Stretching and Conforming?

Financing Urban Climate Change Adaptation in Copenhagen?

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BUILDINGS & CITIES

Stretching or conforming? Financing urban climate change adaptation in Copenhagen

SPECIAL COLLECTION: TRANSFORMATIONAL CLIMATE ACTIONS BY CITIES

RESEARCH

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ABSTRACT

Cities worldwide are struggling to build resilience to the risks posed by climate change for their infrastructures, economies and quality of life. However, no city government has sufficient capacities to fund the adaptations required to ensure such resilience alone. Copenhagen's efforts to secure financing for adaptation and mitigation are investigated, focusing on its innovative arrangements for funding projects to protect against extreme rainfall and flooding. A mixed-methods approach explores how municipal actors and investors accessed finance for supporting transition to a climate-adapted city. Mobilising concepts from the multilevel perspective to analyse the governance and market conditions that facilitate or impede such financing, this paper contributes to sustainable transition theory and the assessment of different funding approaches. The case study confirms the comprehensiveness and effective implementation of the city's plans, especially its innovative financing product for adaptation to urban flooding. However, this approach has knock-on effects for tackling other climate hazards, partnerships and investment urgency. Although extreme rainfall events in 2011–13 opened a valuable 'window of opportunity' for change at the system landscape level, catalysing a radical shift in government policy and investment, this disruption did not elicit a commensurate response from the city's finance sector.

PRACTICE RELEVANCE

Several challenges exist for municipalities and investors when financing urban adaptation. Innovation is needed not only in technology but also in approaches to financing and investment. A key strength of Copenhagen's adaptation approach lies in its innovative financing arrangements for funding an effective response to the risks of extreme rainfall, *i.e.* combining measures to protect against urban flooding with improvements in the urban public realm. A sustainable transition model can help guide cities in planning and funding adaptation to climate change. Recommendations include equal prioritisation by all actors of climate adaptation and mitigation; the removal of

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constraints on private sector participation; government engagement with a diverse set of private capital providers; experimentation with different financing mechanisms; the development of bankable adaptation projects; and efforts to monetise and unlock the value of adaptation projects.

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1. INTRODUCTION

> These [climate change] impacts are an incredible risk to many cities throughout the world. They will affect their infrastructure, their economies, and the people living there. [...] Cities are where the climate battle will be won or lost. [...] But we can avoid the worst of these impacts if we act now to increase our action and investment towards climate change. [...] On the finance front, making resilient infrastructure investments, growing green bond options, and helping to establish stable, clean energy markets are also important ways cities can contribute.
>
> (Espinosa 2018: 1)

As cities strive to cope with the impacts of ever more frequent storms and floods, heatwaves and droughts (Aakre *et al.* 2010; Sainz de Murieta *et al.* 2021), they also face the complex challenge of building long-term urban resilience to climate change. And while 'local government and the private sector are increasingly recognised as critical to progress in adaptation' to climate change (IPCC 2014: 19), the scale of this challenge is beyond the capacities of city governments to address by themselves, not least on account of the capital required to fund adequate measures to address the multifarious impacts of future climatic events on urban communities and infrastructure. ***Table S1*** in the supplemental data online gives an overview of the types of innovations in urban adaptation the authors are investigating. Climate-adapted cities of the future will need multiple funding sources, entailing a fundamental re-direction of financial capital towards these innovations, new technologies and practices (Hafner *et al.* 2020). As confirmed by Klein & Juhola's (2018) global assessment of urban adaptation to climate change, there is now broad consensus amongst both scholars and practitioners globally that the private sector should be involved in urban adaptation alongside public authorities.

Despite an immense surge of interest in urban climate change adaptation (hereafter 'urban adaptation'), several critical gaps have been identified in this stream of research (Dupuis & Biesbroek 2013). These include the following underexplored and under-theorised areas of particular salience to the present focus on financing urban adaptation (see ***Table S2*** in the supplemental data online for a full list of research gaps in each of these six areas):

- Governance and institutional challenges in developing novel financing mechanisms (Keenan 2018a, 2018b, Keenan *et al.* 2019).
- Knowledge and insights on theory and practice in climate adaptation finance (Bhandary *et al.* 2021).
- The risks, barriers and opportunities for private investment in adaptation (Adhikari & Safaee Chalkasra 2021).
- Financial instrument arrangements for financing urban adaptation (Root *et al.* 2016).
- Insurance approaches (Jarzabkowski *et al.* 2019).
- Who pays and who benefits from adaptation (Tompkins & Eakin 2012).

Most of these gaps relate to the challenges involved in developing financing products to pool and deploy both private and public capital at scale for funding complex multi-party urban adaptation projects.

An in-depth case study of the City of Copenhagen (CoC, or 'the city') is presented to show how it has navigated the challenges of financing its urban adaptation commitments. A highly collaborative process was used. This entailed working for several months with numerous CoC employees, Danish

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investors and other organisations in enabling roles, gathering data and insights from interviews and a workshop held with these actors. The main research question is:

How is urban adaptation financing constrained and enabled in Copenhagen?

This is explored by understanding how the city has leveraged novel funding mechanisms and innovative financing opportunities. The application of sustainability transitions theory and multilevel perspective (MLP) concepts provides valuable insights into how technology, actors, and institutions mutually shape each other and the city's *landscape–regime–niche* system (Geels 2012). To summarise, this research sheds light on the conditions needed to *stretch* a city's *finance regime* (financial sector) to enable finance to flow to *niche-innovations* for urban adaptation.

Copenhagen has a pressing need to respond to climate-induced hazards and it uses innovativeness in both urban adaptation and novel financing approaches (Lund *et al.* 2012) (see ***Table S1*** in the supplemental data online for examples of niche-innovations in urban adaptation to address urban flooding). The city has been notably successful in developing and implementing an innovative financing product for urban flooding through a municipal pooled credit facility called *KommuneKredit*. However, this approach has several important adverse knock-on effects in relation to other climate hazards, partnerships and investment urgency. And while three consecutive extreme rainfall events in the city (in 2011, 2012 and 2013) served to open a 'window of opportunity' for a radical shift in government policy and investment, this disruption did not elicit a commensurate response from the financial sector to tackle other emerging urban adaptation challenges such as rises in sea level.

The remainder of the paper is structured as follows. The next section presents the background to financing urban adaptation. Section 3 outlines the methods. The results are given in Section 4. Section 5 discusses the interactions in the city's landscape–regime–niche system and how this is constraining and enabling finance for urban adaptation. Section 6 concludes, spelling out the key implications and offering recommendations for further empirical work.

2. BACKGROUND

An exponential rise in studies focused on urban adaptation efforts has occurred over the past decade (Biesbroek & Delaney 2020). The majority of this scholarship has been primarily concerned with evaluating the effectiveness of contemporary policy processes of urban adaptation (Olazabal *et al.* 2019). Among the key barriers to urban adaptation identified in this literature, financial and resource constraints are the most frequently highlighted and discussed (Moser *et al.* 2019), indicating that financing of adaptation remains an under-theorised subject. As listed above, key research gaps identified in this area include the institutional and governance implications of financing adaptation, the possible financial products and instruments for funding adaptation, and barriers to and opportunities for private sector involvement.

From the initial scan of the extant scholarship on urban adaptation from multiple disciplines, including urban planning, economic geography, environmental business management and urban climate finance, only very limited research was found on the financing of adaptation (Keenan *et al.* 2019). One exception to this finding is the research on flood management, including a literature review by Bisaro & Hinkel (2018) on public and private financing for coastal adaptation. Another exception includes work by several authors examining adaptation financing mechanisms in the US, such as regional resilience trust funds and credit banking schemes (Cousins & Hill 2021; Keenan 2018a, 2018b; Keenan & Gumber 2019). These authors have provided valuable insights into the governance and institutional challenges for municipalities in developing novel financing mechanisms. A relevant recent study by Keenan *et al.* (2021) has also explored the positive and negative reinforcing relationships between different types of resilience and sustainability goals.

Identifying and examining these relationships and links is crucial for scholars investigating the financialisation of municipal environmental governance in areas such as stormwater management, nature-based solutions and adaptation (Bigger & Millington 2020; Cousins & Hill 2021). For example, Bigger & Webber (2021) have tracked various types of adaptation projects

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that can be funded by green borrowing in the form of green bonds, concluding that such projects can reinforce urban inequalities. Similarly, Taylor & Aalbers (2022) have explored how 'climate risk-rent', defined as new economic value created and captured in relation to climate risk, can lead to the intensification of gentrification processes and hence exacerbate inequality in cities. In sum, these studies have found that the shift to new financing structures in these areas can have unintended consequences for urban sustainability and socio-economic justice (Bracking 2020).

Although finance is widely recognised as a critical enabler of urban adaptation, it is often only covered perfunctorily in the literature, typically in the form of very general suggestions about private sector involvement and private capital with little examination of the underwriting and governance mechanisms entailed in such funding (Bisaro & Hinkel 2018). Only limited research has so far been undertaken on the financial tools available for different adaptation strategies, the willingness to pay for adaptation investments under different financing schemes, and levels of political acceptance for these different financing tools (Woodruff *et al.* 2020). As a consequence, much yet remains to be understood about the relationships between the providers and beneficiaries of adaptation, as well as the motivations and implications of private capital taking actions that create public goods (Tompkins & Eakin 2012).

To meet the projected needs and costs of urban adaptation, global finance for adaptation will need to expand by a factor of 12–22 above the current levels of funding (Tuhkanen 2020). This *adaptation financing gap* is now regularly analysed by the United Nations Environment Programme (UNEP) in its annual *Adaptation Gap Report* (2020). Within the emergent literature on urban adaptation finance, scholars have examined this funding gap from either a global or a Global South perspective (Bigger & Webber 2021; Pauw 2017; Pauw *et al.* 2016, 2022), with debates in this stream typically identifying shortcomings in extant research similar to those listed above (see ***Table S2*** in the supplemental data online). The significant public funding challenge created by this financing gap is most acute for cities, and for coastal cities. Compounding this challenge, urban adaptation projects are inherently complex and expensive, typified by high upfront costs, regulatory complexity, long-term investment horizons, uncertainty in relation to risks and the need to involve multiple levels of government (Bisaro *et al.* 2020; Kok *et al.* 2021).

Urban adaptation measures can include both 'soft' and 'hard' infrastructure investments to address climate-induced urban flooding, coastal inundation, heatwaves, wildfires, storms and drought. The present study focuses exclusively on measures to address urban flooding, including green streets, green roofs, water-retention basins and smart drainage. Public actors responsible for all forms of urban adaptation, including flood risk, invariably face constrained budgets, with public sources of capital typically falling far short of requirements, leading to public interventions that are often incomplete or under-scaled (Keenan *et al.* 2019). As ways of paying for adaptation measures such as beach protection, local financing in the form of raising taxes and levies to pay for them has been explored most widely in the literature. These studies have found limited acceptance of local-level market-based financing instruments (Mullin *et al.* 2019). Here the debate has focused on where and under which terms the burden of payment for adaptation should rest, *i.e.* whether on the general taxpayer or only on the communities directly affected. Resolving these complex questions related to the economics and governance of adaptation is essential for mobilising new partnerships and financing, including the issues of responsibility, trade-offs, equity and accrued benefits (Bisaro *et al.* 2020). This is because, as Bisaro & Hinkel (2018) have argued, investment arrangements must be appealing to both the public actors propounding adaptation projects and the investors.

Several possible routes exist for investing in urban adaptation. The attractiveness of urban adaptation and green infrastructure projects to different types of investment (public provisioning, debt, equity, novel financing vehicles and insurance) is explored in a guide produced by Southend-on-Sea Borough Council (2019). This guide suggests that projects attractive for equity investment produce multiple benefits where economic value is easier to capture. Projects where this is more difficult are good candidates for public provisioning. Urban flood protection, in certain circumstances, where there is an identifiable income stream, can attract debt funding through vehicles such as green bonds. Others such (*e.g.* urban greening with less quantifiable outcomes) are more likely to attract philanthropic and other novel funds. Bisaro & Hinkel (2018) find that

private provisioning, public–private partnerships (PPPs) and public debt arrangements are the most promising for adaptation investment due to the potential of these projects to align public actor and private investor interests.

Questions surrounding the role of private capital in supporting climate action (including how such capital can be lured to fund both mitigation and adaptation measures) have transfixed practitioners and academics alike in recent years, yet still warrant closer investigation (Hafner *et al.* 2020). A review of the US climate adaptation field by Moser *et al.* (2019) found a lack of in-depth analysis on the extent to which private capital mechanisms such as green/climate bonds, resilience bonds, and insurance mechanism meet the adaptation and capacity needs of local governments. Of those few studies that have explored this issue, Tuhkanen (2020) found that green bonds only finance climate adaptation to a very limited degree due to market limitations, risk awareness, and the complex and long-term nature of adaptation investments. Confirming this finding, Fatica & Panzica (2021) have recently estimated that only 2% of green bonds issued worldwide by the corporate sector in the period 2007–19 were issued for adaptation projects. In sum, scholarship on the phenomenon of under-investment in urban adaptation remains at an embryonic stage.

An important conceptual framework of 'capacities for transformative climate governance' has nonetheless been developed by Hölscher & Loorbach (2019: 168) for assessing how:

> transformative climate governance enables climate mitigation and adaptation while purposefully steering societies towards low-carbon, resilient and sustainable objectives,

further applying this framework to explore conditions for transformative capacity in several cities, including Rotterdam and New York (Hölscher *et al.* 2018, 2019). This valuable research into the roles of specific actors, effective governance processes, legitimacy and effective climate governance in the transformative capacity of cities did not explicitly examine financing arrangements, however, the focus here is on the conditions for financing transition to a climate-adapted city.

Insights can be synthesised from numerous prior studies specifically exploring adaptation in the CoC (Camponeschi 2021; Franco-Torres *et al.* 2020; Hallegatte *et al.* 2011; Liu & Jensen 2017) (see also ***Table S3*** in the supplemental data online). Indeed, Copenhagen is often cited in the literature as an 'early adapter' (Olazabal *et al.* 2019), with studies finding the city a 'bellwether' municipality of 'exemplar' status in terms of urban adaptation (Collier & Cox 2021). In analysing the effectiveness of the city's adaptation, however, none of these studies has delved into the workings of financing, from either a city government or an investor angle.

3. METHODS

3.1 CASE SELECTION RATIONALE

Copenhagen was selected as an exploratory index case for this study (Yin 2009) on account of its relatively high level of exposure to the impacts of climate change and its strong lead and reputation in innovating and financing urban adaptation (Camponeschi 2021; Franco-Torres *et al.* 2020; Juhola *et al.* 2012; Olazabal *et al.* 2019; Olazabal & Ruiz De Gopegui 2021). The city's exposure to climate hazards is of great national significance, since Copenhagen is located in the central part of the Capital Region of Denmark, comprising residential, commercial, and some industrial areas and activities, including a major port. This paper focuses on the city's advances in financing its urban adaptation efforts for responding to extreme rainfall and floods, referred to hereafter as the city's *Cloudburst* response.[1] The city has extensive experience of flooding, a strong planning tradition and is very proactive in flood management.

Copenhagen has the status of a 'trend-setting' city in terms of urban adaptation on account of its longstanding commitment to combating climate change (Camponeschi 2021). Although Franco-Torres *et al.* (2020) have identified Copenhagen's approach as a transition to more sustainable stormwater management, no scholarly studies were found that frame Copenhagen's approach as 'transformative' in the sense defined by Hölscher *et al.* (2019). This unique combination of conditions makes the city a promising context for exploring the financing of transition to a climate-adapted city.

Copenhagen experienced three major rainfall events between 2011 and 2022. The largest and most violent of these was an extreme 1000-year cloudburst that caused more than €0.8 billion (DKK6 billion at 2015 prices)[2] of damage (excluding the direct costs of repairing municipal infrastructure and indirect costs such as loss of earnings, business losses, increased insurance premiums, *etc.*) (Climate-ADAPT 2016; CoC 2012; Danish Government 2012). In the course of these storms, contaminated floodwater penetrated street-level buildings and city infrastructure. The extent of impact and scale of the required response to such rainfall events is indicated in Figure 1, which depicts projects included in the city's Cloudburst Management Plan of 2012. Figure 2 depicts the national and city adaptation planning that frames the CoC's Cloudburst work, including comprehensive planning of local climate adaptation as a part of the municipal plan (*Kommuneplanen*) (Danish Government 2012).

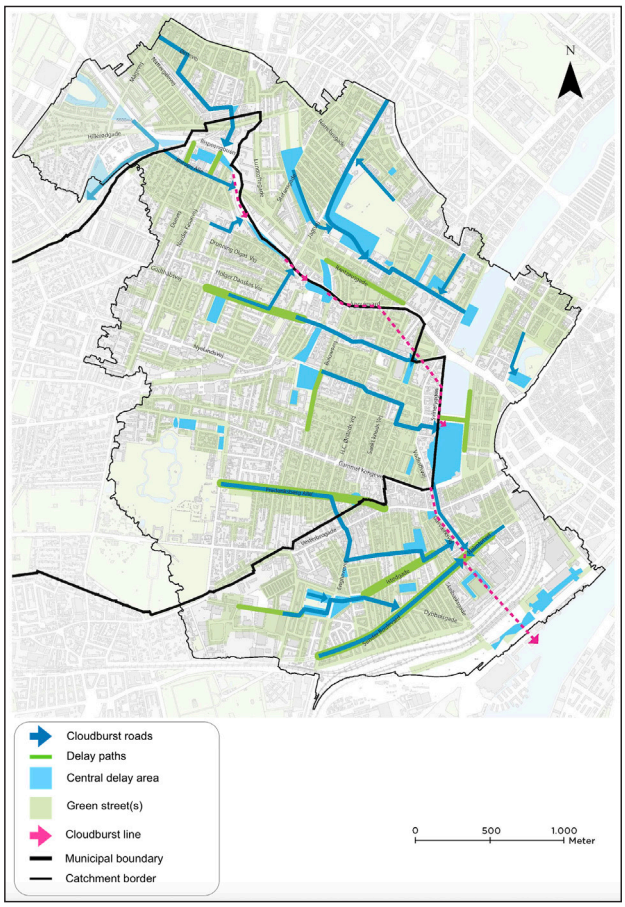

Figure 1: Planned Cloudburst projects: Ladegårds Å, Frederiksberg Øst and Vesterbro.

Source: Ramboll Consultants for CoC (2012).

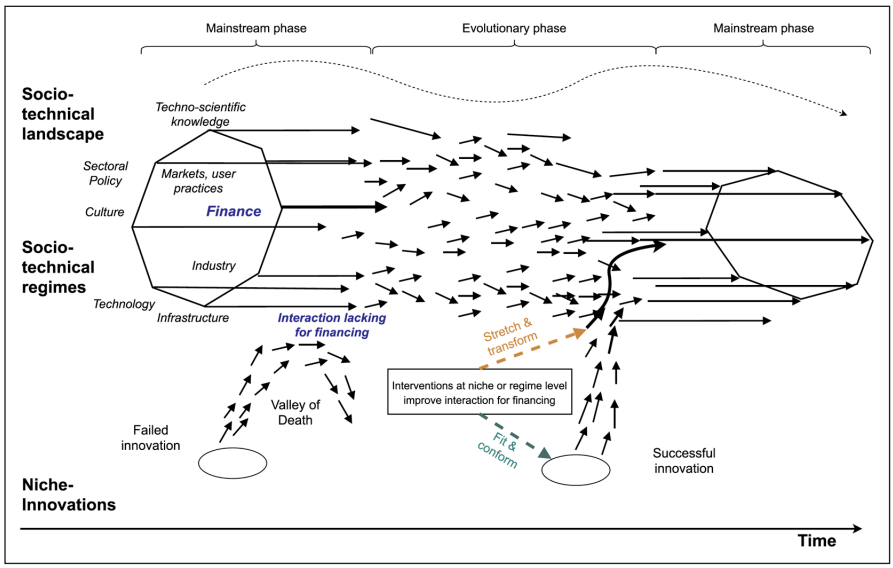

Figure 2: Multilevel perspective (MLP) on transitions.

Source: Geddes & Schmidt (2020).

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The Cloudburst programme includes 300 projects costing a total of €1.5 billion (DKK11 billion at 2015 prices (Climate-ADAPT 2016).[3] Each project needs to have a very detailed cost–benefit assessment in compliance with State regulations. As a strategic adaptation investment plan, the Cloudburst plan can be considered an aspect of urban adaptation response lacking in many other municipalities (Aguiar *et al.* 2018; Olazabal & Ruiz De Gopegui 2021; Reckien *et al.* 2018). The Cloudburst investments are significant when put against, for example, the municipality's 2021 budget of €7.7 billion (DKK52.790 billion) (CoC 2021).[4] The existence of such a comprehensive urban adaptation planning and investment approach is a prerequisite for analysing transition to a climate-adapted city and the role of finance in this transition.

Copenhagen's Cloudburst response is by no means the outcome of the CoC municipality's efforts alone. Its success can be attributed to the labours of numerous actors and the presence of certain key conditions, including a supportive national climate adaptation planning framework, philanthropic support, the involvement of *KommuneKredit* and its municipal pooled credit facility, European Commission grants, inter-municipality collaboration, partnering with city water utilities, private property owners, academic research, climate modelling supported at the national level, and a plethora of well-funded green and climate-focused non-governmental organizations (NGOs) (Table 1). Notwithstanding these favourable conditions, the overall effectiveness of this adaptation programme has rarely if ever been matched elsewhere (Kuller *et al.* 2018). The success of the Cloudburst programme thus further highlights the potential of the CoC's approach to financing urban adaptation.

Table 1: Urban adaptation developments: Copenhagen, 2011–22.

Note: [a] This is an on-line tool, the first of which was launched in 2012.

LANDSCAPE	***FINANCE REGIME***	***SOCIO-TECHNICAL REGIME***	***NICHE INNOVATIONS***
NORMS, PUBLIC ATTITUDES	**FINANCE REGULATION, POLICY, INSTRUMENTS**	**REGULATION, POLICY, INSTRUMENTS**	**TECHNOLOGY, VISION, EDUCATION**
2011–13	**2013–22**	**2012–22**	**2011–22**
Response to extreme precipitation events, 2011–13	Financial agreement for municipalities (Danish Government 2012)	National Adaptation Plan (Danish Government 2012)	Copenhagen Climate Adaptation Plan (CoC 2011)
	Taskforce for Climate-Related Financial Disclosure (TCFD 2016)	Municipal Plans (Danish Government 2012)	National web-based climate risk mapping (2012)[a]
	EU Green Deal/Denmark's Green Transition (Danish Government 2019)	The Global Commission on Adaptation headquarters, established in Copenhagen in 2018	Cloudburst Management Plan (CoC 2012)
	EU Green Bond Standard (EU 2019)	The State Government is in the process of developing a White Paper on storm surge, which is due to be released in 2022	Climate Quarter-St. Kjeld's Neighborhood (CoC 2012)
	The Danish Government introduced the Service Level Act (*Serviceniveaubekendtgøre lsen*) for cloudburst projects in 2018 and updated it in 2020		The CoC launched the Copenhagen Solutions Lab in 2015, which featured cloudburst innovations (https://cphsolutionslab.dk/en)
	EU Taxonomy for sustainable activity (EU 2020)		COHERENT project launched by the Technical University of Denmark (DTU) in 2011
			Copenhagen Storm Surge Plan (CoC 2017)
			A Realdania project to protect sites in Copenhagen from rising seas, which was commenced in 2020 (Realdania 2020)
			Danish Government decision in 2021 to progress the Lynetteholm artificial island (Carlson 2021)

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3.2 THEORETICAL APPROACH

Undertaking an interdisciplinary study of multiple actors accessing finance for urban adaptation measures in a specific case city calls for both meso- and systems-level investigation. Here, socio-technical perspectives and sustainable transitions theory provide a useful basis for assessing changes in systems to illuminate system tensions, including how such tensions function and where they are located. Transition analysis further contributes insights into how agency and governance can develop disruptive interventions to support desirable societal change, including planning and investment for future climatic events. The analytical frameworks applied in such analysis include the MLP developed by Geels & Schot (2007) and its later elaboration by Geddes & Schmidt (2020) to include the role of finance (Figure 2). The latter study is one of only a handful of transitions articles so far to have closely examined the finance regime (Geddes *et al.* 2020; Geels 2012; Hafner *et al.* 2020; Steffen & Schmidt 2021). According to Geddes & Schmidt's (2020: 4) elaboration of MLP theory:

> the financial market is its own regime with its own actors, institutions, sets of norms, rules and [...] routines that affect actors' resistance or compliance with system change.

From this perspective, a finance regime is viewed as overlapping and interacting with all other socio-technical regimes. In particular, Geddes & Schmidt (2020) have found that the role of finance is especially relevant for *niche–regime interactions*. Two useful concepts for discerning niche–regime interactions and interventions to overcome regime resistance are the processes of 'stretch and transform' (S&T) regimes/systems as opposed to a process of 'fit and conform' the niche-innovation to the regimes/systems (F&C) (Smith & Raven 2012). As these MLP terms suggest, S&T processes fit in with existing rules and institutions, whereas F&C processes require the system to adjust to them (Lauber & Jacobsson 2016; Smith & Raven 2012). Few empirical studies have attempted to apply these F&C and S&T concepts to the phenomenon of innovation niche–financial regime interactions. The current research, therefore, aims to provide empirical and theoretical insights into the dynamics of these processes in the finance regime for urban adaptation in the case city.

MLP is applied to examine the niche–regime interactions in Copenhagen that served to catalyse and facilitate progress in niche-innovations in the city's Cloudburst programme. In parallel, the interactions and interventions of Danish investors are examined. This highlights how different actors accessed finance from the regime by ascertaining the critical factors that facilitate or impede the flow of finance to niche technologies and projects. Differentiating between the finance regime and other socio-technical regimes, Figure 2 illustrates these interactions between the levels of landscape–regime–niche by applying key MLP concepts. These concepts include 'windows of opportunity', 'F&C versus S&T', 'technology lock-in' and the 'valley of death', with the last named usefully referring to a stage in innovation chains when a niche technology strives to advance beyond the demonstration phase to commercialisation and diffusion (Nemet *et al.* 2017).

Examples of radical niche-innovations are provided such as Cloudburst streets, nature-based adaptations and climate-adapted homes (*e.g.* see ***Table S1*** in the supplemental data online). A catalogue of enablers of sustainable transitions is extracted from relevant and frequently cited MLP literature (*e.g.* see ***Table S4*** online).

The MLP literature also emphasises the need for niche-innovations to gain social acceptance and legitimacy (Geels & Schot 2007). Shared positive expectations can contribute to legitimising the success of a niche-innovation by protecting and nurturing that innovation. MLP scholars further stress the importance of *narratives and storylines* in expressing socio-political problems and in subsequently conveying the parts that different actors play in contributing to innovations and *transition pathways* (Geels 2019; Loorbach 2010). Creating and maintaining a common narrative and space for new niche actors is especially important. In the present study, this entails capturing how new actors potentially break the dynamics of the prevailing systems (Geels 2019).

In the transition literature it is widely maintained that 'control policies' are required to exert pressure on incumbent regimes (finance and socio-technical), since without such policies niche-innovations will not transition (Rotmans *et al.* 2001). Control policies that further 'stretch' or 'transform' the finance regime, including interventions that extend beyond those suggested by Geddes & Schmidt (2020) are specifically necessary for innovations that fail or can never be commercialised, including innovative urban adaptation projects. The use of incentives such as pricing mechanisms, likewise, can help create an 'extended level playing field' for niches to contend with incumbent technologies and economic parameters (Gazheli *et al.* 2015).

3.3 DATE SOURCES, COLLECTION AND ANALYSIS

Following a mixed-method approach, an extensive review of the literature and of relevant policy documents was conducted before collecting qualitative data from interviews and from a problem-solving workshop subsequently held with the interviewees. Table 2 explains the different parts of the methodology, how they connect, which research outputs they provide, and how they feed into the different areas analysed within socio-technical transitions and MLP theory. This approach was employed to ensure both breadth and depth of understanding, including by gaining rich contextual and explanatory insights into the how different actors accessed finance from the regime. This enables the key factors that govern the flow of finance to niche-adaptation technologies and projects to be ascertained in the present case.

Table 2: Methodology: stages, connections and outputs.

Note: CPH = Copenhagen; MLP = multilevel perspective.

RESEARCH STAGE	LITERATURE REVIEW	POLICY DOCUMENT ANALYSIS	INTERVIEWS: INVESTORS	INTERVIEWS: MUNICIPAL	WORKSHOP: ALL INTERVIEWEES
Research tasks	Review of multiple scholarly fields for adaptation financing	Analysis of CPH government and Danish investor policy documents relating to financing adaptation measures	Questions regarding factors in access to finance for urban adaptation	Questions regarding factors in access to finance for urban adaptation	Deep dive with municipal and investor actors on financing of cloudburst and storm surge
MLP theory analysis	Niche innovation enablers/interventions Research gaps Key MLP concepts	Finance regime and socio-technical regime elements: legislation, regulation, policy, budgets, cost estimates, commitments, targets *etc.*	Investor MLP factors and interventions Coding and mapping data to MLP concepts	Municipal MLP factors and interventions Success and deficiencies: Cloudburst finance product Coding and mapping data to MLP concepts	Interplay of MLP factors and interventions Success and deficiencies: Cloudburst finance product
Key research ingredients, elements and outputs	***Figure 2***: MLP ***Table S2***: Research gaps ***Table S4***: MLP enablers/ interventions ***Table S5***: CPH planning and investment framework	***Table 1***: Urban adaptation in CPH ***Table S5***: CPH planning and investment framework ***Table S6***: CPH policy documents ***Table S7***: CPH adaptation needs and allocation	***Figure 3***: Factors/ barriers (grouped by MLP concepts) ***Figure S1***: Changes needed to transition ***Table S9***: Informant quotations (MLP coded)	***Figure 3***: Factors/ barriers (grouped by MLP concepts) ***Table S9***: Informant quotations (MLP coded)	***Table 4***: Factors/barriers (grouped by MLP concepts) ***Figure 4***: MLP model for CPH ***Table S9***: Informant quotations (MLP coded)

More specifically, a content analysis of policy documentation involving 10 years of the city's urban adaptation planning was performed (for examples from these data, see ***Tables S5–S7*** in the supplemental data online). Also reviewed were the green/climate finance policy documents of Danish investors. Together these data afforded a better understanding of how adaptation financing is conceptualised in Copenhagen.

The second dataset is a qualitative analysis of semi-structured interviews with the relevant actors involved in planning and financing urban adaptation (n = 29: municipal (n = 14), investors (n = 13), academics (n = 2)). State Government representatives were approached for an interview but

declined due to timing and political issues as they were in the midst of writing a White Paper on financing storm surge. To fill this potential gap interviews were secured from other enabling stakeholder organisations working closely with the State Government and able to relay information on their approach.

A workshop was held with actors who were previously interviewed (n = 18: municipal (n = 10); investors (n = 4), and academics (n = 4)) in order to take a deep dive into the municipal credit product used for Cloudburst (see ***Table S11*** in the supplemental data online). One of the exercises in this workshop made use of the MLP model and concepts (Figure 2) to illuminate system tensions (see Table 3 for a list of all participants). Converging the data collected from these three different sources (data triangulation) served to control for the consistency of the findings (Yin 2009).

Table 3: Interviewees and workshop participants.

Note: Actor/participant type: FR = finance regime (investor), NI = niche-innovation (municipal), A = academic, StR = socio-technical regime, DK = Denmark, SE = Sweden, NGO = non-governmental organisation.

ORGANISATION TYPE	NUMBER OF INTERVIEW PARTICIPANTS	NUMBER OF WORKSHOP PARTICIPANTS	MLP LEVEL	COUNTRY
Municipality: Greater Copenhagen Area	6	4	NI	DK
Other municipality or municipal organisation	1	3	NI	DK
Engineering consultant	3	1	NI	DK
Bank	5	2	FR, StR	DK
Government/municipal funds	1	2	NI	DK
Government	0	0	StR, NI	DK
Finance consultants	2	0	FR	Global
Institutional investor/pension fund	2	0	FR	DK
Finance association	3	0	FR	DK
Other	1	0	StR	DK
Climate NGO	1	1	FR, StR, NI	Global
Philanthropic organisation	1	0	FR, NI	DK
Water utility	1	1	FR, NI	DK
Academic	2	4	A	DK, SE

The central aim of the interviews and workshop was to give actors an opportunity to reveal their own versions of events and to tell their deep and rich stories of their involvement in their own words, eliciting these accounts through critical questioning (Crang & Cook 2007). The question format for the 60-minute semi-structured interviews was open-ended (Longhurst 2010), based on an interview guide in accordance with the approach recommended by Guion *et al.* (2011) for conducting in-depth interviews (see ***Table S12*** in the supplemental data online). Following the script for these interviews, the authors asked interviewees to review pre-prepared lists extracted from the literature on drivers, barriers and enablers urban adaptation financing. In addition to more general questions about their experience in climate investment, best practices and the proportion of their investment portfolio dedicated to climate investment, questions were also asked related to different concepts from MLP theory, including 'windows of opportunity' and 'lock-in', and related knowledge and heuristics (see Section 3.2). By way of example, these included the following questions:

> *What would need to be changed in your opinion to make infrastructure investments related to climate resilience or adaptation more attractive for investors?*
>
> *Is the market enabling or constraining of innovation in urban climate resilience or adaptation investment opportunities?*

As Longhurst (2010) suggests, interviewees are preselected based on their experience related to the research topic. All interviewees had a working knowledge or urban climate change adaptation infrastructure projects. This selection was facilitated through email correspondence that included a pre-circulated interview script and definitions of urban adaptation projects. The semi-structured interviews were allowed to unfold in a conversational manner offering participants the chance to explore issues in urban adaptation finance that they feel are important. This approach is useful for investigating complex and diverse experiences opinions and biases and is a route to 'partial insights into what people do and think' (Longhurst 2010: 112). The aim was to be open to hearing about all types of urban adaptation innovations. In this way the interviewers set out to be non-directional in the type of innovation and intervention discussed.

For data analysis, ATLAS.ti 7 qualitative analysis software was used to code the data systematically (ATLAS.ti™ Scientific Software Development GmbH). The theory-driven coding identified key activities related to MLP concepts (Mallette & Saldaña 2019) (see ***Table S8*** in the supplemental data online). The interviewing process concluded once all chronological and subject gaps had been filled and the analysis had reached saturation point (Guest *et al.* 2012).

4. RESULTS

This section describes Copenhagen's financing of adaptation measures through the lens of sustainable transitions MLP theory. Key factors are identified that affected actors' access to both traditional and more novel forms of finance. The primary focus at regime level is on the finance regime. Geddes & Schmidt's (2020) study on 'integrating finance into the multi-level perspective' was one of the few extant studies to have dissected the role of finance in the MLP and inspired this analysis. Informant input data are summarised in this section, but for the full quotations, see ***Table S10*** in the supplemental data online.

4.1 FACTORS IN REGIME–NICHE-INNOVATION INTERACTION

Interviewees were asked to identify and discuss the top three factors and barriers influencing access to finance for adaptation (Figure 3). All the factors/barriers identified in Figure 3 are blocking the flow of finance; informants mentioned them all often throughout the interviews. The informants went into more detail on all these barriers in the workshop (Table 4).

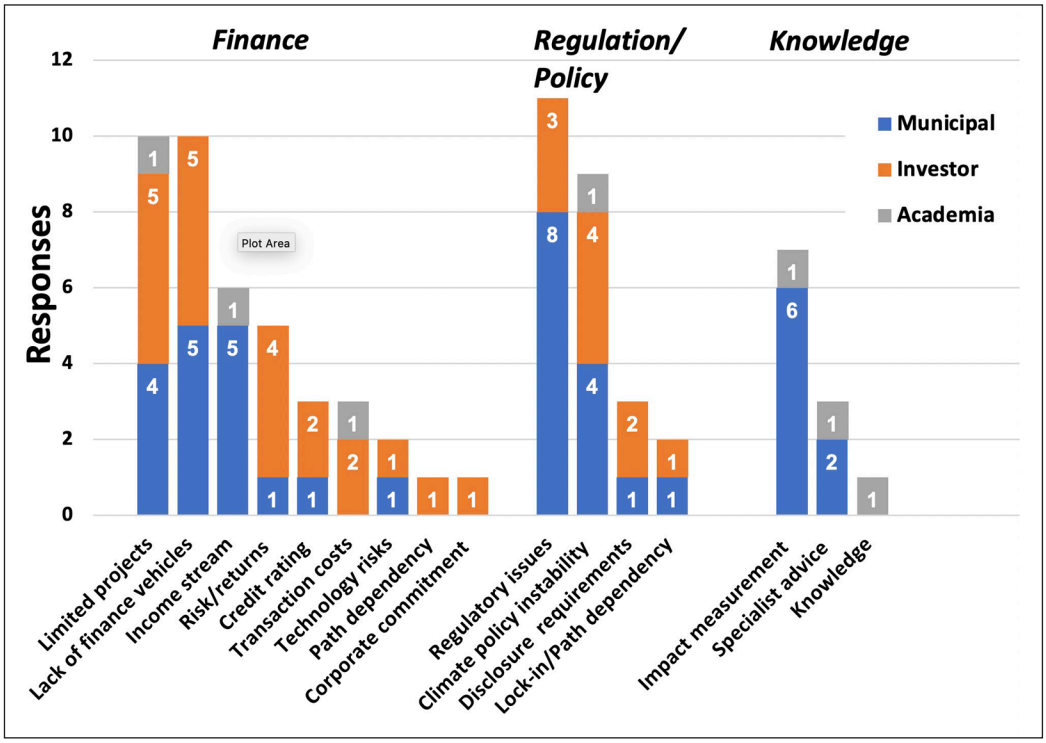

Figure 3: Factors/barriers identified by interviewees.

The factors and barriers cited by the municipal interviewees differed notably from those cited by investor interviewees, demonstrating different priorities, concerns and contexts. For instance, while both sets of actors agreed that finance products, bankable projects and regulatory and policy instability were key limiting factors, key difference emerged in the views of the interviewees on regulatory factors.

4.1.1 Acceptable risk/return

In reaching decisions on investments in incumbent technologies, it is well known that acceptable risk/return is a key factor. However, adaptation projects in many instances exhibit high risks and low rates of returns, meaning the finance regime is typically unwilling to finance the niche-innovation and let it enter the regime. As illustrated in Table 4, most of the profound challenges cited by investors related to identifying investable and bankable adaptation projects, and lack of cash flow and income stream (participants A1, A2, FR1, FR3, FR4, FR11, FR14).[5] Whilst several possible routes exist for investing in urban adaptation, most types of investment (public provisioning, debt, equity, novel financing vehicles and insurance) were not deemed attractive to investors. The majority of investors, despite having freedom to mention multiple sources of financing, were unable to give examples of their financing of urban adaptation infrastructure. Such projects also compete with and exhibit a clear bias towards low carbon and mitigation products such as renewable energy that now have an investment track record and an acceptable risk/return profile (A2, FR14):

> For a long time, I saw a huge gap. There not only no supply of finance but there's no supply of [adaptation] projects.
>
> (NI14)

> We're not investing in something without a clear cashflow [...] and that's caused by the lack of a pipeline of bankable projects.
>
> (A1)

> But that's because there are no profitable adaptation projects.
>
> (FR14)

> So, it's possible, but [...] it hasn't been done anywhere before so there's been no track record.
>
> (R11)

Investors' attitudes regarding the responsibility for adaptation projects and who should bear this burden constitute another important factor (NI6). For example, interviewee FR3 felt that the responsibility for such investment lies solely with the public sector and not with private companies, with similar views expressed by interviewees FR1, FR3 and FR14. Several informants cited the lack of allocation of private capital to adaptation by Danish banks and other investors (FR1), confirming that Danish signature climate initiatives often focus entirely on funding mitigation projects. However, they further stated that in principle there was no reason why these initiatives could not incorporate bankable adaptation projects (NI16).

> Everything that's bankable gets financed. But once we move to increase the technology risk [with] new technologies that aren't yet financially mature, that's when problems start.
>
> (FR1)

Investors motivated by societal impact and value creation took a very different view. As one interviewee from academia commented:

> These investors are willing to take a little lower return on investment or even take a loss to help create these projects or to help create a track record. It depends on the investor's motivation. [...] It's important to try to match projects with the right investors.
>
> (A2)

DOMINANT FACTORS IN THE INTERACTIONS FINANCE REGIME–NICHE	ACTOR DESCRIPTIONS OF FACTORS/BARRIERS
Regulation/policy • Regulatory constraints • Lack of stable climate change adaptation policy	• Lack of long-term stability and credibility in climate change policies and regulation (also CB regulation) (I and M) • Regulations (financial and non-financial) disenabling adaptation investment (I, M) • Contradictory State regulations (CB, planning, water, environment, *etc.*) (M) • Lack of State vision and process for adaptation investment (M) • Distrust by State Government of the municipality's and water utility's appropriation of the water tariff (M) • Municipal spending limits delaying programmed CB investments (M) • Dominant focus on public sector debt ratios stifling borrowing for adaptation (M) • Lack of institutional arrangements (M)
Acceptable risk/return of investments • Unacceptable risk/return • Lack of suitable financial vehicles/instruments	• Business case for adaptation investment lacking (I, M) • No or limited income streams for adaptation (I) • Adaptation projects do not present an acceptable risk/return profile for investors (I) • Absence of investment models for adaptation projects (I) • Lack of investor confidence; lack of adaptation projects, no data, no transaction history and limited disclosure record (I) • Short-term investment horizons of investors present challenges for adaptation investment that require a longer term view (I) • Cash flow rates mismatched to impact and benefit (I) • Lack of demand-side economic policies to incentivise investment in adaptation (*e.g.* taxes, rebates, quotas) (I) • Lack of investment-ready and bankable adaptation projects and project pipeline (I) • Lack of demand and corporations bias towards mitigation projects (I) • Lack of competition in financing products (I)
Knowledge and heuristics • Lack of knowledge • Lack of models • Difficulties measuring impacts	• Unfamiliarity and lack of knowledge of climate change adaptation within the investor community (I) • Lack of understanding of urban climate-related risks (I, M) • Lack of data (all areas) (I, M) • Nowhere to look at best practice internationally (I, M) • Complexity in the assessment of climate impacts (I, M) • Lack of resources in municipalities dedicated to climate change (funds and people) (M)
De-risking investments • Shortage of finance (supply) • Technology risks	• Lack of proactive financing despite long-term economic case for investment (I, M) • Lack State Government assistance (M) • Governments failing to leverage with high-risk capital to create incentives for private capital (I) • Constraints on municipal taxation (M) • Conflicting adaptation technological and infrastructure solutions (M) • Lack of insurance products/mechanisms (I) • Monopolisation of CB investment by public sector (I) • Lack of a track record (I)
Size transformation and capital aggregation • Projects not large enough • Complex capital aggregation	• CB legislation does not allow for larger projects and scaled investment (M) • Lack of scaled investment-ready and bankable adaptation projects and pipeline (I)

Table 4: Factors/barriers (workshop).

Note: CB = Cloudburst, I = investors, M = municipal.

The result is that almost all Cloudburst projects are publicly funded through Copenhagen's single novel financing product, with minimal private capital flowing to adaptation. Several investors referred to the public sector crowding-out of private capital, especially as *KommuneKredit* apply low rates to the municipal credit product that finances Cloudburst that are simply unattainable for them (FR15). Informants described the municipal credit product for Cloudburst in detail along with its successes and deficiencies (W, NI10, NI11, NI23).

> The [Cloudburst model entails the water utility charging tariffs, so in that way the money is secured for the Cloudburst projects with additional money [for urban design coming from the municipality. ...] This money is not very large in comparison to the Council's overall budget, but it generates very many [additional] or co-benefits and represents very economically effective expenditure.
>
> (NI10)

> *KommuneKredit*, a Danish municipal credit pooling entity, is also a very important novel part of the CoC and the Danish [Cloudburst] model. [...] Loans are way below what would be offered on the market [which] explains why we [the municipality] have not worked with bonds of any type.
>
> (W)

> I don't think they [Danish municipalities] are interested in any collaboration with the pension funds and private capital. I don't think they need us.
>
> (FR9)

Opinions also differed greatly amongst the informants regarding the availability of finance and funding (W). Investors stated there is no issue with supply of finance but there is a demand-side problem, meaning there are no projects for them to invest in. Although there is an abundant supply of finance in search of projects, investors are either unwilling or in many instances unable to provide finance at lower than commercial thresholds for return/risk ratios. In contrast, actors from the municipality referred to both finance and funding constraints, including spending caps and lack of state investment (W, FR3). These differences indicate the prevalence of entrenched silos, with each set of actors unaware of each other's respective financing issues, needs, and perspectives.

An important consideration in creating new financing models is whether appropriate institutional arrangements are in place to deliver pooled finance at the required scale and risk/return rate (A2):

> We lack the institutional arrangements. But if you're trying to put together a 'sponge city [nature and natural features such as lakes, waterways, vegetation, wetlands and parks to absorb rain and thus assist in urban flood prevention] project with multiple components [...] and you're going to do all of that by funding through a levy or through land-value capture, then there's nowhere that this has already been done so there's no track record.
>
> (FR11)

4.1.2 Transaction size

Investors have clear notions as to the size of projects they consider acceptable and in which they are prepared to invest, with many adaptation projects considered too small for investment. In MLP terms, this situation can be described as the finance regime being unwilling to invest in niche-innovations and thereby 'lift' them into the incumbent regime. This reluctance on the part of investors relates closely to transaction costs, which can be very high for smaller projects (Figure 3 and Table 4). Conversely, certain urban adaptation projects are too large and complex to be considered acceptable by investors, including projects deemed ineligible according to the city's current Cloudburst-funding arrangements:

> It's not that we lack finance [...] but there are still a lot of projects that aren't eligible within the [Cloudburst] regulations, [and in the case of] the larger projects across municipalities, the regulations simply [aren't being designed for] what is needed today.
>
> (W)

Although the participants were only able to give examples of adaptation projects funded by public money, property owners or philanthropy in Copenhagen, many actors evinced optimism regarding future opportunities for involving the private sector and for creating new types of projects and financing products (FR1, FR11, NI6, NI16, W).

> Many times, it's good to start at home. We've got a lot of experience in Copenhagen, so if we could become investors in huge climate adaptation projects and we get experience and can see how to can earn satisfactory returns [then] we could move that experience abroad.
>
> (R5)

4.1.3 Knowledge

Whilst the interviewees exhibited a wealth of knowledge about investing in incumbent technologies, urban adaptation is an area about which actors lack sufficient knowledge to assess potential investments and make informed decisions about whether or not to invest (NI10). One of the barriers most frequently mentioned by all actors was lack of knowledge (Table 4). For investors, knowledge barriers arise in relation to many different types of adaptation projects, as well as to sustainability (including climate adaptation and mitigation) disclosure requirements.

> I think knowledge [about adaptation as compared to carbon mitigation ...] is much lower. I just don't think people in the finance sector know what [adaptation] investments [...] look like.
>
> (A1)

> It [the adaptation finance market] is a very immature area. There's a lack of a marketplace, so there's a lack of project pipeline and insurance. [...] These all intensify the main [market] barriers.
>
> (NI16)

> There's a broad problem with knowledge about sustainable finance in general [...] a very limited number of people with expertise [throughout the] financial sector. [...] What's problematic here are the interactions and intricacies. You can't easily separate out [adaptation or] biodiversity or nature-based solutions from other impacts.
>
> (FR3)

For municipalities and their partners, meanwhile, knowledge barriers manifest primarily in relation to understanding and measuring the impacts of climate change (A1, A2, NI17) and to finding technical solutions. Advocating nature-based solutions as part of adaptation niche-innovations entails new skills and expertise (FR3), hence all the municipal actors involved in the city's Cloudburst response needed to acquire and engage in 'new thinking' and 'new ways of working' (W, NI6) (Table 4).

4.1.4 Industry networks

For incumbent technologies such as low carbon initiatives, there are already well-established industry networks in Denmark that support investors in their financing of projects. These networks help to build trust, collaboration and knowledge-sharing, thereby building confidence in niche-innovations and increasing the willingness of the finance regime to lift them into the regime. No such industry networks exist amongst investors for adaptation, though strong intermunicipal networks have been developed for adaptation (NI6, NI9).

Participants strongly emphasised the need for cooperation and collaboration for adaptation, as well as the importance of attaining buy-in and support from key urban stakeholders (*e.g.* the Copenhagen metro system):

> We've learned that dynamic planning is not easy. Serious changes in legislation and regulations solved a lot of problems. [...] Things change when you're looking at a programme that's been running for more than twenty years. You need to be sure to involve all city agencies as early on as possible.
>
> (W)

Study participants also described the complex interagency process they had undertaken in designing and implementing Cloudburst projects, including many actors. Remarkably, however, this process includes very little interaction between investor entities and the municipality.

4.1.5 Regulation

All participants stressed that regulation is a major barrier affecting their access to finance for urban adaptation. Regarding this fifth factor, the actors specifically mentioned the lack of an overall stable policy framework covering all types of climate hazards, including cloudbursts and storm surges (NI6) (Table 4). Criticisms of the State Government were also commonly voiced for its lack of municipal financing support and failure to develop an overarching vision of urban adaptation (W, NI7, NI6, NI19, NI20, FR13). There was an evidently strong desire for the State Government to act as a co-player in urban adaptation efforts (and funding) instead of a 'barrier'—as it was commonly described by these actors (W):

> The number one [barrier] is regulation. We need other opportunities and possibilities to secure the financing of climate adaptation projects [...] we need some other regulation that enables us to make the necessary investments.
>
> (NI9)

Differences were evident in the participants' views on regulatory stability, with investors concerned about the current rate and extent of flux in financial disclosure regulation due to significant changes in financial regulations on sustainable finance, disclosure and climate risk, while municipalities are concerned about the flux in specific details of Cloudburst-related regulation and a lack of a financing regulation for storm surge (NI9):

> We still need maybe a clearer framework from the government policy, for example, a Climate Council. Maybe the government should focus and exert more power on new technology (adaptation) [...] the market also depends on governmental regulation.
>
> (FR13)

These changes in regulation relating to the financing of Cloudburst over recent years have made the procedures for expenditure approval more difficult and complex for municipal actors (NI23, NI9, W). These challenges stem from mistrust between actors, especially as the State Government lacks confidence in the ability of the municipality and the water utility to adequately appropriate funds raised via the water tariff. One participant stated a fear that in three or four years' time the municipality may no longer be able to invest in climate change adaptation at all (W). This mistrust is deeply rooted and will be difficult to address:

> Initially there was sort of distrust in the whole idea [Cloudburst], and we [the municipality and their advisors] had to work hard. We had to do a number of business cases.
>
> (NI10)

> They were so afraid when we came up with this idea of Cloudburst Streets, for example. [... They thought] 'Was this just a new manoeuvre by the municipalities to see if we could push municipal maintenance work over on to the (water) tax?'
>
> (W)

4.2 FACTORS IN LANDSCAPE–REGIME–NICHE INTERACTION

Cloudburst niche-innovations moved from the demonstration to early-stage phases in the MLP as a result of a 'window of opportunity' created by three extreme rainfall events. Seizing this opportunity, Danish regulators and other actors devised a novel financing 'workaround' that successfully prevented the niche innovation from entering a 'valley of death', *i.e.* a phase in the innovation chain of sustainable transition in which a technology struggles to attract sufficient funding to move beyond the demonstration phase to commercialisation and diffusion.

4.3 INTERVENTIONS AND ENABLERS IN LANDSCAPE–REGIME–NICHE INTERACTIONS

The participants also proposed interventions to address each of the barriers they had identified (*e.g.* see ***Figure S1*** in the supplemental data online). Of these proposed interventions, most related to regulations, project size, risk/return rations, technical advice, funding and impact measurement. The authors also extracted the main enablers and interventions cited in the MLP literature (see ***Table S4*** in the supplemental data online), including de-risking investments, niche and regime education, industry networks, and transition visions and pathways. Regarding finance regime–niche interventions, Geddes & Schmidt (2020) have identified de-risking, co-financing, size transformation, education (regime and niche) and industry coordination. This study confirmed that all these interventions played an important role in Copenhagen's transition, further identifying the two additional important interventions of 'establishing a sense of urgency' and 'valuing adaptation'.

Two key causes for concern revealed in this case study: (1) a profound lack of buy-in among investors for financing adaptation and (2) a lack of legitimacy and fissure between policymakers at a national level and actors in the municipality and the city's water utility. For example, no evidence was found that the CoC engaged with investors to make investment more attractive and acceptable through measures aimed at de-risking, co-financing and size aggregation of investments, all of which can foster 'learning by doing' and 'trust signalling' over time (FR11, NI6, NI9, NI13). Nevertheless, various private sector and PPPs were found to support the adaptation of several urban infrastructure developments, including protecting the city's metro against cloudburst and the creation a new urban climate-adapted district by the Copenhagen City & Port Development Corporation (Noring 2019) (FR5, FR11).

Despite the large volume of publicly financed adaptation activity in Copenhagen, there is surprisingly little direct investment in the adaptation initiatives of the city municipality and the national government (NI19, NI23) (see ***Table S7*** in the supplemental data online). The Cloudburst costs seem realistic when set against costs of €0.8 billion for clean-up and repair after just one extreme rainfall event in 2011. In spite of the successes of the city's Cloudburst programme, moreover, the allocation of funds to Cloudburst is hampered by current limits on annual municipal spending and borrowing (NI10). As a consequence, only 11% (€0.2 billion) of the €1.8 billion earmarked for Cloudburst projects has been disbursed at the time of writing in 2022 (N22, N23).[6] These challenges confirm there is still considerable room for improvement in the Cloudburst programme and the financing of sustainable transition in Copenhagen.

Urban adaptation was clearly not a top priority for some of the actors in the relevant incumbent regimes, including the State Government. Among Danish investors, for example, financing adaptation currently ranks well below financing climate mitigation and other investments in their priorities (FR10, FR11, NI16). The stability of these incumbent regimes, together with the persistence of traditional approaches to infrastructure planning and financing, is evidently supported and perpetuated by the presence of various lock-in mechanisms. Informants FR3 and FR6 and workshop participants highlighted the need for the valuation of adaptation outcomes, with all actors describing the methods and processes for valuing adaptation as a major shortcoming in current efforts (W). In this regard, the informants alluded to a small number of innovative adaptation finance mechanisms found in other cities where adaptation is valued and priced in through climate risk pricing, climate risk-linked bonds, climate resilience bonds (Buhr 2022), mangrove bonds, catastrophic risk insurance, *etc.* (FR6, FR9, FR11, NI13, NI19, W).

5. DISCUSSION

Figure 4 depicts the MLP model for Copenhagen's niche-innovations in urban adaptation.

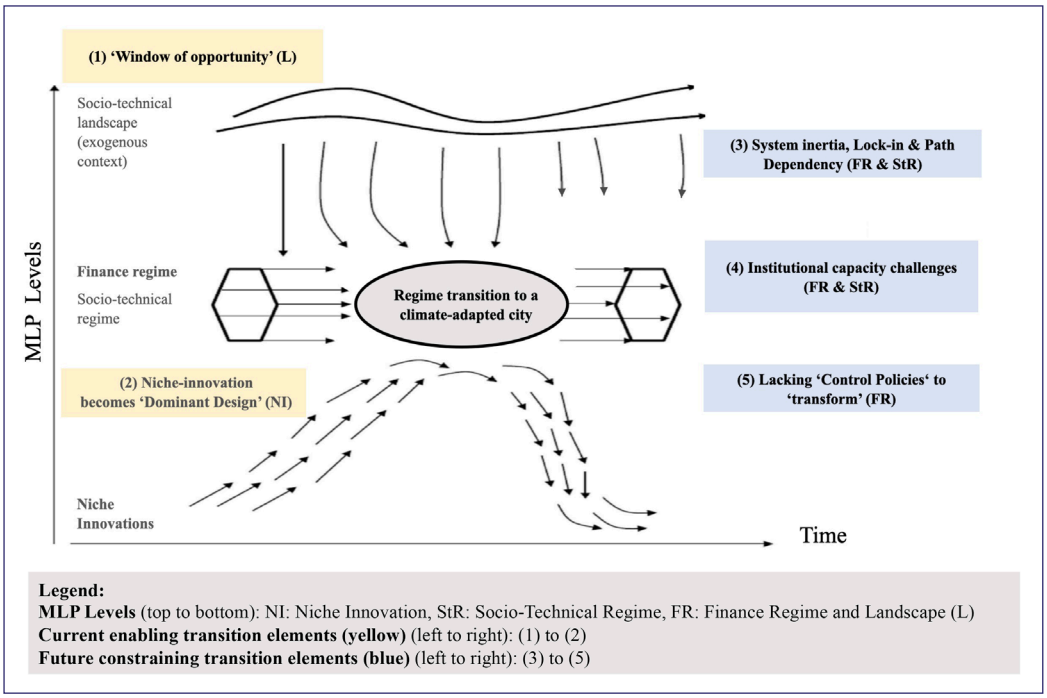

Figure 4: Multilevel perspective (MLP) model of Copenhagen's niche-innovations in urban adaptation.

Sources: Adapted from Geels (2012), Geddes & Schmidt (2020) and Hynes (2016).

5.1 LANDSCAPE DISRUPTION: A 'WINDOW OF OPPORTUNITY'

Three extreme rainfall events in Copenhagen in the period 2011–13 disrupted the city's then incumbent regimes and thereby opened a 'window of opportunity' for niche-innovations in the management of urban flooding to move beyond the demonstration phase to commercialisation and diffusion (Nemet *et al.* 2017). Although such 'landscape disruption' was not studied by Geddes & Schmidt (2020) or incorporated in their model, the present research shows this window of opportunity proved critical in spurring a government response and in enabling niche-innovation in Copenhagen. This achievement is all the more notable given that studies of other cities have found only limited public and regulator acceptance of local market-based instruments such as tariffs, primarily due to potential unequal and distortional benefit and cost distribution (Mullin *et al.* 2019). Notwithstanding this achievement, delays in the implementation of the CoC's Cloudburst measures are of grave concern insofar as any window of opportunity is time-limited and thus requires a time-bound response from the regime. It is also noteworthy that the disruption triggered by the extreme rainfall events of 2011–13 did not extend to investor activity in Denmark, raising the question of what conditions would be needed to elicit a commensurate response from these actors. These circumstances call for further research into ways of further destabilising incumbent regimes and catalysing investment.

5.2 DOMINANT DESIGN

Copenhagen has succeeded in supporting the Cloudburst programme to break through to the regime level and ultimately emerge as the 'dominant design', with Cloudburst planning now routinely integrated in all urban planning. Such niche support is critical in the MLP, and many examples of supportive developments can be found in CoC's approach, including municipal pooled credit financing, experimentation, municipal learning networks and knowledge base development (Geels 2012; Geels & Ravin 2006; Loorbach 2010). The CoC is working hard to build knowledge through experimentation, often in the absence of best-practice examples from other municipalities. However, knowledge development in capital markets is less well developed. And while municipal learning networks on adaptation are strong and prominent, no such networks are in place for investors, amongst whom knowledge and capacity regarding adaptation remains extremely low.

No evidence was found either for interactions between investors and the municipality nor of any fora on adaptation for investors. Such interactions are prerequisites for any transition to climate-adapted cities, as noted in two recent studies on the financing of urban adaptation (Moser *et al.* 2017, 2019) which highlighted a 'void' between actors in the private and public sectors and the consequent difficulties of navigating between their respective worlds.

This study confirms the absence in Copenhagen of numerous known niche-enablers specifically related to finance. Whereas the literature has long stressed the need for *bankable* adaptation projects to be developed based on identified income streams, project markets, historical performance data, project preparation and end-user demand (ADB 2021). The findings accord with research conducted by Bisaro & Hinkel (2018) and Svendsen (2021), which likewise uncovered little evidence of institutional investment for adaptation and nature-based projects in coastal cities. Other studies have similarly concluded that mobilising new partnerships and financing for adaptation projects crucially depends on first resolving the complex governance and economic issues related to responsibility for funding, trade-offs, equity and the accrual of benefits at the urban level (Bisaro *et al.* 2020). Although public investment can be highly effective in mobilising and de-risking private investment, the present study shows these outcomes have not been achieved in the case of Copenhagen (Deleidi *et al.* 2020).

5.3 SYSTEM INERTIA

Breaking *system inertia* by inducing fissures in incumbent regimes and triggering landscape disruption is crucial for catalysing the kinds of regime changes needed to enable transition. Despite recognising the importance of disruption for catalysing such changes, however, few informants were able to suggest feasible ways of triggering sufficient disruption to bring about change in the city's regimes and its actors, regulations, institutions and practices. In this regard, scholars have stressed the importance of 'control policies' to exert pressure on regimes (Geddes & Schmidt 2020; Rotmans *et al.* 2001). For example, it has been proposed that a control policy for pricing climate risk could create an 'extended level playing field' for niches to contend with incumbent technologies and economic parameters (Antal & van den Bergh 2016). Despite the success of the city's Cloudburst response, many actors in Copenhagen have neither fully acknowledged the urgency of urban adaptation nor fully committed themselves to prioritising such adaptation, further compounding the problem of system inertia (Geels 2012). The delays in implementation of the CoC's Cloudburst measures, lack of a financing arrangement for storm surge and small size of municipal adaptation teams are other symptoms of system inertia. Olazabal & Ruiz De Gopegui (2021) and Olazabal *et al.* (2019) similarly found these deficiencies as Copenhagen's climate plan budget which they assess as insufficient for planned actions at just 0.0002% of city gross domestic product (GDP).

5.4 INSTITUTIONAL ARRANGEMENTS

Developing appropriate institutional arrangements to ensure finance can be delivered at scale is a fundamental step in any process aimed at enabling transition to climate-adapted cities (Hölscher & Loorbach 2019). However, the CoC currently lacks the institutional arrangements to scale its efforts and developed more complex adaptation projects with multiple components and actors and diverse financing products. Inventive institutional arrangements for supporting other kinds of urban developments, including major infrastructure projects, have been implemented in Denmark, but these arrangements have so far not been widely applied in the case of urban adaptation. Although such projects/arrangements require very different organisational structures, logistics and planning, previous cases and prior experiences are available to draw upon. In addition, Moser *et al.* (2019) have proposed several possible municipal arrangements, including 'life-long funding sources' for adaptation, pooled risk insurance through a 'climate resilience authority', block grants and state interventions to support the establishment of PPPs. Again, however, the informants were unable to suggest suitable arrangements, with most being much clearer about the things they did *not* want rather than what they did want. For instance, there is also concern that the Danish Government's forthcoming White Paper on financing storm surge defences will not go far enough in terms of regulatory and institutional reforms.

As a means of facilitating such reforms, Geddes & Schmidt (2020) have emphasised the need for industry education and coordination in both the finance regime and niche. Geels (2019) and Loorbach (2010) have suggested that interventions need to include a transition narrative or vision and should include additional niche actors. Narratives and storylines are crucial for expressing socio-political problems and capturing the roles of actors, innovations and transition pathways.

5.5 'STRETCHING AND TRANSFORMING' THE FINANCE–REGIME

The majority of interviewed investors attributed the city's lack of finance for urban adaptation to the competition and predominance of mitigation finance and the lack of clear income streams for adaptation projects. As a consequence of these combined challenges, the city's capital market for urban adaptation remains very much at a nascent stage of development. The dominance of the public sector means there is also weak project identification and preparation by the municipality, with many projects simply not framed to match investor requirements (Bisaro & Hinkel 2018). Such mismatches clearly violate the principle that investment arrangements must be appealing to both public actors and investors alike. Accordingly, strengthening market formation and price performance (Jacobsson & Bergek 2011) will continue to be extremely challenging for the CoC as long as project proponents struggle to commercialise their projects.

This case study complements the MLP model offered by Geddes & Schmidt (2020) in finding evidence of elements in the CoC's system that are more conducive to 'fit and conform' of the niche-innovations to the finance regime than to 'stretch and transform' the finance regime. In addition, the CoC has not yet mobilised private finance in urban adaptation, despite its world-renowned success in doing so for mitigation.

Theoretical insights also include several additional interventions that will be critical for adaptation, but which are absent from Geddes & Schmidt's (2020) model. These interventions include instilling a sense of urgency among actors regarding the city's response to the need to tackle the physical impacts of climate change, as well as efforts to foster a higher appreciation of the value of adaptation. Other interventions not mentioned by the interviewees but critical to future success include efforts to diversify investors and financing products, to cultivate PPPs, to develop financial incentives for adaptation, and to reform financial regulations (FR11). Such interventions would contribute to fostering the level of social acceptance and legitimacy of adaptation projects and their funding (Geels & Schot 2007).

6. CONCLUSIONS

The City of Copenhagen (CoC) has an ambitious urban adaptation approach that is widely considered exemplary among capital cities throughout the world. In particular, it has been successful in developing an innovative financing product for funding adaptation. However, this approach has had several important deficiencies for other climate hazards, partnerships and the level of investment urgency. Namely, the financing approach cannot be applied to other hazards, it has failed to include private capital partners and has not engendered a sense of urgency amongst key actors such as investors and the State Government. The findings highlight that more could still be done to facilitate funding for innovative adaptation measures and projects, and that the city is experiencing problems in realising its ambitious goals/plans.

Despite the innovativeness of the city's approach to financing urban adaptation, this approach is predominantly based on public finance and there is little evidence of any mobilisation of private capital or of the use of state-of-the-art climate-pooled or blended financing mechanisms. The CoC's slow rate of progress in completing its Cloudburst Management Plan (2012) and Climate Change Adaptation and investment statement (CoC 2015) due to financing constraints testifies to the extent that barriers to funding have impeded Copenhagen's transition to a fully climate-adapted city, rendering the city's adaptation more challenging, uncertain and fragile.

Key landscape–regime–niche interactions and interventions for transition have been identified in this study. Whereas sustainable transitions theory has been extensively applied in analyses of the transition to low carbon economies, this study is the first to apply this theory to the financing of

urban adaptation to climate change. Mobilising concepts from the multilevel perspective (MLP), it was shown how the city's nascent urban adaptation market remains dominated by the public sector. More radical 'stretching' and 'transforming' of this market is required to overcome current barriers to investment and enable the market to mature. Numerous factors restricting access to finance are deeply entrenched, with the negative consequence that niche-innovations either struggle or are unable to attain commercial viability.

As one of the first attempts to bring finance into the MLP and apply this perspective to study the transition to a climate-adapted city, this research inevitably has certain limitations, further indicating future avenues of research. In particular, the role of finance in MLP model needs to be further elaborated to account for a fuller range of multi-actor interactions in future research on the role of finance in the MLP.

This study has helped to address major gaps in research into how urban adaptation finance is constrained or enabled. This case study identifies and highlights the challenges faced by municipalities and investors alike when financing urban adaptation. These challenges arise because successful financing requires innovation not only in technology but also in the approaches taken by all actors to financing and investment in niche-innovations. Several recommendations include the need for constraints on private sector participation to be removed, for equal prioritisation of climate adaptation and mitigation, for government engagement with diverse private capital providers and new financing mechanisms/capabilities, for the development of 'investment-ready' and bankable adaptation projects, and steps to unlock the value of adaptation projects.

NOTES

1 Although Copenhagen's response to hazards related to rising sea levels is not the focus of this article, it should be noted for context that the city's harbour sea levels are expected to rise permanently by 1 m by 2110, and that storm surges of varying intensity have been predicted in association with this rise in sea level from 2020 to 2100 (CoC 2017).

2 Municipal calculations of the damage costs of the 2011 event were converted to euros on 12 September 2022 (DKK1 = €0.13) (CoC 2012).

3 Municipal net present value (NPV) calculations at 2015 prices were converted to euros on 12 September 2022 (DKK1 = €0.13) (CoC 2012).

4 Municipal budget conversion to euros was made on 12 September 2022 (DKK1 = €0.13) (CoC 2021).

5 Actor/participant type: FR = finance regime (investor), NI = niche-innovation (municipal), A = academic; also W = workshop.

6 See note 3.

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Stella Whittaker: conceptualisation, formal analysis, validation, writing—original draft. Kristjan Jespersen: conceptualisation, editing and review—original draft.

COMPETING INTERESTS

The authors declare no conflict of interests.

DATA AVAILABILITY

Owing to the nature of this research, the participants agreed to take part in the study on the understanding that their input would be anonymised and not shared publicly, hence the supporting data are not available.

ETHICAL APPROVAL

The study did not require ethical approval from the Copenhagen Business School as it conformed with guidelines set by the university. All participants were informed of the purposes and task of the study and consented to participate. The identities, opinions and roles of all participants have been fully anonymised in accordance with ethics and data management procedures.

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