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URBAN FUTURES AND CLIMATE CHANGE: UNDERSTANDING VULNERABILITY DYNAMICS

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DOCTORAL DISSERTATION

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ABSTRACT

There is a scientific consensus on the need to account for the dynamics of non-climatic factors of climate risk, i.e., vulnerability and exposure. However, there are a number of gaps and challenges associated with defining, conceptualizing and operationalizing it methodologically. Accounting for vulnerability dynamics is most pertinent in the urban context, due to the rapid pace of population and economic growth in cities, and a large concentration of people and assets subject to potential climate change risks.

This thesis contributes to the understanding of urban vulnerability dynamics, which presupposes studying urban futures and socio-economic change. It studies the phenomenon from theoretical, conceptual and methodological perspectives. Furthermore, it examines vulnerability dynamics from the perspective of urban adaptation governance and information needs. Primarily positioned in vulnerability and adaptation research with the focus on urban vulnerability, this thesis also draws on other fields for auxiliary concepts, methods and theoretical foundations. More specifically, it draws on the epistemological and methodological foundations of futures research to advance the methods for studying urban futures. It does so by engaging with the forecast and foresight as two dominant ways to study futures. It also draws on the adaptation governance and planning literature, and by connecting futures studies and local level adaptation governance, contributes to the understanding of how different types of knowledge can be used in adaptation governance. The connections between all these fields are drawn to make a theoretical, methodological and conceptual contribution to understanding vulnerability dynamics and the use of such knowledge in urban adaptation governance and planning.

The thesis begins with a systematic literature review, which canvasses the state of the art in urban vulnerability dynamics. The findings show that vulnerability dynamics is not widely taken into account in risk and vulnerability assessments at sub-national level. Moreover, many empirical studies assess future hazards while vulnerability and exposure are assessed at their current state. Furthermore, the findings of the review draw connections between conceptual approaches and methods to operationalize vulnerability dynamics, as well as the main bottlenecks in its inclusion. Next, the status of adaptation in local-level decision-making is explored with a survey to understand practitioners' needs for adaptation and climate risk management information. The findings show that while practitioners use a wide range of information, there is still a need for non-climate services, i.e., tailored information on vulnerability and exposure as well as how it can be applied in risk management. Building on these results, I develop a novel mixed methods approach to study urban vulnerability dynamics as a process at the case of

Helsinki, Finland, with the timeframe up to 2050. The aim of the study is to understand what socio-economic and land use changes influence future urban vulnerability, and to reconstruct pathways of vulnerability development. I integrate quantitative, qualitative and participatory methods for data collection, as well as quantitative and qualitative methods for data analysis. More specifically, to identify socio-economic and land use change drivers, I conducted a round of ranking survey and expert elicitation. I used locally developed socio-economic scenarios to reconstruct possible urban futures. To spatially reflect the changes in vulnerability indicators resulting from each scenario, I conducted a stakeholder workshop with a participatory mapping exercise. The integrated analysis of maps and scenarios qualitatively and quantitatively elicited the direct, indirect and cascading effects of changes in drivers onto vulnerability, allowing for the reconstruction of vulnerability development pathways and the establishment of patterns of indicator changes.

The novel mixed methods approach highlighted the need for appraisal from the perspective of urban adaptation governance, specifically considering its epistemological and methodological foundations. I draw on the epistemological foundations of futures research and on governance literature to find connections, and critically appraise the approach developed and the results of the case study to discern the methodological and conceptual contributions. I also draw connections between futures research, governance and vulnerability assessment literature, and, as a result, propose a framework for the epistemological positioning of vulnerability assessments, clarifying the connections between research paradigms, goals of the assessments, vulnerability conceptualizations, methodological approaches, futures research traditions and governance modes.

To conclude, this thesis advances our understanding of vulnerability dynamics, develops the methods to account for it and explores the implications of such knowledge for adaptation governance and urban planning. The empirical results of the thesis show that vulnerability is driven by a multitude of interconnected socio-economic factors and processes, which have direct, indirect and cascading effects on vulnerability. The conducted vulnerability dynamics assessment differs from commonly conducted quantitative assessments due to its epistemological positioning and methods used, thus, having pre-requisites for its possible uses in adaptation governance and urban planning. More specifically, foresight based assessments utilizing qualitative and participatory methods are better fitted with anticipatory governance compared to predominant predict-and-plan approaches. However, to respond to 'wicked' and highly uncertain challenges of adapting to climate change, planners and decision-makers need to engage with anticipatory governance and use more flexible approaches in adaptation and urban planning.

TIIVISTELMÄ

Ilmastonmuutoksen riskiarvioinnissa on tärkeää huomioida sosioekonomiset riskitekijät, toisin sanoen haavoittuvuus ja altistuminen. Vaikka asiasta vallitsee tieteellinen yhteisymmärrys, se on hankala viedä käytäntöön, koska ymmärrys tekijöistä, niiden välisestä dynamiikasta ja arviointimenetelmät ovat puutteellisia. Haavoittuvuuden dynamiikan huomioiminen kaupunkien riskiarvioinneissa on erityisen tärkeää, koska altistuneita ihmisiä on kaupungeissa paljon. Lisäksi, kaupunkiympäristö vaikuttaa haavoittuvuuden tasoon.

Tämä väitöskirja edistää haavoittuvuuden dynamiikan teoreettista ymmärtämistä ja sen arvioinnin menetelmäkehitystä. Lisäksi, tässä väitöskirjassa tarkastellaan haavoittuvuuden dynamiikan arvioinnin vaikutuksia sopeutumishallintoon sekä sen tiedontarpeita.

Aloitin tutkimuksen kirjallisuuskatsauksella, jonka tulokset osoittavat, että haavoittuvuuden dynamiikka on otettu huomioon riskiarvioinneissa heikosti. Monissa tapauksissa tulevaisuuden ilmastoriskiarvioinnit toteutetaan haavoittuvuuden ja altistumisen nykytilanteen arviointiin perustuen. Tämä voi johtaa vääriin käsityksiin tulevaisuuden riskeistä ja antaa puutteellisen kuvan sopeutumissuunnittelun tueksi. Seuraavaksi, kyselytutkimuksen avulla tein kartoituksen kuntatason sopeutumisen nykytilasta Suomessa. Tulokset osoittavat, että kunnat tarvitsevat enemmän tietoa liittyen ihmisten haavoittuvuuteen ja altistumiseen sekä tukea näiden tietojen käyttöön.

Kehitin näiden kahden osuuden pohjalta uudenlaisen arviointimenetelmän, joka tarkastelee haavoittuvuuden dynamiikan prosessina. Sen avulla arvioin sitä, miten haavoittuvuus kehittyy Helsingissä vuoteen 2050 mennessä. Tulokset näyttävät miten erilaiset sosioekonomiset tekijät, niiden välinen vuorovaikutus sekä näiden prosessien suorat, epäsuorat ja ketjuvaikutukset muovaavat haavoittuvuutta. Nämä tekijät liittyvät, muiden muassa, talouteen, väestökasvuun, kaupunkisuunnitteluun ja -rakenteeseen, ympäristöpolitiikkaan, sosiaaliseen eriytymiseen, ja ilmastomuutoksen toissijaisiin vaikutuksiin. Arvioin menetelmää ja sen tuottamia tuloksia kriittisesti sopeutumishallinnon näkökulmasta. Samalla kehitin uudenlaisen viitekehyksen haavoittuvuuden arvioinnin suunnitteluun, jossa huomioidaan sekä teoreettinen pohja että sopeutumishallinnon tarpeet.

Lopuksi väitän, että käsitystämme ilmastoriskeistä pitää syventää ja ottaa huomioon haavoittuvuuden kehitys. On suositeltavaa palata haavoittuvuuden teorian alkujuurille ja kysyä *miksi* ihmiset tulevat haavoittuviksi. Haavoittuvuus on suureksi osaksi seurausta yhteiskuntamme toiminnasta, politiikasta ja kaupunkisuunnittelusta, ja juuri haavoittuvuuteen voimme vaikuttaa sopeutumispolitiikalla ja ilmastoriskejä ennaltaehkäisevällä kaupunkisuunnitelulla.

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Alexandra
Helsinki, October 2021

CONTENTS

LIST OF ORIGINAL PUBLICATIONS

This thesis is based on the following publications:

I
Jurgilevich, Alexandra, Aleksi Räsänen, Fanny Groundstroem, and Sirkku Juhola. 2017. "A Systematic Review of Dynamics in Climate Risk and Vulnerability Assessments." *Environmental Research Letters* 12 (1): 013002.

II
Räsänen, Aleksi, Alexandra Jurgilevich, Simo Haanpää, Milja Heikkinen, Fanny Groundstroem, and Sirkku Juhola. 2017. "The Need for Non-Climate Services – Empirical Evidence from Finnish Municipalities." *Climate Risk Management* 16, 29-42.

III
Jurgilevich, Alexandra, Aleksi Räsänen, and Sirkku Juhola. 2021. "Assessing the dynamics of urban vulnerability to climate change" *Environmental Science and Policy* 125, 32-43.

IV
Jurgilevich, Alexandra. 2021. "Governance modes and epistemologies of future-oriented vulnerability assessments: example of a mixed methods approach." *Futures* 128: 102717.

The publications are referred to in the text as 'chapters' and followed by their roman numerals.

AUTHOR CONTRIBUTIONS IN THE ARTICLES

	I	II	III	IV
Original idea	AJ	AR, SJ	AJ	AJ
Study design	AJ	AR, AJ, SJ, SH	AJ	AJ
Data collection	AJ	AR	AJ, SJ	AJ
Analysis	AJ, FG	AR	AJ, AR	AJ
Article preparation	AJ, FG, SJ, AR	AR, AJ, SJ, MH, FG, SH	AJ, AR, SJ	AJ

AJ=Alexandra Jurgilevich; AR=Aleksi Räsänen; SJ=Sirkku Juhola; SH=Simo Haanpää; FG=Fanny Groundstroem; MH=Milja Heikkinen

I

Original idea and study design is by AJ. AJ conducted the data collection. AJ and FG coded and analysed the data, where FG conducted the bibliometric analysis of the sample and AJ conducted the qualitative data analysis. The article was led by AJ, while FG, SJ and AR contributed to different parts of the article.

II

The original idea of the study was developed by AR and SJ. The study was designed by AR, SJ, AJ and SH. AR collected the data and conducted statistical analysis and interpretation of the results. AR took the leading role in the article, while AJ, SJ, MH, FG and SH contributed to different parts of the article.

III

The original idea of the study was developed by AJ. The study and the methodology were designed by AJ with the comments form SJ and AR. AJ collected the data, while SJ facilitated the data collection in the workshop. AJ analysed the literature, ranking survey and conducted qualitative analysis of scenario and map datasets. AR conducted the quantitative analysis of the map dataset with spatial statistics. AJ took the leading role in the article, SJ and AR contributed to different parts of the article.

IV

The study was solely conducted by AJ.

ABBREVIATIONS

etc.	et cetera
i.e.	id est
e.g.	exempli gratia

1 INTRODUCTION

The impacts of climate change on society are inevitable, and climate change is happening faster than previously thought (IPCC, 2019). The questions on governments' and academic agenda concern the identification of the climate risks we need to prepare for or adapt to, who/what is vulnerable, and what we do about it now (Oppenheimer et al., 2014; Adger et al., 2018). Answering these questions presupposes that climate risk and vulnerability assessments are conducted, and that this information is used to plan and implement adaptation and risk management policies and measures.

To assess climate change risk and vulnerability, one needs to conceptualize and operationalize them. The Intergovernmental Panel on Climate Change (IPCC) refers to climate risk as "the potential, when the outcome is uncertain, for adverse consequences on lives, livelihoods, health, ecosystems and species, economic, social and cultural assets, services (including environmental services) and infrastructure" (IPCC, 2014a, p. 127). The IPCC conceptualizes and operationalizes climate risk to society as a function of biophysical (hazard) and socio-economic (vulnerability and exposure) elements in the same location at the same moment in time (Oppenheimer et al., 2014). Hazard is defined as a "climate-related physical event or trend and their impacts" (IPCC, 2014a, p. 124) and exposure as the presence of objects at risk (e.g. people, livelihoods, assets) in places and settings where they can be adversely affected (IPCC, 2014a). Vulnerability is understood as the predisposition to be adversely affected and presumes certain socio-economic characteristics that make an object at risk sensitive to potential impacts of climate change (Oppenheimer et al., 2014).

Risk and vulnerability assessments are far from a trivial exercise; even though the concepts and their operationalization have evolved over time (Oppenheimer et al., 2014; Adger et al., 2018; Ford et al., 2018). Risk and vulnerability are theoretical concepts which means that they are not directly measurable or observable phenomena, as opposed to, e.g. heat or sea-level rise (Hinkel, 2011). Thus, talking about risk and vulnerability assessment does not mean measuring them as such, but operationalizing them through observable categories (Hinkel, 2011). The theoretical nature of these phenomena entails philosophical debates on what constitutes these phenomena and how they can be reliably observed. While this debate has been ongoing for several decades, and many conceptual issues and definitions have been clarified and harmonized, there still are and likely will be different approaches and perspectives to them (Hinkel, 2011; Adger et al., 2018; Ford et al., 2018). However, the multitude of perspectives to vulnerability is not necessarily a hindrance, rather it can open up different facets of vulnerability. Most importantly, one should be aware of different approaches and explicit about the concepts used (Nightingale, 2016; Ford et al., 2018).

It is important to acknowledge and approach vulnerability and risk as complex, constantly changing phenomena (Oppenheimer et al., 2014; Dilling et al., 2015; Ford et al., 2018). Risk and vulnerability are closely linked to socio-economic development. They span across geographical and institutional scales, and across multiple sectors, all of which needs to be considered in assessments (Räsänen et al., 2016; Bennett et al., 2016; Ford et al., 2018; Lede et al., 2021). Thus, the assessment of future risks and vulnerabilities should include two important factors. First, the assessments should be placed into a multi-scale context,

where international, national and local broad socio-economic determinants and their cross-scale interactions are considered. Second, the assessments need to account for the socio-economic change, i.e. vulnerability dynamics. Dynamic as an adjective means a feature of a system that is characterized by continuous change, activity, or progress (Merriam-Webster, 2019). The need to account for vulnerability dynamics was first recognized in the early 2000s (e.g. Leichenko & O'Brien, 2002) and highlighted in the IPCC reports (Cardona et al., 2012; Lavell et al., 2012; Oppenheimer et al., 2014) and later studies (e.g. Dilling et al. 2015). Recent reviews still highlight vulnerability dynamics as an important but neglected issue (Mcdowell et al., 2016; Ford et al., 2018). These two factors, the dynamic and multi-scale nature of vulnerability development, make risk and vulnerability assessments highly complex and underlined with both inherent uncertainty stemming from predicting as well as uncertainty stemming from conceptual and operational ambiguity (Adger et al., 2018).

Climate risk and vulnerability assessments are carried out to supply information to decision-makers and actors for risk management and adaptation (Adger et al., 2018). Preparing for the future risks means including the assessment results into current urban planning and governance, which are inherently future-oriented (Quay, 2010). Thus, supplying this information for current planning and governance should provide actionable information on potential futures (Voros, 2007). Scientifically, this means engaging with futures research, paying special attention to the aims and, most importantly, to the object, which is not the future but its images (Voros, 2007). In practice, this requires forward looking and flexible planning and governance in order to operationalize and utilize the results of futures research (Fuerth, 2009; Quay, 2010; Vervoort & Gupta, 2018).

The question of vulnerability assessments and their translation into actionable information for risk management and adaptation is especially urgent for cities. Cities are centres of high population growth, and economic activity is growing in volume and intensity (Ruth & Coelho, 2007; Revi et al., 2014; Apreda et al., 2019). Thus, the impacts of climate change occurring in cities pose a risk to an increasing share of population, livelihoods and assets (Birkmann et al., 2010). At the same time, while cities face generally same climate events as their surroundings, the urban form and socio-economic activities can potentially amplify cities' vulnerability to climate change impacts (Revi et al. 2014; Apreda et al. 2019). The rapid population growth and economic activity in cities means that urban adaptation governance should also take into account the socio-economic change if we want to prepare for the future. Thus, risk and vulnerability assessments should include not only biophysical dynamics, but also socio-economic dynamics, i.e. vulnerability dynamics.

The preparation for and management of urban climate risks and the reduction of the vulnerability of urban population or assets are usually part of urban adaptation governance (Birkmann et al., 2010). While cities generally function in a multi-level governance structure (Betsill & Bulkeley, 2006), and many countries have adopted a national-level strategy or an action plan, planning and implementation of adaptation measures is most often carried out at the local level (Betsill & Bulkeley, 2006; Birkmann et al., 2010; Anguelovski & Carmin, 2011; Aylett, 2015), e.g. a city or municipality. To plan for adaptation, local actors require actionable and relevant information, which includes but is not limited to climate risk and vulnerability assessments, climate modelling and forecasting, and lately, also information and tools supporting adaptation and risk management (Cortekar et al., 2016; Adger et al., 2018).

Overall, the adaptation context for urban decision-makers and actors is very challenging. There is high uncertainty with regards to future risks and vulnerability, both inherent to their forecasting as well as stemming from the complexity of the phenomena, and difficulties in conceptualizing and assessing them (Adger et al., 2018). Urban adaptation governance needs to manage future risks and vulnerabilities, and these decisions and actions must be taken now, and most importantly, in a coordinated manner. At the same time, local actors make these decisions in conditions of high uncertainty and high responsibility and accountability (Rothstein, 2006), while the information needed to make these decisions is often difficult and not necessarily easy to translate into actual policy (Bowyer et al., 2015; Brasseur & Gallardo, 2016).

1.1 FOCUS AND OBJECTIVES OF THIS THESIS

This thesis addresses several of the challenges discussed above. At the core of this thesis is urban vulnerability dynamics. I pose and address the question of what constitutes urban vulnerability dynamics, focusing on urban futures and socio-economic change, while taking into account cross-scale interactions. I also address other related challenges and questions associated, such as methodological operationalization and the implications of such knowledge for practice, i.e. urban adaptation governance. Thus, this thesis pursues the following conceptual and methodological research questions (RQ):

1 What constitutes urban vulnerability dynamics? (Chapters I and III)
2 How to account for urban vulnerability dynamics? (Chapters I, III and IV)
3 What kind of information do practitioners need and how can vulnerability dynamics be taken into account in adaptation governance? (Chapters II and IV)

2 STATE OF THE ART IN VULNERABILITY ASSESSMENT AND URBAN ADAPTATION GOVERNANCE

2.1 DEVELOPMENTS IN VULNERABILITY ASSESSMENT AND CURRENT CHALLENGES

Vulnerability as a concept has been present in many fields for some decades (Adger, 2006). Overall, research on urban vulnerability mirrors research on vulnerability. Most often, urban vulnerability is framed as that of urban population, urban infrastructure, assets and livelihoods (Romero Lankao & Qin, 2011). It is critical to embed urban vulnerability studies and assessments into a broader socio-economic, political and institutional context, which presupposes accounting for its drivers at local, regional and international scale (Romero Lankao & Qin, 2011), as well as for the cross-scale interactions of these drivers (Ford et al., 2018).

Current research on vulnerability to climate change stems from several antecedent traditions. On the one side is the natural hazards tradition, focused on the physical elements of exposure, probability and impacts of hazards (Burton et al., 1993; Adger, 2006). In urban vulnerability literature, this tradition is referred to as "urban vulnerability as impact" (Romero Lankao & Qin, 2011). It demonstrates that natural hazards impact different groups of society differently, depending on where these groups reside and what resources they have at use. In this tradition, vulnerability is explained by technical and institutional factors. What this tradition neglects is the political and structural causes of vulnerability or *why* social groups are different, and thus differently impacted.

On the other side is human ecology/political ecology, which addresses the *why* (Cutter, 1996; Adger, 2006). It emphasizes the role of economic development in adapting to external risks and highlights the differences in social, political and economic structures as to why different groups are vulnerable. In the urban context, this tradition is referred to as "inherent urban vulnerability" (Romero Lankao & Qin, 2011). This approach has contributed significantly to understanding the determinants of differential vulnerability and the embeddedness and contextualization of these determinants as well as mechanisms of their development (Romero Lankao & Qin, 2011; Bulkeley & Tuts, 2013). The criticism of this tradition has been mainly focused on disregarding the physical elements of exposure and falling short of providing full causal sequence and relation of vulnerability determinants to impact and susceptibility over time (Eakin & Luers, 2006).

Finally, there is the pressure and release model, which bridged and synthesized the natural hazards and political/human ecology traditions (Blaikie et al., 1994). It gives equal weight to both physical and social aspects and to the understanding of processes and mechanisms. Overall, since the early 2000s, vulnerability research has been characterized by the interdisciplinarity and integrative character of the framework, attempting a system portrayal and treating vulnerability as a property of a socio-ecological system, elaborating the mechanisms and processes in a coupled manner (Turner et al., 2003).

In the past two decades, several major changes in risk and vulnerability research can be observed. These include a change in the focus of assessments from vulnerability to

risk, a higher inclusion of social sciences in addition to biophysical, and a further conceptual clarification of what comprises risk and vulnerability, as well as how it can be assessed (Parry et al., 2007; Adger et al., 2018; Ford et al., 2018). These changes have entered the mainstream understanding of risk and vulnerability via the IPCC reports. In the following, I will discuss these developments and current challenges.

First, definitions and frameworks for vulnerability and risk assessments have been further clarified and harmonized. The earlier frameworks most commonly used for vulnerability assessments were presented in the Third and Fourth Assessment Reports (TAR and AR4) by the Working Group II of the IPCC (IPCC WGII) in 2001 and 2007, respectively. In these and in similar frameworks, vulnerability is defined as "the degree, to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes" (IPCC, 2007, p. 89). Vulnerability is the function of exposure, sensitivity and adaptive capacity (McCarthy et al., 2001; Parry et al., 2007). Most notable change with regards to risk and vulnerability concepts and frameworks was brought forward by the IPCC Fifth Assessment Report (IPCC AR5) in 2014, which united the two conceptually diverse fields of disaster risk management (DRM) and vulnerability proposing the climate risk framework (Oppenheimer et al., 2014). In IPCC AR5, climate risk is a central element of assessment, combining vulnerability, exposure and hazards. Vulnerability is defined as "the propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt" (IPCC, 2014a, p. 128).

The second change in IPCC reports is related to the role of socio-economic processes as factors influencing non-climatic components of risk, i.e. vulnerability and exposure (Oppenheimer et al., 2014). After the IPCC TAR, there has been a notable development in vulnerability conceptualization: the recognition of non-biophysical (non-climatic) factors of climate risk and vulnerability (O'Brien et al., 2004). Fourth assessment report (IPCC AR4) brought the discussion of societal context and social change to vulnerability and its assessment (Parry et al., 2007). Vulnerability has been contextualized, and the role of socio-economic drivers has been highlighted more and more (O'Brien et al., 2007; Joakim et al., 2015; Räsänen et al., 2016). Finally, the latest IPCC AR5 risk framework sealed the contextual nature of vulnerability and the high role of socio-economic factors and processes in risk formation and alleviation. These processes and factors are present at different levels, from local to international, and this means that vulnerability assessment is placed in a context larger than the object of assessment (e.g. vulnerability of a city population is assessed taking into account national and international factors) (Oppenheimer et al., 2014).

However, it is observed that biophysical factors still prevail over socio-economic factors in vulnerability and risk research (Ford et al., 2018). A shift towards analysing the socio-economic nature of vulnerability is taking place, and this is evident from the studies on non-climatic drivers of vulnerability (Räsänen et al., 2016; Bennett et al., 2016; Lede et al., 2021). However, more should be done empirically and theoretically to re-engage with the foundations of vulnerability research (Ford et al., 2018), i.e. human/political ecology tradition of vulnerability assessments exploring the *why*: the causes of vulnerability (Cutter, 1996; Adger, 2006; Romero Lankao & Qin, 2011). Moreover, studies still highlight the neglect of cross-scale interactions as a concern in empirical vulnerability research, and

observe that attention is drawn away from broader socio-political and socio-economic determinants of vulnerability (Bennett et al., 2016; Ford et al., 2018).

Related to this is the recognition of vulnerability as a constantly changing phenomenon, driven by a multitude of socio-economic factors and processes (Lede et al., 2021). The need to account for vulnerability dynamics was brought forward in the early 2000s (e.g. Leichenko & O'Brien 2002; O'Brien et al., 2004), and later highlighted by the IPCC Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (IPCC SREX) and IPCC AR5 (Cardona et al., 2012; Oppenheimer et al., 2014). More recently, the dynamics of vulnerability and exposure has become of increasing interest (Birkmann et al., 2015; Dilling et al., 2015; Mcdowell et al., 2016; Sorg et al., 2018; Naylor et al., 2020). Latest reviews, however, still conclude that vulnerability research largely focuses on "snapshots", and does not examine the changing social context that vulnerability is embedded in, nor the changing character of vulnerability itself (Mcdowell et al., 2016; Ford et al., 2018).

Finally, it has been observed that vulnerability research has had limited influence on decision-making (Ford et al., 2018). Many aspects need to be taken into account to support effective adaptation. While it is not always possible to draw direct causalities, several factors have been discussed in the context of insufficient uptake of vulnerability research into decision-making. These factors include rationalism and functionalism in vulnerability and adaptation research, and neglect of cross-scale interactions, institutional context, actors, structures and processes both in vulnerability research and adaptation planning (Wellstead et al., 2013; Wellstead et al., 2017; Ford et al., 2018). Rationalism and functionalism refer to the perception of adaptation governance as a linear straightforward process in vulnerability research, without taking into account the complexity and dynamics of decision-making, institutional arrangements and actual implementation processes (Wellstead et al., 2017). Finally, effective adaptation governance and planning require tailored, demand-driven, actionable and usable information (Birkmann et al., 2010; Cortekar et al., 2016).

2.2 VULNERABILITY DYNAMICS AND FUTURES RESEARCH

Temporally, vulnerability can be assessed at its past, present or future state. Assessments of current vulnerability have been most common so far and are carried out by using recent data (McDowell et al., 2016; Ford et al., 2018). Still, while the number of future risk and vulnerability assessments is growing, there are relatively few examples that evaluate future changes in vulnerability and exposure, while the assessment of future hazards is much more common (McDowell et al., 2016; Bennett et al., 2016).

In this thesis, I deliberately distinguish between assessing vulnerability dynamics as a snapshot of a future state and as a process. This difference is not often discussed in literature, neither from the conceptual point of view nor regarding its implications for the utilization of assessment results. While one does not exclude the other, there is an important difference, which influences goals, methods and further use of assessments. On the one hand, assessing future vulnerability can be done as a snapshot of

future state, much like assessing current vulnerability. This approach builds on the natural hazards and pressure and release traditions (Burton et al., 1993; Blaikie et al., 1994; Adger, 2006) and is less suitable for tracing the root causes of vulnerability. Methodologically, this is most often visible in the use of statistical projections of vulnerability indicators. The goal of the assessments is to know vulnerability levels at a certain point in time. On the other hand, vulnerability dynamics can be treated as a process, exploring changes in vulnerability, building on human/political ecology traditions as well as the pressure and release model (Blaikie et al., 1994; Cutter, 1996; Adger, 2006). The goal of such an assessment would be to reconstruct vulnerability development, identify larger socio-economic determinants and structural causes of vulnerability. This presupposes the identification of the processes driving vulnerability and understanding the interactions between different drivers, as well as the examination of the socio-economic and institutional context that vulnerability is embedded in, and accounting for system complexity and cross-scale interactions. In this thesis, I focus on the dynamics of vulnerability as a process, which determines certain conceptual and methodological decisions discussed further in Sections 3 and 4.

Studying future vulnerability falls under futures research, which started to shape as a field in the 1960s-70s and has its own specific traditions and limitations (Masini, 2006; Voros, 2007; Inayatullah, 2008). Futures research builds on several philosophical foundations, on which one can draw while assessing future vulnerability as a state or as a process. I focus on two ways to take future into account in research: forecast and foresight (Cuhls, 2003; Masini, 2006).

Forecast broadly speaks to the "prognosis" tradition, which emerged from the need to face rapid changes. It builds on empirical past and present data to predict the way forward, and to understand what is probable among the possible. Forecast, or prediction, relies heavily on trend extrapolations and indicator projections. This tradition is underpinned by the assumption that "something *is* changing" (Masini, 2006) and that we prepare for the future (Cuhls, 2003), signalling a weaker agency compared to foresight. Foresight has a different agenda and a stronger agency. It builds on the assumption that "something *can and/or must be* changed" (Masini, 2006), and thus the aim is to shape the future (Cuhls, 2003). Foresight broadly corresponds to the "project building" tradition (Masini, 2006).

These traditions find their reflection in governance and planning, and this needs to be taken into account in vulnerability assessments, since assessments form the first step in adaptation and risk management (Lesnikowski et al., 2015; Adger et al., 2018). Forecast forms the basis of the most common "predict-and-plan" (also called rationalistic) governance and urban planning (Bracken, 1981; Quay, 2010). The predict-and-plan mode relies on prediction and, to some extent, on envisioning the future to achieve a desired state or to tackle predicted problems. Most often, it relies on trend extrapolations and predictions, but can also build on a backcasting scenario – if one vision is chosen and followed without space for flexibility and adjustment (Quay, 2010). Foresight forms the basis of scenario planning, strategic planning, and anticipatory governance. Anticipatory climate governance takes scenario planning further by extending futures exploration with the delineation of flexible adaptation strategies and creating mechanisms for monitoring and continuous adjustment (Quay, 2010; Vervoort & Gupta, 2018). It has been argued recently that traditional governance and planning paradigms based on forecasting are unsuitable for tackling climate challenges due to the high levels of uncertainty, long-term horizons, and,

most importantly, the high complexity of 'wicked' problems, all of which are characteristic of future climate risks and vulnerability (Quay, 2010; Hurlbert & Gupta, 2016). Anticipatory climate governance, including adaptation governance, has emerged as a response to govern in such conditions (Vervoort & Gupta, 2018), and methods to include flexible governance in uncertain conditions into planning started to emerge, e.g. dynamic adaptive policy pathways (Haasnoot et al., 2013).

2.3 URBAN ADAPTATION GOVERNANCE AND CLIMATE SERVICES

Since vulnerability assessments present information to support adaptation governance and planning (Adger et al., 2018), it is pertinent to discuss adaptation governance and its information needs. Most often adaptation is planned and implemented at the local level (Betsill & Bulkeley, 2006; Anguelovski & Carmin, 2011). Municipalities and cities are key adaptation actors, planning adaptation strategies and implementing adaptation measures (Cortekar et al., 2016). Adaptation can be planned and implemented as stand-alone adaptation strategies, as part of overall climate strategies together with mitigation, or integrated into overall urban planning (Anguelovski & Carmin, 2011; Carter & Lawson, 2011; Bulkeley & Tuts, 2013).

Adaptation governance, planning and implementation need actionable and useful information (Goosen et al., 2014). Climate services have emerged to respond to this need. Initially, climate services pertained mainly to climate information, i.e. the biophysical side of risk assessments and risk management (Dutton, 2002; Hulme, 2009; Goosen et al., 2014). For example, WMO defined climate services as a range of activities that produce and provide information on past, current and future climate and its impacts on human-environmental systems (WMO, 2011).

Effective urban governance for adaptation needs to address the political, social and economic determinants of vulnerability (Castán Broto, 2017). For that, decision-makers need not only climate information, but also information on vulnerability and exposure, as well as guidance on how to use it in risk management and planning for adaptation. More recently, the understanding and content of climate services has expanded; for example, Bowyer et al. (2015) suggest that climate services' content should include information beyond the climate modelling and forecasting, for example, risk and vulnerability assessments, decision-support tools, and projections of societal impacts. The production of such services should be conducted in an inter- and transdisciplinary process including climate, environmental, political and social scientists, economists and stakeholders (Bowyer et al., 2015). Similarly, Goosen et al. (2014) suggested the term 'adaptation services', where climate information should be translated into consequences for the land use, where, according to them, most of the adaptation takes place.

Another critical issue widely discussed with relation to adaptation governance and planning information needs is the usability and usefulness of information, which is closely linked to the larger debate on science-policy interface, and more specifically to the question of supply-driven versus demand-driven services (Dilling & Lemos, 2011; Kirchhoff et al., 2013; Lourenço et al., 2016). Climate services have been criticized for being too supply-driven, neglecting the needs of climate information users (Dilling & Lemos, 2011; Kirchhoff

et al., 2013; Lemos & Rood, 2010; Lourenço et al., 2016). To overcome this, suppliers of climate services need to know what kind of information is used and required by the users, as well as for what purposes. Moreover, the way risk in general, and climate risks in particular, are managed, depends on the institutional context; thus, the producers of climate services need to also know the users of the information, the context in which they operate, including decision-making and implementation procedures, labour division, accountability, mandate and resource allocation (Rothstein et al., 2006; Krieger, 2013; Wellstead et al., 2013; Wellstead et al., 2017).

Overall, to support effective urban adaptation governance and planning, vulnerability research needs to address at least the following: the inclusion of vulnerability dynamics, provision of actionable information on future vulnerability and exposure, in addition to hazards, and taking into account cross-scale interactions and institutional context. These gaps and concerns frame the research in this thesis. I start with systematically reviewing the scientific and grey literature on vulnerability dynamics to understand how it is conceptualized and operationalized methodologically (RQ1 and RQ2, Chapter I). Next, I explore the adaptation governance context by surveying the status of adaptation and information needs in Finnish municipalities (RQ3, Chapter II). Based on the review and survey results, I develop a novel mixed methods approach to assess vulnerability dynamics (RQ2) and apply it to the case of Helsinki with the timeframe up to 2050 (Chapter III). The aim is to understand what constitutes vulnerability dynamics, to reconstruct its development, and to identify and address the socio-economic determinants and root causes of vulnerability (RQ1, Chapter III). In the approach and methodology design, I draw on foresight and anticipatory governance, taking into account the institutional context, cross-scale interactions and adaptation needs. Finally, I appraise the developed approach from the perspective of conceptual contribution to vulnerability dynamics, and from the practice perspective of supplying actionable information on vulnerability that is useful for urban planning (RQ3, Chapter IV).

3 RESEARCH APPROACH OF THIS THESIS

3.1 RESEARCH PARADIGM

The point of departure in any research is a research paradigm. There has been much discussion about research paradigms, including, for example, Kuhn's understanding of paradigms as exemplars and community cultures (Kuhn, 1977), inquiry paradigms focusing on philosophical questions (e.g. Guba & Lincoln, 1994), and methodological paradigms giving foundation to qualitative, quantitative and mixed methods research (e.g. Johnson et al., 2007). In this thesis, I rely on the definition of a paradigm as "a set of beliefs, values and assumptions that a community of researchers has in common regarding the nature and conduct of research. The beliefs include, for example, ontological beliefs, epistemological beliefs, axiological beliefs, aesthetic beliefs, and methodological beliefs. In short, …, research paradigm refers to a research culture" (Johnson & Onwuegbuzie, 2004, p. 24). This is similar to what Kuhn calls community culture, something "what the members of a scientific community share" (Kuhn, 1970, p. 176). The three main questions to frame a research are the nature of reality and what can be known about it (ontology), the nature of this knowledge and the position of an inquirer in the process of knowing (epistemology), and how this knowledge can be attained (methodology).

This thesis is positioned in a mixed methods research (MMR) paradigm (Johnson & Onwuegbuzie, 2004). The postpositivistic paradigm and its ontology are at the heart of this thesis[1]. However, epistemological pluralism and mixed methodological approaches were required to respond to the research questions. Studying the state of the art in vulnerability dynamics (Chapter I) was exploratory and was conducted within an objectivist[2] epistemology and with mixed methods: quantitative methods in data collection and qualitative analysis. The survey on the status of adaptation and information needs in Finnish municipalities was conducted with objectivist epistemology and quantitative methods (Chapter II). Chapter III is based on MMR worldview: ontologically postpositivistic, it mixes not only methods but also objectivist and subjectivist epistemologies (Greene et al., 1989; Johnson et al., 2007). This was driven by the goal of the study – to explore and reconstruct vulnerability dynamics as a process, and to some extent conditioned by the positioning of Chapter III in futures research – the study being empirical, but non-evidential (Voros, 2007). Thus, Chapter III is MMR, based on postpositivistic paradigm, drawing on plural epistemologies and integrating qualitative and quantitative methods both in data collection and data analysis to respond to specific goals and sub-

[1] In positivism, the reality is real and apprehendable (Guba & Lincoln, 1994). Post-positivism is a response to the criticism of positivism and perceives reality as real, but only probabilistically and imperfectly apprehendable (Guba & Lincoln, 1994).

[2] Objectivist epistemology presupposes that the knowledge and the object of knowing is independent from the observer. In subjectivist epistemology, the knowledge is no longer objective and independent from the knower, but is influenced by the knower's value system to a different extent depending on the paradigm and/or ontology (from shaping the inquiry to co-creating knowledge) (Guba & Lincoln, 1994). In Chapters III and IV, the created knowledge was inevitably influenced by my personal values both in framing of the inquiry and in results' analysis and interpretation.

questions. The rationales behind these mixed epistemologies and methodological approaches in data collection and analysis include study development (using the results of one method to inform the other, i.e. sequential mixed methods design), expansion (expanding the breadth of inquiry by using different methods for different inquiry components), probing a new dataset, facilitating the thickness and richness of data, and augmenting interpretation (Greene et al., 1989; Morse, 1991; Sechrest & Sidani, 1995; Collins et al., 2006). Chapter IV is a qualitative subjectivist study to appraise the MMR case as well as to explore the epistemological links between vulnerability assessments and governance modes.

3.2 CONCEPTS, DEFINITIONS AND ANALYTICAL FRAMEWORKS IN THE THESIS

This thesis is situated at the crossing of vulnerability, risk and adaptation, urban vulnerability, futures research, and urban adaptation governance and planning. I draw on (urban) adaptation and vulnerability literature (Adger, 2006; Romero Lankao & Qin, 2011; Oppenheimer et al., 2014) to explore vulnerability dynamics as a phenomenon (RQ1) and to explore its methodological development (RQ2). Central concepts, definitions and frameworks of this thesis are drawn from vulnerability, risk and adaptation research (Table 1).

Table 1. Main concepts and definitions used in this thesis.

Concept / definition	**Definition**	**Chapter**	**RQ**
(Urban) vulnerability	Vulnerability is defined as the propensity to be adversely affected and includes sensitivity and adaptive capacity (IPCC, 2014a). Urban vulnerability pertains to that of urban population, urban infrastructure, assets or economic sectors (Romero Lankao & Qin, 2011)	I, II, III, IV	RQ1, 2, 3
Adaptation	Adjustment to actual or expected climate change, moderating or avoiding harm or exploiting beneficial opportunities (IPCC, 2014a)	I, II, III, IV	RQ1, 2, 3
Risk	Risk is a function of hazard, exposure and vulnerability. It is the potential for the adverse consequences on lives, livelihoods, health, economic, social and cultural services, infrastructure and services, among others (IPCC, 2014a)	I, II, III, IV	RQ1, 2, 3
Socio-economic development/change	Broad IPCC understanding of socio-economic development that includes demographics, economic development, technological development, institutions and governance, and broader societal factors (e.g. worldviews) (Carter & La Rovere, 2001; Oppenheimer et al., 2014)	I, II, III, IV	RQ1, 2, 3

Governance	Steering effort, means or mechanism for governing systems/actors to allocate resources in a controlled and coordinated manner (Rhodes, 1996; Bulkeley, 2005)	IV	RQ3
Planning	A determined effort/a systematic activity to make comprehensive long-range forecasts of future trends and to formulate and execute a system of coordinated policies aimed at bending foreseen trends towards realizing definite goals (Myrdal, 1968; Bracken, 1981)	III, IV	RQ3
Non-climatic information/services /factors	Factors/services/information pertaining to risk management and vulnerability/risk assessment domain, including socio-economic factors and information and excluding climate-related information (IPCC, 2014b)	II, III	RQ 2, 3

I rely on urban vulnerability literature to frame the research with regards to the object of the study (vulnerability of urban population), as well as placing the study into a broader (national and international) context and accounting for the drivers at different scales. I draw on futures research to advance methodologies to account for vulnerability dynamics as a process (RQ2) (Masini, 2006; Voros, 2007). Finally, I engage with the philosophical foundations of both vulnerability and futures research, as well as with the existing adaptation governance literature to study vulnerability assessments and their use in urban adaptation governance and planning (RQ3) (Bracken, 1981; Cutter, 1996; Cuhls, 2003; Masini, 2006; Adger, 2006; Voros, 2007; Fuerth, 2009; Quay, 2010). The research questions of this thesis were operationalized through more specific questions handled in Chapters I-IV (Table 2).

Table 2. Chapters, their link to thesis' research questions and question operationalization through chapters.

Chapter	**Thesis research questions**	**Research question as operationalized in the chapters**
Chapter I: Review article A systematic review of dynamics in climate risk and vulnerability assessments	RQ1, 2 and 3	1. Is the dynamics of vulnerability and exposure taken into account in vulnerability and risk assessments? 2. How is it taken into account?
Chapter II: Empirical article The need for non-climate services – Empirical evidence from Finnish municipalities	RQ3	1. What is the status of climate risk management in Finnish municipalities? 2. What are the useful information sources? 3. What are the ways to improve climate risk assessment and management?
Chapter III: Empirical/ methodological article Assessing the dynamics of urban vulnerability to climate change: Case of Helsinki, Finland	RQ1, 2 and 3	1. What are the drivers of socio-economic and land use change in Helsinki up to 2050? 2. How do these drivers and changes increase/decrease vulnerability?
Chapter IV: Theoretical/case study article Governance modes and epistemologies of future-oriented vulnerability assessments: Example of a mixed methods approach	RQ2 and 3	1. What are the connections between governance and planning modes and epistemological positioning of vulnerability assessments? 2. What is the contribution and what are the limitations of the developed mixed methods approach to science and use of vulnerability assessments?

To analyse the state of the art in the assessing vulnerability dynamics (RQ1, Chapter I), I developed a matrix to position the assessments according to their temporal framing and inclusion/exclusion of dynamics methodologically (Figure 1). Here, the axis "Current and future risks" represents the temporal frame of an assessment. The axis "Static and dynamic assessment" represents the methods to include dynamics. Thus, four ways of categorising the assessments emerge. The category "Future risks/Static assessment" includes studies that conduct assessments of future risks, where future hazards are assessed, but vulnerability is assessed at its current state. The category "Future risks/Dynamic assessment" represents studies that have assessed future risks, including changes over time in vulnerability with various methods. The category "Current risks/Static assessment" includes studies that have assessed current risks and vulnerabilities, using current or historical data. Naturally, current risk assessments do not presuppose the inclusion of dynamic components, since there is no change over time. Therefore, I assume the category "Current risks/Dynamic assessment" to be redundant.

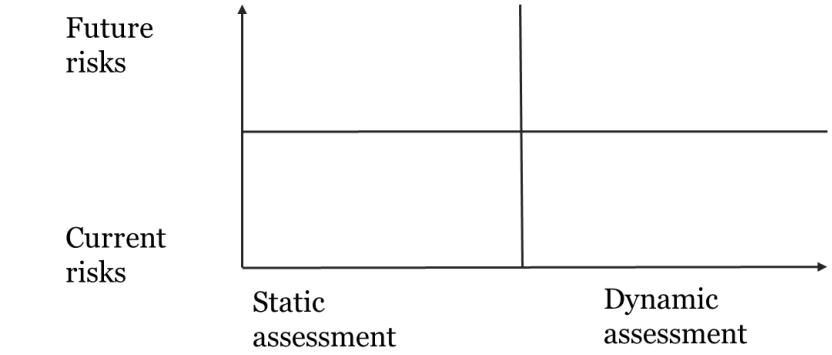

Figure 1. A matrix to analyse vulnerability assessment according to their temporal frame and inclusion of dynamics.

To understand what constitutes vulnerability dynamics (RQ1), I relied on the analytical framework in Figure 2 that connects vulnerability aspects, operationalized through indicators (Table 3). More specifically, vulnerability comprises of sensitivity, adaptive capacity and enhanced exposure (Figure 2). Adaptive capacity pertains to social factors – ability to prepare, respond and recover (Figure 2).

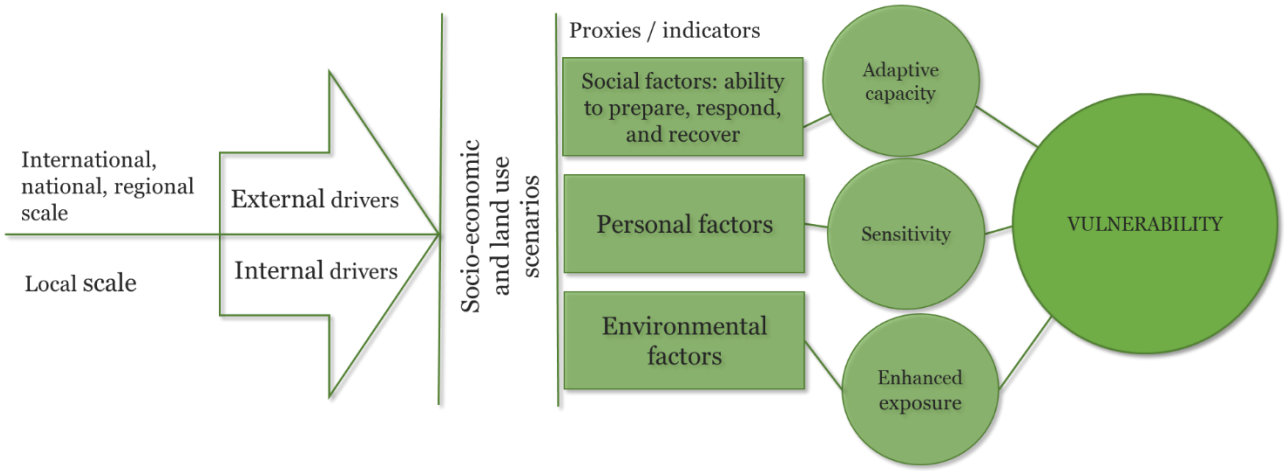

Figure 2. Framework to analyse risk and vulnerability (used in Chapter III to respond to RQ1 and 2). Adapted from Oppenheimer et al., 2014; Kazmierczak, 2015; Bennett et al., 2016.

These factors are operationalized through such aspects as occupancy, and economic and social inequality (Table 3). Enhanced exposure includes environmental factors (Figure 2), operationalized through such aspects as physical environment, and infrastructure and housing (Table 3). Sensitivity pertains to social factors, such as age, health status, and education. There are no data for such factors up to 2050 at the level of a city district, nor is it reasonable to produce such data, thus I did not include sensitivity. Vulnerability factors are influenced by a multitude of socio-economic drivers at different levels (Figure 2). The mixed methods approach as presented in Chapter III builds on the identification of drivers, their integration into socio-economic and land-use scenarios, according to which the changes in vulnerability factors are analysed.

Table 3. Chosen indicators in the SoftGIS questionnaire and their justification (based on Kazmierczak, 2015).

Vulnerability dimension	**Aspect of vulnerability**	**Indicator**	**Justification and link to planning/adaptation needs**
Enhanced exposure	Physical environment	Green areas	Green areas have a cooling effect in case of heat waves as well as serve as a natural drainage outlet in case of increased precipitation
		New residential areas	New residential areas are used to indicate newly developed districts where an influx of new citizens may occur. That should be considered in adaptation planning, particularly if new area development occurs at a loss of green space
	Infrastructure and housing	State of residential buildings	Residential areas that are in need of retrofitting, depending on the building type, may not provide enough cooling effect in heat waves or may not have enough capacity to withstand severe flood events
		State of critical infrastructure	Critical infrastructure (water supply, storm water drainage, electricity, road network) may not have enough capacity to withstand climate hazards or critical weather events
Adaptive capacity	Occupancy	Population density	Areas with high population density are associated with more challenges in times of evacuation and providing accommodation in recovery phase
	Economic and social inequality	Housing prices	Housing prices may serve as a proxy for income. Citizens with higher income have better ability to prepare for floods and heatwaves by investing in structural modifications to houses as well as are more likely to insure property against loss & damage
		Social inequality (district segregation)	Social inequality by district serves as a proxy for income (similarly to housing prices) and indicates capacity to prepare, respond, and recover in cases of floods or heatwaves

To understand the contribution of the developed approach and its fit with adaptation governance (RQ3), I critically appraised the methodology and results according to the framework in Figure 3. It was adapted and developed from the framework by Juhola & Kruse (2015), which was used to analyse adaptive capacity assessments from the science-practice perspective and is applicable to analyse vulnerability assessments in the same manner. I expanded the framework by adding governance and epistemology-related elements to draw connections between vulnerability conceptualizations, epistemological positioning, methods and governance modes (Figure 3). More specifically, according to the framework, the goal of the assessment influences the conceptual approach to vulnerability (practice pillar). It also further conditions the epistemological positioning of an assessment and determines methodological choices (science pillar). Epistemological positioning has implications for the use and usability of the assessment results in different governance modes. Alongside that, governance modes and the institutional context of result use and adaptation should be taken into account in the assessment design stage (practice pillar) as it has implications for the usability of results (practice pillar).

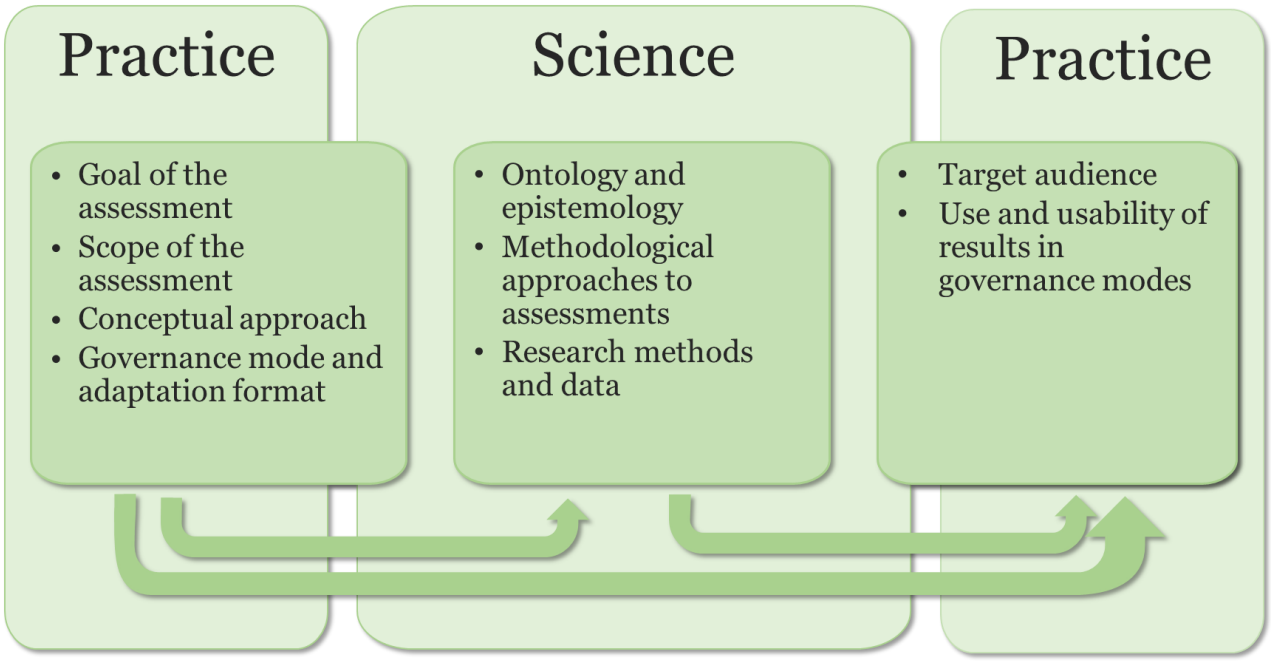

Figure 3. Framework to analyse vulnerability assessments from the science-policy perspective (adapted and developed from Juhola & Kruse, 2015).

4 MATERIALS AND METHODS

Overall, this thesis is a qualitatively-led mixed methods research, with different Chapters using different quantitative (extensive) or qualitative (intensive) approaches (Table 4), as well as plural epistemologies and MMR (Johnson et al., 2007; Birkenholtz, 2012). In terms of an overall research strategy, qualitative means that I aim at obtaining a deep understanding of an urban vulnerability dynamics phenomenon from different facets: conceptual and methodological as well as its use in urban adaptation governance. This thesis follows an iterative research strategy using both deductive (in applying frameworks and concepts) and inductive (in qualitative analyses) reasoning (Srivastava & Hopwood, 2009). Review and survey studies (Chapters I and II, respectively) lay groundwork for further methodology development and case application (Chapter III), and theory building (Chapters III and IV). As the research progressed, chapter questions were re-visited, and the understanding of urban vulnerability dynamics has evolved with the course of knowledge accumulation (for example, the vulnerability dynamics as a process vs. future state, see Section 2.2). In Chapter IV, I connect adaptation governance and futures literature with the data from Chapters I and III for theory building to develop a framework on epistemological positioning of vulnerability assessments from the perspective of adaptation governance and information needs.

Empirical evidence gathered in this thesis is diverse, including surveys, a systematic literature review, scenario work, and participatory mapping (Table 4). The mixed methods approach presented below is also a methodological contribution of this thesis, responding to RQ2.

Table 4. Overview of Chapters, materials and methods.

Chapter	Data collection and datasets	Data analysis
Chapter I: Review article	Systematic search and review; 42 sub-national vulnerability assessments	Quantitative bibliometric analysis Qualitative content analysis with a directed approach, performed by two co-authors
Chapter II: Empirical article	Quantitative survey and a follow-up workshop	Quantitative (statistical) analysis Validation of survey results in a workshop
Chapter III: Empirical/ methodological article	Literature review, two rounds of expert elicitation and a ranking survey, participatory mapping in a workshop; ranking survey data, scenarios and maps of expert opinion	Qualitative analysis of changes in maps and changes in key drivers in scenarios, quantitative analysis of maps using spatial statistics (Local Moran's I and Jaccard index)
Chapter IV: Theoretical article	Literature review and methodology and case results from Chapter III	Qualitative analysis with a directed approach

4.1 RESEARCH CONTEXT

The empirical studies took place in the context of local-level Finnish climate and adaptation governance, since most adaptation planning and implementation takes place at the local level (Betsill & Bulkeley, 2006; Bulkeley & Tuts, 2013). In Finland, adaptation and climate risk management are the responsibility of municipal authorities (Kuntalaki, 2015). Chapter II gathers evidence from Finnish municipalities and Chapter III presents the application of the developed mixed methods approach to the case of Helsinki with the timeframe up to 2050.

Most of Finland has cold continental cold summer subarctic climate (DfC subtype according to the Köppen Climate Classification), with the exception of Southern Finland, which has warm summer humid continental climate. Natural hazards do not cause as significant damages as in other Nordic countries or many other countries globally. However, Finland has fairly severe climatic conditions (e.g. winter temperatures down to -45°C), coping with which can be attributed to improved adaptive capacity, good governance and learning processes (Pilli-Sihvola et al., 2018b). Being a Nordic welfare state, having high social cohesion, relative wealth and mild natural hazards levels, Finland is considered to face overall low climate risks (Pilli-Sihvola et al., 2018a). At the same time, Finnish climate is already witnessing warming and the future warming is expected to be significantly higher than globally (Ruosteenoja et al., 2013; Mäkelä et al., 2016).

Helsinki, the capital of Finland, had the overall population of 648, 042 in 2019, representing 11,7% of total population in Finland (Vuori & Kaasila, 2019). Its population growth rate is one of the highest in the country. According to the baseline projections, Helsinki population will grow by 173 000 residents by 2050 (Vuori & Kaasila, 2019). Helsinki lies on the coast of the Baltic Sea (60.17 °N; 24.94 °E), and has warm summer humid continental climate with mean annual temperature of 5.9 °C and precipitation of 655 mm. The identified risks associated with climate change in Helsinki are sea flooding (e.g. in the Gulf of Finland sea level rise is projected to be 29 cm by 2100), urban flooding, heatwaves, storms, traffic and slipping injuries, vector-borne diseases, risks to biodiversity and cross-border impacts (Johansson et al., 2014; Pilli-Sihvola et al., 2018a).

From the perspective of national-level adaptation strategy, Finland can be considered a frontrunner in adaptation, being the first country in Europe to publish its national adaptation strategy in 2005 (Marttila et al., 2005) and its updated plan in 2014 (Ministry of Agriculture and Forestry, 2014). Still, it has been pointed out in research in other Nordic countries that with the perception of risk being low, there is a threat of inaction and complacency, despite the existing high adaptive capacity (O'Brien et al., 2006;

Johannessen & Hahn, 2013). In addition to that, progress in national-level adaptation does not equal successful adaptation planning and implementation locally. Indeed, it has been pointed out earlier that Finnish local level adaptation is rather fragmented, project-based and depending on external funding (Juhola et al., 2012; Parviainen, 2015).

The City of Helsinki works in a foresight governance mode: it has developed a city development vision, where a range of alternative scenarios were handled (same scenarios are also used in the case in Chapter III), and a development strategy was developed using a backcasting approach (Kaupunkisuunnitteluvirasto, 2013). With regards to adaptation, the City has developed an adaptation vision up to 2050, as well as an adaptation strategy with specific guidelines for the term 2017–2025 (Helsingin kaupunki, 2017). The strategy and guidelines are revisited and adjusted with each new government term. This model reflects anticipatory governance mode, containing all three steps (futures analysis and anticipation, flexible adaptation strategy, and monitoring and adjustment). The adaptation strategy is intended to be further integrated into all sectors of urban planning (Helsingin kaupunki, 2017).

4.2 EMPIRICAL MATERIAL COLLECTION

Systematic literature review

To respond to RQ1, I started with systematically searching and reviewing (Grant & Booth, 2009) all the empirical assessments of risk and vulnerability of population at sub-national level, including scientific and grey literature. The process of search and further elicitation, as well as keywords and search results are presented in Figure 4. In addition to the main research question, I wanted to systematize the literature in terms of conceptual approaches in conjunction with the purpose of the assessment (RQ3), methods and data (RQ2).

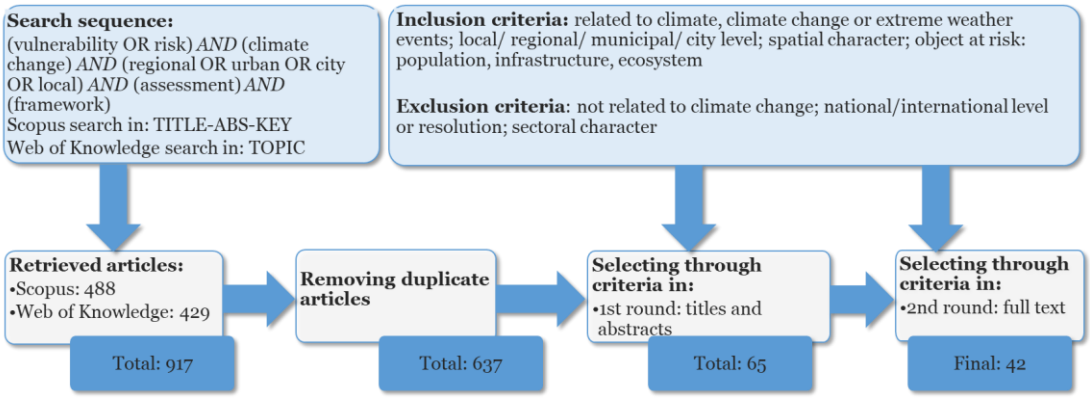

Figure 4. Systematic search and review procedure, including keywords, inclusion/exclusion criteria and resulting number of articles after each step of elicitation

Survey

To examine the local adaptation governance context (RQ3), an online survey was sent to the Finnish municipalities active in climate change planning (122 in total) (Chapter II). The online link to the survey was sent via e-mail to the selected individual in each municipality responsible for climate change issues or strategy, or to the head of environmental or technical administration; it was allowed to forward the link to the most knowledgeable person. The survey activation period was from 30 November 2015 to 13 December 2015, and two reminders were sent to those municipalities that had not submitted their responses. The survey contained questions about the municipalities' assessment of climate risks; their planning for climate change adaptation; their risk assessment methods and their perception of main climate hazards, useful information sources, barriers to risk assessment/management, and possible improvements to risk assessment/management.

As a follow-up to the survey, a stakeholder workshop was organized, where all respondents were invited. A total of nine participants, including three survey respondents were present to discuss the results of the survey, and more broadly municipal risk management work and a possible vulnerability assessment framework.

Mixed methods approach using SoftGIS

To respond to RQ 1, 2, and 3, this thesis presents a novel mixed methods approach to account for urban vulnerability dynamics as a process (Chapters III and IV). It was developed as a response to the gaps and challenges identified in literature (Section 2) and draws on the findings of Chapters I and II. The study relies on the sequential mixed methods design, i.e. results of one method inform the other (Morse, 1991). The novelty of the approach lies in the way it combines qualitative, quantitative and participatory methods, as well as in the methods and tools it combines. First, I integrated scenario work with participatory mapping. Here, the novelty lies in bringing the spatial reflection to the scenarios. This is critical, since vulnerability is a place-bound concept (Oppenheimer et al., 2014). Second, in contrast to typically used statistical projections of indicators (e.g. Viguié et al., 2014; Rohat, 2018), the mapping here was done by stakeholders, i.e. using expert opinion. Third, I used a novel tool for the participatory mapping - SoftGIS (Rantanen & Kahila, 2009). SoftGIS is an online platform for map-based surveys, which allows the study of local knowledge, experiences, and behaviours (Rantanen & Kahila, 2009), as well as locating data spatially. In particular, it complements spatially resolved "hard" GIS data with "soft" subjective data. The developed approach consists of three stages and six steps detailed below (Figure 5).

In Stage 1, the drivers of urban socio-economic development and land use change were identified with a literature review and validated with

expert elicitation (Figure 5). The expert validation and elicitation were conducted with the help of two practitioners from the City of Helsinki environmental administration in a face-to-face meeting, as well as with an online questionnaire targeted to seven climate change and urban planning researchers from the University of Helsinki and Aalto University.

In Stage 2, scenarios were constructed to account for a range of possible urban socio-economic developments. The results obtained in Stage 1, namely the list of drivers of urban socio-economic and land use change in Helsinki up to 2050, were used in this stage to construct the scenarios. Socio-economic scenarios are a commonly used method in future-oriented research (Bradfield et al., 2005; Moss et al., 2010; Birkmann et al., 2015) and have also been used in future-oriented vulnerability and climate risk assessments (e.g., Lawson & Carter, 2009; van de Ven et al., 2010; Angell and Stokke, 2014; Flynn et al., 2018). Rather than predicting the future, they inform policy-making on the interacting drivers and deepen the understanding of underlying mechanisms of future development (Viguié et al., 2014; Birkmann et al., 2015). The scenario stage is divided into two steps: ranking of the drivers and integration of the drivers into socio-economic scenarios (Figure 5). First, to enable the construction of comprehensible scenario narratives, I reduced the number of drivers with a web-based driver ranking questionnaire during 2 to 24 June 2017. An email invitation to the survey was sent to the City of Helsinki working group on climate change and adaptation that included 24 representatives from multiple city departments (city planning, environment, construction, safety and preparedness, rescue services, and social and health services). The respondents were asked to rank the drivers according to their importance in socio-economic and land use change in the city of Helsinki up to 2050. The scale was from 1 to 5 (1 – being not important and 5 – being highly important). A reminder was sent out once. The final key driver list contained 12 drivers, which were used for the next step: scenario construction. To account for the driver dynamics I used three local socio-economic scenarios developed for the Helsinki 2050 Master plan (Kaupunkisuunnitteluvirasto, 2013) and integrated the key drivers into these scenarios following the scenario logic. The Master plan scenarios were developed in a participatory process by the city's planning department based on two axes: city structure and state of economy.

In stage 3, to reflect the spatial patterns of future vulnerability, potential areas of vulnerability indicator changes were mapped by the stakeholders in a participatory mapping workshop. Expert opinion is useful when future-oriented data on vulnerability indicators are not available at a fine resolution or are unreasonable to produce. This stage is elaborated with two steps: SoftGIS survey construction and participatory mapping (Figure 5). First, I constructed a SoftGIS survey to be used in a stakeholder workshop for the three scenarios (the full questionnaire can be found in the Supplementary materials to Chapter III). The survey was implemented with Maptionnaire software (Mapita Oy, Helsinki, Finland), which is based on a SoftGIS approach

for map surveys (Rantanen & Kahila, 2009). The SoftGIS survey questions were constructed on the basis of the vulnerability indicators and their proxies used in a previously published index-based assessment of current social vulnerability for the Helsinki Metropolitan Area (Kazmierczak, 2015).

Finally, the participatory mapping took place in a workshop on 1 November 2017 with 11 participants from the City of Helsinki. I invited the members of the working group on climate risk and adaptation within the city administration, as in step 3. Some of the participants were the same as in steps 2 and 3. The workshop participants represented the following departments: city planning (2 participants), environment (5), construction (2), safety and preparedness (1), and rescue services (1). The only department not represented in the workshop was healthcare and social services. The participants were provided with a summary table and full narratives of the scenarios one day before the workshop. During the workshop, I presented one scenario in detail and asked the participants to answer the questionnaire related to that scenario, repeating the process for the remaining scenarios. In the questionnaire, I asked the participants to answer the questions by drawing polygons on maps, as many as they considered relevant. Depending on the question, a polygon represented an area where changes in indicators/proxies were likely to take place in each scenario. Answering questions was not mandatory in order to avoid forcing answers if the question was irrelevant to a respondent's expertise. I accounted for uncertainty by asking respondents to consider how certain they were of each polygon they had marked, on a scale of 1-100%. As the respondents did not give a certainty value to each polygon, the average certainty value for each question per scenario was reported. Nevertheless, the data on uncertainty were incoherent and could not be analysed further. Finally, I conducted a post-workshop feedback survey about the mapping exercise, background materials (scenarios), facilitation, SoftGIS usability as a tool and its suitability for locating spatial changes in dynamics of vulnerability indicators or their proxies (full questionnaire and results are in Supplementary materials to Chapter III). The total number of responses was five out of 11. I asked the respondents to reply to Likert-scale statements (1 = I fully disagree; 5 = I fully agree), as well as provided an open field for free-form feedback.

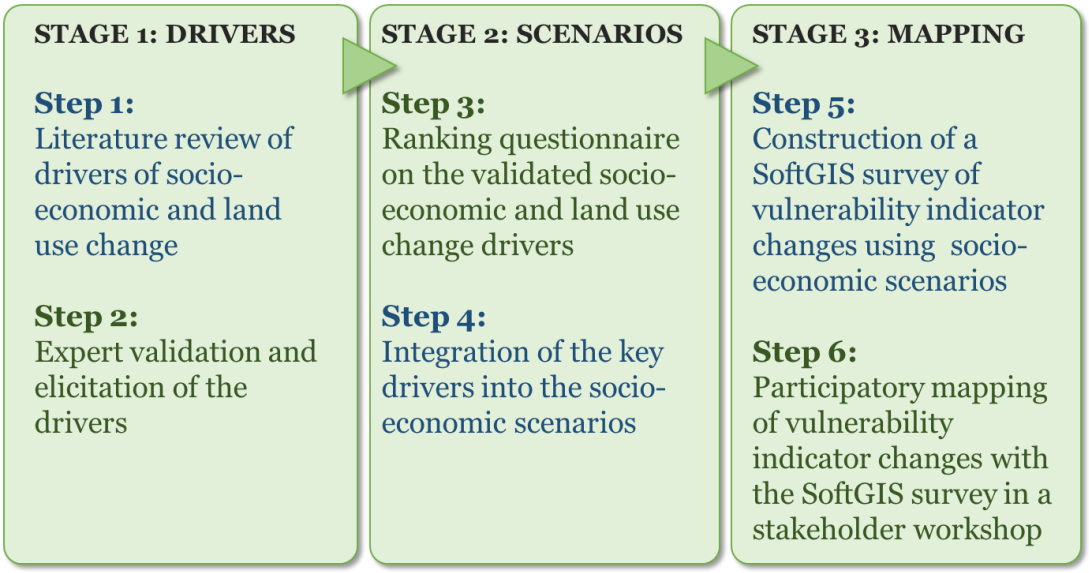

Figure 5. A flow chart of the methods used in the mixed methods approach. The empirical parts of the methods are in green and steps conducted solely by the authors in blue

4.3 DATASETS AND METHODS OF ANALYSIS

Literature review

The dataset of a systematic literature review (Chapter I) consisted of a pool of 42 articles (the full list is available in Supplementary materials to Chapter I). To analyse how dynamics is assessed, I utilized a qualitative content analysis methodology with a directed approach (Hsieh & Shannon, 2005). More specifically, I used a pre-coded questionnaire with categories pre-identified through the literature, and categories left open for a deeper inquiry that would advance the methodological categories. Pre-coded categories included bibliographic information (year of publication, type of literature), background information (temporal scale, spatial scale, geographic area, object at risk, and short description of the study), conceptual approaches to exposure and vulnerability, methods to include dynamics, and data used. For the conceptual approaches of vulnerability, I used the classification by Joakim et al. (2015). According to it, vulnerability can be conceptualized as a pre-existing condition, as a threshold, as an outcome and as exposure to hazards. Vulnerability as a pre-existing condition pertains to certain socio-economic characteristics that make an object at risk more vulnerable to climate change impacts. Vulnerability as a threshold presupposes the identification of thresholds or tipping points when damage occurs. Vulnerability as an outcome is residual vulnerability after adaptation measures have taken place. Finally, the last conceptual approach treats vulnerability as direct exposure to hazards and disregards socio-economic characteristics of an object at risk, which is not in line with the latest and commonly accepted vulnerability definitions as in e.g. IPCC AR4 or AR5 (IPCC, 2007, 2014a). As Joakim et al. (2015) point out,

this approach is very rare, rather technocratic and is more typically used in vulnerability assessments for infrastructure. For these reasons, I included only the first three approaches into further analysis. Open input categories included other methods and data, as well as summary and remarks (notes on the purpose of assessment, challenges and limitations of the study).

Survey

The response rate of the survey was 27% (33 out of 122 municipalities answered). The answers were analysed by the lead author with SPSS statistics. For the analysis purposes, the municipalities were divided into less and more active in climate risk management, based on their answers regarding the status of adaptation/climate risk management/assessment. The comparisons between groups were carried out using non-parametric Kruskal-Wallis H Test for identical distributions.

SoftGIS methodology

A multi-step methodology yielded three different datasets, which were fed consequently into the next stage of the study (Chapter III). As a result of stage 1, I collected a dataset of drivers, which was used to construct the socio-economic scenarios. As a result of stage 2, I obtained three scenarios, which were integrated into the SoftGIS survey in a stakeholder workshop. As a result of stage 3, I obtained a set of maps that were first analysed qualitatively together with the scenarios using a directed approach (Hsieh and Shannon, 2005) to examine what kind of similarities and linkages there are between the identified key driver changes in the scenario narratives and spatial patterns in vulnerability indicator maps; and second - quantitatively to establish patterns of changes across indicators and across scenarios.

Driver dataset

The literature review and review of Helsinki Master Plan socio-economic scenarios yielded 32 drivers. After expert validation and elicitation, the list comprised of 33 drivers, as the respondents excluded some drivers, while adding several others to the list. These lists of drivers are presented in Supplementary materials to Chapter III. In order to ease driver interpretation, I clustered the drivers into the following groups: demographics, economy, governance, city structure, development and infrastructure, and macro-context factors, similarly to Bennett et al. (2016). After the ranking questionnaire, having selected the drivers with top-5 values, I had a list of 12 key drivers (Chapter III). During the driver analysis, I classified the validated and ranked drivers into external and internal drivers to illustrate diversity and different scales. The starting point for the classification was the city level for internal drivers, and the sub-national, national, and international for external drivers (Leichenko & O'Brien, 2002; Luers, 2005). All the internal key drivers fell into one category: "city structure, development, and infrastructure", while

the external drivers fell into the categories “economy,” “governance,” and “macro-context factors”. The driver “migration” from the category “demographics” was both external and internal (migration into Helsinki and out of Helsinki). The external drivers can also be divided by scale, with macro-context factors having international character, economy and governance having national character, and migration both national and international character. Overall, there was moderate variation in answers. All the drivers were considered as “highly important” by at least one respondent. The highest variation was observed in macro-context drivers.

Scenario dataset

Scenario 1 titled “Negative: slowing development – dispersed city structure” explores the pathways in the situation of an economic decline internationally and locally, and its consequences for the local demography, economy and city maintenance. In this scenario, urban planners develop a city with a dispersed structure, i.e. a number of centres of economic activity in addition to the city centre. In Scenario 2 called “Balanced: balanced growth of the region – multi-centred structure”, the city structure presupposes a balanced development of the capital region, and a steady growth of global and Finnish economies. Scenario 3 titled “Fast: fast growth – dense mono-centred city” features economic and demographic boost and a strong mono-centred city structure. A short summary of the scenarios with the integrated key drivers is presented in Chapter III and full narratives of the scenarios are available in Supplementary materials to Chapter III.

Map dataset

As a result of the participatory workshop using SoftGIS survey, I obtained a set of 27 qualitative maps representing expert opinion on each indicator in question. To process the results of the workshop, the polygons were converted into 50 m spatial resolution raster datasets. For each question, the polygons of one respondent were not allowed to overlap. The sum of votes in each grid cell was calculated, so that each cell included the result value of how many respondents had drawn a polygon over it. The maps were first analysed qualitatively and then quantitatively. In the qualitative analysis, I conducted visual interpretation of indicator changes and linked them to the driver changes in the scenario narratives, guided by the operational framework of climate risk and following the qualitative content analysis method with a directed approach (Figure 2). The quantitative analysis was first carried out to support the results of the qualitative analysis, to increase robustness, and then to establish spatial patterns. More specifically, to find statistically significant spatial clusters of likely changes, a Local Moran’s I analysis (Anselin, 2010) of sum maps with fixed 500 m spatial neighbourhood distance and a 95% confidence level was conducted. High clusters were mapped, including both High-High clusters of larger contiguous areas with likely changes and High-Low outliers denoting smaller areas of likely changes surrounded by areas with

no likely changes. The pairwise similarity of different binary indicator maps (i.e. areas in high clusters and areas not in high clusters) was calculated between different indicators within each scenario and between the same indicators across scenarios with the Jaccard index (Jaccard, 1912). The index is calculated by dividing the size of the area mapped to high clusters in both maps (i.e. intersection) by the size of the area mapped into high clusters in either one of the maps (i.e. union). Analyses were conducted in ArcMap 10.3.1 (ESRI, Redlands, CA, USA) and in R (R Core Team, R Foundation for Statistical Computing, Vienna, Austria) with the package 'vegan' (Oksanen et al., 2019)

Critical appraisal of the developed methodology

Finally, I critically appraised the developed methodology to respond to RQ2 and RQ3, discerning the conceptual and methodological contribution to vulnerability assessment literature, as well as analysing its usability in different governance modes. The dataset for the appraisal was the methodology per se, as well as the results it produced. I used a qualitative analysis with a directed approach (Hsieh & Shannon, 2005), where the framework (Figure 3) provided pre-identified categories.

4.4 LIMITATIONS OF METHODS

Small samples

This limitation can be observed in the survey to Finnish municipalities (Chapter II), expert elicitation and ranking surveys (Chapter III), literature search (Chapter I) and in participatory mapping (Chapter III). It is due to the focused nature of inquiry when talking about literature review, as well as the small number of relevant respondents and participants in the surveys and the workshop. More empirical studies in other case cities or countries can be carried out in order to investigate if the results are generalizable and to what extent.

Researcher's subjectivity

A typical limitation that is inherent to a subjectivist epistemology is the bias or subjectivity of the researcher constructing the inquiry and interpreting the results. I observed this limitation, for example, in setting the threshold of top-5 values in the ranking questionnaire (Chapter III). The establishment of a threshold for key driver selection done subjectively by the researchers can potentially lead to the exclusion of important drivers or the inclusion of less important ones. This is particularly relevant when the number of ranking responses is low, and the differences are marginal. For example, if I had decided to set the threshold ≥4 in the driver ranking, "economy" drivers would have been excluded from the final list. This issue can potentially affect

the results and should be addressed in further methodological development. This could be balanced by including a larger pool of respondents or a stakeholder workshop in designing the list of drivers, in order to have more data to back the driver rankings.

Reliability of expert judgement

The third limitation is related to the robustness of the qualitative approach and analysis, including the reliability of expert judgement in the participatory workshop (Chapter III). I observed some illogicalities in experts' answers, probably caused by diverging opinions among the respondents and by uncertainty in forecasting. I addressed the issue of reliability by giving the participants an option to state their uncertainty related to each of the marked polygons. This issue can be improved in further methodological and tool development.

Oversimplification of complex phenomena

Addressing a complex phenomenon of future vulnerability and city development in this study inevitably led to some oversimplification, for example, of the mechanisms of housing pricing or social inequality as vulnerability indicators and proxies for income (Chapter III). I do not necessarily see it as a disadvantage, but rather as potential for complementing the proposed methodology with quantitative methods to provide a comprehensive analysis to the assessment that the quantitative methods may lack, and to increase the robustness of the suggested mixed methods approach.

5 RESULTS

In this section, I present key findings based on the research questions. Section 5.1 presents the findings related to RQ1, section 5.2 presents findings related to RQ2 and partially to RQ3 (methodology appraisal). Moreover, RQ2 is also partially addressed in section 4.1, as the mixed methods approach is a methodological contribution of this thesis. Finally, findings related to RQ3 are presented in section 5.3.

5.1 WHAT CONSTITUTES URBAN VULNERABILITY DYNAMICS

5.1.1 VULNERABILITY DYNAMICS IS UNDERSTUDIED

Despite being widely acknowledged as a pertinent issue, the dynamics of vulnerability is not taken widely into account (Chapter I). At the time of the systematic literature review, half of the risk and vulnerability assessments at the sub-national level were future-oriented. Of these future-oriented assessments, half accounted for the dynamics of either exposure or vulnerability, and one third for the dynamics of both.

Vulnerability is most often conceptualized as a 'pre-existing condition' (Figure 6). This approach is used to explore, understand and trace the causes of vulnerability and often serves a practical purpose of identifying 'hot spots' or most vulnerable population groups and areas. The second most common conceptual approach is 'vulnerability as an outcome', where vulnerability is a net result after adaptation measures have taken place. 'Vulnerability as an outcome' is used specifically for supplying information for adaptation planning and identification of adaptation measures. Finally, approach to 'vulnerability as a threshold' is the least used. This approach is useful in identifying adaptation measures and, most importantly, their timing and prioritization, especially beneficial in conditions of resource limitations and other constraints. There are controversies associated with this method, related to the assumption that some level of damage is acceptable. In other words, it is ethically challenging to determine what the "bearable level" is and who has the power to make such decisions (Chapter I).

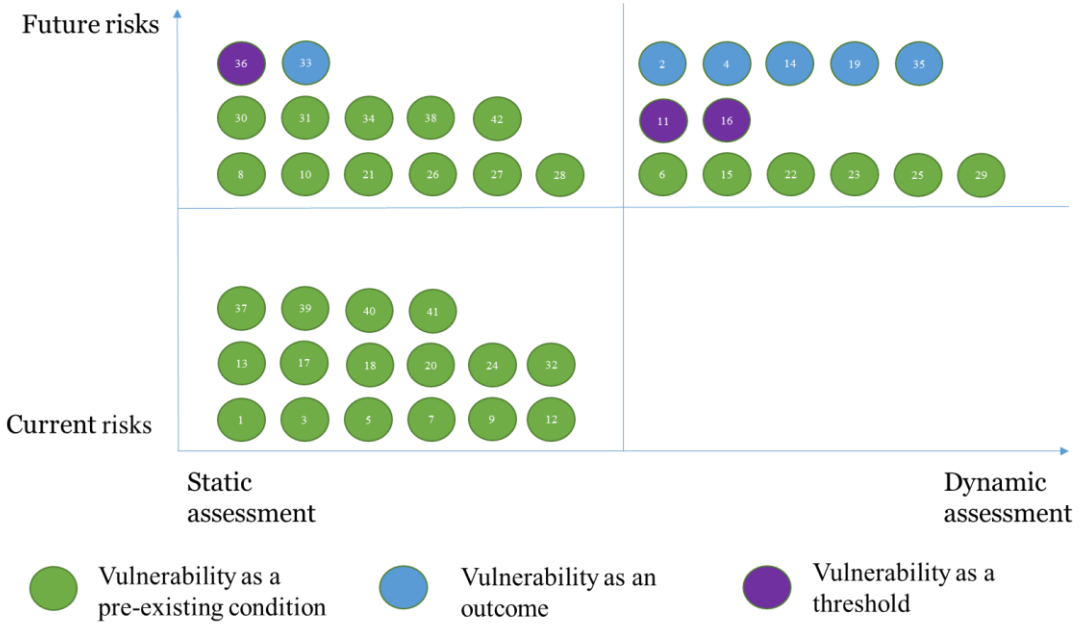

Figure 6. Vulnerability assessments' analysis according to their temporal orientation and inclusion of dynamics

Overall, the number of assessments accounting for the dynamics of non-climatic factors has grown in the past five years. However, the biophysical factors and accounting for their dynamics still prevail in the assessments, and vulnerability dynamics is not taken widely into account in future-oriented assessments. Moreover, there is a discrepancy in the assessments that account for future biophysical changes (hazards) but assess current vulnerability and exposure.

5.1.2 VULNERABILITY IS DRIVEN BY A MULTITUDE OF INTERCONNECTED FACTORS

This sub-section is based on the empirical results of a case study (Chapter III). While there will likely be a difference in separate drivers in every potential case city, most driver categories and driver levels are applicable across other cases and are generalizable for conceptual development of vulnerability dynamics. For Helsinki in 2050, I analysed the vulnerability drivers and spatiotemporal changes in vulnerability indicators across the scenarios to identify patterns of change, as well as for each scenario to construct vulnerability development narratives. This integrated analysis allowed me a) to uncover the direct, indirect and cascading effects of socio-economic changes on vulnerability (presented below); and b) to reconstruct vulnerability development pathways (presented in Chapter III).

Based on the integrated analysis of maps and scenarios, I observe that the vulnerability of urban population in Helsinki up to 2050 can be driven by such factors as state of economy, social inequality/district segregation, population growth and migration, environmental and mitigation policies,

transport and accessibility, public sector as the driver of city development, type of city structure and level of densification, form and functioning of critical infrastructure, and climate change secondary effects. The drivers can be clustered into categories such as 'economy', 'demographics', 'governance', 'city structure, development and infrastructure', and 'macro-context factors'. These drivers can be divided into internal and external to the city. Internal drivers belong to the category 'city structure, development and infrastructure'. External drivers include subnational, national and international drivers and belong to such categories as 'economy', 'governance' and 'macro-context factors'. Migration as a demographic driver is both internal and external to the city. Both internal and external drivers were identified as key in increasing or decreasing urban vulnerability (Chapter III).

The identified drivers have direct, indirect and cascading effects on vulnerability development. In the case of Helsinki, economic decline (state of economy) was identified as the main driver of vulnerability in the Negative scenario. It *directly* affects citizens' adaptive capacity by decreasing individual income, resulting in lower household capacity to prepare to, respond to and to recover from climate change impacts (Figure 2). Additionally, economic decline has *direct* effect on deepening social inequality and district segregation indicating decreased adaptive capacity. Economic decline affects citizens' vulnerability *indirectly* by affecting the city's financial situation. City's economic decline affects the capacity to modernize infrastructure and upkeep residential stock, thus increasing enhanced exposure of the residents (Figure 2). There is a strong spatial similarity (Figure 7) between the maps of areas with high population density (Figure 8) and areas where critical infrastructure needs to be modernized (Figure 9). This suggests an overlap in vulnerability indicators and forecasts a larger concentration of people with potentially increased vulnerability (Figure 2).

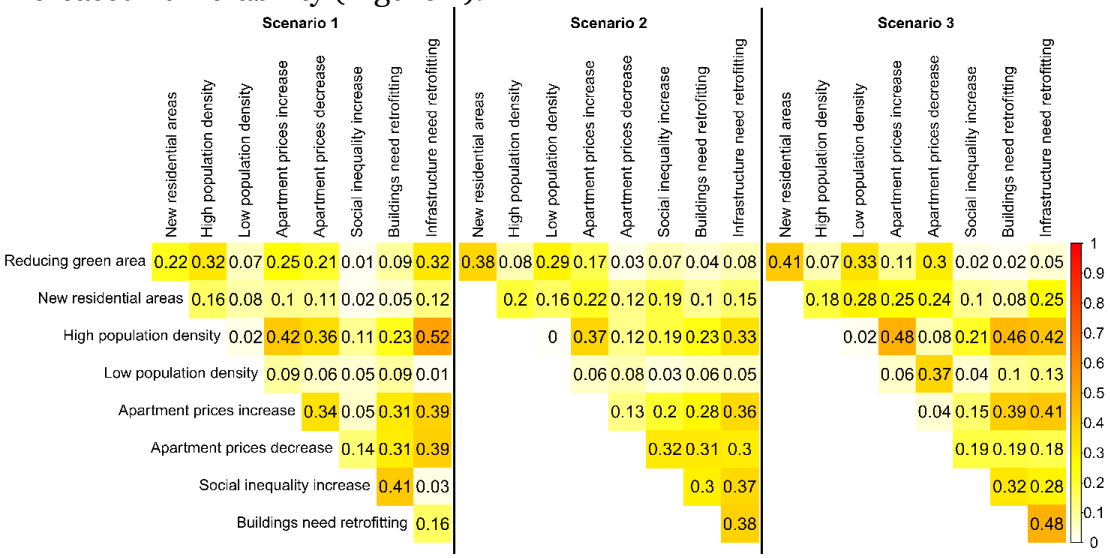

Figure 7. Jaccard similarity between different indicators in each scenario

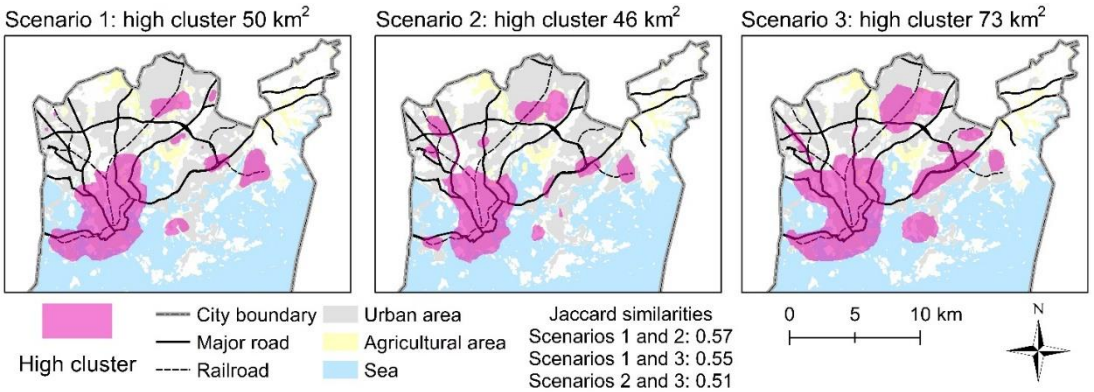

*Figure 8. Local Moran's I high clusters (both High-High and High-Low) with 0.95 confidence level, based on answers on SoftGIS survey question 2: "According to scenario X, can you mark the areas where **population density will be high**?" In addition, Jaccard similarities between maps and the size of high cluster area are shown.*

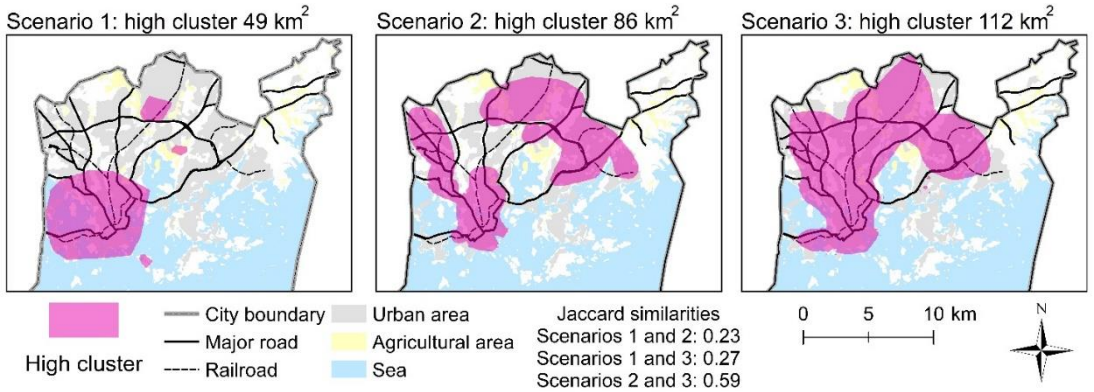

*Figure 9. Local Moran's I high clusters (both High-High and High-Low) with 0.95 confidence level, based on answers on SoftGIS survey question 9: "According to scenario X, can you mark the areas where **critical infrastructure** (energy, water, etc.) is getting old and needs modernizing?" In addition, Jaccard similarities between maps and the size of high cluster area are shown.*

In addition to that, the areas with high social inequality (Figure 10) show strong similarity (Figure 7) with the areas where the residential stock needs retrofitting (Figure 11), which increases all three dimensions of vulnerability (i.e., lower adaptive capacity, higher sensitivity and enhanced exposure, Figure 2). Finally, economic decline has *cascading* effects on other vulnerability drivers: private sector as a driver of city development, transport and accessibility and city densification. More specifically, in the Negative scenario, economic decline has increased the rent and land prices, thus driving the workplaces outside Helsinki, resulting in increased dependence on cars and the inability of public transportation to compete in the conditions of dispersed city structure. Economic decline has an impact on governance and policy, resulting in disregard to sustainable planning, and the implementation of environmental and sustainable policies is ad hoc and fragmented. This can be potentially exacerbated by the increased share of privately-owned land, which the City, according to the scenario, has to privatize due to the worsened economic situation.

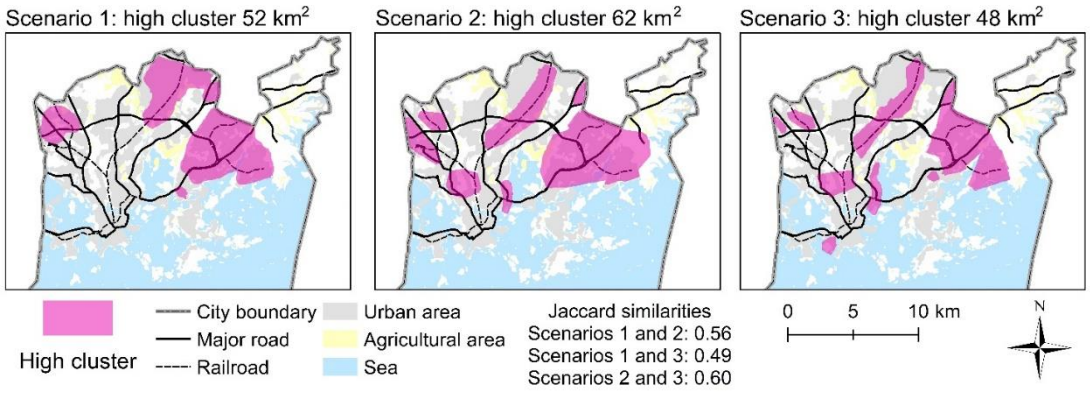

*Figure 10. Local Moran's I high clusters (both High-High and High-Low) with 0.95 confidence level, based on answers on SoftGIS survey question 6: "According to scenario X, can you mark the areas where **social inequality** may increase significantly?" In addition, Jaccard similarities between maps and the size of high cluster area are shown.*

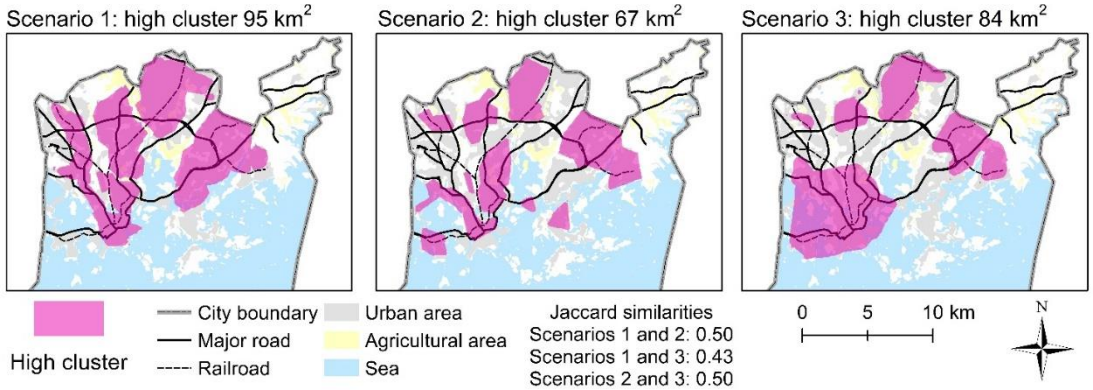

*Figure 11. Local Moran's I high clusters (both High-High and High-Low) with 0.95 confidence level, based on answers on SoftGIS survey question 8: "According to scenario X, can you mark the areas where **residential buildings** are getting old and need retrofitting?" In addition, Jaccard similarities between maps and the size of high cluster area are shown.*

City structure can have different positive and negative effects on citizens' vulnerability. For example, a dispersed city structure in the Negative scenario does not increase population vulnerability. However, the effect of the city structure is not directly dependent on the type as such but is conditioned by other factors. For example, a multi-centred city structure and a mono-centred city structure in Balanced and Fast scenarios are accompanied by the loss of green areas (Figure 12), and there is a similarity (Figure 7) across all scenarios in the areas where green areas are decreasing (Figure 12), and new residential areas are developed or densified (Figure 13). Thus, citizens' enhanced exposure is potentially increased (Figure 2). However, a reduction in green areas does not equal increased enhanced exposure if green infrastructure is an essential part of residential and critical infrastructure, offsetting the loss of natural drainage and cooling from green areas. The prioritization of green infrastructure in Balanced and Fast scenarios is interconnected with such drivers as the state of the economy, public sector as city developer and the inclusion of sustainable/environmental policies in urban planning. Overall, high and fast population and economic growth

together with high urbanization/densification can pose challenges to sustainable urban planning. Here, environmental and adaptation policies integrated into urban planning play an important role in offsetting vulnerability increase. This highlights the interconnected nature of all drivers, as well as the indirect and cascading effects that changes in drivers may cause.

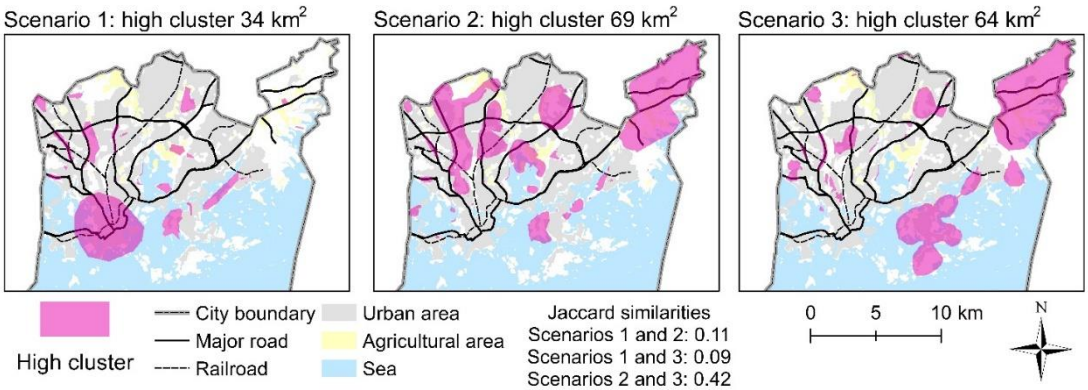

*Figure 12. Local Moran's I high clusters (both High-High and High-Low) with 0.95 confidence level, based on answers on SoftGIS survey question 1: "According to the scenario X, can you mark the locations where the **green areas** may reduce significantly?" In addition, Jaccard similarities between maps and the size of high cluster area are shown.*

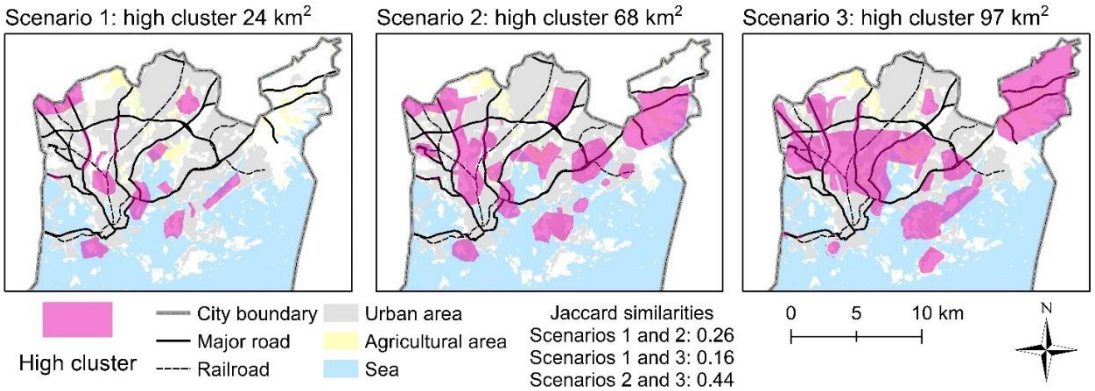

*Figure 13. Local Moran's I high clusters (both High-High and High-Low) with 0.95 confidence level, based on answers on SoftGIS survey question 7: "According to the scenario X, can you mark the locations where **new residential areas** will be built?" In addition, Jaccard similarities between maps and the size of high cluster area are shown.*

5.2 HOW TO ACCOUNT FOR URBAN VULNERABILITY DYNAMICS

5.2.1 METHODS USED TO ACCOUNT FOR DYNAMICS AT THE SUB-NATIONAL LEVEL

When vulnerability is conceptualized as a 'pre-existing condition', the dynamics is accounted for using socio-economic projections, population growth simulations and local development scenarios (Chapter I). Assessments where vulnerability is conceptualized 'as an outcome' use simulation of

adaptation measures, adaptation pathways or a discussion of adaptation measures to account for vulnerability dynamics. Finally, the conceptualization of 'vulnerability as a threshold' is operationalized through, first, the identification of thresholds when damage becomes unbearable and, next, the simulation of exposure/hazard impact on vulnerable population. Table 5 summarizes the identified methods to account for the dynamics of vulnerability grouped by the conceptual approach.

Most commonly reported limitations and bottlenecks to account for the dynamics of non-climatic factors include lack of future-oriented data, uncertainty and usability of projections, as well as lack of methodological development (Chapter I).

Table 5. Methods to include dynamics in vulnerability according to conceptual approach.

Conceptual approach to vulnerability	**Methods to include dynamics**
Vulnerability as a threshold	- Demographic projections - Impact threshold simulation/tipping point simulation - Simulation of hazard scenarios coupled with socio-economic scenarios
Vulnerability as a pre-existing condition	- Simulation of population growth - Urban growth and development scenarios - Projections of vulnerability indicators
Vulnerability as an outcome	- Urban development plans - Simulation/discussion of adaptation measures - Local development scenarios including external and internal change factors - Scenarios for adaptation - Socio-economic growth scenarios - Population growth scenarios - Adaptation pathways

5.2.2 APPRAISAL OF THE MIXED METHODS APPROACH

The developed mixed methods approach contributes both to science of vulnerability assessments and to their users. The study advances methodologies to account for the dynamics with mixed methods and makes use of intensive approaches by combining scenario work with participatory mapping. The analysis of obtained datasets, i.e., scenarios and maps, provides a conceptual contribution to understanding vulnerability, or to be more precise, insights into the complexity of vulnerability development and the socio-economic processes driving it. More specifically, the scenarios enable the identification of direct, indirect and cascading effects of changes on socio-

economic and land use drivers, whereas spatial statistical analysis of clusters and comparison of similarities enable the identification of patterns of likely spatial changes, and provide insights into the validity and uncertainty related to expert opinion.

The study fits well in the governance mode and adaptation format. It forms the first step in anticipatory governance, which is the working paradigm in the City of Helsinki. It does so by exploring a multitude of scenarios and providing information for flexible adaptation and urban planning. It also fits well with the format of adaptation planning, which in the case study is to be integrated into different sectors of urban planning. It does so by addressing vulnerability indicators separately and linking them with the relevant sectors of urban planning in the analysis. The epistemology of the assessment as well as the chosen methodological approaches create certain preconditions for the usability of the results. In the case study, Helsinki works in an anticipatory governance paradigm and steers participation in planning. Thus, designing the study within these premises creates favourable conditions for the results' reception and use. Table 6 provides a short summary of the approach appraisal according to the framework.

Table 6. Appraisal of the developed mixed methods approach according to its contribution to science and practice of vulnerability assessments.

PRACTICE	**SCIENCE**	**PRACTICE**
Goal of the assessment: Explore and reconstruct vulnerability development **Scope of the assessment:** Vulnerability of the urban population to heat and floods up to 2050 **Conceptual approach:** Vulnerability as a pre-existing condition **Governance mode and adaptation format:** Anticipatory governance mode. Adaptation as a stand-alone strategy to be further integrated into different sectors	**Ontology and epistemology:** Post-positivistic research paradigm, drawing on realist ontology, and plural (subjectivist and objectivist) epistemologies **Approach to assessment:** Mixed: extensive and intensive **Research methods and data:** Data collection with quantitative, qualitative and participatory methods. Data present a set of qualitative maps, analysed qualitatively in conjunction with scenarios and quantitatively with spatial statistics	**Target group:** Local level decision-making (city administration) **Use and usability in the governance mode and adaptation format:** Foresight framing of the study and use of participatory approaches provide ground for the results' uptake; however, usability study is needed for evidence-based conclusions. The assessment fits well with the adaptation format, providing insights for adaptation planning and its integration into different sectors of urban planning

5.3 VULNERABILITY DYNAMICS AND ADAPTATION GOVERNANCE

5.3.1 PRACTITIONERS NEED NON-CLIMATIC INFORMATION AND CAPACITY BUILDING

To outline the landscape of the overall progress in adaptation in Finnish municipalities, risk assessment, management and adaptation planning are quite modest (Chapter II). Climate governance and planning are mainly focused on mitigation rather than adaptation. The findings also show that climate risk management has fragmented character, being mainly focused in rescue services and technical departments, and is not integrated into all municipal decision-making. Both long and short-term climate risk assessment are carried out in the municipalities. The well-being of inhabitants and the functionality of infrastructure and municipality are the major drivers of climate work, and this goes in line with the Finnish municipal law, according to which it is the duty of municipalities to ensure residents' well-being and sustainable development.

Municipalities use many different sources of information, the most useful being contacts with experts and tools that illustrate climate change impacts, and the least useful being the media and historical datasets. In the follow-up workshop, the participants emphasized that the information on climate impacts and consequences would be extremely useful for risk management. The participants also stressed that the information on vulnerability and climate change impacts is more meaningful to population's well-being than the information on the biophysical factors of climate change, but that they are often neglected. Additionally, survey respondents indicated that they need more tailored information, more usable information and more guidance on how to use the climate information and/or strengthen their capacity. Municipalities need more capacity building to assess vulnerability and exposure, as well as guidance on how to use this information. Even though municipalities obviously are aware of the location of their assets (e.g. infrastructure) and characteristics of population (vulnerability and exposure), they may not necessarily know how to link this information to climate risk management and adaptation.

5.3.2 EPISTEMOLOGY OF VULNERABILITY DYNAMICS ASSESSMENTS AND THEIR USE IN GOVERNANCE MODES

Having synthesized governance, futures and vulnerability assessment literature through the framework to analyse vulnerability assessments from the science-policy perspective in Figure 3 (Chapter IV), I propose recommendations for science and practice communities with regards to epistemological positioning and framing of vulnerability assessments (Table 7). The first issue to consider while designing a vulnerability assessment is the identification of the goal of the assessment (predict vulnerability, identify hot spots, plan adaptation options, prioritize adaptation measures, and investigate the causes, drivers and mechanisms of vulnerability development). These will influence the epistemological positioning, methodological choices, and conceptual approach to vulnerability. For example, vulnerability conceptualized as a pre-existing condition fits well the purpose of identifying the hot spots of vulnerability, as well as identifying vulnerability causes and understanding its development. To identify adaptation measures, one can conceptualize vulnerability as an outcome. Vulnerability as a threshold is a useful approach to identify and prioritize adaptation measures.

At the same time, it is important to consider governance modes in the design of an assessment, as certain types of knowledge are more acceptable within a specific governance mode than others. For example, the results of objectivist assessments carried out with extensive approaches support rationalistic planning well. The results of subjectivist assessments carried out with intensive approaches are more challenging to use in such modes due to their inherent limitations, which include the reliability of expert judgement, replicability and overall robustness. Practitioners operating within foresight-driven governance and planning can be more responsive to such assessments. Finally, goals of the assessment and conceptual approach to vulnerability have implications for the suitability of assessment results to an existing adaptation format (stand-alone strategy or integrated into overall planning). For example, the results of assessments identifying vulnerability causes and development pathways can be better integrated into urban planning and development. Similarly, assessments identifying hot spots of vulnerability and/or adaptation measures provide inputs for stand-alone adaptation strategies. Adaptation that is intended to be integrated into multiple sectors of urban planning requires a systemic approach and would benefit from a foresight-driven vulnerability assessment based on complexity. Naturally, in practice there may be an overlap in governance modes presenting a mix of tools, thus this framework should be treated rather as a starting point than a strict delineation of choices.

Table 7. A framework for planning vulnerability assessments based on governance modes, assessment objectives, research paradigms and methodological approaches (adapted and distilled from Voros, 2007; Fuerth, 2009; Birkenholtz, 2012; Joakim et al., 2015).

	Forecast-based governance: strategic planning, predict and plan	**Foresight-based governance:** scenario planning, strategic planning, anticipatory governance
Research paradigms and epistemologies	Primarily rationalistic paradigms (positivistic, post-positivistic), objectivist epistemologies	Primarily subjectivist epistemologies, however, mixed methods and postpositivism are not excluded depending on the operationalization
Objectives of the assessment	Predicting vulnerability, identification of hot spots, planning adaptation, and prioritization of adaptation measures	Planning adaptation, investigating the causes of vulnerability and the socio-economic processes driving, preventing vulnerability
Conceptual approach to vulnerability	Vulnerability as a pre-existing condition, as a threshold, as an outcome	Vulnerability as a pre-existing condition, as a threshold, as an outcome
Assessment approaches	Primarily extensive approaches	Primarily intensive approaches, mixed methodologies in triangulation
Adaptation format	Primarily suitable for stand-alone strategies	Suitable for stand-alone strategies and especially for integrating into multiple sectors of urban planning due to systems approach

6 DISCUSSION

6.1 MAIN CONTRIBUTIONS TO THE LITERATURE AND WAYS FORWARD

6.1.1 UNDERSTANDING URBAN VULNERABILITY DYNAMICS

This thesis makes *a conceptual contribution* to (urban) vulnerability and adaptation literature by enhancing the understanding of urban vulnerability dynamics as a phenomenon (RQ1), a gap identified as pertinent in multiple studies and in IPCC AR5 and IPCC SREX (Lavell et al., 2012; Oppenheimer et al., 2014; Dilling et al., 2015; Mcdowell et al., 2016; Ford et al., 2018).

First, having examined the state of the art in literature, I conclude that, although dynamics has been previously identified as a pertinent issue (Lavell et al., 2012; Hewitson et al., 2014; Oppenheimer et al., 2014), it has not been taken widely into account in sub-national assessments (Chapter I). This is in line with the previous studies by Dilling et al. (2015) and Mcdowell et al. (2016), and a more recent review by Ford et al. (2018). I also observe a temporal discrepancy in assessing future biophysical changes and current socio-economic state within the same assessment: only half of the future-oriented assessments considered the dynamics of either exposure or vulnerability (Chapter I). This thesis further contributes to the conceptual development of vulnerability assessments. Specifically, it accounts for dynamics by linking the conceptual approaches to vulnerability, as identified by Joakim et al. (2015) with methods to account for its dynamics, establishing a systematic understanding of vulnerability dynamics conceptualization and methodological operationalization. Additionally, I have identified numerous challenges in assessing vulnerability dynamics. These include the lack of future-oriented socio-economic data at fine spatial scale, lack of conceptual and methodological development concerning vulnerability dynamics, and resource constraints (Chapter I).

Conceptualization matters not only for the methodology but also for the use and users of the outcome. Vulnerability thresholds help to identify priorities and decide on prevention measures. They are beneficial when one cannot know the timing of the event (like flood return periods) (Chapter I, Joakim et al. (2015). Vulnerability conceptualized as a pre-existing condition helps to look at the causes of vulnerability and prioritize sectors and measures for strengthening adaptive capacity. In vulnerability as an outcome, adaptation simulation/analysis is beneficial for the identification of adaptation measures and exploring their efficacy and net end-point

vulnerability (O'Brien et al., 2007). These differences should be taken into account when considering the use of the assessments results.

Second, this thesis explores vulnerability development as a process (see Section 2.2 on the difference between treating vulnerability dynamics as a process and as a snapshot of future state). Responding to RQ1, it identifies what constitutes urban vulnerability at the case study of Helsinki. More specifically, I identify the drivers of urban vulnerability, explore direct, indirect and cascading effects of socio-economic changes on future urban vulnerability and reconstruct pathways of its development (Chapter III). The results go in line with earlier and more recent studies suggesting that the drivers are in constant dynamic interaction and thus, the impacts on vulnerability can be direct, indirect and cascading, and outcomes can vary (Ruth & Coelho, 2007; Bennett et al., 2016; Räsänen et al., 2016; Naylor et al., 2020; Lede et al., 2021). Driver scales have been previously mentioned in literature (see e.g. O'Brien et al. (2004) but the implications of different levels of jurisdiction of drivers and risk management options have not been studied widely empirically. The results of this thesis place the case city in a cross-scale context and provide further ground on evaluating and planning options on risk management and vulnerability reduction, depending on the driver levels. This is especially pertinent to consider from the perspective of vertical adaptation mainstreaming, taking into account national and local scales, mandates, and resource allocation.

6.1.2 METHODOLOGICAL DEVELOPMENT

This thesis provides a *methodological contribution* to vulnerability and adaptation (RQ2), as called for by previous research (Cardona et al., 2012; Hewitson et al., 2014; Mcdowell et al., 2016). The methodological gap is mainly related to the underdevelopment of methods and lack or absence of suitable data to account for the dynamics of urban vulnerability (Chapter I). The first contribution here lies in systematizing conceptual approaches to vulnerability with the methods to include dynamics (Chapter I). The main methodological contribution is the novel mixed methods approach that integrates qualitative, quantitative and participatory methods (Chapter III). Overall, intensive approaches to vulnerability assessments are not common (Chapter I, see, e.g. Angell & Stokke, 2014). Scenarios are commonly used in future-oriented vulnerability assessments (Chapter I, see, e.g. Carter, 2018), and PPGIS tools have been used in vulnerability assessments (see e.g. Cavan et al., 2010; Cavan & Kingston, 2012). The approach presented here combines scenario work and participatory mapping in a map-based survey, executed during a stakeholder workshop.

As for the data-related obstacles, specifically future socio-economic data at local scale, there are several ways to overcome it. One way is to downscale global or macro-regional socio-economic scenarios (van Ruijven et al., 2014; Viguié et al., 2014). Shared Socio-Economic Pathways (SSPs) are one of the most commonly used tools in assessing future vulnerability (O'Neill et al., 2014), although they have been criticized for the neglect of the local context (van Ruijven et al., 2014). SSPs have also been extended for the regional level (e.g. EUSSPs) (Rohat, 2018; Kok et al., 2019). This thesis, however, took a different approach. Instead of top-down downscaling, it takes a bottom-up approach (Birkmann et al., 2015) and uses locally developed scenarios to examine changes at the city level or finer, while placing the city into a multi-scale context. In this way, this thesis also responds to the criticism of neglecting cross-scale interactions, expressed by Ford et al. (2018).

The use of intensive methods in this study allows for a deep examination of different facets of vulnerability, and deepens the understanding of how socio-economic processes work in a particular case and the patterns they create (Birkenholtz, 2012). More specifically, the qualitative analysis of scenarios in conjunction with the maps allowed the identification of socio-economic drivers and the changes they cause in vulnerability indicators, as well as the reconstruction of the pathways of vulnerability development. The integration of extensive methods by using spatial statistics was conducted to identify and analyse spatial patterns of indicator changes, motivated by the triangulation for complementarity, study development and expansion (expanding the breadth of inquiry by using different methods for different inquiry components), probing a new dataset, facilitating the thickness and richness of data, augmenting interpretation and seeking for corroboration for the data and qualitative analysis (Greene et al., 1989; Morse, 1991; Sechrest & Sidani, 1995; Collins et al., 2006; Birkenholtz, 2012; Morgan, 2019). Building on this, I see several possibilities to develop and complement the methodology. First, the drivers and change patterns identified provide variables and mechanisms for inputs in further exercises, e.g. for vulnerability threshold simulations (as in Veerbeek & Husson, 2013), adaptation simulation or adaptation policy analysis (e.g. reducing future social inequality). This enables the conceptualization of vulnerability in other ways (as a threshold and as an outcome) and thus tailors the assessment to specific urban planning needs, responding to the need for tailored climate and non-climate services (Kirchhoff et al., 2013; Cortekar et al., 2016; Lourenço et al., 2016; Lemos et al., 2018), while increasing the potential for the uptake of information (Ford et al., 2018). Moreover, the identified drivers and mechanisms provide inputs for vulnerability modelling and simulation of separate indicators and proxies, the purpose of which would be to explore causal links between drivers and changes, as well as to increase the robustness of the mixed methods approach (Birkenholtz, 2012). Overall, I suggest that more empirical and methodological MMR studies should be conducted to deepen our

understanding of vulnerability development and its implications for urban development.

6.1.3 URBAN VULNERABILITY DYNAMICS IN ADAPTATION GOVERNANCE

Finally, this thesis explores the local adaptation governance context and an overall place of vulnerability dynamics in adaptation governance (RQ3). The case study results of adaptation status in Finnish municipalities reveal that local adaptation planning has been quite modest so far (Chapter II), albeit progress can be observed (Parviainen, 2015). Our findings show that adaptation in Finnish municipalities is rather fragmented. Earlier (e.g. Juhola et al., 2012; Parviainen, 2015) and later (Pilli-Sihvola et al., 2018b) studies confirm this as an existing issue. There is a number of possible reasons for this. For example, in a study prior to the adoption of the updated national climate change adaptation plan in 2014 (Finland's National Climate Change Adaptation Plan 2022), Juhola et al. (2012) pointed out that prior local adaptation has been based on individual projects, dependent on external funding, and lacking national steering. The mid-term evaluation of plan implementation suggests that coordination between local operators should be improved, roles and responsibilities clarified, and sector-specific guidance is needed (Mäkinen et al., 2019). Climate risk management has been mainly carried out by rescue services, and partly by the environmental and technical departments (Chapter II), indicating that so far vertical mainstreaming has been more successful than horizontal. This could be possibly explained by a certain divide between DRM and CCA in the Finnish context (Pilli-Sihvola et al., 2018b). This is evident in the emphasis of rescue services and technical departments on climate risk management with DRM focus, while adaptation planning and mainstreaming has been most developed in spatial planning (Pilli-Sihvola et al., 2018b). Still, Pilli-Sihvola et al., (2018b) point out that other priorities (e.g. housing targets) come into question and hinder adaptation mainstreaming. Additionally, Finland is a Nordic welfare state with an overall high adaptive capacity, well-functioning institutions, prioritized well-being of residents, and currently low vulnerabilities, which may explain why adaptation is approached more from the risk management perspective (Pilli-Sihvola et al., 2018b). However, future vulnerability here is a pertinent issue for both research and adaptation/risk management, considering the socio-economic changes (Chapter III), the estimate that projected temperature increase in Finland is higher than global average in the future (Ruosteenoja et al., 2013; Mäkelä et al., 2016), and a threat of inaction and complacency as a consequence of a current low risk situation (O'Brien et al., 2006; Johannessen & Hahn, 2013). With that in mind, in the long-term it is

beneficial to mainstream adaptation also horizontally, in addition to vertical mainstreaming, which means that adaptation should be integrated into all sectors of planning (Rauken et al., 2015).

The need for horizontal mainstreaming has its prerequisites for climate services. The case study results show that the practitioners have sufficient climate information (Chapter II). Most used sources of information are long-term climate forecasts by the Finnish Meteorological Institute, and different Internet sources of climate information and impact modelling. This highlights the prevalence of biophysical information in climate risk and adaptation, an issue that has long been a concern in the vulnerability research community (Ford & Pearce, 2010; Ford et al., 2018). In the follow-up workshop, the participants highlighted that assessment of vulnerability and impacts is more meaningful to ensure citizens' well-being than the assessment of the cause and biophysical implications of climate change; however, in practice, they often get too little attention (Chapter II). While the practitioners are naturally aware of the location of people and assets and of the socio-economic characteristics of the population, there is a need for this information to be explicitly linked to risk and vulnerability. Also, information on how to use such services in risk management and local planning, is necessary, indicating a wider need for non-climate services and capacity building, in addition to climate services (Chapter II). These results are in line with previous findings, suggesting that there is a need to move from supply-driven climate services towards tailored demand-driven non-climate services, i.e. translating risk information into actionable information for adaptation and urban planning (Goosen et al., 2014; Lourenço et al., 2016).

This need becomes more apparent from the point of view of horizontal mainstreaming, and it involves other sectors in addition to rescue services, and environmental and technical departments. Vulnerability and risk assessments can approach this in two complementary ways. First, modelling or assessment of impacts for all sectors of urban planning (including but not limited to housing, social services, healthcare) can help with the identification of adaptation needs and their prioritization. Second, the assessments that trace the root causes of vulnerability and risk, based on complexity and systems approach, can provide information necessary for horizontal mainstreaming with a preventative approach.

In 2017, Helsinki adopted an adaptation strategy for 2017-2025. It is meant to be integrated into all sectors of urban planning, indicating horizontal mainstreaming of adaptation (Helsingin kaupunki, 2017). The mixed methods approach developed in this thesis is designed to respond to that need. Specifically, the vulnerability development pathways (Chapter III) provide insights for strategic planning in such sectors as social and health care, building and construction, housing, rescue services, safety and preparedness, infrastructure as well as environment and adaptation planning.

Finally, I explore the epistemological positioning of vulnerability assessments from the perspective of use in different governance modes. So far,

this discussion has been fairly limited, and almost entirely absent with regards to the assessments of future vulnerability. The few examples include studies by O'Brien et al. (2007), Birkenholtz (2012), Carr & Owusu-Daaku (2016) and Nightingale (2016). I see this as a pertinent issue to discuss, especially with regards to future vulnerability and vulnerability dynamics, since there are methodological and conceptual challenges associated with it (Chapter I), and there is a need for new approaches or the development of less used or untypical assessment approaches (Chapter I, Nightingale, 2016). The results of the methodology application (Chapter III) and critical appraisal of the approach (Chapter IV) support the call to use hybrid methodologies and plural epistemologies expressed by Birkenholtz (2012) and Nightingale (2016), and the need to re-engage with the foundations of vulnerability research expressed by Ford et al., (2018).

6.2 BROADER MESSAGE AND FUTURE RESEARCH DIRECTIONS

Overall, there is a broader need for the vulnerability assessment scholarship to engage more with the philosophical foundations of vulnerability, as also urged by Ford et al., (2018). This thesis brings forward the discussion on the epistemology of future vulnerability (assessments), a topic that has not gained much attention despite the ambiguous nature of vulnerability and a noticeable shift from purely natural science-based approaches towards social sciences and a pluralistic perspective (Birkenholtz, 2012; Nightingale, 2016). The need for future-oriented assessments (Cardona et al., 2012; Oppenheimer et al., 2014; Dilling et al., 2015; Ford et al., 2018), and, as a consequence, the need to apply methods from futures research, puts pressure on the scientific community to develop untypical approaches and methods to vulnerability assessments. I agree with the proposition by Nightingale (2016) and Birkenholtz (2012) to explore plural epistemological and hybrid methodological approaches to the assessments with the aim to deepen the understanding of the phenomenon and to provide more generalizable results. The results of Chapter III of this thesis demonstrate the depth of the investigation of the root causes of vulnerability achieved within an epistemologically plural study with mixed methods, something that more typical (e.g. index-based quantitative) studies are not able to deliver (Birkenholtz, 2012; Chapter IV). More empirical studies using intensive and mixed methods are needed to explore vulnerability pathways and gather a larger evidence base. More specifically, vulnerability assessment literature and practice would benefit from the use of mixed methods with different epistemological and methodological entry points to aim for convergence or complementarity triangulation, the final objective being not to provide the same results but rather to open different facets to the phenomenon in question

(Greene et al., 1989; Johnson & Onwuegbuzie, 2004; Birkenholtz, 2012; Nightingale, 2016; Johnson, 2017).

The other critical issue in vulnerability assessment scholarship is the neglect of the institutional context for the intended use of the assessment results. Empirical assessments should engage with the analysis of governance modes, adaptation planning and mainstreaming, and with building a complex picture of a dynamic system that a city is (see e.g. Naylor et al., (2020) in order to improve the result uptake and avoid functionalism (Wellstead et al., 2013; Wellstead et al., 2017; Ford et al., 2018). This is, however, rarely the case (Chapter I, Ford et al., (2018). This presupposes the consideration of cross-scale interactions, the identification of the levels of vulnerability drivers, the inclusion of all sectors of (urban) planning as well as building a systematic understanding of direct, indirect and cascading effects of socio-economic changes within the city and outside. It has been observed that the neglect of cross-scale interactions can impede the uptake of assessment results and mainstreaming of adaptation, both vertically and horizontally, as there can be, for example, conflicts in resource prioritization, sectoral agendas and national and municipal jurisdictions (Koks et al., 2014; Rauken et al., 2015; Ford et al., 2018; Landauer et al., 2019). Similarly, the analysis of institutional context should be integral to vulnerability and risk assessments, at least in the assessment design stage, as different conceptualizations, and epistemological and methodological choices have implications for the result uptake in difference governance modes and adaptation formats (Chapter IV). For example, rationalistic or 'predict and plan' governance mode is less receptive to the results of non-evidential research, whereas anticipatory governance is more receptive to various types of knowledge. The results of the qualitative study should not be utilised in a fixed plan without creating flexible implementation and monitoring mechanisms, but should instead be used in other instruments of planning, for example, in no-regrets strategies or flexible plans (Fuerth, 2009; Quay, 2010). To improve the usability and uptake of assessment results, climate risk and vulnerability assessment scholarship would benefit from insights from other fields, including but not limited to public policy, planning, and futures research (Volkery & Ribeiro, 2009; Haasnoot & Middelkoop, 2012; Wellstead et al., 2017).

7 CONCLUSIONS

This thesis explores vulnerability dynamics theoretically and conceptually, advances methodological approaches to account for it as well as studies the implications of such knowledge for the adaptation governance and urban planning. Vulnerability dynamics means a range of change in vulnerability, both temporally and spatially. The empirical results of this thesis show that it is driven by a multitude of interconnected socio-economic drivers, changes in which have direct, indirect and cascading effects on vulnerability development. Accounting for vulnerability dynamics methodologically requires engaging with the foundations of vulnerability and futures research and drawing on futures research methods. The results of such assessments differ from more common assessments based on quantitative projections, and should be treated differently. For the adaptation governance and urban planning this means expanding governance modes towards more flexible tools and approaches compared to the use of predictions as well as using non-climate services in addition to climate services. Below, I will elaborate in more detail on the theoretical, methodological, and practical contributions of this thesis to vulnerability and its assessment scholarships, as well as to adaptation governance.

The theoretical contribution of this thesis lies in the conceptual clarification of what constitutes vulnerability dynamics and the exploration of the epistemological foundations of future-oriented vulnerability assessments. I treat vulnerability dynamics as a process, analyse the factors driving it, as well as examine the direct, indirect and cascading effects of socio-economic changes on future vulnerability. I engage with the epistemological foundations of future-oriented vulnerability assessments, and, by linking them with futures and governance paradigms, propose a framework for epistemological positioning of vulnerability assessments from the perspectives of use in governance and planning – depending on the aim of the assessment, vulnerability conceptualization, governance mode and adaptation format.

This thesis explores the existing methodological base to account for vulnerability dynamics. The findings clearly show that despite the long-standing criticism of vulnerability being perceived as a static phenomenon, vulnerability dynamics is not accounted for enough in empirical assessments. The main barriers to it are related to data, underdevelopment of methods, and overall lack of understanding of dynamics as a phenomenon. In this thesis, I provide a methodological contribution to vulnerability assessment scholarship and adaptation practice by developing a novel mixed methods approach to account for urban vulnerability dynamics, overcoming the data gaps by using expert opinion. The approach draws on futures research methods, is driven by foresight and takes into account the complexity of urban futures.

Epistemologically, this knowledge is different from common quantitative assessments utilizing projections or modelling, and thus needs to be utilized in governance and planning differently, for example, in flexible planning tools and strategies.

The practical contribution of the thesis lies in the results of the empirical case study and in the approach application in general. The results of the case study draw connections between vulnerability pathways and sectors of urban development and adaptation governance, providing insights on anticipatory measures to prevent vulnerability. Scoping the status of local level adaptation and management in Finland has revealed that practitioners need non-climate information – information on vulnerability and exposure, as well as guidance on how this information can be used in local adaptation planning and governance. The mixed methods approach developed in this thesis can be used as part of non-climate services to support local actors in adaptation planning and risk management.

On a concluding note, I argue that we need a thorough re-thinking of our cognitive and applied approaches to vulnerability, assessments and their use. More specifically, this implies a shift towards a higher level of inclusion of social sciences, re-engaging with the foundations of vulnerability research and closer collaboration with other research fields, including but not limited to public policy, governance, and futures research. I suggest that we need unconventional ways of thinking about vulnerability, moving away from functional assessment-action-implementation approaches towards flexible and dynamic governance (Haasnoot et al., 2013), and using a multitude of methods to gain the most comprehensive picture of the future upon which we can act now. These thoughts are reflected in Chapters III and IV, and recent studies indicate progress in this direction (Birkenholtz, 2012; Haasnoot et al., 2013; Dilling et al., 2015; Nightingale, 2016; Wellstead et al., 2017; Ford et al., 2018), but much more needs to be done to further it also empirically. Moreover, I propose that it is upon the research community to induce not only a shift in approaching vulnerability in science, but also to induce a shift in the practice community by supplying also other types of data than typical index maps and projections. More importantly, vulnerability research should supply tailored information on how to use these services, including the information on the types of measures, mechanisms and procedures that can be planned based on these assessments, while taking into account flexibility and complexity of urban adaptation governance and planning.

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