessment of learning, i.e. whether instrumental and transformative knowledge generated by the LCIs has been used for horizontal and vertical scaling-up (yes; no; likely in the future).

Case	Use of instrumental knowledge for horizontal scaling-up	Indicators	Use of transformative knowledge for vertical scaling-up	Indicators
Ryesgade 30	Yes	Initiative 'Ryesgade 25', application of similar technologies	Yes	Nation-wide awareness-raising activities and collaboration within the building sector
Klimakarré	Likely in the future	Ambition to continue with the platform for further development of the facade so that more initiatives can be realized	Likely in the future	Local awareness-raising activities and collaboration within the building sector
Urban renewal Sudhavn	Likely in the future	Ambition to grow and replicate the community-based approach for promoting energy conservation through urban renewal in other districts of the City of Copenhagen	Yes	Development of local policy programs for promoting energy conservation through urban renewal
Hedebygade	Yes	Some of the urban ecology solutions have been used in other initiatives in Fredericksberg and Copenhagen	Yes	Development of national standards for urban renewal projects; demonstration activities to enhance awareness of the concept of urban ecology among policy-makers and planners
Carbon 20	Yes	New partnerships realized within the commercial and Service Companies Policy Initiative; Energy Leap	Yes	Development of local policy initiative 'Commercial and Service Companies' for reducing energy consumption in commercial and service companies
Energy Leap	Likely in the future	Ambition to grow the partnership and involve more stakeholders	Yes	Lobbying activities to influence national legislationon energy efficiency of heating installations
Energy pilot projects	Likely in the future	Ambition to apply the energy monitoring and management approach in other municipal buildings	Yes	Development of educational material for technical personnel in collaboration with labor union; awareness-raising activities in the building sector

for new initiatives, i.e. horizontal scaling-up. They reported that instrumental lessons have been embedded within decision-making processes and used as a reference for future initiatives. Knowledge distribution within project teams and departments was quite goodand accordingly when the same project team or department came to work on similar initiatives, the links between lessons learned and subsequent initiatives were more direct. As one respondent said: "*We oversee a lot of projects, and we try to promote all the good aspects of previous projects*" (R2). When initiatives have followed each other in quick succession and have been implemented by the same project team, the influences of lessons learned on project design have been evident For example, the municipality project team that worked on Ryesgade 30 also worked on Ryesgade 25, for which similar innovations and approach were adopted. "*They have applied many from the solutions from No. 30 to No. 25, but they have developed and improved them*" (R2). For instance, a similar interior insulation was used, but was improved to avoid mold affecting the construction—a challenge identified during the first project. However, respondents noted that assessment of learning becomes more challenging when there is a long interval between initiatives and when other project teams or departments work on initiatives. They opined that this is because learning occurs through an indirect aggregation process during which the experiences from different initiatives are accumulated, as this can make it difficult to find out one-to-one causal relationships between lessons learned and scaling-up of processes.

While respondents were generally positive about the local government's ability to generate instrumental knowledge and learn from LCIs, they suggested that there is more potential for actors involved in different types of initiatives (e.g. different focus areas or sectors) to learn from each other. Lesson sharing often occurs within departments or groups working on similar issues (e.g. retrofitting heritage buildings), but valuable lessons that are transferable and relevant for a broader array of initiatives that have or will be implemented in other sectors (*e.g.* transport, greening). Examples include practical guidelines on stakeholder involvement, communication, and financing that are not specific to a certain sector.

Respondents also opined that because many LCIs are implemented in partnerships with other local governments, the community, or private actors, it is important that learning does not remain within the local project team and local government but is distributed across the wider policy network. Decision-makers noted that the City of Copenhagen aims to strengthen its function as an intermediary actor in demonstrating low-carbon innovations and disseminating lessons learned among actors within the policy network (see section 4.2.3) but that it is difficult to assess how knowledge generated by the LCIs has been used by other actors in the field.

4.2.2.2. Use made of transformative knowledge for vertical scaling-up processes. Successful LCIs provide the evidence base for alternative institutional arrangements, generating transformative knowledge on the institutional barriers that need to be addressed (see Table 3), which can be used to influence the institutional context of these arrangements through vertical scaling-up processes. Respondents underlined the importance of vertical scaling-up processes, but also noted that achieving this scaling-up is challenging. As one policy-maker (R18) noted: "*In this area, you can really move forward. But it is the difficult part*". It is important to note that there was general consensus among respondents that local government learns about the institutional conditions that need to be addressed (i.e. acquires transformative knowledge) not only by implementing LCIs but also by learning from the experiences of other cities, discussions with stakeholders in the field, and failed experiments.The examples respondents gave of institutional barriers being addressed include the municipality's lack of regulatory powers to promote energy savings in buildings and a lack of training and expertise in energy conservation among building operators. Ways in which the City of Copenhagen is trying to resolve these institutional barriers at different political scales and in relation to different context conditions include awareness-raising activities, lobbying, the writing of policy briefs, education, stimulating media debates, participating in issue networks, and the creation of partnerships between sector actors. For instance, lessons from the Energy Leap initiative have been used to lobby for changes in regulations concerning the energy-labeling scheme. Respondents involved in this LCI pointed out that it is important to create coalitions or partnerships because these can be deployed as an advocacy coalition for lobbying. "*Some of the structural barriers you cannot address on your own*" (R19). "*Some of the partners have connections at a higher level. They have political entrance and if there are obstacles they can address them. Of course, we have our own politicians too. But when we are all together, we are stronger*" (R3). National networks (such as the association for municipalities) or transnational networks (such as C40) can be used to creating momentum for policy issues and disseminating ideas. The

respondents' comments attest to the widespread belief that when writing policy briefs or engaging in lobbying or media debates, the 'policy windows', occurrences and events that generate public and political attention for institutional reform should be strategically used. For example, the national Energy Agreement will be used to lobby for more regulatory power to promote energy savings in buildings, a barrier to scaling-up that has been identified in various LCIs. Partnerships and sector collaborations are also important means for addressing non-regulatory barriers. For instance, in order to share lessons learned on how optimization of technical installations and energy management can lead to energy conservation, the municipal actors involved in the energy pilot projects collaborated with the labor union to develop training courses directed at the technical personnel in buildings.

The findings described above suggest that vertical scaling-up processes aimed at transforming the institutional conditions of the regime occur ad hoc and are influenced by the likelihood of success and the resource capacity. "*It is also a matter of how much we should prioritize resources for that [i.e. time and budget]. We do it when we think we have a good case. When we see possibilities in the political landscape we bring in facts, figures, and arguments*" (R16).

4.2.3. Learning practices

In the following, practices related to the different phases of the learning process will be described.

4.2.3.1. Knowledge accumulation.
Piloting and prototyping within LCIs and the monitoring and follow-up thereof are important activities for accumulating knowledge about the success of and potential for low-carbon socio-technical innovations. "*We are in a transition period. Despite that we already have a lot of technologies on the shelf, there is a need for innovation and testing of new products and processes in different types of contexts*" (R17). The City has set goals to become carbon neutral, but since the pathways toward achieving this have not yet been set in stone, LCIs have an important function in acquiring knowledge about successful solutions. Strategies and solutions set out in the City's Climate Plan are therefore accompanied by demonstration projects "*which, on a small scale will provide Copenhagen with knowledge and experience relating to the strengths and challenges of each individual solution model*" (CHP, 2012, p. 15). In order to take user behavior into consideration when developing solutions, it is important to monitor the energy consumption in buildings before innovations are implemented. Accordingly, an energy surveillance system has been developed jointly by Copenhagen Properties and Purchase and the City's utility company HOFOR. It allows the municipality to monitor and optimize energy consumption. The system is also used in the Energispring program, to identify opportunities for energy savings. After the initiative has been completed, it is important to continuously monitor of key indicators (including indoor climate and energy consumption) yearly, monthly, or even daily, in order to demonstrate and develop the business case for LCIs, without which horizontal scaling-up is impossible. Respondents emphasized that to learn how different technologies interact and to learn about the impact of user behavior on the performance of measures, the monitoring must continue for a long period—until several years after project completion.

4.2.3.2. Knowledge articulation.
Respondents identified three practices for knowledge articulation at project level: *project evaluations*, *project team meetings*, and *dialogos with stakeholders*. These practices offer a context for reflecting on past actions and for identifying what could be improved in the next phase or future LCIs. During such reflective occasions, project managers have the opportunity to reflect on their actions and to articulate causal relationships between actions and outcomes. "*This is important for monitoring success, achievements and identifying problems*" (R17). As there are no formal project evaluation mechanisms, evaluations can differ per initiative. Project evaluations

often focus on generating instrumental knowledge relating to innovation features and on strategies contributing to success that are relevant for horizontal scaling-up processes. However, to identify lessons for vertical scaling-up processes, project teams should also reflect on broader institutional barriers that need to be addressed. But acquiring this type of information from project leaders is challenging, as they are primarily concerned with project implementation. "*The project leaders are working on a daily basis with project implementation. They are aware of the problem [institutional barriers], but maybe not of the entire political situation. But is it also important to get this kind of information from the project leader*'" (R17). Given this, various organizational structures, such as the *use of program coordinators* and *program evaluations* of the City's Climate Plan, have been set up with the aim of stimulating the articulation of both instrumental and transformative knowledge. Various program coordinators function as intermediaries between LCIs that are being implemented by project teams in different municipal departments and the Climate Unit, which is responsible for implementing and monitoring the implementation of the City's Climate Plan. They coordinate initiatives regarding specific policy domains, such as energy conservation in buildingsor renewable energy generation, andthey also encourage the aggregation of global instrumental and transformative knowledge. In addition, general evaluations of the Climate Plan are used to articulate transformative knowledge. In the period up to 2025, the year by which the City of Copenhagen aims to be carbon neutral, three general evaluations of the CHP2025 will be conducted. Each will entail preparing an overview of the current status and initiatives, and a reflection on how national institutional framework conditions can help the City achieve its targets. Examples of national institutional framework conditions that can help the City of Copenhagen achieve its goals on energy consumption include the need to focus on the performance of renovation projects (rather than theoretical performance), enhancement of the energy-labeling scheme to improve quality and to make it possible to upgrade energy-level ratings after retrofitting without additional costs, and the need to address the owner/tenant paradox (City of Copenhagen, 2016a, b, p. 14) (see Table 3).

4.2.3.3. Knowledge codification.
Knowledge articulation processes can promote individual and team learning, but the knowledge remains within the heads of the individuals. Knowledge codification practices, such as *the writing of project reports and project evaluations*, guarantee that internal, tacit knowledge is externalized and becomes available to those outside the project team. Other ways to codify knowledge include the *development of prototypes* or the *writing of issue papers or articles*. In addition to project-specific evaluations, general *program evaluations* and annual reports published by the Climate Department to evaluate actions and monitor progress also constitute a way to codify knowledge. Knowledge codification practices occur ad hoc. Yet the respondents note that codification of lessons learned is deemed valuable for sharing knowledge with external audiences and for promoting learning across LCIs and aggregating global knowledge.

4.2.3.4. Knowledge distribution.
Knowledge can be distributed via a codification strategy (distribution of codified knowledge) or personification strategy (distribution through people-to-people communication). Although, in principle, project reports are available to everyone, in practice, actors outside the project team often do not read them because they are unaware these are available or have too little time. "*Project reports often end up on the shelf*" (R19). Knowledge distribution about LCIs is encouraged via weekly or monthly *department or team meetings*. In some cases, project *workshops* or *training events* are organized at the end of a project, during which the results of the project evaluation are presented to key stakeholders. Organizational structures such as *interdepartmental meetings* for experts working on similar policy domains are set up to promote collaboration and sharing between different departments. Ways to promote awareness and share knowledge about a project to a

wider audience include *dissemination of program or project evaluations and reports, publication of articles in professional journals*, and *project visits* or *workshops. Conferences, partnerships*, and *membership of issue networks* are also deemed effective practices for transmitting knowledge about LCIs and best practices for reducing energy consumption in buildings to external actors. Copenhagen City organizes a conference annually, during which national and international stakeholders meet for dialog on experiences and future opportunities. For instance, during the City's most recent climate conference (2017), experiences on successful retrofitting initiatives were shared and a workshop was organized around issues of financing building refurbishments, a key barrier to scaling-up (Table 3). The establishment of partnerships, as was done in the Energy Leap initiative, is also considered important for the dissemination of knowledge within the sector.

4.2.4. Explanatory factors for learning

The following section will reflect on the explanatory factors that impede or drive learning. In accordance with the analytical framework, the factors have been grouped into three categories: 'motivation', 'resources', and 'skills'.

4.2.4.1. Motivation.
The Mayor of Copenhagen and leaders of the City's departments recognize the importance of low-carbon development and understand how they can increase the City's attractiveness and competitiveness through experimentation with LCIs. *Political leadership* is therefore identified as an important factor that enables LCIs to be experimented with and learned from. "*An important factor is the motivation to push things forward. […] It is key that you have strong political commitment and that there is an overall target […] Because if there was uncertainty about the City's Climate goals, then it would be really difficult for our CEO to prioritize the resources for this*" (R17). Respondents noted that *a clear mandate for experimentation with LCIs, project evaluations, and conducting general evaluation of the Climate Plan* are important for embedding learning practices within the local government organization. Without a mandate, project teams are quickly dissolved and actors will jump into the next project without critically reflecting on the lessons learned. "*If there is no requirement for evaluation you will skip it and start with a new project, because that is what you are being assessed on*" (R19). The *availability of ambitious leaders* (i.e. institutional entrepreneurs) at municipal and department level is also important for promoting sustainability among project leaders and staff and ensuring that knowledge is used for vertical scaling-up processes. Respondents noted that knowledge distribution occurs primarily through people-to-people communication and informal channels, and is facilitated by a *co-operative and open culture* and *ownership of the City's Climate Plan by employees*. Nevertheless, as transfer of knowledge or sparring about projects is more likely to occur between actors working in the same units or in working groups that operate 'within walking distance' of each other, it is challenging to prevent the creation of knowledge silos.

4.2.4.2. Resources.
As noted above, political leadership fosters the mobilization of the *human and financial resources* required for experimenting with LCIs and conducting project and program evaluations. In addition, *team diversity*—project team members with different professional backgrounds—can promote knowledge accumulation and articulation, as it allows the team to be confronted with diverse perspectives and promotes the sharing of experiences. Challenges to learning relate to the *availability of sufficient structural human and financial resources* for the accumulation, articulation, codification, and distribution of knowledge. Annual budgets for experimentation are influenced by the political climate and may fluctuate, and external sources often only offer sufficient financing for project implementation, but not for evaluation. By way of illustration: whereas the long-term monitoring of innovations is regarded as an important practice for learning (see section 4.2.3), many projects receive short-term financing (1–2 years) and when they end (e.

g. when a particular building has been retrofitted) no financial resources remain for long-term monitoring and follow-up. As for the availability of structural human resources, respondents noted that for certain projects, primarily those totally externally funded (e.g. by the European Commission), temporary staff are hired who secure new employment before project completion, thereby hampering knowledge articulation and distribution processes. When staff contracts terminate on project completion, "*how do you secure that the knowledge in their brain is transferred to new people? […] And how can you bring it out there in the organization?*" (R17). Moreover, while much learning may have accumulated within departments or teams, there are not always sufficient resources available for knowledge distribution practices, as illustrated by the following quote from a policy-maker about the project team involved in the Ruysgade building initiative: "*within their department they [i.e the project teams] have been very good at learning about specific technologies. However, one thing that is a challenge for them— when you are talking about scaling-up—is that they don't always have the resources to communicate the results*" (R15). Knowledge distribution can also be impeded by changing the composition of the team. It is reasonable to expect that when the same people are working on similar types of projects, knowledge from former LCIs can be referred to for the design of future initiatives. However, one respondent (R5) noted that sometimes team compositions and project leaders are assigned on availability rather than experience, which may increase the barriers to learning from previous projects Some respondents, however, argued that although staff continuity can be valuable for use of knowledge for horizontal scaling-up, in practice it is neither always possible nor desirable because there is a risk of groupthink and the team becoming less creative due to lack of external, critical perspectives.

4.2.4.3. Skills.
Learning practices at project level are highly influenced by the competences of the project and program leaders. Project leaders must be good at *communication, intermediation, and collaboration,* as such skills can encourage discursive processes directed at generating instrumental and transformative knowledge. The perspective and questions of external stakeholders can stimulate discussions and thinking outside the box, as illustrated by a respondent: "*When you are from the outside you are allowed to ask any kind of questions. Why don't you do it like this? If you are working within the municipal organization you cannot ask these questions because you know what the answer is. We know what the struggles and challenges are and why we do things a certain way*" (R19). Institutional entrepreneurs (see above) working at the department level must be effective in intermediation and in working across sectors to use transformative knowledge and address institutional barriers.

5. Reflection

5.1. Contribution to the literature

The City of Copenhagen aims to be a frontrunner in the field of sustainability and actively aims to foster the low-carbon transition by experimenting with LCIs. Our explorative case study has offered helpful insights into how local government can learn from LCIs to promote scaling-up processes. The findings confirm the importance of experimenting with LCIs to learn how low-carbon technical (e.g. insulation material, BMS systems) or social innovations (e.g. innovation platforms, partnership agreements) can help solve societal problems concerning sustainability (e.g. Castán Broto and Bulkeley, 2013; Sengers et al., 2016). The case study has also shown that different types of knowledge—instrumental and transformative—can be derived from LCIs. The instrumental knowledge is used to foster the development of low-carbon innovations and successful approaches for launching initiatives. This knowledge is relevant for the growth and uptake of new initiatives, i.e. horizontal scaling-up. LCIs also generate transformative knowledge about institutional barriers that need to be addressed. Transformative

knowledge can be used by local governments to promote institutional reform favorable to the low-carbon innovations being experimented with, i.e. vertical scaling-up.

The findings indicate that assessing the lessons learned can be difficult due to the long interval or indirect relationship between projects. Although the respondents were generally positive and maintained that learning from LCIs does occur, we found it challenging to establish what and how lessons are re-used. This finding aligns with previous studies in the field of sustainability transitions that maintain that learning from experimentation with innovations occurs through the accumulation and aggregation of various experiences (Geels and Deuten, 2006; Schot and Geels, 2008).

The case study also enabled us to concretize practices and to identify factors that can foster learning from LCIs. Learning from experimentation within LCIs requires local governments to engage in practices related to knowledge accumulation, articulation, codification, and/or distribution (Zollo and Winter 2002). With regard to factors promoting learning, the case study showed that learning results from the interplay of factors related to motivation, resources, and skills on the part of the local government organization. As for motivation, the factors found to be critical for prioritizing resources for experimentation with LCIs were political leadership on climate change, a mandate for evaluation of the Climate Plan, and the presence of institutional entrepreneurs willing to accelerate the low-carbon transition. These findings underline the importance of leadership for learning and for accelerating the low-carbon transition (e.g. Bulkeley, 2010; Bulkeley and Kern, 2006; Kingdon, 1995; Senge, 1993; Zollo and Winter 2002). The findings also show that a local government's resource capacity facilitates learning processes, as a local government is better positioned to amortize the costs of learning and acquire new knowledge when it has sufficient budget and staff with know-how (Holgate, 2007; Bulkeley and Kern, 2006; Fichman et al., 1997; Geels and Kemp, 2007; Vegt and Bunderson, 2005; Yohe, 2001). Finally, the case study highlights that project

managers and program coordinators working in local government must possess strong negotiating, communication, and cooperation skills in order to get initiatives off the ground, govern learning practices, and to ensure that knowledge derived from LCIs is used for scaling-up processes (e.g. Bulkeley and Kern, 2006; Geels and Kemp, 2007; Klein Woolthuis et al., 2013).

Incorporating our findings into the conceptual model presented in Fig. 1 yields a framework that can be used for future analyses of how local governments learn from LCIs so as to promote their scaling-up (see Fig. 2). It is important to note that while Fig. 2 suggests a linearity and rationality of the learning process, in practice the learning processes are generally more complex and non-linear.

5.2. Limitations

Because—as an explorative case study—this paper has limitations in terms of generalizability, we propose that future studies are conducted to examine whether and how learning practices differ between local governments that demonstrate climate leadership. We believe that learning more about how local governments learn from experimentation with LCIs is critical for understanding and accelerating the transition to low-carbon cities.

6. Conclusions and policy implications

Theory on climate governance and sustainability transitions recognizes that experimenting with LCIs and learning from them are important in order to learn how the transition to low-carbon cities can be advanced (Bulkeley et al., 2011; Castán Broto and Bulkeley, 2013; Kivimaa et al., 2017; Sengers et al., 2016). Although local governments play an important role in leading and enabling LCIs (Bulkeley, 2010; Castán Broto and Bulkeley, 2013), the issue of how local governments learn from LCIs to promote scaling-up processes has received little
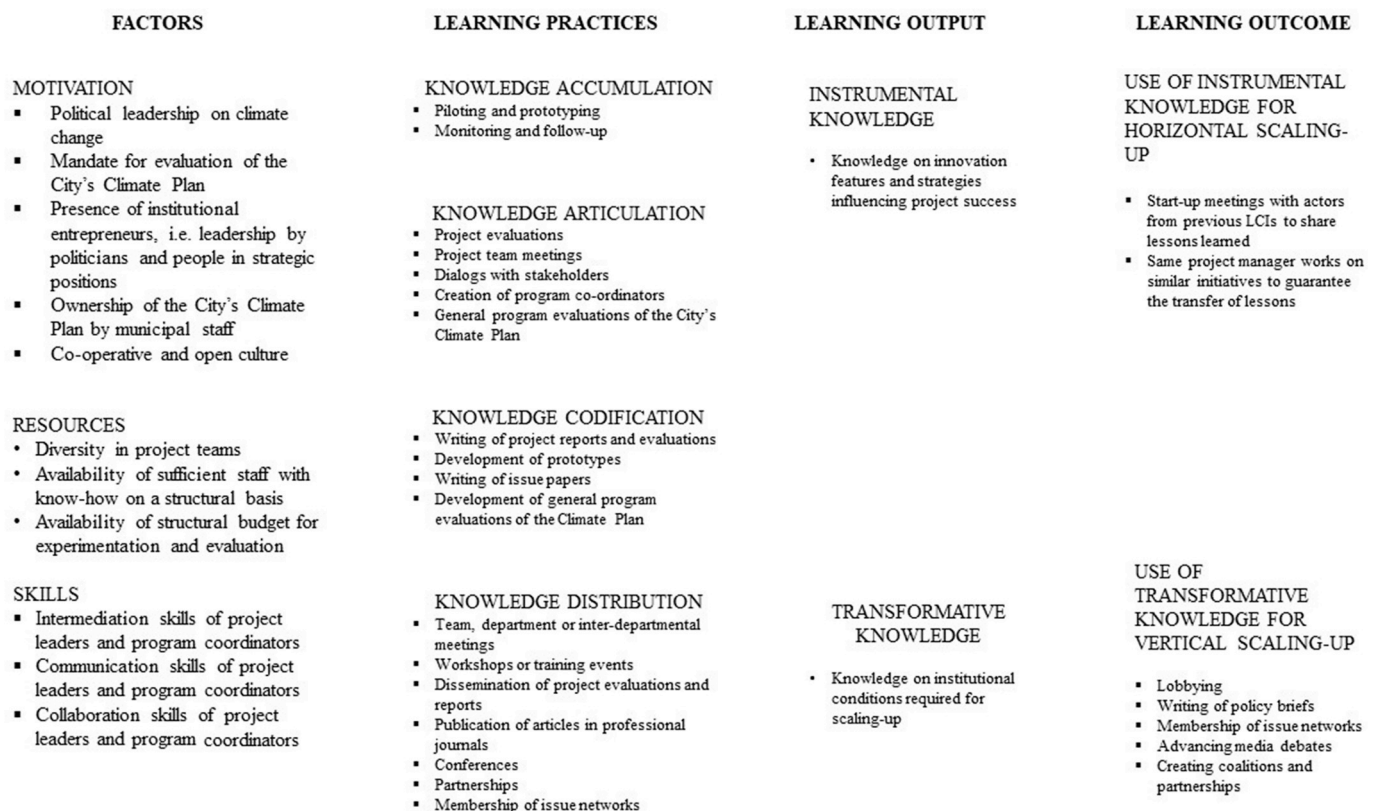
FACTORS	LEARNING PRACTICES	LEARNING OUTPUT	LEARNING OUTCOME
MOTIVATION - Political leadership on climate change - Mandate for evaluation of the City's Climate Plan - Presence of institutional entrepreneurs, i.e. leadership by politicians and people in strategic positions - Ownership of the City's Climate Plan by municipal staff - Co-operative and open culture	**KNOWLEDGE ACCUMULATION** - Piloting and prototyping - Monitoring and follow-up **KNOWLEDGE ARTICULATION** - Project evaluations - Project team meetings - Dialogs with stakeholders - Creation of program co-ordinators - General program evaluations of the City's Climate Plan	**INSTRUMENTAL KNOWLEDGE** - Knowledge on innovation features and strategies influencing project success	**USE OF INSTRUMENTAL KNOWLEDGE FOR HORIZONTAL SCALING-UP** - Start-up meetings with actors from previous LCIs to share lessons learned - Same project manager works on similar initiatives to guarantee the transfer of lessons
RESOURCES - Diversity in project teams - Availability of sufficient staff with know-how on a structural basis - Availability of structural budget for experimentation and evaluation	**KNOWLEDGE CODIFICATION** - Writing of project reports and evaluations - Development of prototypes - Writing of issue papers - Development of general program evaluations of the Climate Plan		
SKILLS - Intermediation skills of project leaders and program coordinators - Communication skills of project leaders and program coordinators - Collaboration skills of project leaders and program coordinators	**KNOWLEDGE DISTRIBUTION** - Team, department or inter-departmental meetings - Workshops or training events - Dissemination of project evaluations and reports - Publication of articles in professional journals - Conferences - Partnerships - Membership of issue networks	**TRANSFORMATIVE KNOWLEDGE** - Knowledge on institutional conditions required for scaling-up	**USE OF TRANSFORMATIVE KNOWLEDGE FOR VERTICAL SCALING-UP** - Lobbying - Writing of policy briefs - Membership of issue networks - Advancing media debates - Creating coalitions and partnerships

Fig. 2. Analytical framework that can be used for future analyses of how local governments learn from LCIs so that they can scale them up.

attention up to now. Using the City of Copenhagen—regarded as a sustainability frontrunner—as a case study, this paper has explored the complex relationships between LCIs, learning processes within local government, and scaling-up processes. The paper has three key contributions that not only enrich the literature but can also assist local governments worldwide in enhancing their capacity to learn from LCIs, thereby promoting scaling-up processes.

First, the paper discussed the types of knowledge that can be derived from initiatives and showed how such knowledge can be used for scaling-up. LCIs can generate instrumental knowledge related to innovations and approaches influencing project success, both of which are relevant for expanding the initiative in question or launching new initiatives, i.e. horizontal scaling-up. In addition, LCIs should also generate transformative knowledge so that vertical scaling-up processes aimed at addressing institutional barriers can be encouraged. We therefore advise local governments to ensure that learning practices are oriented toward capitalizing on both instrumental and transformative knowledge.

Second, the paper has provided a concrete overview of learning practices and an overview of explanatory factors for learning that can help local governments when optimizing learning practices and creating organizational frameworks fostering capitalizing on knowledge from LCIs. The paper has offered an overview of learning practices that can encourage the accumulation, articulation, codification, and distribution of knowledge. Experimentation with LCIs is critical for generating instrumental knowledge and transformative knowledge, as are continuous monitoring and follow-up. Local governments can enhance the articulation of knowledge through, among others, structural project and program evaluations, stakeholder dialogs, and creating program coordinators who act as intermediaries between 'projects on the ground' and a city's broader Climate Plan. Through organizing workshops and conferences and membership of national and international issue networks, local government can distribute knowledge with a broader, external audience, thereby promoting the construction of a learning community fostering niche development and creating advocacy coalitions to address institutional barriers hampering the scaling-up of LCIs.

Third, the paper has reflected on resources and skills that can influence a local government's capacity to learn from LCIs. First and foremost, the findings point to the importance of local political leadership on climate change and of having a mandate to experiment. The City of Copenhagen has developed an ambitious Climate Plan and experimentation with LCIs is an important means to achieve the City's climate goals. Such climate leadership has enabled the Climate Department to develop and structurally evaluate collective efforts to achieve climate neutrality. Leadership by politicians and persons in strategic positions has fostered a shared vision and ownership of climate neutrality among civil servants and local stakeholders, thereby promoting sharing of lessons learned and the creation of a sense of the urgent need to scale up LCIs. Political leadership on climate change also creates a context in which resources can be mobilized for experimentation and practices aimed at the articulation, codification, and distribution of knowledge. The implication for policy is that it is important that resources required for experimentation and learning are stipulated on a structural basis because, as noted, even a frontrunner city like Copenhagen can experience internal struggles to secure structural resources, such as funding and permanent staff.

In sum, it is expected that the findings of this paper can assist local governments in optimizing learning from LCIs, which is greatly needed in order to accelerate the transition to low-carbon cities.

Appendix A. List of interviewees

Interviewee	Function	Topic	Date and length of interview
R1	Project leader, Technical and Environmental Administration, City of Copenhagen	Ryesgade 30	06-03-2017; 60 min
R2	Architect, Technical and Environmental Administration, City of Copenhagen	Ryesgade 30	06-03-2017; 60 min
R3	Project manager, Climate Unit, City of Copenhagen	Energyleap	09-03-2017 & 14-03-2017; 90 min
R4	Project manager, Climate Unit, City of Copenhagen	Energyleap	02-03-2017 & 15-03-2016; 90 min
R5	Project manager HOFOR	Energyleap	23-03-2017
R6	Project manager, Climate Unit, City of Copenhagen	Carbon 20	13-03-2017 & 29-03-2017; 90 min
R7	Project leader, Technical and Environmental Administration, City of Copenhagen	Klimakarré	09-03-2017 & 31-03-2017; 90 min
R8	Project leader, Technical and Environmental Administration, City of Copenhagen	Klimakarré	30-03-2017; 60 min
R9	Project leader, Technical and Environmental Administration, City of Copenhagen	Hedebygadekarree	31-03-2017; 60 min
R10	Project leader, Technical and Environmental Administration, City of Copenhagen	Integrated urban renewal initiative Sydhavnen	24-03-2016; 60 min
R11	Project coordinator, Technical and Environmental Administration, City of Copenhagen	Integrated urban renewal initiative Sydhavnen	24-03-2017; 60 min
R12	Department leader, Copenhagen Properties, City of Copenhagen	Municipal pilot projects	06-03-2016; 90 min
R13	Project leader, Copenhagen Properties, City of Copenhagen	Municipal pilot projects	06-03-2017; 90 min
R14	Program coordinator, Climate Unit, Technical and Environmental Administration, City of Copenhagen	Climate policy and learning practices City of Copenhagen	15-03-2017; 90 min
R15	Energy specialist, Climate Unit, Technical and Environmental Administration City of Copenhagen	Climate policy and learning practices City of Copenhagen	15-03-2017; 90 min
R16	Political coordinator, Climate Unit, Technical and Environmental Administration City of Copenhagen	Climate policy and learning practices City of Copenhagen	15-03-2017; 70 min
R17	Project Director Carbon Neutral Strategy, Climate Unit, Technical and Environmental Administration City of Copenhagen	Climate policy and learning practices City of Copenhagen	28-03-2017; 70 min
R18	Project leader, Climate Unit, Technical and Environmental Administration City of Copenhagen	Climate policy and learning practices City of Copenhagen	20-03-2017; 70 min
R19	Project leader, Technical and Environmental Department, City of Copenhagen	Climate policy and learning practices City of Copenhagen	10-03-2017; 60 min

Appendix B

Interview questions for stakeholders involved in the LCIs.

A. General characteristics of the low-carbon initiative

- What are/were the sustainability goals of the initiative?
    - o Coding: environmental, social and/or economic goals
- To what extent will/have these been achieved?
    - o Coding: goals are/will be achieved; goals are not/will not be achieved
- What are the innovation characteristics of the initiative?
    - o Coding: social or technical innovation
- Why and how can this initiative offer a solution for reducing energy consumption in the building stock?
    - o Open coding

B. Lessons learned from the low-carbon initiative

- What are key lessons learned from the implementation of the initiative (until now) related to:
    - o The innovation(s) applied
- Coding: instrumental knowledge
    - o The approaches or strategies applied that contributed to the successful implementation of the initiative
- Coding: instrumental knowledge
- What are key institutional conditions that need to be addressed to make the large-scale application of the initiative possible
    - o Coding: transformative knowledge. Institutional barriers can relate to the: policy, market, industry, or the socio-cultural institutional context

C. Learning outcomes: use of knowledge for scaling-up processes (dependent variable)

- Have the lessons derived from the initiative been used as a reference for horizontal scaling-up processes?
    - o Coding: yes (use of knowledge for other initiatives), no (no use of knowledge for other initiatives), likely (in the future) (it is expected that knowledge will be used for other initiatives)
- Have the lessons derived from the initiative been used as a reference for vertical scaling-up processes?
    - o Coding: yes (use of knowledge for promoting institutional change), no (no use of knowledge for promoting institutional change), likely (in the future) (it is expected that the knowledge will be used for promoting institutional change).

D. Learning practices

- Were there mechanisms in place to accumulate knowledge generated by the initiative? If yes, what mechanisms?
    - o Open coding
- Did the project team reflect on experiences and lessons learned during the initiative? If yes, how?
    - o Open coding
- Have the articulated lessons been codified? If yes, how?
    - o Open coding
- Has the knowledge generated by the low-carbon initiative been distributed within and outside the local government? If yes, how?
    - o Open coding

E. Explanatory factors for learning

- What factors can enable or impede learning from low-carbon initiatives? How and when can these factors promote or impede learning?
    - o Coding of factors: resources, skills, motivation
    - o Coding per stage of the learning cycle: knowledge accumulation, knowledge articulation, knowledge codification, knowledge distribution

Interview questions for policy-makers and decision-makers

- What is the function of low-carbon initiatives, such as pilot projects, for accomplishing the local government's goal to become a carbon neutral city?
    - o Open coding
- What formal and informal mechanisms or practices are in place to promote that knowledge derived from low-carbon initiatives are used for scaling-up processes? Please reflect on practices related to the different stages as depicted in Fig. 1.
    - o Open coding in accordance with different stages of the learning cycles
- What factors facilitate the capability of the local government to learn from initiatives? During what stage(s) do these factors play a role?
    - o Coding factors: resources, skills, motivation
    - o Coding stages: knowledge accumulation, knowledge articulation, knowledge codification, knowledge distribution
- What factors challenge learning from initiatives? During what stage(s) do these factors play a role?
    - o Coding factors: resources, skills, motivation
    - o Coding stages: knowledge accumulation, knowledge articulation, knowledge codification, knowledge distribution

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