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Innovation and Implementation Pathways for Urban Climate Change Adaptation

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Publication date:
2018

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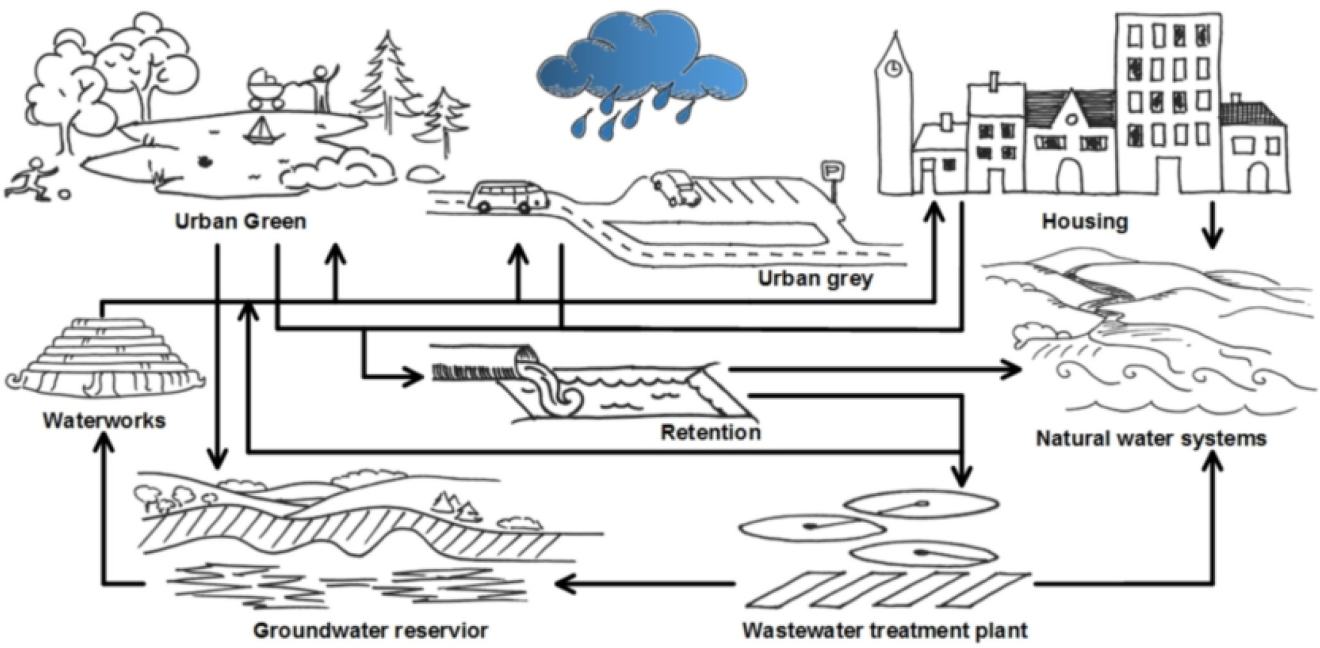

Herle Mo Madsen

PhD Thesis
November 2018

DTU Environment
Department of Environmental Engineering

Innovation and Implementation Pathways for Urban Climate Change Adaptation

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The synopsis part of this thesis is available as a PDF file for download from the DTU research database ORBIT: http://www.orbit.dtu.dk.

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Preface

This thesis presents the outcome of a PhD project carried out in collaboration between the Department of Environmental Engineering (DTU Environment) and the Department of Management Engineering (DTU Management), Technical University of Denmark (DTU), in the period from December 2014 to October 2018. The project was supervised by Professor Peter Steen Mikkelsen and Associate Professor Martin Rygaard (DTU Environment), and Senior Researcher Maj Munch Andersen (DTU Management). The PhD project was funded by DTU and is one of the first initiatives under Water DTU, Centre for Water Activities at DTU.

The thesis is organized in two parts: the first part puts into context the findings of the PhD in an introductive review; the second part consists of the papers listed below. These will be referred to in the text by their paper number written with the Roman numerals **I-IV**.

- **I** **Madsen, H.M.,** Andersen, M.M., Rygaard, M., Mikkelsen, P.S. Innovation dynamics and responsibility sharing in climate change adaptation on private property for pluvial flood mitigation in Copenhagen. (Manuscript).
- **II** **Madsen, H.M.,** Andersen, M.M., Rygaard, M., Mikkelsen P.S. (2018). Definitions of event magnitudes, spatial scales, and goals for climate change adaptation and their importance for innovation and implementation. *Water Research* 144, 192-203.
- **III** **Madsen, H.M.,** Mikkelsen, P.S., Blok, A. Framing professional climate risk knowledge in the city: changes in pluvial and coastal flood risk knowledge due to actualized extreme weather as a cause of adaptation innovation in Copenhagen, Denmark. (Submitted, under review)
- **IV** **Madsen, H.M**, Rygaard, M., Mikkelsen, P.S., Andersen, M.M. Change at the urban scale - Systemic innovation of climate change adaptation in Copenhagen. (Manuscript)

In this online version of the thesis, papers **I-IV** are not included but can be obtained from electronic article databases e.g. via www.orbit.dtu.dk or on request from DTU Environment, Technical University of Denmark, Bygningstorvet, Building 115, 2800 Kgs. Lyngby, Denmark, info@env.dtu.dk.

In addition, the following publications, not included in this thesis, were also concluded during this PhD study:

Papers:

Madsen, H.M.. (2015) LAR i Melbourne – Perspektiver på den danske udvikling. *moMentum special issue: "Den Klimarobuste by"*, volume 2, May 2015, 27-27.

Madsen, H.M. Brown, R., Elle, M., Mikkelsen, P.S. (2017) Social construction of stormwater control measures in Melbourne and Copenhagen: A discourse analysis of technological change, embedded meanings and potential mainstreaming. *Technological Forecasting & Social Change* 115, 198–209.

Conference proceedings:

Madsen, H.M., Andersen, M.M., Rygaard, M., Mikkelsen, P.S. (2015) Change in the Urban Water Management Regime – Successful Technology and Institutional Pathways. *European Climate Change Conference* 12-14 May 2015.

Lerer, S.M., **Madsen, H.M.**, Andersen, J.S., Rasmussen, H., Sørup, H.J.D., Arnbjerg-Nielsen, K, Mikkelsen, P S. (2016) Applying the "WSUD potential" tool in the framework of the Copenhagen Climate Adaptation and Cloudburst Management Plans. *International Conference on Planning and Technologies for Sustainable Urban Water Management*. 28 June- 1 July 2016, Lyon, 4 pp.

Madsen, H.M., Andersen, M.M., Rygaard, M., Mikkelsen, P.S. (2017) Challenges to application of the three points approach (3PA) – ambiguity in definition of events, scales and goals. *International Conference on Urban Drainage (ICUD)* 10 September – 15 September 2017, Prague, 4 pp.

Madsen, H.M., Andersen, M.M., Rygaard, M., Mikkelsen, P.S. (2017) Characterizing Climate Change Adaptation in Copenhagen. *DTU Sustain*, 6 December 2017, Abstract L-2, 1 pp.

Madsen, H.M., Andersen, M.; Rygaard, M.; Mikkelsen, P.S. (2018). A Typology for Climate Change Adaptation: Event Magnitudes, Spatial Scale and Goals. *Danish Water Forum Annual Meeting*, 30 January 2018, Abstract book, p 34.

Acknowledgements

I would like to thank my supervisors Peter Steen Mikkelsen, Martin Rygaard and Maj Munch Andersen for their guidance, support and excellent discussions throughout my PhD study. Special thanks go to Peter Steen Mikkelsen for suggesting this PhD study to me and guiding me before and during my studies, Martin Rygaard for his guidance on urban water systems and help in the writing process and Maj Munch Andersen for the constant inspiration in the form of courses, conferences and literature and for guidance on innovation theory. Additionally, I would like to thank Carsten Nystrup from Novafos, Lykke Leonardsen from the City of Copenhagen and Søren Gabriel from Orbicon for their valuable direction, inspiration and discussions throughout the study.

I wish to thank both my colleagues at the Urban Water Systems section at DTU Environment and the Technology and Innovation Management section at DTU Management for many engaging discussions about water and society, and for creating not only one but two bases for my PhD study. Furthermore, I would like to thank Anders Blok from Department of Sociology, Copenhagen University for hosting my stay at Copenhagen University and for a stimulating collaboration.

I extend my thanks to all of the interviewees and participants in the focus groups, who, throughout my PhD study, were kind enough to take the time to tell me about their work.

Finally, I would like to thank my family for supporting me throughout the study. Especially my husband, for never leaving me with any doubt that he would manage everything at home while I was away on conferences and courses, and for supporting me through the tough parts of this PhD. I am also indebted to my parents, for always supporting me with my vision of attaining a PhD.

Herle Mo Madsen

Kongens Lyngby, November 2018

Summary

Throughout the world, climate change is influencing the water cycle. Precipitation patterns are changing and there is an increase in the frequency and severity of extreme events such as droughts and floods, all of which affect human livelihoods. Additionally, urbanisation will adversely affect the urban water cycle. Today, more than half of the world's population live in an urban area, and this is projected to increase. Urbanisation puts stress on the freshwater security of supply and quality, and it also increases the load on infrastructure such as storm- and wastewater systems. In order to survive and thrive, cities are therefore making and implementing adaptation plans. Existing urban environmental, human and technological systems are flexible to some degree, but there is still a limit to how far existing systems can be adapted. In the face of such monumental challenges, radical innovation is bound to happen. Cities' adaptation plans however vary greatly in regards to the scope of adaptation, by either following existing paradigms or outlining new radical ones.

Little is known about how cities go through such changes, how systemic change is initiated or what actors play which roles. This project therefore examines how the work and interactions of actors in urban water management contribute to innovation and the implementation of multifunctional solutions for climate change, using Copenhagen as a case. In the last ten years, Copenhagen has experienced a series of extreme rain events. As a result, over the last six years, the city has published, improved and started implementing a cloudburst management plan outlining a combination of grey and green stormwater infrastructure, above and below ground, to create multifunctional solutions.

Semi-structured interviews and focus groups were conducted with professional actors working with climate change adaptation in the urban area of Copenhagen. The qualitative data were collected in three interconnected rounds, thus allowing for the validation and testing of preliminary hypotheses and results. The research builds on the evolutionary perspective of innovation system theory in the study of changes in the City Innovation System, and innovation system theory has therefore been part of the data collection and analysis.

Innovation system actors in Copenhagen define climate change adaptation in different ways. The dominant discourse, however, is that climate change ad-

aptation is a combination of alternative above-ground and traditional below-ground cloudburst solutions, set within a surface water catchment system and designed both to prevent damages and to generate day-to-day values for the citizens. The actors use the terms traditional and alternative with reference to the legal use of the terms usual and alternative solutions. However, both the legal and the actor's definitions of the terms are ambiguous. In order to combat the ambiguity, this thesis proposes a novel inclusive framework for characterizing climate change adaptation according to three features: event magnitude (extreme, design and everyday domain), spatial scale (international/national, urban and local scale) and a range of goal categories (innovation; urban; water quantity; water quality; nature; economic; health and safety; social; aesthetic expression; and multifunctional goals).

This thesis concludes that the core group of actors in the City Innovation System includes the traditional innovation system actors, private companies and knowledge institutions, but it also includes utility service providers. The study showed the utility service providers as key actors who play a central role, because in the development process they function as a sparring or financing partner, and in the diffusion process they are considered a large customer or they provide links to other customers, i.e. local authorities and private citizens.

The Copenhagen City Innovation System is showing signs of change through a new paradigm for climate change adaptation, what this thesis names the optimised system. The Copenhagen case is in accordance with existing theory, in that systemic changes towards a new technological trajectory are influenced strongly by external shocks, i.e. localised extreme weather events; however, a base of existing niche work is needed to catch the opportunity when it arises. As a novelty this thesis shows how risk perception plays an important role in the collaborative learning process following the extreme events. In Copenhagen a series of cloudburst have changed the public and professional risk perception and helped create a solution span for climate change adaptation for pluvial flooding. The study shows that actors in the optimised system paradigm implement below- and above-ground solutions for a range of event magnitudes; they value efficient systemic and locally adapted solutions, aiming to improve the interplay between the existing water management system and a range of new solutions. Informed system actors, both inside the optimised paradigm and outside, work with breaking and creating new institutions. Several actors are advocating for changing existing regulation and norms, which do not match the new paradigm of the optimised system. Additionally, the new knowledge paradigm and responsibility norms are now being codified and appearing in internal notes and public standards. Copenhagen is slowly transforming, as climate change adaptation are being implemented throughout the city. However, in Copenhagen a full transformation of the urban water system has not yet happened. The change process is currently at an unstable early phase partly explained by the strong path dependency of the existing drainage system.

Dansk sammenfatning

Klimaændringer påvirker vandkredsløbet i hele verden. Regnmønstre ændres og ekstreme hændelser så som tørke og oversvømmelser øges i hyppighed og styrke. Alt dette influerer menneskers levevilkår. Dertil kommer urbaniseringen, der også påvirker det urbane vandkredsløb. I dag lever mere end halvdelen af klodens befolkning i byområder, og det forventes at denne andel øges. Urbanisering truer stabiliteten af vandforsyning og vandkvalitet og det øger belastningen på infrastruktur så som regn- og spildevandssystemer. For at overleve og trives implementerer byer derfor klimatilpasningsplaner. De eksisterende urbane naturlige, menneskelige og teknologiske systemer kan til en vis grad tilpasses. Der er dog en grænse for den mulige tilpasning af eksisterende systemer, og stillet overfor så monumentale udfordringer, er der et åbenlyst behov for radikal innovation. Byers klimatilpasningsplaner varierer dog meget i forhold til hvor omfattende tilpasning der lægges op til. Det varierer også, om der følges eksisterende paradigmer for vandhåndtering, eller om der skitseres nye radikale løsninger.

Det er begrænset hvor meget man ved om, hvordan byer gennemgår sådanne ændringer; hvordan den systemiske ændring igangsættes, og hvilke aktører der spiller hvilke roller. Dette projekt har derfor undersøgt, hvordan aktørerne i den urbane vandhåndtering arbejder og interagerer i deres bidrag til innovation og implementering af løsninger til klimaændringer. København har i de sidste ti år oplevet en række ekstreme regnhændelser med store ødelæggelser til følge. Som reaktion derpå har byen over de sidste seks år udgivet, forbedret og begyndt implementeringen af en skybrudsplan, som skitserer en kombination af grå og grøn regnvandsinfrastruktur, over og under jorden, for dermed at skabe multifunktionelle løsninger.

Ph.d.-afhandlingen baserer sig på semistrukturerede interviews og fokusgrupper afholdt med professionelle aktører, der arbejder med klimatilpasning i Københavns byområde. De kvalitative data blev indsamlet i tre forbundne runder, hvilket tillod validering og test af hypoteser og indledende resultater. Forskningen bygger på Innovationssystems teoris evolutionære perspektiv i studiet af ændringer i by-innovationssystemet, og Innovationssystems teori har derfor været en del af dataindsamlingen og analysen.

Resultaterne viser at aktørerne i innovationssystemet i København definerer klimatilpasning forskelligt. Den dominerende diskurs er dog at klimatilpasning er en kombination af alternative skybrudsløsninger over jorden og tradi-

tionelle skybrudsløsninger under jorden, som optimeres indenfor et vandopland, designet til både at mindske skader og generere merværdi for borgerne i dagligdagen. Aktørerne bruger termerne traditionel og alternativ med reference til den juridiske brug af termerne sædvanlig og alternativ. Imidlertid er både den juridiske og aktørernes brug af termerne ikke entydig. For at komme flertydigheden til livs forslår denne afhandling en ny inkluderende definition af klimatilpasning med følgende tre karakteristika: begivenhedsstørrelse (ekstrem, design og hverdags domæne), geografisk skala (international/national, urban og lokal skala) og en række kategorier af mål (innovation, urban, vandkvantitet, vandkvalitet, natur, økonomi, sundhed og sikkerhed, social, æstetisk udtryk, og multifunktionelle mål).

Denne afhandling konkluderer at kernegruppen af aktører i by-innovationssystemet inkluderer de traditionelle innovationssystems aktører, private virksomheder og videninstitutioner, men den inkluderer også forsyningsvirksomheder. I udviklingsprocessen fungerer forsyningsvirksomhederne som en sparrings- eller finansieringspartner, og i diffusionsprocessen kan de betegnes som en stor kunde eller som en forbindende aktør til lokale myndigheder og private borgere.

Det københavnske by-innovationssystem viser tegn på ændringer, der former et nyt paradigme for klimatilpasning, hvad denne afhandling kalder det optimerede system. København casen viser, i overensstemmelse med eksisterende teori, at systemiske forandringer i en ny udviklingsbane er stærkt influeret af eksterne chok, i denne case lokalt manifesterede ekstreme vejrhændelser. Dog kræves der en base af eksisterende nichearbejde for at opfange muligheden, når den opstår. Som noget nyt viser denne afhandling hvordan risikoopfattelse har en vigtig rolle i den fælles læringsproces der følger ekstreme hændelser. I København har en serie af skybrud ændret den offentlige og professionelle risikoopfattelse og været med til at skabe et løsningsrum for klimatilpasning som adresserer regnrelaterede oversvømmelser. Dette studie viser at aktørerne i det optimerede system paradigme implementerer løsninger over og under jorden for en række af hændelsesstørrelser, de værdsætter effektive, systemiske og lokalt tilpassede løsninger, med det mål at forbedre samspillet mellem det eksisterende vandhåndteringssystem og en række nye løsninger. Informerede systemaktører, både indenfor det optimerede paradigme og udenfor, arbejder med at bryde og skabe nye institutioner. Flere aktører er fortalere for at ændre eksisterende regulering og normer, som ikke matcher det nye paradigme for det optimerede system. Derudover bliver det nye vidensparadigme og de nye normer for ansvar fra det optimerede system kodificeret og optræder nu både i interne notater og i publicerede standarder. Som følge af implementeringen af klimatilpasning i hele byen, forandrer København sig langsomt. Dog er der i København endnu ikke sket en fuld transformation af det urbane vandhåndteringssystem. Forandringsprocessen er på nuværende tidspunkt i en tidlig og ustabil fase, blandt andet på grund af en stærk sporafhængighed sat af det eksisterende rørsystem.

Table of contents

1 Introduction

1.1 Cities as the battleground for climate change adaptation

Cities throughout the world are transforming, in order to adapt to climate change. Furthermore, urban living conditions are now coming under pressure as climate change becomes more and more evident, with changes in hydrological systems, such as ice-melting, changed precipitation patterns and increases in the frequency and severity of extreme events like floods, droughts and cyclones, becoming the norm (IPCC, 2014). On top of climate change, urbanisation is also changing our society. In 2016, 55 per cent of the world's population lived in an urban area, and this figure is projected to be 60 per cent by 2030 (United Nations, 2016). Moreover, it is anticipated that cities in 2030 will be larger, including all city sizes, from so-called "megacities" with more than 10 million inhabitants, to cities with fewer than 1 million inhabitants (United Nations, 2016). Urbanisation will increasingly influence the (urban) water cycle, placing stress on both freshwater supply and quality, and increasing the pressure on existing infrastructure for water supply and storm- and wastewater management, thus challenging the systems' capacity.

In order to thrive and survive, cities have to respond to these challenges and many more. Adaptation plans to counter climate change vary globally across cities, and only a fraction of cities have a plan, with even fewer in the implementation stage (Reckien et al., 2018). Those plans that are in place correspond to local challenges with e.g. water supply, energy supply, flood protection or storm- and wastewater management, and thus their contents vary greatly. Existing environmental, human and technological systems have some capacity to adapt; however, there is a limit to this adaptation, and therefore radical innovation or system changes are bound to happen (Dow et al., 2013). The adaptations plans can thus vary greatly in their strategies, by following existing paradigms or outlining new and more radical options. For example, Copenhagen's adaptation plan focuses, among other things, on stormwater management, outlining grey and green stormwater infrastructure both above and below ground, to create multifunctional solutions that fulfil several needs of society: technical (such as water supply, sanitation, flood protection), social (such as aesthetics, health, culture and education) and environmental (such as natural water resources and biodiversity) needs. The multifunctional green and grey strategy is judged both beneficial for the environment

(Brudler et al., 2016) and economically beneficial (Københavns Kommune, 2015).

In the face of this climate change challenge, cities need to adapt on the urban scale; however, it seems that cities' adaptation activities affect the adaptation at other scales, such as the national, too. Cities are the battleground for the adaptation process, in that they are both consuming vast amounts of resources and provide material and knowledge resources for change. Cities are dense locations of resource consumption, where more than half of the world's population lives. As such they are crucial for an overall adaptation process towards a more sustainable and resilient future. In fact, cities are taking more and more responsibility for initiating adaptation (and mitigation). When the Paris Accord recently was threatened at a national level, cities across the globe rallied signing a voluntary agreement to uphold the Accord and reduce carbon emissions (Boffey, 2017). Similarly, cities are pledging to uphold the UN Sustainable Development Goals, among other things committing to making the transition to a climate-resilient economy (Moloney, 2018). Cities therefore are the battleground of the adaptation process, and so understanding exactly how and why they are adapting was a key aim of this study.

1.2 Research questions

This PhD project examined the technical and institutional pathways for the innovation and implementation of multifunctional solutions to climate change, using the city of Copenhagen as a primary case.

The main research question was:

How does the work and interaction of actors in urban water management in Copenhagen contribute to innovation and implementation of multifunctional solutions to climate change?

From the main question, a set of supporting questions arose:

1. What climate change adaptation technologies currently exist, and what are being developed?
2. What characterises the key actors in social networks around climate change adaptation technologies?
3. What characterises the current dominant technological paradigm, and what other paradigms are emerging?
4. What characterises multifunctional climate change adaptation technologies?

5. Why are multifunctional alternative technologies being developed and implemented?
6. How can we overcome obstacles to implement multifunctional alternative technologies?

The research questions were answered in a Danish context, with Copenhagen being the primary case. Additionally, there were two premises to this project. First, the spatial scale investigated was the urban option, and as such the City Innovation System (CIS) was the theoretical core of the project, which aimed to further the development of CIS theory. Second, the technological focus of the research was solutions for multifunctional climate change adaptation, which is an important component of Copenhagen's adaptation strategy.

1.3 Thesis structure

In order to answer the research questions, this thesis first goes through the background, methodology and theoretical underpinnings of the PhD study in Chapters 2-4.

Chapter 2 describes the background of the main case, namely Copenhagen, including the spatial delineations of the city, expected climate change predictions for the area and an overview of climate change adaptation in the city, which is in focus in **PAPERS I-IV**.

Chapter 3 outlines and discusses the theoretical background of this thesis, which is fundamental to everything from data collection to writing the articles in all papers **(PAPERS I-IV)**.

Chapter 4 describes the methods of this thesis that were used to conduct the research presented in **PAPERS I-IV**: data types, sampling strategy, analysis and validation. Furthermore, the chapter discusses the limitations of these methods, which is especially relevant when handling the comprehensive, detailed and sensitive data collected in this thesis.

Second, Chapters 5-7 outline, connect and conclude on the research presented in the different papers.

Chapter 5 characterises what climate change adaptation is in Copenhagen, and it discusses the terms "multifunctionality," "traditional" and "alternative," which part of the thesis from the beginning. Chapter 5 builds on especially **PAPER II**.

Chapter 6 describes the different actor types and institutions, and their interactions in the CIS **(PAPER I and IV)** then it discusses possible causes of innovation **(PAPER III)**, and finally different technological paradigms are identified and signs of change are discussed **(PAPER IV)**.

The conclusions are found in Chapter 7, which summarises the previous chapters and concludes on the research questions.

Finally, a series of recommendations for future research on the innovation of climate change adaptation are given in Chapter 8.

2 Copenhagen

2.1 Background

Copenhagen is the main case of this thesis. In this thesis the urban area of Copenhagen is referred to as Copenhagen. Copenhagen with a population of 1.3 million people in 2017 is the largest urban area in Denmark, and it is the capital city. The city centre is home to the municipalities of The City of Copenhagen and Frederiksberg Municipality; however, the entire urban area covers 18 municipalities in total (Figure 1).

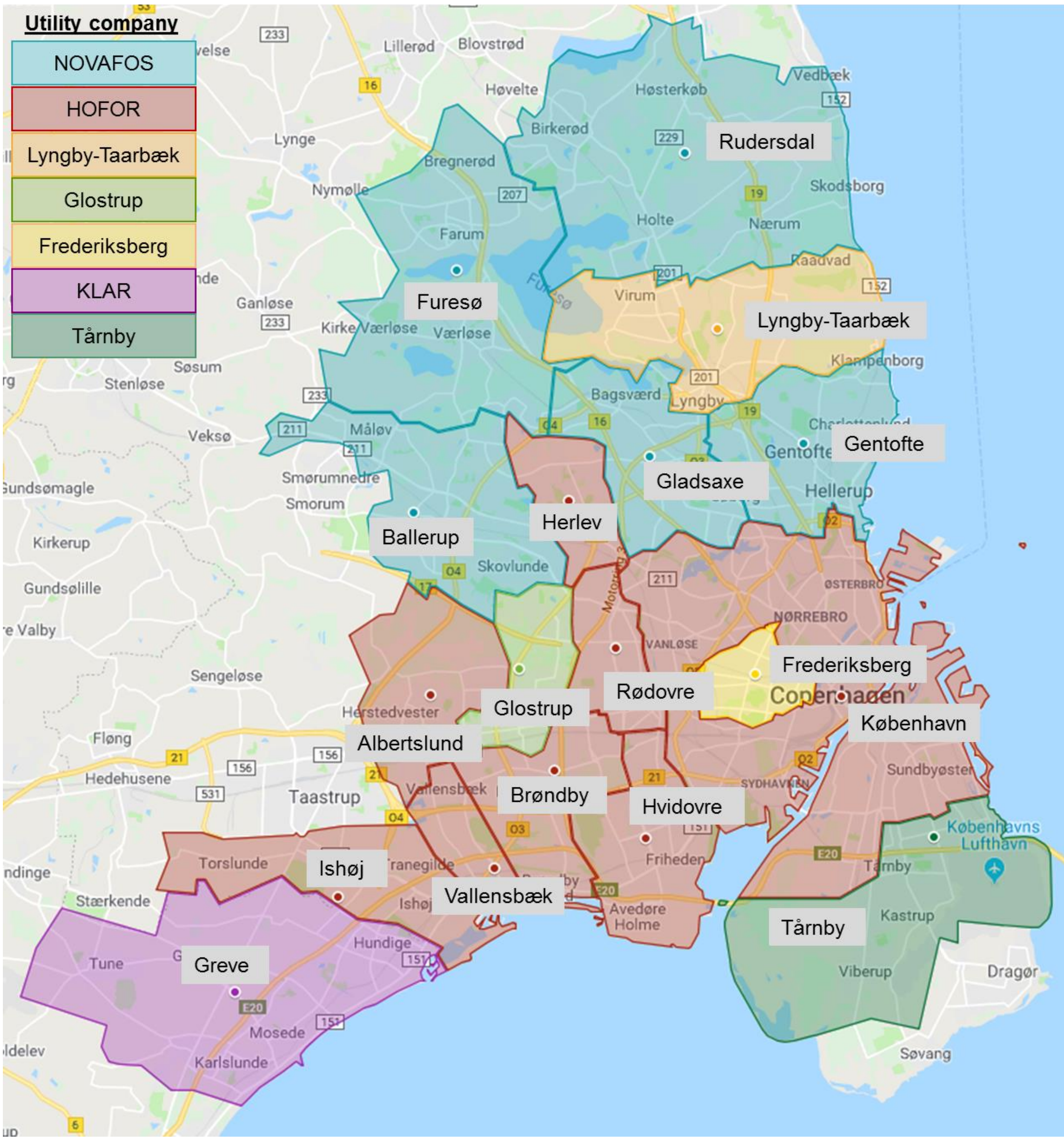

Figure 1. The contiguous urban area of Copenhagen's 18 municipalities (names in grey) and the corresponding utility company per October 2018 (fill colour), in this thesis they are referred to as Copenhagen. Figure based on google maps.

2.2 Climate change adaptation in Copenhagen

Copenhagen, as with many cities across the world, is experiencing climate changes, specifically changes in rainfall, which have gained a great deal of public attention as a result of more frequent extreme events. A particularly strong cloudburst on 2 July 2011, for instance, is often referenced both by the public and practitioners as a turning point in understanding climate change and adaptation needs for Copenhagen and Denmark as a whole **(PAPER III)**. This cloudburst hit exactly in the centre of the city (Figure 2), and rain with more than a 2,000 year return period was registered locally (Arnbjerg-Nielsen et al., 2015). The event caused damage totalling more than 800 million EUR in insurance claims (Institut for Beredskabsevaluering, 2012) as well as additional intangible damages to both businesses, private homes, roads and public transport. In the last 10 years, Copenhagen has experienced a series of other significant extreme rain events: in 2007 (71 mm on 11 August), 2010 (97 mm on 14 August), 2011 (132 mm on 2 July) and 2014 (103 mm on 31 August) (Cappelen, 2016). However, it is the 2011 event that has become a focal point for both the professional and the public narrative.

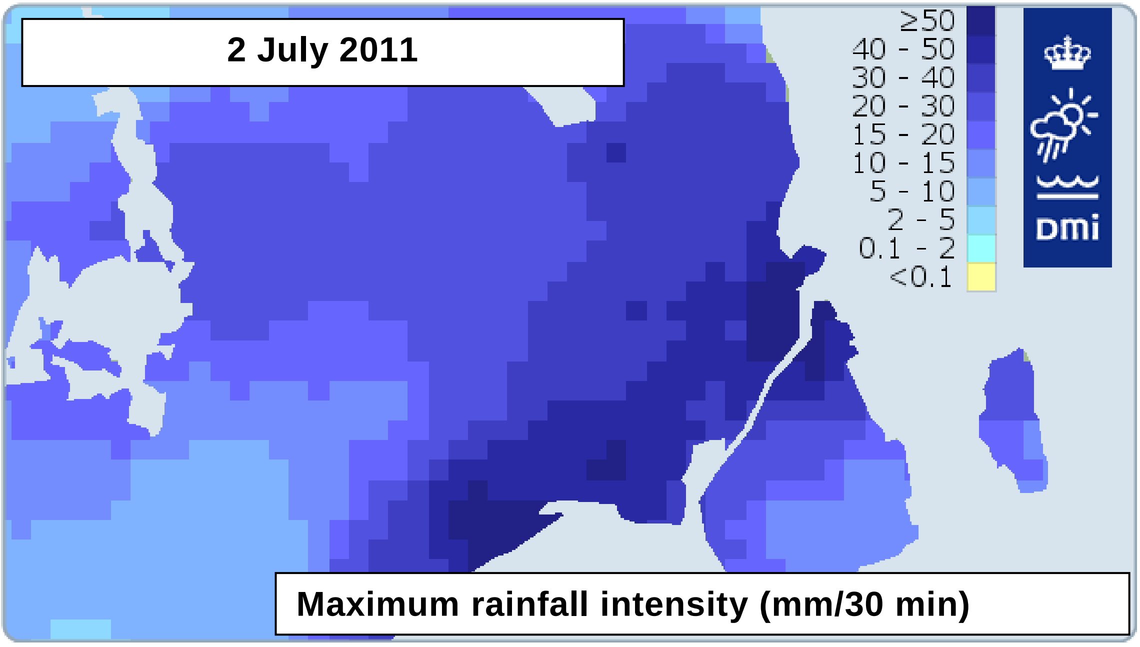

Figure 2. July 2nd, 2011, maximum rainfall intensity (mm/30 min). Events are named "cloudbursts" by the Danish Meteorological Institute when the intensity exceeds 15 mm/30 min, but the term is used more broadly within flood risk management and climate change adaptation for rainfall events that cause flooding. From Danmarks Meteorologiske Institut (2011).

It is expected that the city will experience more heavy precipitation and extreme weather, increases in temperature, sea level rises and increased wind magnitudes (Olesen et al., 2014). Before the 2011 cloudburst, a Climate Adaptation Plan outlining adaptation needs for coastal flooding, pluvial flooding, temperature rises, groundwater changes and indirect effects, had been submitted to the city council in the central municipalities, the City of Copenhagen and Frederiksberg Municipality (Københavns Kommune, 2011). However, after the cloudburst, the plan was followed by a Cloudburst Management Plan, which later (Københavns Kommune, 2015, 2013, 2012) outlined more than 300 public adaptation projects and investments of 1.6 billion EUR in the City of Copenhagen and Frederiksberg Municipality alone. Since then, a climate adaptation plan has been required for all municipalities, as a result of an agreement between the government and the Local Government Denmark in 2012 (Naturstyrelsen, 2013). All 18 municipalities in Copenhagen therefore follow their own adaptation plans and investment policies in relating to new infrastructure. Most of the climate change adaptation planning and implementation in Copenhagen has focused on pluvial flooding, but other topics are also addressed in the municipal adaptation plans, for example has a Storm Surge plan recently been published (Københavns Kommune, 2017).

The City of Copenhagen and Frederiksberg's Cloudburst Management Plans outlines a series of specific climate change adaptation solution typologies for pluvial flooding, namely surface solutions (cloudburst road, retention road, retention space and green roads, Figure 3), which together with underground cloudburst pipes and tunnels will act in a city-wide cloudburst system. A cloudburst road will e.g. on terrain discharge water from part of a surface water catchment, the retention road will retain and store water in grey and green elements alongside and on the road, a retention space will retain and store water in multifunctional basins and a smaller green road will remove and retain water in green elements. The cloudburst pipes and tunnels are larger underground stormwater structures, which will store and transport large volumes of water to recipients by diverting it under railroads and other restrictions.

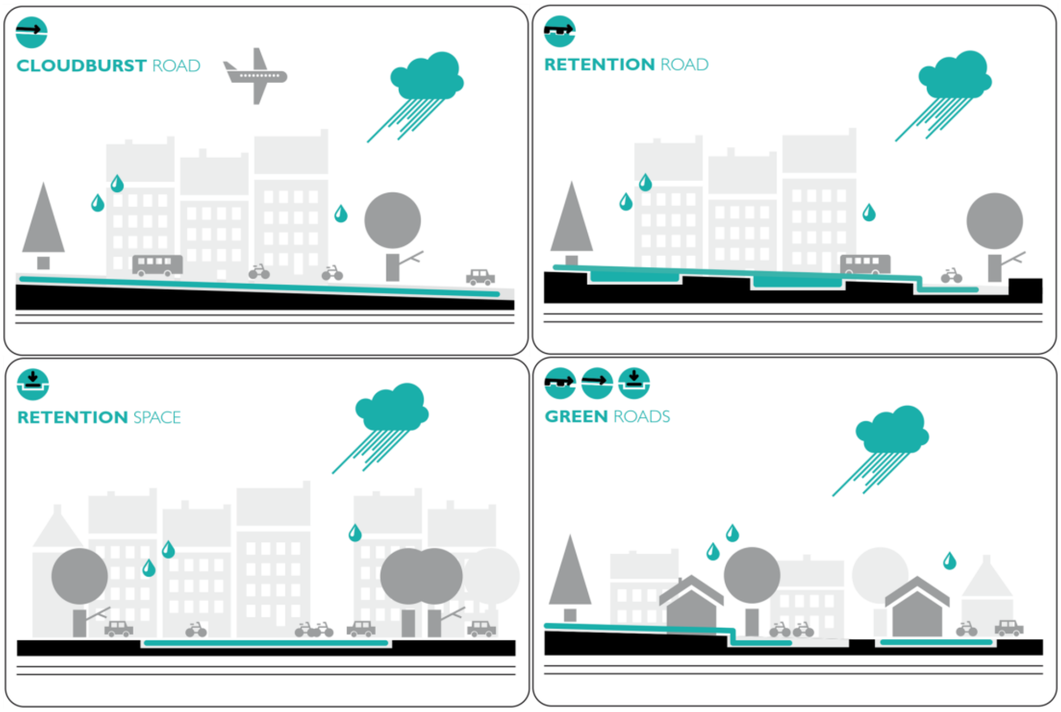

Figure 3 The surface solution typologies of the Cloudburst Management Plan in the City of Copenhagen and Frederiksberg municipality (Københavns Kommune, 2015)

2.3 Embedded innovation cases

In order to reflect the change processes of actors and technologies following extreme events, three embedded innovation cases were selected (section 4.3.3, Sampling strategy). The first case was a process innovation, where three private companies, namely a start-up, a contractor and a small engineering consultant, tried to build a business facilitating public climate change adaptation on private property in the City of Copenhagen. The idea originated from the fact that much of the public cloudburst plan is located on private property and on privately-owned roads. Figure 4 shows that in this catchment there is an overlap of private-ownership and many green roads (smaller residential roads allocated for retention and potential disconnection), some detention roads (larger roads allocated for detention) and cloudburst roads (larger roads allocated for transport on terrain). None of the three companies succeeded in facilitating any projects through the use of the Co-financing Act (Regeringen, 2016), which allows utilities to finance municipal and – in principle – private climate change adaptation, which was the original plan. Figure 5 shows a timeline for national and local events relevant to the implementation of climate change adaptation, from the July cloudburst in 2011, the publication of the adaptation and the cloudburst management plan, to the submission of 300 co-financing projects and finally the approval of the option to issue enforcement notices for the disconnection of stormwater. The failure of the three companies' original concept was due to financing, liability and competency issues and normative institutions that impeded the projects **(PAPER I)**. As such, the issue still stands: how will the public cloudburst management plan be implemented on privately-owned roads?

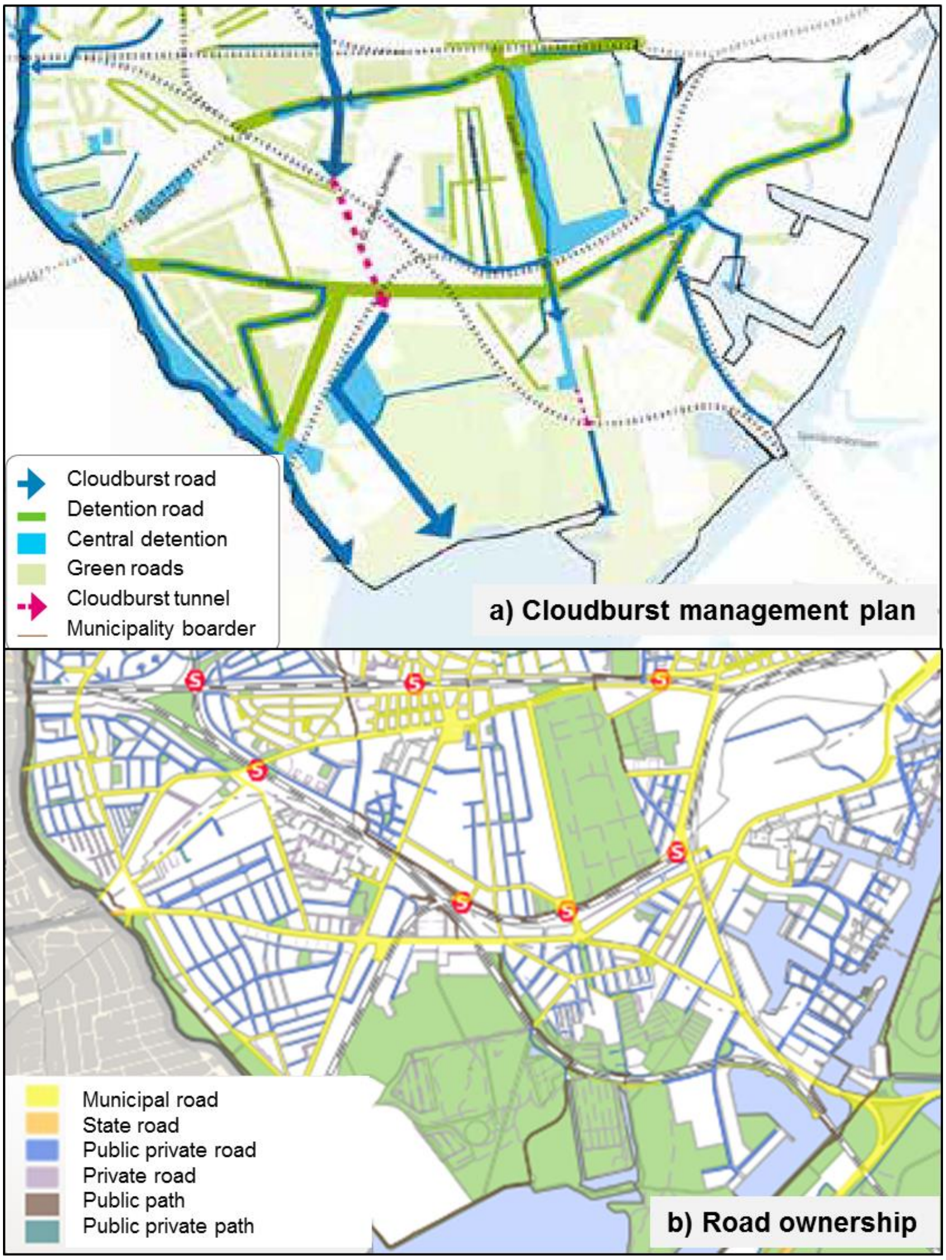

Figure 4. Comparison between the public cloudburst management plan a) and private road ownership in the cloudburst catchment of Copenhagen West, adapted from (Københavns Kommune, 2018, 2012).

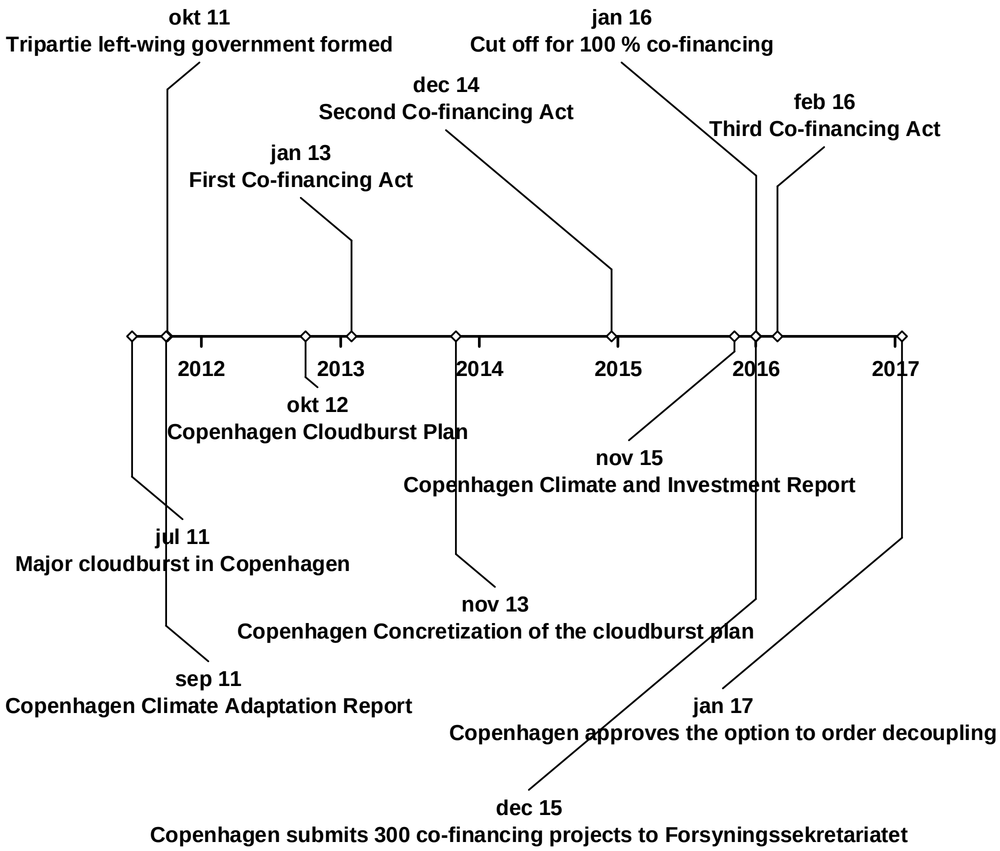

Figure 5. Timeline for national events and events in regards to the City of Copenhagen and Frederiksberg's municipality, relevant to the implementation of climate change adaptation on private roads (simplified from **PAPER I**).

The second case was a product innovation, the Cloudburst Valve (Leth and Christensen, 2016), which allows water to be disconnected from downspouts onto terrain when it exceeds a pre-designed flow, as illustrated in Figure 6. The idea originated as a result of the 2011 cloudburst, and the inventors have licenced the patent to Plastmo A/S, which tested the system first in Tårnby Municipality and then put it into production. In this manner, the private homeowner can reduce basement flooding, if there are capacity problems in the service pipe. However, as with stormwater solutions in general, the greatest benefits come if the valve is implemented throughout catchments, thereby freeing capacity in the sewer system during extreme rain events.

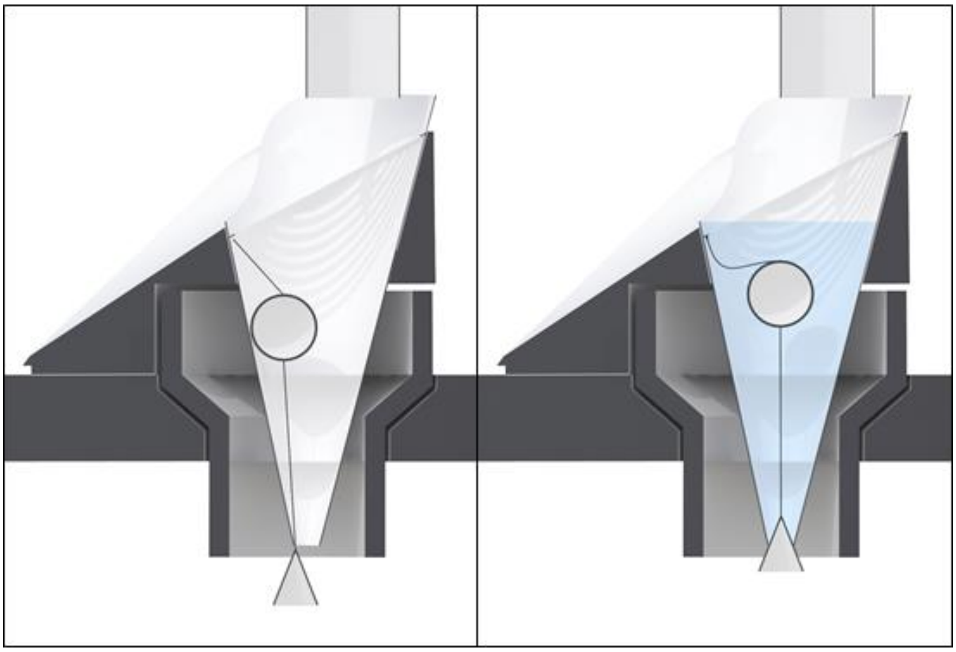

Figure 6. The Cloudburst Valve (Leth and Christensen, 2016), in the form licenced to be produced by Plastmo A/S. The figure shows a valve placed at the bottom of the downspouts on terrain. The left figure shows the valve open, the right figure shows the valve filled with water and the floater closing the outlet to the pipe. Figures kindly provided by the inventors.

The third case was a diffusion case where the emerging climate change adaptation paradigm of a utility company, in the northern part of Copenhagen, was investigated. In the interviews, past, current and future climate change adaptation projects were followed, and when the utility merged with five other utility companies, focus groups were conducted in the new, very large company. The case interviews shows how the utility, its owners and other collaborating partners arrived at a stable definition of and plan for climate change adaptation. Historic, current and future implementation projects have built the idea that adaptation should be developed at the catchment scale to create cost reductions, while other projects have shown the importance of citizen participation to build local ownership and, finally, current projects are evaluating what the level of adaptation should be in a societal cost-benefit analysis at the catchment level. Finally, after the merger, a process of new debate can be observed, due the merger of six previously different climate change adaptation paradigms. In this process, the difficulty of one utility company servicing many different municipalities with many different demands also stands out. At the time of the focus groups, the consolidation process was not complete and a new common paradigm had not been established.

3 Literature review

3.1 Theoretical overview

This PhD project worked in the tension field between technology and society with a focus on developing technologies and their implementation in society, i.e. innovation in the sociotechnical system. The sociotechnical system consists of actors, institutions, artefacts and knowledge (Pinch and Bijker, 1984), and there exists a current technological trajectory of dominant solutions that influence the day-to-day actions of the system and the innovation of new solutions. Furthermore, there exists a series of alternative solutions to the current trajectory, which, with differing levels of success, influences, merges and replaces the current paradigm. Central above all is the idea of *change in a sociotechnical system*, which is focal point of the project.

Crucial to this investigation into change are the different strands of economic evolutionary theory. However, this field does not stand alone; it is itself inspired and related to a series of other fields, namely organisational studies, institutional theory and, not least, science and technologies studies. Organisational studies and institutional theory are both closely interrelated and essential inspirations for economic evolutionary theory. Especially the actor/institution-related theories have inspired the debate of agency vs. structure, which continues in the field today. Complexity theory and other organisational theories are also found in economic evolutionary theory. Science and technologies studies are essential for economic evolutionary theory, forming the idea of regimes and paradigms, sociotechnical systems and the cycles of temporary optimal equilibria. Some of the science and technologies studies frameworks are or can be applied from an economic evolutionary perspective, for example actor network theory (ANT), social construction of technology (SCOT) or large technical systems (LTS).

3.2 Actors and institutions

The concepts of actors and institutions are traditionally well discussed in social science, both traditionally in organisational theory and more recently in the broader perspectives of institutional theory. These concepts relate to the discussion of how society is organised and whether agency or structure is the dominant organising force.

Institutions are defined as resilient, general and transposable social structures (Battilana and D’Aunno, 2009; Sewell, 1992) , and they are the rules and structures of society that actors navigate, i.e. formal and informal rules. Sewell (1992) formulated the notion nicely: 'structure is to practice as language is to speech. Institutions thus include regulative, cognitive and normative dimensions' (Scott, 1995). Regulative institutions are explicit formal rules, for example government regulation and market structures of property rights as well as trade laws and contracts. Normative institutions include informal values, norms, roles, rights and responsibilities. Finally, cognitive institutions include beliefs, knowledge paradigms and problem and search heuristics. Actors navigate institutions, and often they have a tendency to reproduce them in their behaviour. However, sometimes they act differently from the institutional setting, and the ability to make individual and independent choices is called 'agency' (Battilana and D'Aunno, 2009).

The debate as to whether agency or structure is the dominant organising force is ongoing and relates to whether individuals (actors) are a product of their environment (structure) or whether they are autonomous in this regard (Battilana and D'Aunno, 2009). This debate is especially clear when looking at changing societal structure. In reality, it is of course not an issue of picking one perspective over the other but rather a complex process involving both agency and structure. Some researchers describe the process of change and organisation as duality, whereby agency comes from structure and structure comes from agency (Sewell, 1992), which draws both on Giddens and Bourdieu's work on the two aspects (Bourdieu, 1977; Giddens, 1976). Change thus comes from both internal and external forces of power (Sewell, 1992). Structures are hereby not seen as fixed in a steady-state but rather as developing throughout a continuous process (Sewell, 1992), thereby reflecting the embedded agency of actors in institutions (Battilana and D'Aunno, 2009).

The concept of duality is also central to the new institutional theory of institutional work (Lawrence, 2009, 2006; Lawrence et al., 2010), the main tenet of which is embedded agency. Actors are considered informed and consequently able to act voluntarily or involuntarily according to institutions, thus creating, maintaining or disrupting them (Lawrence, 2009, 2006). Creating institutions relates to the concept of institutional entrepreneurship (Lawrence, 2006), and actors can engage in activities to form formal institutions such as rules, property rights and resource allocation, but they can also create new normative institutions by constructing new identities, norms and networks. Additionally, they can create new cognitive institutions by creating new knowledge paradigms through education, mimicry and theorising. Maintaining work for institutions is necessary even though they are self-enforcing

(Lawrence, 2006), and this includes supporting and recreating institutions in order to ensure compliance through formal rule systems and informal beliefs and norms. Although institutions are strong structural forces, actors can disrupt them and thereby try to force a change in the system (Lawrence, 2006). Disrupting work can target both formal regulative institutions and normative and cognitive institutions.

3.3 Innovation System Theory

Innovation system theory is a field of studies evolving from economic studies to incorporate technical and institutional change (Freeman, 1988). It was first described in full as national systems of innovation (Nelson, 1988), but earlier similar incarnations were found in technological regimes (Nelson and Winter, 1977) and path dependence theory (Dosi, 1982).

The different strands of the field have some similarities that help structure it: (i) innovation and learning are central concepts for system change; (ii) change is historical, cumulative and evolution-dependent; (iii) comparisons between systems are important, because there are no optimal systems for comparison; (iv) the change process is interdependent and non-linear; (v) there exist two main types of innovation, namely product and process innovation; and (vi) institutions are important in the process of change and change can only be analysed using an interdisciplinary approach (Edquist, 2004, 1997; Freeman, 1988; Lundvall, 2007). The main differences relate to spatial delimitations and to the theorising of the field. **PAPER IV** outlines the different spatial delimitations and proposes how the urban scale, the City Innovation System (CIS), can be characterised.

3.4 Transition Science Theory

Transition science is a field of study that has developed and grown over the last 15 years (Markard et al., 2012). It includes a range of research strands and draws on a wide range of different, older theories, amongst the most prominent of which are economic evolutionary theory, science and technology studies, complex adaptive systems (Markard and Truffer, 2008) and institutional theory.

Transition science investigates changes in socio-technical systems towards more sustainable modes. The socio-technical system is defined as actors, institutions, artefacts and knowledge, which together fulfil functions for society (Geels, 2004). This definition reflects the connection to large technological systems of science and technology studies (Pinch and Bijker, 1984), whereby systems are defined as webs including artefacts, organisations, natural resources, scientific elements, legislative artefacts and university teaching programmes (Geels, 2004; Hughes, 1989; Markard et al., 2012). Transition is a fundamental but slow change to all of the components in a sociotechnical system (Elzen et al., 2004; Geels, 2004; Markard et al., 2012). Important concepts for transition science, differentiating it from innovation systems theory, are regimes as an overall stabilising logic imposed on and socially embedded within system actors (Dosi, 1982; Elzen et al., 2004; Hughes, 1989; Markard et al., 2012; Pinch and Bijker, 1984) and a focus on a broad group of actors, including societal groups, users and public authorities (Geels, 2004).

Overall, there are four different strands of transition science: the multi-level perspective, strategic niche management, transition management and technological innovation systems (Markard et al., 2012). The multi-level perspective divides the system into three further levels, namely the micro-, meso- and macro-level, each of which is nested in the other. The macro-level corresponds to the landscape, which is the structural context surrounding the actors (Elzen et al., 2004; Geels, 2002). The meso-level corresponds to the regime definition of Rip and Kemp (Elzen et al., 2004; Geels, 2002; Kemp et al., 1998), and the micro-level compromises niches where technology and supportive networks can develop and influence the system (Elzen et al., 2004; Geels, 2002). Strategic niche management analyses how niches form and influence regimes by linking to tension in the regime and providing growth feedback for the niche (Kemp et al., 1998; Smith, 2002), providing cases of bottom-up transitions. A further development of strategic niche management is transition management, which draws on complex system theory (Rotmans, 2005; Rotmans et al., 2001) and governance (Rotmans et al., 2001). Transition management focuses on developing a model to purposefully influence transitions through long term processes of learning in multiple domains, with multiple actors and at multiple levels (Rotmans et al., 2001). The transition cycle involves structuring the problem, forming a transition vision, creating transition experiments and mobilizing resulting networks and evaluating and learning from these (Rotmans, 2005; Rotmans et al., 2001). **PAPER IV** references transition management development, which breaks a transition into different phases and shows that a transition might not always happen. Figure 7 shows that in the take-off and at the top of the acceleration phase there is a low degree of stabilisation, making them interesting points where pathways may change and resulting in not always transformation but potentially also lock-in, backlash or a system breakdown.

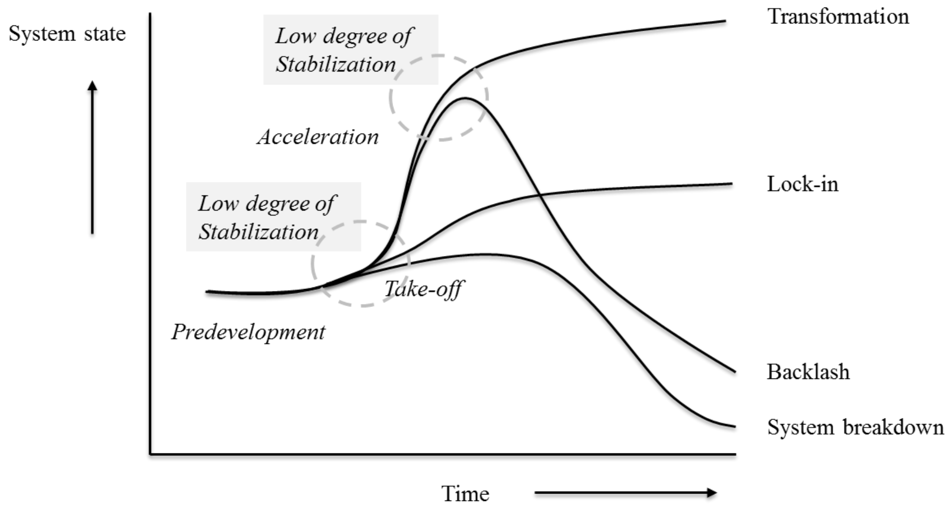

Figure 7. The different pathways and phases of system change, modified from van der Brugge & Rotmans (2007) in (Madsen et al., 2017).

Finally, technological innovation systems are related to innovation systems theory, in that they clearly originate in the parallel theoretical strand and study a vertical technological innovation system (Cooke, 1992; Edquist, 1997; Nelson, 1993). However, the development in technological innovation systems theory that differentiates it from innovation systems theory and relates it more closely to especially transition management is the functional approach (Bergek et al., 2008; Hekkert et al., 2007). The functions of innovation approach should support the evaluation of performance (Hekkert et al., 2007) and the study of radical innovation (Hekkert et al., 2007; Markard et al., 2012), it thereby assesses performance and aims at optimising the system (Edquist, 2004).

3.5 Theoretical standpoint of the thesis

This paragraph summarises the theoretical standpoint of the thesis, based on the state-of-the-art literature outlined in this chapter. Both institutions and actors are important for my study in societal change when applying the perspectives of innovation systems and transitions science. Neoclassical economics takes the extreme position of agency in the agency/structure debate, assuming that agents always select the most efficient alternative (Battilana and D'Aunno, 2009); it hence has a tendency to isolate actors and organisations from the context. Evolutionary economics has reacted to this issue and focused on the relational perspective of interaction between the micro-, meso- and macro-levels of society, a perspective I share and seek to develop in this thesis at the urban scale. This corresponds more closely to new institutional theory as opposed to organisational studies.

There are central perspectives of innovation system theory applied in this research. The first one is the evolutionary perspective of innovation and change. Incremental innovation involves innovation inside the dominant paradigm, and radical innovation is a shift to a new paradigm. However, this means that innovation can happen through both incremental and radical innovation. The points of co-evolution and a broader perspective of actors are also present in innovation system theory, and these two points are also central to this research. Next, I have valued the systemic approach of innovation system theory, valuing interactions between actors as essential to the innovation process. This study has also found valuable the micro and meso focuses of innovation systems theory and has taken a micro- and meso-level approach similar to that of TIS (in its original form), where I concentrate on actors' relations in the innovation process. This does not mean that I have excluded the macro level; it is just not the central focus of my analysis. Finally, I value highly the purpose of analysing innovation system theory, since analysis is undertaken in order to try to explain the characteristics and dynamics of the system, not to compare it to an optimal system.

Transition science fundamentally relates to this research, in that it seeks to investigate changes in the sociotechnical system of climate change adaptation in Copenhagen. It looks at the co-evolution of institutions and technology through a wide range of actors, which is central to transition science (Geels, 2004), albeit it is also present in innovation system theory (Nelson, 1995, 1994). Nevertheless, because I do not believe there is an optimal system, I distance myself from the concepts of steering or managing sociotechnical systems towards such a "predefined optimal," as it is sometimes described by strategic niche management, transition management and TIS (in the functions of innovation form).

I have also sought to define a new spatial dimension of system change, and overall the spatial scale appears empirically in several places in this study. I have also taken a relational approach to space, which is constructed through interaction. Additionally, an analysis of linkages between scales is necessary, in order to draw conclusions about success factors and barriers to innovation. I have been very aware, and my empirical work has made me very aware, that if an analysis of different spatial scales is not to some degree present, the conclusions could easily be unjustifiably generalised. In this study, I have concentrated on a specific scale, namely the city scale, as a place where radical innovation can be found often and where the study of micro-dynamics is possible, as they are nexuses of actors and resources.

4 Research design

4.1 Introduction

A research design comprises the strategies of enquiry, research methods and a philosophical world view (e.g. post positivism, or social constructivism) of the study (Creswell, 2013a), which is reflected in the structure of this PhD's research design and this chapter.

The enquiry was in the form of an explicative qualitative strategy, and the research methods were qualitative, in-depth interviews supplemented with literature analysis and focus group interviews. The philosophical world view of my study was strongly inspired by constructivism, which is reflected in several places: in the qualitative strategy enquiry, the interpretive parts of the research methods, the analytical generalisability of the study and the main research questions focus on actors' construction and reconstruction of reality (Bryman, 2012).

4.2 Strategy of enquiry

The study took a qualitative approach in an attempt to further the understanding of how actors work with climate change adaptation, taking Copenhagen as a primary case. The study tried to understand their day-to-day problem-solving procedures, their interactions and their innovation capabilities, in order to make strategy recommendations to further innovation in climate change adaptation in Copenhagen. The strengths of the qualitative approach cover natural settings, details and complexity (Bryman, 2012). The interviews and focus groups aimed at letting the interviewees and participants tell their own stories, thus providing opportunities to express opinions, in order to cover the entire network of actors and institutions utilising multiple technologies when working with climate change adaptation. The weaknesses of the qualitative approach are non-predictability, time consumption and risk of researcher bias (Flyvbjerg, 2006; Yin, 2013). The non-predictive nature of the qualitative approach is connected to the generalisability of the research. Qualitative research is analytically generalizable and consequently the research cannot be used predictively. Second, the time consumption involved in the qualitative approach is connected to the level of detail in the data, resulting in very time-consuming collection and analysis and an extensive dataset. This is an inherent feature of the qualitative approach; however, the study aimed to keep the richness of the data in the reduction and condensation process. Finally, because of the interpretation that is needed in the qualitative approach, it is prone to researcher bias, so this study aimed at reducing this issue through validation, as illustrated in section “4.3.6 Validation.”

The study took an inductive approach to further existing theory. However, it also had some deductive perspectives, in that the methods were partly inspired by existing theory. Traditionally, deductive studies conduct hypothesis testing (Bryman, 2012), but this was not the case for this project. Nevertheless, the study was guided in the data collection and analysis by existing theory, with interview questions guided by existing analytical aspects and coding referencing theoretical terms (Yin, 2013). This was done to support the inductive process, by applying at an early stage current theoretical perspectives and terminology.

4.3 Research methods

4.3.1 Structure

The case study approach relies on multiple sources of evidence and applies methods of triangulation (Yin, 2013). This study therefore applied interviews and focus groups as primary data, supported by the literature as secondary data and thus providing an opportunity for triangulation.

The study was structured in several primary data collection rounds, thereby providing an opportunity for advancing through the research questions and the understanding of the CIS. Secondary data were collected throughout the study, providing up to date and specific information; however, an initial theoretical literature study was done, to provide the basis for the primary collection and analysis, and covered economic evolution theories, institutional theory, organisational theory, science and technologies studies, urbanism and sustainability theory. These theories have in newer times developed into the transition science and innovation systems theories, studying the evolution of and change in sociotechnical systems.

The primary data were collected in three rounds. The first round’s purpose was to identify the central characteristics of technologies, actors and institutions in the CIS. The research questions in focus were #1-4. The round included eight semi-structured, in-depth interviews with key actors who were selected in collaboration with three informants from key positions in the climate change adaptation industry. The second round aimed to investigate the day-to-day processes of innovation and implementation in climate change adaptation by focusing on three specific innovations and the surrounding actors, which were identified following the first round. Analysis of these innovations was done through 24 semi-structured in-depth interviews with the relevant actors. The research questions in focus were # 3-6. The third and final data collection round aimed at providing in-depth and validated knowledge on the innovation and implementation process, by establishing three focus groups that provided the opportunity for actors to interact and reflect on the data analysis from the previous rounds. The research questions in focus were #1-6, and the groups started with a broad discussion about the definition of climate change adaptation, moving into a more sensitive discussion about responsibility and collaboration.

4.3.2 Data

The interviews were semi-structured, in-depth interviews with actors working professionally with climate change adaptation in Copenhagen. The focus group participants consisted of a selection from the same group of actors as the previous rounds, providing an opportunity for interaction and to validate previous results (Barbour, 2008). The secondary data consisted of peer-reviewed journal papers on theory and similar case studies, grey literature such as relevant research and governmental plans and reports and articles from newspapers and non-peer-reviewed journals (Table 1).

Table 1. Overview of different types of data.

Round	Type of data	N	Purpose	Period
1	In-depth semi-structured interviews	8	Case context	Sep15 – Feb 17
2	In-depth semi-structured interviews	24	Three innovations and surrounding networks	Sep 16 – Feb 17
3	Focus-groups	3	Actor interaction and validation	Nov 17
-	Literature, peer-reviewed journals	-	Theory and similar cases	-
-	Literature, grey: reports and plans	-	Context and supportive case knowledge	-
-	Literature, newspapers and non-peer-reviewed journals	-	Context and supportive case knowledge	-

4.3.3 Sampling strategy

The main case of innovation of climate change adaptation in Copenhagen was illustrated through embedded cases, three innovation stories and their surrounding networks. The embedded cases were chosen in order to place a high level of detail into the findings rather than broad statements. The strategies behind the choice of case differed between the main case and the embedded cases. Copenhagen was chosen as representing a medium-sized city with high concentrations of actors and technology development. The innovation stories were chosen as maximum variation cases, in order to illustrate the main case through the different power relationships between municipalities and utility companies, which in the first data collection round had proven to be a significant innovation factor for the development and the diffusion process (see Table 2 for an overview of innovation cases, and “2.3 Embedded innovation cases” for more details).

Table 2. Innovation cases for the study, including innovation type and main actors involved in the case.

Case description		Utility company	Municipality	Private companies
Climate change adaptation on private property	Process innovation	HOFOR: Greater Copenhagen Utility	City of Copenhagen	Klimavej ApS MT Højgaard A/S PKP Regnvandsteknik ApS
The Cloudburst Valve	Product innovation	Tårnby Utility	Tårnby Municipality	Vandvenderne ApS Plastmo A/S
Path creation in a transitioning water utility	Diffusion	Nordvand Utility	Gentofte Municipality Gladsaxe Municipality	[several hired engineering consultancies]

The data collection sampling strategy varied across the different collection rounds, as shown in Table 1. The interviews in the context round were chosen based on the intensity criteria and maximum variation criteria (Creswell, 2013b), in order to reflect different actors with a high degree of knowledge and innovation capabilities and power. The interviewees were selected from an initial screening, which was done in collaboration with three informants, all of whom can be considered front-runners in the network. The interviews in the second round were selected based on the snowball criterion (Creswell, 2013b), whereby interviewees’ mentions of other actors were used for selecting other interviewees. The point of saturation was when no new knowledge was obtained from the interviewees.

The third round of data collection was based on the maximum variation criterion (Creswell, 2013b), as the previous data collection rounds had shown that a primary factor for climate change adaptation innovation and implementation is the relationship between two important actors: municipalities and utilities – and their different cultures. The focus groups were thus conducted in connection with one of the cases from the second data collection round, at Novafos, which is a newly (January 2017) formed utility company, which is located in the north of Copenhagen. Novafos is a merger of six existing utilities including Nordvand, which supplies eight different municipalities with waste -, storm - and drinking water management. The new utility company covers the area from the Roskilde fjord to the Sea at Øresund and has become the third largest water utility in Denmark. The different cultures of the six smaller utilities could be observed as they worked on forming consensus on a new culture. The focus groups were segmented according to the existing system of employees as illustrated in Table 3; however no operation workers were included due to the nature of the research questions. Recruitment was done by accessing the top management of the utility company and getting permission to run the focus groups in their premises.

Table 3. Overview of focus groups by segment in the third data collection round.

Segment	Description	Participants
Plan and project	Engineers or employees with similar degrees, who work with planning or implementing climate change adaptation	6
Operations managers	Team managers or experienced supervision employees, with experience in climate change adaptation	4
Middle management	Heads of sections or working groups, who work with climate change adaptation. Personnel responsibility not necessary.	4

4.3.4 Data collection

The data collection process was also dependent on the type of data in the different research rounds. Interviews in the first and second rounds differed in relation to the question themes provided to the interviewees, see interview guides translated to English in “10.1 Appendix A” and “10.2 Appendix B”). However, the collection procedure remained the same. Before the interview, the interviewees were introduced to the topic via email, phone or both. The interviewees themselves selected a location and time for the meeting, which was their workplace, their home, a public place or in a few cases at the researcher’s university. The interviews were conducted in Danish and were recorded with consent on a Dictaphone, while additional information was registered in an interview log. Data collection connected to the focus groups was structured in the same way as the interviews, as they were considered a mediated group interview (Barbour, 2008). However, the following elements differed, namely that the focus groups were all conducted at the participants’ workplace, the group sessions were recorded on video as well as on a dictaphone and by field notes, present were both the moderator and one or two assistants and each group interview was conducted as a moderation (Barbour, 2008). The moderation technique was more directive in regards to group dynamics and less so in regards to the content of the discussion. The moderator used a topic guide (see “10.3 Appendix C) and expanded with a few follow-up questions relating to the study’s existing hypotheses, thus moderating toward group consensus.

4.3.5 Data analysis

The interviews were analysed in the Atlas.ti software. First, the interviews were transcribed in full, to a level of a clean read or a smooth verbatim transcript. It was furthermore noted whether or not the interviewee wanted to be directly quoted for specific sections. Following the transcription, the interviews were coded, the strategy for which was a mixture of deductive and inductive coding. The codes were deduced from innovation system theory and induced from the transcription (see the coding list in Table 4). The coding was consequently done in cycles, first by going through the interview once, coding with all coding families, and then the interviews were coded once for each coding family, with a relatively high level of abstraction resulting in larger text sections.

Table 4. Coding scheme developed both deductively and inductively through the interviews * = deductive categories, theory-inspired.

Case story	Innovation system characteristics	Climate change adaptation definition	Causes of innovation
Case 1	Power	Event size	Risk of damage
Case 2	Frames*	Scale	Coastal flooding
Case 3	Responsibility	Goal	Pluvial flooding
	Innovative capacity	Technologies	Fluvial flooding
	Collaborations/cooperation		Extreme events
	Relations/networks		Average rise
	Utility/municipality		Planning
	Actor description		Time inertia
	Regulative institution*		Political event
	Normative institution*		Institutional inertia
	Cognitive institution*		
	Maintaining work*		
	Constructing work*		
	Disrupting work*		
	Paradigms*		
	City dynamics		

The focus group sessions were not transcribed in full; rather, summaries of each group interview were produced, including notes on behaviour, topics, posters produced through the moderation and a review of group recordings. These summaries were compared to written summaries of the previous findings from previous data collection rounds, in order to validate them accordingly.

After coding, the actual analysis was conducted, and here the coded material was reorganised in the writing process, resulting in a detailed analysis. In general, the secondary data were not part of the analysis before this point. The analysis was supported by software analysis in Atlas.ti. Nevertheless, the main analysis was done manually by looking for tendencies in the coded transcripts, focus group summaries and the supporting literature. The analysis was strengthened by visual representations of the data and quotes.

4.3.6 Validation

The study aimed at different criteria of validity: construct validity, internal validity, external validity and reliability (Yin, 2013). To strengthen construct validity, the study used several sources of evidence and provided a clear chain of evidence in data collection by utilising the interview log, transcripts and coded transcripts. Furthermore, the study was informed by three key informants, who also piloted the interview guide and commented on the draft conclusions after the data analysis. Construct validity was also strengthened by introducing the third data collection round as validation of the results of the two previous rounds. To strengthen the internal validity of the study, different explanations were addressed inside the research group as part of the data analysis, by the three informants, and by providing the interviewees with an opportunity to correct and supplement their interview in a summary given at the end of the session. External validity, and therefore also generalisability, was strengthened by seeking inspiration in innovation system theory from the beginning of the study. The results can thus be analytically generalised and to inform other cases using innovation system theory as a frame. Finally, the reliability of the study was strengthened through the use of the interview log, the Atlas.ti database and a method log, all continuously updated throughout the study.

4.4 Limitations of the research design

The overall structure of the research design was planned in the initial stages of this PhD project, but each research round informed the following, and throughout the study a series of methodological considerations was made. The most important limitations are listed in Table 5.

Table 5. Limitations of the research design and their influence on the thesis.

Limitation	**Influence**
Missing networks?	Sampling inside a familiar network may have left other separate networks unexplored.
Recruitment strategy of focus group segments	Recruitment of different segments is less successful, as the participants have very similar backgrounds.
Sensitive material	Relevant knowledge that was also sensitive could not be published.
Implicit and explicit knowledge	Some knowledge was implicitly explained or over-explained by interviewees, which resulted in some interpretation or simplification in the writing process.
Rigidness and recruitment	Some interviewees could not set aside the allotted time for the interviews; as a result, some of these interviews were less successful.
Collecting case specific knowledge	Collection of case-specific knowledge was difficult at the fringe of the case, resulting in some case interviews being similar to the context interviews.
Temporality and spatial specificities	Qualitative case study data are temporal and spatially specific, and as such the case developed further during the period of the study.

The first methodological consideration is that of familiarity versus strangeness. I have previously worked in the field of climate change adaptation in Copenhagen, and so there was a consequential benefit of familiarity with central concepts and easy navigation of the settings (Yanow, 2012). However, the benefits of strangeness with critical questioning and investigation of taken-for-granted knowledge (Yanow, 2012) were harder to achieve. This familiarly became especially intense when snowballing through the actor network, as recruitment went very fast, and initial declines were turned around through networking. However, as soon as the snowballing brought me out my network (e.g. to lawyers in the state authorities), the easy recruitment stopped, and it was thus very difficult to gain access in particular to the different state authorities. In general, the snowballing order seamed to follow a pattern of "project owner" -> "consultants hired by project owner" -> "local and state authorities”. As such, networks separate to the ones explored in this thesis were not explored.

The two tables in “10.4 Appendix D” and “10.5 Appendix E” present an overview of the interviewee and focus group participants’ education and work experience in each data collection round, with prevalent education and experience shaded grey. The tables were assembled based on data from the interviews and a questionnaire given to the focus group participants. When evaluating the sampling in the first round of data collection, it seems that the maximum variation goal in terms of actor type was met. The second round applied the snowball sampling method, and therefore the patterns in interviewees were also different, hopefully reflecting how innovation and implementation projects are organised. Generally, there is a broad representation of professions, in regards to both education and experience. However, there are indications that some professions dominate the actor network, especially actors with an engineering education working within engineering consultancies and utility companies, actors with an architectural or landscape architectural education, and a varying group in authorities (“10.4 Appendix D”). It is also worth noting that there is an over-representation of male interviewees (23/32 interviewees were men), which might be attributed to the sampling or the general composition of the actor network. This gender aspect can influence the analysis and make traditional male aspects appear more prevalent than in general society. The third round sought homogeneous groups, as the focus groups were mediated towards consensus. As “10.5 Appendix E” indicates, the groups were very homogeneous and consisted almost exclusively of engineers with experience in utility companies and engineering consultancies. However, during the group sessions it was quite clear that the organisational position within the utility company led to different responses, especially in regards to regulations and relations with other actors. For example, plan and project engineers would often explicitly mention specific challenges with regulation that did not match with their everyday work, while middle management would not directly refer to these issues. Similarly, operations managers would refer to challenges when collaborating with other stakeholders, while middle management would hint more discreetly at the issues.

Familiarity also played a role in regards to the more sensitive parts of the innovation cases in the second interview round and in the third round. Often, the interviewees and focus group participants told me a lot, in regards to personal experiences, financial losses, prices and preferences in regards to collaborators; however, a great deal of this information could not be directly published and had to be treated as sensitive material. In a few of the interviews and focus groups, I also experienced problems with implicit knowledge, whereby the interviewee/participant knew that I knew what was being referred to, e.g. standard methods of design and calculation and exemplar projects. However, as part of the research project, I often wanted them to be explicit. This specific problem was mediated by bringing and referring to the interview guide and the Dictaphone, which created an experimental and official setting. However, there were also a few situations with older engineers who I had not known previously, in which they considered me a stranger and explained technical aspects in great detail.

The aim of rigidness in the data collection process also experienced some problems. Some interviewees could not set aside the required time for the interview, and so in these cases the interview guide was shortened in the introduction, leaving out the interviewees' background, which was collected instead from a CV. This was successful in most cases, but the introduction and the interview background generally created a common frame for the interview, which when missing in some cases resulted in less successful discussions.

In regards to differences between the first context interview round and the second case round, it became necessary in the case interviews to talk about the specific cases rather than abstractly about the industry. This was especially important when the interviewees had project-based jobs, i.e. implementation of climate change adaptation. However, this case-specific strategy was hard to complete when interviewing people on the fringe of the case or in more development oriented jobs, e.g. knowledge-sharing, facilitation, sales or general management, as they often had not been involved in the details of the projects.

As with all data, time and development after data collection were also issues for this study. Qualitative data are very time-consuming to analyse, and through the four years of this study, the field of climate change adaptation developed rapidly. Temporality and spatial specificities were considered in the generalisation process of this study, which is why the results are not statistically generalised; rather, they are analytically generalised. Furthermore, updated literature continuously informed the study and therefore allowed for updated information on, for example, new regulatory institutions.

5 Multifunctionality in climate change adaptation

5.1 Event magnitude, spatial scale and goal as defining features

Climate change adaptation in Copenhagen includes adapting to mitigate both pluvial and coastal flooding. As previously described in Chapter 2 "Copenhagen", up until recently, actors' focus had fallen almost exclusively on pluvial flooding. The emphasis of this project has consequently also been pluvial flooding, with interview guides and embedded cases centred on the same subject. However, in the course of every interview, coastal flooding was referenced as a parallel case, as something that must receive attention subsequently. Many actors named it as the next step in an overall transformation/adaptation process of the urban landscape. In fact, there was a surprisingly overlap between the two actor networks with consultants, utilities and local authorities working in both fields. This was the case even though coastal and pluvial flooding technologies do not intersect.

This thesis has developed a framework, based on the empirical work, to characterise climate change adaptation. The framework, presented in Figure 8, defines climate change adaptation according to event magnitude (extreme, design, and everyday domain), spatial scale (international/national, urban, and local scale) and a range of goal categories (innovation, urban, water quantity, water quality, nature, economic, health and safety, social, aesthetic expression and multifunctional). The aim was to develop an inclusive framework that could be used irrespectively of the specific actor constellation in innovation and implementation projects. Furthermore, the framework could also be used analytically, as in **PAPER II**, to describe how climate change adaptation is defined in a larger setting, in this case Copenhagen.

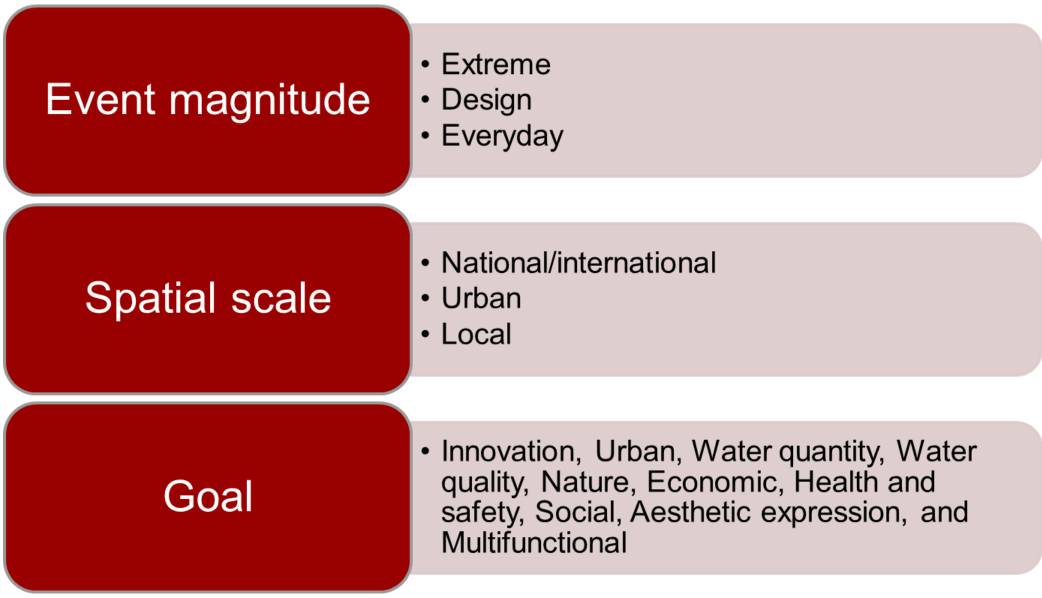

Figure 8. Characterising attributes of climate change adaptation (**PAPER II**).

The framework was developed throughout the empirical work whilst also building on the existing literature. Specifically, the idea that different actors work in different domains stems from the three-point approach (3PA), which presents an everyday design and extreme domain in which stormwater management materialises (Fratini et al., 2012b; Sørup et al., 2016). Other sources define more than three domains (Digman et al., 2014; Gersonius et al., 2016), but in this empirical work, it became clear that the 3PA has diffused into practice. Nonetheless, it also became clear that actors define domains in different ways, which results in conflicts in the innovation and implementation processes. Through data analysis it became clear that the imagination of different event magnitudes, spatial scales and goals results in different definitions of climate change adaptation – and therefore potential conflicts. As such, the three characterising attributes were used analytically to describe how climate change adaptation is defined in Copenhagen. This was done in regards to pluvial flooding, but the framework is true to the aim inclusive, and it is the claim of the present study that it can also be used to describe other types of climate change adaptation, e.g. coastal flooding or drought.

5.2 Traditional and alternative solutions

The actors mentioned a wide range of climate change technologies.
Figure 9 shows how the entire urban water cycle is affected by climate change adaptation, from green solutions such as swales and raingardens, to grey solutions like permeable pavements, below-ground basins, and waste- and stormwater reuse. It additionally shows how broadly climate change adaptation technologies are defined, which is a result of the actors' large variations in their choices of event magnitudes, spatial scales and goals when innovating and implementing climate change adaptation **(PAPER II)**.

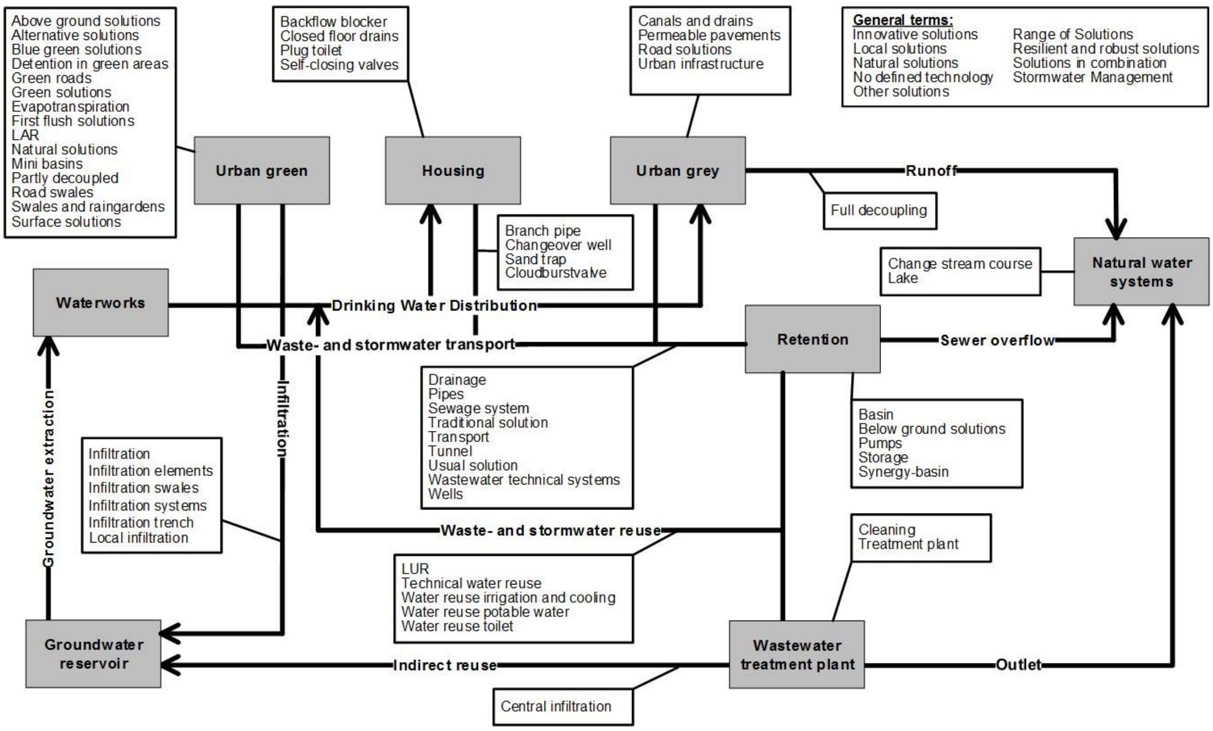

Figure 9. Technologies mentioned in the interviews and their locations (white boxes) in the urban water system (grey boxes) **(PAPER II)**.

When talking to the actors working with climate change adaptation, they referred to what they called 'traditional' and 'alternative' solutions. It is not uniquely defined what types of technologies are traditional and alternative, but the majority of the actors called above-ground solutions alternative, e.g. raingardens, permeable pavements, swales and different infiltration measures, and below-ground solutions traditional, e.g. separated or combined sewers, tunnels, pipes and basins. Following our own framework, the actors did not define a distinct set of event magnitudes, spatial scales or goals matching alternative and traditional solutions, respectively. There was, however, a tendency to agree that many alternative solutions such as raingardens, green roofs and permeable pavements can be used on the local and urban scales for the everyday and design domain, thus generating social, nature, aesthetic expression and multifunctional goals. This is in line with the 3PA literature (Fratini et al., 2012b; Sørup et al., 2016), but some actors also considered the alternative solutions suitable for the extreme domain, even arguing that they are the only solutions for the extreme domain. Many actors associated the alternative term with greening of the city, and as such the term is (also historically) associated with the urban ecology movement (Madsen et al., 2017). The green discourse is also prominent in other cities, where it is connected to the local and everyday domains (Wachsmuth and Angelo, 2018). Finally, it is also worth noting that the alternative, often above-ground, solutions were prioritised by the majority of the actors, with reference to both multifunctional and cost reduction goals.

The use of the terms "traditional" and "alternative" indicates that there is an ongoing switch in the search heuristics of the actors, moving from one set of dominant design to another. However, the words are also used with reference to legal terms in the Co-financing Act's use of "usual solutions" and "alternative solutions" (Regeringen, 2016). In the Co-financing Act, no specific technologies are mentioned as usual or alternative. I asked the Danish Consumer and Competition Agency about how they, as the controlling agency, differentiate between technologies. They referenced their internal guidelines, which state that alternative solutions are solutions above ground that handle surface and roof water; however, it cannot be LAR (Lokal Afledning af Regnvand) if the solutions are located on private recreational areas. When asked to detail what technologies they define as LAR, they answered that it is not clearly stated; however, no applications for co-financing ae approved with LAR on private recreational areas. The legal definitions of what alternative and traditional solutions, in line with the actors' use of the words, are thus ambiguous. **PAPER I** outlines the details behind different attempts to implement climate change adaptation on private property in Copenhagen, which is linked closely to issues in the legal framework.

5.3 Multifunctionality in the dominant discourse

The dominant discourse among actors in Copenhagen is that the solution to climate change is to link alternative above-ground and traditional below-ground cloudburst solutions (event magnitude: extreme) within a surface water catchment system (spatial scale: medium), designed to both prevent damage and generate day-to-day value for citizens (goal: cost, multifunctional) (**PAPER II**). This current discourse is a combination of the use of alternative and traditional solutions and represents a time-instance in an ongoing change process, wherein the alternative becomes part of a first step in a search heuristic for the actors. The fact that alternative solutions are becoming more dominant in the field has become more profound throughout the time period of this study (2014-2018), with more actors directly naming alternative solutions as their first choice when working with climate change adaptation.

Multifunctionality is, as stated above, fundamental to the dominant discourse surrounding climate change adaptation. Actors not only use this term, they also use related indirect terms such as “added benefits”, “added value”, “holistic solutions”, “integrated solutions”, “synergies” or “sustainability”. The multifunctional perspective is used as part of an argumentation together with societal cost-benefit analyses when choosing alternative above-ground solutions. As a result, the multifunctional goal does not stand alone but is connected to an overall discourse of societal cost reduction.

As mentioned above, multifunctionality, for some actors, is also linked to sustainability, which can be found generally on the public agenda, in that it is part of public policy, political discourse, business and the media debate. Sustainability lacks a clear definition, though, and is often defined very differently in its different application areas (Bayulken and Huisingh, 2015; de Haan et al., 2014; Johnson and Lehmann, 2006). However, the concept is at the heart of studies of change and transition in sociotechnical systems (de Haan et al., 2014), which also can be referred to as “sustainability transition” (Markard and Truffer, 2008). Sustainability is also related to ecological modernisation, eco-efficiency and thereby innovation systems.

The definition of sustainability by Brundtland (1987) is a well-cited starting point for many sustainability discussions: ‘Humanity has the ability to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs[…]’. Sustainability therefore entails meeting needs, later defined as the social, environmental and economic aspects thereof. The definition also includes an equity time perspective, which equalises current and future generations, although this broad definition is used mainly by scientists working with sustainability. The public discourse often tends to focus on one or two of the different perspectives of sustainability, such as economic sustainability, environmental sustainability or social sustainability, and because of its many different and often unclear uses, the concept is sometimes abandoned.

The link between multifunctionality and sustainability comes from the fact that multi-functional solutions just like sustainable solutions fulfil multiple needs. Multifunctionality needs can in fact be connected to any of the eight other categories identified in **PAPER II**: innovation, urban, water quantity, water quality, nature, economic, health and safety, social and aesthetic expression (see **PAPER II** for more on actors' goals in Copenhagen).

In the academic literature, several attempts are made to describe the multiple functions of the water system that can be considered in a sustainable urban water system. Table 6 compares the goal categories of **PAPER II** to three other frameworks that outline different needs, aspects and services that urban water systems should fulfil to become more sustainable. The first framework is that of Water Aspects (Fratini et al., 2012b), which outlines 11 different aspects of water, or meanings added to it. The framework builds on existing philosophical theory (Geldof, 2005; Lems, 2008) of modalities and meant be used as an analytical framework. The 11 aspects are: biotic, sensitive, logical, historical, linguistic, social, economic, aesthetic, legal, ethical and ideal

Table 6. Comparison of goals categories identified in **PAPER II** and the three other frameworks outlining, societal needs, services and aspects fulfilled by water.

Goal categories **PAPER II**, Table 4.	**Water Aspects** Fratini et al. (2012)	**Needs of Society** de Haan et al. (2014)	**Sustainable urban water systems service functions** Belmeziti et al. (2015)
Innovation	Economic	Growth	[Value water for urban life], [Maximise the capacity of adaptation of the system]
Urban	Social	Relatedness	[Respect uses of the aquatic environment], [Avoid nuisances and risks]
Water quantity	Biotic, Legal	Existence	[Optimise the management of resources], [Protect against flooding]
Water quality	Biotic, Logical, Legal	Existence	[Preserve the natural environment]
Nature	Biotic, Economic	Relatedness	[Preserve the natural environment], [Optimise the management of resources]
Economic	Economic	Growth	[Optimise the management of resources], [Control the cost of the system]
Health and safety	Biotic	Existence	[Manage crises], [Protect human health], [Protect against flooding]
Social	Historical, Linguistic, Social, Ethical, Ideal	Growth	[Value water for urban life], [educate and inform], [Guarantee social equality]
Aesthetic expression	Sensitive, Aesthetic	Relatedness	[Maximise the capacity of adaptation of the system]
Multifunctional	Water infrastructure can relate to several water aspects	Systems can fulfil multiple needs	Systems fulfil more functions than drainage

Secondly, the needs of society framework seeks to define transitions of sociotechnical systems by changes in which needs the systems fulfil (de Haan et al., 2014). The framework describes the different needs of society in accordance with Alderfer's existence-relatedness-growth theory, stating that systems can fulfil multiple needs and that even the core need can be overshadowed by other needs. Finally, it states that a system becomes more liveable when it fulfils more needs, and that it is the actors' frustration as a result of their needs being unfulfilled that drives change. The authors outline urban water needs as:

- Existence (potable water, non-potable water, flood protection, sanitation, water-supported thermal protection).
- Relatedness (water-supported public spaces, water-supported productivity, healthy ecosystems, water literacy, water system knowledge, enjoyment of water, aesthetic urban environment, accessible water services, water-based mobility, water-supported thermal comfort).
- Growth (water-based culture and identity, equitable access to water services, pursuit of purpose and expression through water, meaningful influence on and contribution to water servicing, water independence, water choice and liberty, open water dialogue).

A third framework describing the functions of sustainable urban water systems is found in Belmeziti et al. (2015). The authors here argue that urban drainage systems no longer need to fulfil only one service, i.e. handling storm- and wastewater, but multiple services in what might be considered a sustainable urban water system. The framework outlines 14 services that can be use in a decision support process, matching the services to specific project objectivities. The 14 services are: to preserve the natural environment, to respect uses of the aquatic environment, to value water for urban life, to educate and inform, to guarantee social equality, to optimise the management of resources, to avoid nuisances and risks, to maximise the capacity of the system to adapt, to control the cost of the system, to improve integrated management of the urban environment, to manage crises, to protect against flooding and to protect human health.

Multifunctionally is a core part of the dominant discourse on climate change adaptation in Copenhagen, since it is used as an argument for implementing both below-ground and surface solutions, in relation to societal cost-benefit analyses. Multifunctionally encompasses a variety of actors' goals for climate change adaptation, and it is linked to sustainability, in that both multifunctional and sustainable solutions fulfil several functions or needs of society. However, sustainability can be misused in the public agenda, and perhaps therefore the concept has been abandoned for multifunctionality in regards to climate change adaptation.

6 Actor dynamics and emerging technological trajectories in Copenhagen's innovation system

6.1 Actor types and interactions

In the CIS, the group of core actors is broader than what may be found on larger spatial scales, as highlighted in Figure 10. **PAPER IV** outlines a general model of actors and their interactions in the CIS. It builds among other things on classical innovation system theory and on **PAPER I**, which outlines the model based on the specific case of climate change adaptation in relation to private property in Copenhagen. The core innovating actors in the CIS are knowledge institutions, private companies and utility service providers, the latter of which are new in relation to existing innovation theory, and their role in the CIS is often as a sparring or financing partner. Additionally, utility service providers are essential to the diffusion process, as they are large customers for most of the technologies and services developed, and they link other customers such as local authorities and private citizens. Another type of linking actor is the knowledge network, which can provide links to both technical knowledge in the development process and links to customers in the diffusion process. Knowledge networks can be based locally within the CIS or cross-cut to other CIS or spatial scales. The literature has already pointed to local authorities as being involved in multiple roles in the innovation process (Makkonen et al., 2017), but our study sees them in a double role as governing the innovation and implementation process and as vision creators for the larger visions of the change process. They are therefore crucial to a potential paradigm change, as local authorities' visions must match the dominant paradigm. Macro elements classically frame the innovation process, and in the context of the climate change adaptation in Copenhagen it is especially discrepancies between the regulative, normative and cognitive institutions at the macro level that are discussed as a barrier of change.

The cognitive institutions, including knowledge paradigms, in Copenhagen are showing signs of changing towards a new dominant paradigm of an optimised system, as discussed in the next paragraph, and the actors in this paradigm are trying to get other institutions to follow. Normative institutions include among other things rights and responsibilities, which specifically is a very current and sensitive topic in Copenhagen. This includes the division of responsibility between public and private actors, as regulation gives responsibility for climate change adaptation on private property to property owners, whereas the greatest benefits of climate change adaptation come only if there is a system-wide implementation. **PAPER I** reports an elaborate discussion on the public/private barrier of climate change adaptation in Copenhagen. Additionally, the responsibilities and opportunities of municipalities and utility companies have long been discussed. Since the two actor types were separated by the Water Sector Law in 2009, it has been unclear who should take responsibility for what types of adaptation projects. Moreover, many actors not only from utilities and municipalities have expressed that they wish for the utilities to legally have more responsibility, in order to allow additional integrated solutions for example across multiple event magnitudes. The division of roles and responsibilities between municipalities and utilities is slowly being formalised between the two partners; however, no regulatory changes have yet been made (see also **PAPER IV**). The mismatch between regulative institutions is also a topic for private citizens' adaptation, since they, along with other actors, when trying to facilitate implementation on private property, have a hard time using existing regulation (**PAPER I**).

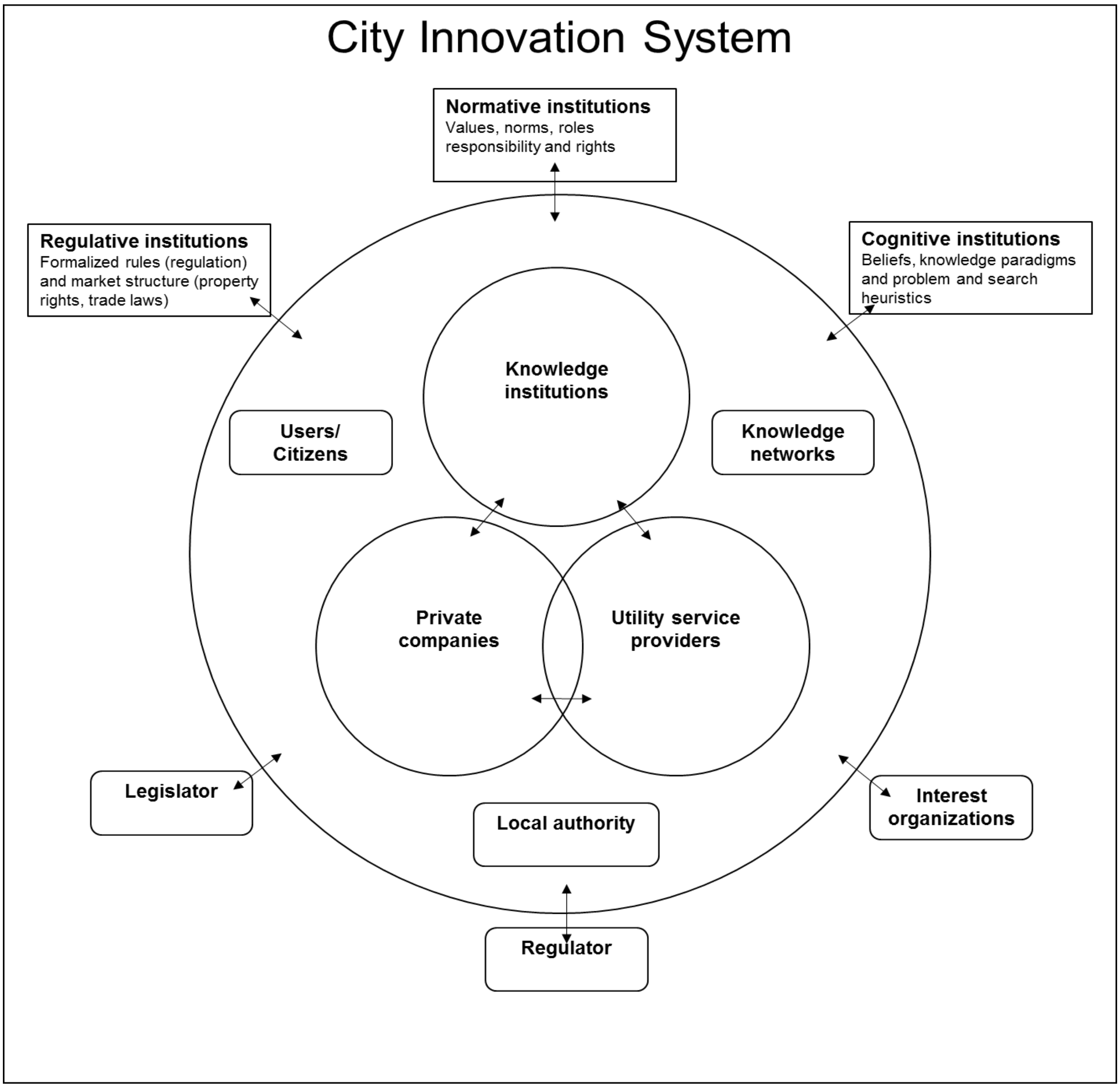

Figure 10. Conceptualisation of the City Innovation System related to climate change adaptation in Copenhagen (**PAPER IV**).

6.2 Causes of change in the innovation system

Classical path dependence theory argues that external shocks are needed to remove an innovation system from a lock-in (David, 1986). However, others have since indicated that perhaps system change can also come from a slower adaptation of new technologies (Martin and Sunley, 2006). The multi-level perspective (Geels, 2002; Geels and Schot,

2007) relates to how niches form at the micro-level and seek influence at the meso- and macro-levels, and how the macro-level forms pressure that drives responses from the other levels, both of which might result in transitions. In transition management, the discussion of whether transitions emerge as a result of agency or structure have led to the proposal of four ideal types thereof (Smith et al., 2005): reorientation of trajectories (internal resource transition with a low degree of steering), endogenous renewal (internal resource transition with a high degree of steering), emergent transformation (external resource transition with a low degree of steering) and purposive transition (external resource transition with a high degree of steering).

PAPER III shows how extreme localised weather events have been an important factor of change in the technological trajectory for pluvial flooding in Copenhagen. The paper illustrates how a series of extreme pluvial flood events with resulting damage, most importantly 2 July 2011, have created a space for innovation in climate change adaptation. These events changed the risk perceptions of both the public and professionals and led to an opportunity for creating a new solution span as part of a new technological trajectory. As a contrast, there has been no recently actualised damage from coastal flood events in Copenhagen. The public and professionals therefore perceive the risk of coastal flooding lower, and there is a slower form of niche innovation.

In the case of pluvial flooding, our study also shows that there is clear evidence of niche work existing before the pluvial flood events started occurring around 2007 (**PAPER III**). Indications are that this niche work perhaps originates in a surface system paradigm, with a strong emphasis on LAR (local diversion of rainwater) which in Denmark has its origins in environmental protection and urban ecology groups (Madsen et al. 2017 and **PAPER IV**). In the case of coastal flooding, despite the absence of an event causing localised damage in Copenhagen, ongoing innovation activities form the solutions to the distant of increased risk of storm surges. Professionals are feeding of the momentum of pluvial flooding and naming coastal flooding the next step (**PAPER III**).

I will underline that in the urban water system, a full systemic change has not yet happened. A new technological trajectory is formed, but a transition of the city has not yet happened (**PAPER IV**). It is in the context of causes of change also worth noticing that during the development of new trajectories, there has been an expansion of the actor group to include a broader group of professional disciplines, including engineers, landscape architects and urban planners. As such, the new trajectory also draws from external resources rather than the previous drainage system regime. This PhD hereby indicates, along the lines of existing theory, that systemic change towards a new technological trajectory is strongly influenced by external shocks; however, a base of existing niche work is needed to catch the opportunity when it arises.

6.3 Emerging technological trajectories

As the paragraph above indicates, the Copenhagen CIS shows signs of a changing technological trajectory. It is of course uncertain how the innovation system will look in the future, but there are some indications of the direction of change. First, a series of actors is deliberately breaking existing regulations, e.g. by considering larger event magnitudes than required by the regulations. They do this out of frustration that the existing normative and regulative institutions do not match the paradigm within which they work and often also publicly advocate for changed regulations and norms. Second, many actors' search patterns automatically converge towards optimising systemic multifunctional solutions within an entire surface catchment looking for additional societal benefits, which was not the case a few years ago. A new paradigm is thus beginning to dominate and even be codified in standards such as Report 31 by the Water Pollution Committee of the Danish Society of Engineers (Spildevandskomiteen, 2017). **PAPER IV** outlines these signs of change and three main current paradigms for climate change adaptation in Copenhagen (Table 7). The new trajectory works within the paradigm of the optimised system, the dominant design of which is above- and below ground solutions for a range of event magnitudes. Actors working within this paradigm value and innovate towards cost- efficient multifunctional and systemic solutions that are adapted to local circumstances. The aim of the paradigm is to create an interplay between the existing system and new solutions such as both cloudburst tunnels and green roads containing raingardens.

Table 7. Current main paradigms in the climate change adaptation CIS in Copenhagen, with dominant design, values and aims **(PAPER IV)**.

Paradigm	Dominant design	Values	Aim
Underground system	-Underground drainage solutions for design rain events	-Prefers well-known solutions -Prefers solutions hidden from civil society	-Maintain and improve existing combined urban drainage system
Surface system	-Grey and green multifunctional surface solutions for everyday events	-Values added through benefits of creating urban spaces, visibility -Works across multiple disciplines	-Transforms the existing combined urban drainage system
Optimized system	-Above and below ground solutions for everyday, design and extreme events	-Values cost efficient systemic solutions -Prefers variable and locally adapted solutions	-Create interplay with existing combined urban drainage system and new above- and underground solutions.

The actors are as such not building an alternative new system or a stand-alone solution, which some would consider is represented by the surface system. Rather, they are innovating within the optimised system, so that it matches the existing system to accommodate path dependency tendencies such as, especially, quasi-irreversible investments. To some degree, this matches Smith et al.'s (2005) ideal transition-type "re-orientation of trajectories”, whereby actors form a response to pressures within the regime. Nevertheless, it is once again worth noting that external resources are in play in the change process in the form of a much wider group of professionals, which relates to Smith et al.'s, (2005) emergent transformation. Even though a new dominant paradigm is emerging, there is still internal tension in and between paradigms, which reflects the evolutionary perspective of innovation (**PAPER IV**). At the political scale the surface and optimized system paradigms are supportive of change, at a professional level there are disagreements about the legitimacy of both paradigms, and internally there is continued debate regarding the practical implementation of the optimized system paradigm.

As a transformation has not yet happened, it might also be that it never will. Currently the system is an early transformation process, and as such it is very unstable (**PAPER IV**), Figure 7. Existing research in sustainable transformations of urban water systems points to several obstacles. A series of research papers have investigated urban water systems transition in Australia, mostly emphasising stormwater and water supply e.g. (Bettini et al., 2014; Brown et al., 2013; Fuenfschilling and Truffer, 2016; Madsen et al., 2017), in this literature it is pointed out that there is as strong existing hydraulic institutional logic, and that transformations are supported by full-scale demonstration projects, supportive policies at all governmental levels, and an inclusivity in the stabilisation process in regards to including different actor values. Inclusivity as a strategy for transformation is supported by the notion that technologies requiring more reconfiguration of, for example, recycling in the case of water supply in Australia, have a harder time diffusing. This is comparable to the reconfiguration aim of the surface paradigm in Copenhagen, which thereby must indicate that more institutional work is needed in order for this paradigm to diffuse. Specifically for Denmark, there have been previous calls for industry standards to accommodate the new green solutions (Fratini et al., 2012a) and for reforming the regulative framework to match the new types of solutions and collaborations (Lund, 2016). In Copenhagen, because of the lack of stabilisation, due to the strong path dependency of the underground drainage system, the system might go into a lock-in between the existing system and its newly optimised counterpart, which is being implemented now. A backlash could also still be experienced, for example as a result of how the new cloudburst tunnels or raingardens are implemented. The implementation of cloudburst tunnels is extremely costly; however, it is happening under existing regulation which match the underground system paradigm and is consequently easy for the actors to employ. If the upstream system, i.e. either stormwater pipes or surface solutions, is not connected to these tunnels, there might be a backlash. The current implementation of raingardens on smaller roads throughout Copenhagen risks locking the system onto a path that cannot handle a range of events but instead focuses on the everyday and design domain, which goes against the core of the new optimised paradigm and as such might result in further backlash.

7 Conclusions

This PhD project has examined how the work and interactions of actors in urban water management in Copenhagen contribute to innovation and the implementation of multifunctional solutions for climate change. The research builds on the evolutionary perspective of innovation system theory and seeks to contribute more fundamentally to an understanding of changes in the City Innovation System. The main conclusions are as follows.

Climate change adaptation technologies are considered by innovation system actors to include a very wide range of technologies throughout the entire urban water system. These can vary somewhat, from green solutions like raingardens, over grey solutions like permeable pavements and underground solutions like pipes and storage basins, to waste- and stormwater reuse. Actors working with climate adaptation often divide the solutions into the terms "traditional" versus "alternative" solutions. The terms are ambiguous, but commonly the actors call above-ground solutions such as raingardens and swales alternative, while below-ground solutions such as sewers and basins are termed traditional. The terms are used with reference to the legal terms "usual solutions" and "alternative solutions" in the Co-financing Act, which allows utility companies to finance alternative solutions. However, the legal definition of the terms is, in line with the actors' use of the words, ambiguous. In order to combat this vagueness and further the innovation and implementation of multifunctional climate change adaptation, I propose an inclusive framework characterising climate change adaptation according to three features: event magnitude (extreme, design and everyday domain), spatial scale (international/national, urban and local scale) and a range of goals (innovation, urban, water quantity, water quality, nature, economic, health and safety, social, aesthetic expression, and multifunctional). This novel framework is built on existing literature regarding climate change adaptation and urban water management, but it is ultimately the result of this PhD's empirical work with actors working with climate change adaptation. The framework can be used analytically to examine definitions and codifications in an actor network, but it can also be used in practice as an offset for discussions between actors working in innovation and the implementation of climate change adaptation.

Along with the large variations in climate change adaptation technologies, there is a growing dominant discourse that climate change adaptation is a combination of alternative above-ground and traditional below-ground cloudburst solutions. The solutions are all considered in the context of a surface water catchment system, delineated to prevent damage and to generate day-to-day value for citizens. Multifunctionality is a central tenet in the dominant discourse of climate change adaptation, and it is used as argumentation, through societal cost-benefit analyses, for implementing above-ground solutions that contribute with added societal value. Multifunctionality is not a stand-alone goal, but it is often connected to a goal of cost reduction and any of the features identified in the framework above.

I conclude that on the city scale, the innovation system can be characterised by a series of different actors not usually considered. The core group of actors in the City Innovation System includes utility service providers additionally to the traditional innovation actors, such as private companies and knowledge institutions. Throughout the interviews and focus group sessions, the utility service providers were identified as important in terms of innovation, even though they rarely initiate innovation projects themselves. In the development process, though, they are often a sparring or financing partner. Additionally, they are important for the diffusion process, as they are large customers and an influential link to other customers such as local authorities and private citizens. Our study also points to local authorities as important in the innovation process, as they hold a double role as the governing actor and simultaneously target creators for the long-term visions of the urban change process. Another linking actor is knowledge networks, which provide technical knowledge and links to customers, including citizens, which can also be included in the innovation process.

Change is happening in Copenhagen through an emerging dominant technological paradigm, the codification of new institutions and the implementation of new climate change adaptation solutions. The developing dominant paradigm is the optimised system, which in line with the dominant definition of climate change adaptation implements below- and above-ground solutions for everyday, design and extreme events. The paradigm actors value efficient, systemic and locally adapted solutions, aiming to improve the interplay between the existing system and a range of new solutions. Currently, these actors are trying to get other institutions to follow the new cognitive institutions. The actors' work in changing the trajectory for pluvial flooding is related to breaking existing – and creating new – institutions. Several actors advocate for changing the existing regulations and norms that currently do not match the new paradigm of the optimised system. Additionally, the new knowledge paradigm and responsibility norms are now being codified and appear in internal notes and public standards. However, a full transformation of the urban water system in Copenhagen as a result of climate change has not yet happened, and so it is currently in an unstable early phase of the change process. The instability of the new trajectory is due, among other things, to the strong path dependency of the existing drainage system, and thus the system might go into a lock-in whereby the existing underground system and the optimised system co-exist. There is also a possibility of a backlash, or a breakdown later in the stabilisation phase, now that cloudburst tunnels or raingardens are being implemented in parallel, and this may create controversies between the optimised system paradigm and other paradigms.

This study concludes, in accordance with existing theory, that systemic change towards a new technological trajectory is influenced strongly by external shocks, i.e. extreme rain events. However, a base of existing actor work is needed to catch the rising opportunities. As a novelty I propose that public and professional risk perception plays an important role in the collaborative learning process following the events. In Copenhagen extreme localised weather events have been an important factor creating a space for innovation of climate change adaptation for pluvial flooding through a change in both public and professional risk perception. In contrast, with no recent local coastal flood events causing damage in Copenhagen, the public and professionals perceive such a risk as relatively low, thus leaving the coastal climate change adaptation trajectory unaffected.

Overall, this PhD proposes three recommendations to further the innovation and implementation of the new multifunctional climate change adaptation solutions. First, I propose to apply the framework for defining climate change adaptation developed in this PhD in innovation and implementation projects. This will combat ambiguity in the actors' use of the terms and concepts. Second, I recommend that regulatory actors look into the mismatching regulatory institutions outlining responsibilities and roles, and then adjust these institutions to what other actors are advocating directly and indirectly. Finally, I recommend that actors responsible for the implementation process, namely local authorities and utilities, for example through knowledge networks, are made aware of the systemic properties of how climate change adaptation is implemented. They should understand that the existing drainage system binds the change process, and the new systemic solution cannot break completely with this path dependency. Additionally, they should be aware that committing to implementing both cloudburst tunnels and raingardens in parallel but disconnected also binds the change process for a number of years and that not considering the full visions of the optimised paradigm of valuing both everyday values and flood protection simultaneously introduces a risk of overall system failure. I hope that the actors viewing these recommendations will further their collaborative development on implementation of climate change adaptation in Copenhagen.

8 Recommendations

Several interesting aspects of innovation of climate change adaptation could be developed further by building on the work of this PhD. First, future research could further the understanding of climate change adaptation in Denmark. Copenhagen contains different actor constellations than many other cities, including several municipalities and utility companies, whose relationship is a determining factor in the innovation and implementation process. In order to study the importance and context of this relationship, it would be relevant to perform a broader study of municipalities and utility companies in Denmark. With 98 municipalities and multiple water utility companies, such a study should not go into detail. Rather, it should focus on identifying different types of relationships and comparing their impact on the innovation and implementation process. Since some utilities have responsibility for multiple infrastructural systems, such a study could broaden the scope even further to include other sectors. It would therefore be relevant to examine the level of integration between the different systems. Water supply is currently not a central part of the climate change adaptation agenda. However, with the changing climate seeing drought periods such as those witnessed in the summer of 2018, the integration of the water supply with climate change adaptation and stormwater management could become very relevant. In fact, the integration of stormwater management and water supply is very well known abroad and has driven the agenda promoting stormwater control measured, for example, in Melbourne (Madsen et al., 2017). In Denmark, there is to some degree already some integration between wastewater management and stormwater management in respect to climate change adaptation, because a great deal of the Danish stormwater system is a combined sewerage system. A future study of all utilities in Denmark on the weighing of the agenda of stormwater management, i.e. quantity control, and wastewater management and/or quality control, could further understanding of the integration of the management of these two systems.

The smart city agenda was not a direct part of this PhD. Nonetheless, throughout the empirical work of this study the agenda appeared increasingly frequent in the data collection stage, and in research institutions such as the one where this PhD was conducted the smart city agenda is similarly gaining traction. The meeting of the (water) smart city agenda with the current optimized system paradigm could be a future study. Can the two discourses co-exist or will there be conflict between the two? Will the smart city agenda fuse into the optimized system paradigm? Firstly, there are also indications in this PhD that "smart cities" and "water smart cities" are not defined in the same way by all actors, which is very comparable to the ambiguity in "climate change adaptation" pointed to in this PhD. There are some indications that the smart city agenda can fuse into the optimized system with solutions such as model predictive control of for example green stormwater elements and cloudburst roads. Additionally, the central values of the smart city agenda and the optimized system paradigm do somewhat align; they both value cost efficient systemic solutions. Conversely, the smart city agenda has also been mentioned in this PhD's empirical work as an alternative where the drained system persists because it now can be utilized in a smart way. In addition, despite needing further technological innovation to be implemented full-scale, it is sometimes argued as a faster solution than e.g. green surface solutions and separation of the sewerage system. Finally, I speculate that the actor group currently working with smart city water technologies is aligned more closely to those in the underground system paradigm, which does not normally include architects, landscape architects and urban planners.

The PhD has established that there is an overlap between the groups of professionals working with coastal and pluvial flooding in Denmark. Future studies precisely mapping the innovation systems of these two technological systems and their overlap are thus recommended in order to understand why, how and to what extent this overlap has appeared. Such a study could indeed focus on the urban scale and Copenhagen, but perhaps more interestingly it could be broadened to the national scale or cities in different countries, because as determined in this PhD localised extreme events matter for the innovation of these systems.

These more case-specific topics could be combined with a series of further studies in city innovation systems. This PhD has elaborated on CIS theory with a first general model of the micro-dynamics of the system. Future CIS studies could include connections between the institutions and actors, such as integrating institutional work theory. Additionally, this PhD's empirical work and the existing literature point to further studies into the connection between different spatial scales. The Copenhagen CIS is importantly an inspiration for other CIS's in Denmark and through networks such as C40 globally, but what is the importance of such network connections? How do innovations spread through such networks, and what are the other values cities are gaining from participating? This PhD highlights that the Copenhagen CIS has a national influence; for example, its climate adaptation plan was a significant motivator for developing the Co-financing Act, though it remains unclear how much influence the actors and institutions at the city scale have now and will have in the future.

The story of how risk perception and collaborative learning after localised extreme events changed climate change adaptation in Copenhagen indicates a general connection between risk perception and collaborative learning. Further studies in this theory should be done in other actor constellations, both inside and outside of cities. Such studies could elaborate further on the mechanisms employed after localised extreme weather events and corroborate the results of this PhD.

Finally, the novel and inclusive framework developed herein, which characterises climate change adaptation is developed not only on existing literature, but also on a case study basis in which pluvial flooding is the most prominent climate challenge. As a result, it is recommended that the framework is tested in other cities where other climate challenges are dominant for example drought and coastal flooding.

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10 Appendices

10.1 Appendix A: Interview guide, context interviews, English

Innovation of Multifunctional Climate Change Adaptation - Interview Guide UK 1st round

Introduction
This study wishes to get a deeper understanding of the stakeholders daily and new practices with innovation of (rainwater) climate change adaptation, and therefore focusing on the technologies handling the additional rain connected to climate change from it falling on a surface until it enters the recipient.

The interviews are to be used in my PhD at The Technical University of Denmark. I'll record this interview, and your information will then be used both as descriptions of the interview and as quotations. If you at any point in the interview want anything to be confidential, you just have to say so. Do you consent to me using the interviews in my thesis?

The interview is divided into 5 parts. We will in the end return to all of them with a small summary of the interview. I'm interested in your story and you are therefore encouraged to speak freely. You should therefore also know that there is no right or wrong answer.

Background
- What is your education?
  - When did you enter the job market?
  - What jobs have you held? And Where?
- Are you member of any professional networks?
  - How much time do you spend on these?
  - What are the most important ones?

Technologies
- What climate change adaptation technologies/solutions do you supply or use today?
  - Have these technologies/solutions changed in the last couple of years?
  - What did you use to supply/implement?
  - How did your solution develop into what they are today?
  - What new values/benefits do your solutions bring?
- On what terms do you compete with similar companies?
  - Have this changed historically?
- Can you tell me about a successful climate change adaptation (innovation) project which you participated in?
  - One that went wrong?
- How do you chose which solution to develop or implement?
  - What factors influences this choice and the solution? In a positive and negative way? Support and obstacles?

Internal innovation strategies
- What do you do to keep updated on new knowledge?
- What does your company do?
  - What is your company's vision regarding climate change adaptation?
- Have an organisational change been needed in your company there in recent years to accommodate climate change adaptation solutions?

External innovation strategies

- What other actors do you collaborate with?
- What type of collaborations do you have? Implementation? Planning? Development?
  - Who initiated the project?
  - Who put up demands for the project?
- How does your collaboration partners perceive the climate change adaptation area?
  - Have their perception changed?

Copenhagen

- Do you believe that you could work with climate change adaptation in the same way outside the Greater Copenhagen Area?
  - Why/why not?
- Does the city offer any specific resources or opportunities for your work?
  - Are there any specific barriers connected to the city?
- What role does Copenhagen have in relation to the national climate change adaptation?

Debriefing

I will now try to summarize what we have talked about. Please interrupt if I have misunderstood anything or if you wish to elaborate on anything. [Summary]

Is there anything else that you wish to say? Anything I should have asked?

Now I'll go back and transcribe the interview and then later use the data for my thesis and articles about my findings. Again thank you for your time. I'm happy to make my thesis or the any papers available to you, if you want it.

10.2 Appendix B: Interview guide, case interviews, English

Innovation of Multifunctional Climate Change Adaptation - Interview Guide UK 2nd round

Introduction
This study wishes to get a deeper understanding of the stakeholders daily and new practices with innovation of (rainwater) climate change adaptation, and therefore focusing on the technologies handling the additional rain connected to climate change from it falling on a surface until it enters the recipient.

The interviews are to be used in my PhD at The Technical University of Denmark. I'll record this interview, and your information will then be used both as descriptions of the interview and as quotations. If you at any point in the interview want anything to be confidential, you just have to say so. Do you consent to me using the interviews in my thesis?

The interview is divided into 4 parts. We will in the end return to all of them with a small summary of the interview. I'm interested in your story and you are therefore encouraged to speak freely. You should therefore also know that there is no right or wrong answer.

Background
- What is your background?
- What types of work assignments do you currently have?
- Are you a member of any professional networks?

Climate Change Adaptation?
- What is the special/different parts of this project?
- What is the purpose of this project?
  - How did this change over time?
  - Who set up these purposes?
  - How was they decided upon?
- At what scale should this project function? National? Urban? Water catchment? Cadastre?
- What event magnitude should this project function in?

Innovation
- What is the prehistory to this project?
- Why was this project initiated?
- Why aren't existing solutions good enough?
- In what way is your work affected by climate change?
  - More rain? Sea level rises? Other?
  - Extreme events or gradual increases?

Actors
- How did this project develop?
- Was there any obstacles during the project`?
  - Technical, legal, other?
  - How were these solved?
- What other organisations and persons were involved? How?
  - Who initiated the project?
  - Who put up project demands? What kind?
- What limitations did the project have?
  - Did you push the frames or did you adapt your project?

Whom do you recommend that I also talk to?

Debriefing

I will now try to summarize what we have talked about. Please interrupt if I have misunderstood anything or if you wish to elaborate on anything. [Summary]

Is there anything else that you wish to say? Anything I should have asked?

Now I'll go back and transcribe the interview and then later use the data for my thesis and articles about my findings. Again thank you for your time. I'm happy to make my thesis or the any papers available to you, if you want it / I'll send you the manuscripts for commenting when they are ready.

10.3 Appendix C: Subject guide, focus groups, English

Innovation of Multifunctional Climate Change Adaptation – Focus Group subject guide UK

Session	[min]	Manuscript	Moderation
Reception	-		Camera and dictaphone running. Smalltalk and introduction to persons. Try not to talk about the subject until everybody has arrived.
Intro	5	Hi and welcome. Thank you so much for taking time to participate in this group. Me you have met before, but with me today to assist me I have… We are interested I hearing your discussions and I will try not to interfere. I is also important to say, that there are no right or wrong answers to my questions today, so please state your opinions even if it is already stated. The discussion is segmented into two parts. The first session is 30 min, then we will have a short break, and then the second session which is 1 hour. There are snacks, water and coffee on the table. You are welcome anytime to take some of it. And then please let us handle pen and paper. We hope your discussions just will flow, but we have some rules to help the flow: - I'll be writing down the discussion up here on the posters, so that everyone can follow the discussions. - Second, no statements can last more than 30 seconds - Third, I you wish to ask anything or has anything to ad to what someone else is saying, then signal me. Then I will mark this with a lightning bolt on the board, and we can later return to the topic and make sure everyone	Moderator introduces

		gets to say what they want to. Let us start. Today we are talking about climate change adaptation.	
S1	30	What is climate change adaptation?	Allow discussion to flow, organise statements in regards to existing framework: Event magnitudes, spatial scale, goal and technologies.
Break	15	Okay, now we will have 15 minutes break- Please remember to take something to eat and drink.	Camera and dictaphone is running. Note discussion that are ongoing in the breaks, but do not engage in discussions.
S2	15	Who should pay for and implement climate change adaptation? Hvem skal betale for og udføre klimatilpasning?	Build op possibilities on board: Actors, process, legal framework / Actors, process, maintenance/supervision
	15	I would like that you now two-and-two create a story that tells the good example of how climate change adaptation should be implemented, what legal framework are used/ what are the maintenance/supervision done, what actors participates and what is the process? You will have 15 minutes and your partners are…	The group will split into 273 couples, which was put together in advance. We will listen and make notes in each group. They will have a pen and paper given by us.
	30	Now it is time for you to tell us your story. When all groups have told their story, you will together agree on one new common story.	Moderation of differences in speaking time. OBS: Consensus is the goal. Organise statements according to a timeline.
Outro	5	Is there anything more you wish to say? Then we are out of time. Thank you so much for your time and participation.	Moderator finishes.
			Camera and dictaphone is running. Note any discussions ongoing after the outro, but do not participate in the professional discussions.

10.4 Appendix D: List of interviewees, case and context round

Appendix D. Interviewee's education (Ed) and experience (Ex) organised by each data collection round and in round 2 innovation case. The current position at the time of the interviews are marked with parenthesis. Education and experience categories with high levels of sampling (>5) are marked dark grey, medium levels of sampling are marked light grey (2-5), and low level of sampling are white (1).

Round and case	Ed: Landscape management	Ed: Environmental planning	Ed: Biology	Ed: Architect	Ed: Landscape architect	Ed: Civil Engineering	Ed: Hygiene engineering	Ed: Environmental engineering	Ed: Design and innovation	Ed: Engineering management	Ed: Chemical engineering	Ed: Craftsman	Ed: Trade	Ed: Business management	Ed: Political science	Ed: Jurist	Ex: Local authority	Ex: Regional authority	Ex: State authority	Ex: Interest organisation	Ex: Non-governmental org.	Ex: Landscape Architect	Ex: Architect	Ex: Entrepreneur	Ex: Engineering consultancy	Ex: Utility company	Ex: Concrete & gravel production	Ex: Education	Ex: Research	Ex: State owned enterprise	Ex: Construction	Ex: Production	Ex: Product design	Ex: Process consultancy	Ex: Landscape management	Ex: Other
1: Context	X																X	(X)		X																
1: Context				X																		(X)		X												
1: Context						X	X																		X	(X)										
1: Context						X						X												X	(X)											
1: Context													X														X					(X)				
1: Context								X									(X)	X																		
1: Context				X										X								(X)						X								
1: Context															X		X		X		(X)															
2: Process								X																		(X)										
2: Process		X																								(X)				X						
2: Process					X														(X)																	
2: Process														X			(X)							X												

Round and case	Ed: Landscape management	Ed: Environmental planning	Ed: Biology	Ed: Architect	Ed: Landscape architect	Ed: Civil Engineering	Ed: Hygiene engineering	Ed: Environmental engineering	Ed: Design and innovation	Ed: Engineering management	Ed: Chemical engineering	Ed: Craftsman	Ed: Trade	Ed: Business management	Ed: Political science	Ed: Jurist	Ex: Local authority	Ex: Regional authority	Ex: State authority	Ex: Interest organisation	Ex: Non-governmental org.	Ex: Landscape Architect	Ex: Architect	Ex: Entrepreneur	Ex: Engineering consultancy	Ex: Utility company	Ex: Concrete & gravel production	Ex: Education	Ex: Research	Ex: State owned enterprise	Ex: Construction	Ex: Production	Ex: Product design	Ex: Process consultancy	Ex: Landscape management	Ex: Other
2: Process								X																	(X)			X								
2: Process				X													X		X					X										(X)		
2: Process						X											X								X						(X)					
2: Process						X																			(X)						X					
2: Process																X			X																	
2: Process		X																							(X)											
2: Product														X						X												(X)				
2: Product			X																X										(X)					X		X
2: Product								X																X	(X)										X	
2: Product						X																						X	(X)							
2: Product				X																			X	X									(X)			
2: Product						X											X									(X)										
2: Product									X																X									(X)		
3: Diffusion										X															(X)	X		X			X	X				X

Round and case	Ed: Landscape management	Ed: Environmental planning	Ed: Biology	Ed: Architect	Ed: Landscape architect	Ed: Civil Engineering	Ed: Hygiene engineering	Ed: Environmental engineering	Ed: Design and innovation	Ed: Engineering management	Ed: Chemical engineering	Ed: Craftsman	Ed: Trade	Ed: Business management	Ed: Political science	Ed: Jurist	Ex: Local authority	Ex: Regional authority	Ex: State authority	Ex: Interest organisation	Ex: Non-governmental org.	Ex: Landscape Architect	Ex: Architect	Ex: Entrepreneur	Ex: Engineering consultancy	Ex: Utility company	Ex: Concrete & gravel production	Ex: Education	Ex: Research	Ex: State owned enterprise	Ex: Construction	Ex: Production	Ex: Product design	Ex: Process consultancy	Ex: Landscape management	Ex: Other
3: Diffusion						X																				(X)					X					
3: Diffusion		X																							X	(X)										
3: Diffusion											X						(X)		X						X			X								
3: Diffusion						X																			(X)											
3: Diffusion					X												(X)																			
3: Diffusion						X																			(X)											

10.5 Appendix E: List of focus group participants

Appendix E. Focus group participants' education (Ed) and experience (Ex) organised by segment. The current position at the time of the focus groups are marked with parenthesis. Education and experience categories with high levels of sampling (>5) are marked dark grey, medium levels of sampling are marked light grey (2-5), and low level of sampling are white (1).

Segment	Ed: Landscape management	Ed: Environmental planning	Ed: Biology	Ed: Architect	Ed: Landscape architect	Ed: Civil Engineering	Ed: Hygiene engineering	Ed: Environmental engineering	Ed: Design and innovation	Ed: Engineering management	Ed: Chemical engineering	Ed: Craftsman	Ed: Trade	Ed: Business management	Ed: Political science	Ed: Juristr	Ex: Local authority	Ex: Regional authority	Ex: State authority	Ex: Interest organisation	Ex: Non-governmental org.	Ex: Landscape Architect	Ex: Architect	Ex: Entrepreneur	Ex: Engineering consultancy	Ex: Utility company	Ex: Concrete & gravel production	Ex: Education	Ex: Research	Ex: State owned enterprise	Ex: Construction	Ex: Production	Ex: Product design	Ex: Process consultancy	Ex: Landscape management	Ex: Other
Plan and project						X											X									(X)										
Plan and project					X												X					X			X	(X)										
Plan and project						X																			X	(X)										
Plan and project						X																			X	(X)										
Plan and project						X																				(X)					X					
Plan and project		X				X																			X	(X)										
Operations manager												X														(X)					X					X

Segment	Ed: Landscape management	Ed: Environmental planning	Ed: Biology	Ed: Architect	Ed: Landscape architect	Ed: Civil Engineering	Ed: Hygiene engineering	Ed: Environmental engineering	Ed: Design and innovation	Ed: Engineering management	Ed: Chemical engineering	Ed: Craftsman	Ed: Trade	Ed: Business management	Ed: Political science	Ed: Juristr	Ex: Local authority	Ex: Regional authority	Ex: State authority	Ex: Interest organisation	Ex: Non-governmental org.	Ex: Landscape Architect	Ex: Architect	Ex: Entrepreneur	Ex: Engineering consultancy	Ex: Utility company	Ex: Concrete & gravel production	Ex: Education	Ex: Research	Ex: State owned enterprise	Ex: Construction	Ex: Production	Ex: Product design	Ex: Process consultancy	Ex: Landscape management	Ex: Other
Operations manager						X											X									(X)										
Operations manager						X											X	X								(X)										
Operations manager																										(X)										
Middle management						X											X									(X)										
Middle management						X											X								X	(X)										
Middle management						X											X								X	(X)										
Middle management						X											X									(X)			X							

11 Papers

- **I** **Madsen, H.M.,** Andersen, M.M., Rygaard, M., Mikkelsen, P.S. Innovation dynamics and responsibility sharing in climate change adaptation on private property for pluvial flood mitigation in Copenhagen. (Manuscript).
- **II** **Madsen, H.M.,** Andersen, M.M., Rygaard, M., Mikkelsen P.S. (2018). Definitions of event magnitudes, spatial scales, and goals for climate change adaptation and their importance for innovation and implementation. *Water Research* 144, 192-203.
- **III** **Madsen, H.M.,** Mikkelsen, P.S., Blok, A. Framing professional climate risk knowledge in the city: changes in pluvial and coastal flood risk knowledge due to actualized extreme weather as a cause of adaptation innovation in Copenhagen, Denmark. (Submitted, under review)
- **IV** **Madsen, H.M**, Rygaard, M., Mikkelsen, P.S., Andersen, M.M. Change at the urban scale - Systemic innovation of climate change adaptation in Copenhagen. (Manuscript)

In this online version of the thesis, **papers I-IV** are not included but can be obtained from electronic article databases, e.g. via www.orbit.dtu.dk, or on request from:

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The Department of Environmental Engineering (DTU Environment) conducts science-based engineering research within five sections: Air, Land & Water Resources, Urban Water Systems, Water Technology, Residual Resource Engineering, Environmental Fate and Effect of Chemicals. The department dates back to 1865, when Ludvig August Colding gave the first lecture on sanitary engineering as response to the cholera epidemics in Copenhagen in the late 1800s.

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