Department of Real Estate, Planning and Geoinformatics

Are the Right Actors Taking the Right Action?

Climate Change Management in Finnish Urban Housing

Riikka Kyrö

Aalto University

DOCTORAL DISSERTATIONS

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Abstract

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Abstract

Anthropogenic climate change is one of the most severe environmental challenges facing the planet today, and it is certainly one of the most debated. The built environment is a known major culprit, and cities as consumption centers account for a large share of the world's consumption-based carbon footprint. It may well be argued that urban communities are at the very core of the climate change problem.

The five individual studies included in the dissertation provide an understanding of the most significant urban activities generating GHG emissions, and the potential of different actions and actors to mitigate them. The research was conducted on three different scales addressing the issue from the viewpoint of individual city dwellers, urban housing companies, and finally, cities. For an individual city dweller, some 40% of the carbon footprint was found to derive from housing related activities, indicating a need to further study the impact of urban housing. The results on the housing company scale showed that, in the context of multi-family housing, occupant behavior has only limited influence on the overall energy consumption and consequent carbon footprint. Instead, housing managers who are responsible for the most significant source of GHG emissions, the heating system, appeared more influential. It was further discovered that housing managers' attitudes and practices differ, and that the differences affect the carbon footprint.

The dissertation argues that the social constructiveness of the climate change issue should be acknowledged and considered in planning for mitigation action. More attention should be paid to the management and motivation of individuals, particularly on the housing manager and individual city dweller level. On the policy maker level, while ensuring prompt action, a vigorous attempt to establish the true effects of the action should be maintained.

The research concludes that no single action or actor will suffice in mitigating the climate change impact of urban communities. Within the context of urban communities, it would be of essence to improve interaction between the three studies scales (Individual – Housing Company – City). This would in turn require enhancing communication between the three identified decision makers (City Dweller – Manager – Policy maker) acting on said scales.

Keywords carbon footprint, life-cycle assessment (LCA), climate change management, mitigation action, urban communities, housing

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Tiivistelmä

Ihmisen aiheuttama ilmaston lämpeneminen on yksi aikamme suurimmista ja kiistanalaisimmista ympäristöongelmista. Vaikka haaste on globaali, paikalliset toimet ovat välttämättömiä. Rakennettu ympäristö, erityisesti kaupungit kulutuskeskittyminä ovat ilmastonmuutoksen torjunnassa keskeisessä roolissa.

Tämän väitöskirjatutkimuksen tavoitteena on ollut selvittää mahdollisuuksia ilmastonmuutoksen torjuntaan kaupunkimaisessa ympäristössä. Tutkimuksessa tarkasteltiin tapaustutkimuksin kolmea eri kaupunkiympäristön tasoa: yksittäistä asukasta, taloyhtiötä ja kaupunkia. Tutkimuksessa on hyödynnetty ja kehitetty hybridi-pohjaista elinkaarilaskentamenetelmää hiilijalanjälkien mitallistamiseen. Lisäksi tutkimuksessa on käytetty laadullista aineistoa, kuten tapaustutkimuskohteina olleiden taloyhtiöiden isännöitsijöiden haastatteluja.

Tutkimuksessa nousi esiin, että ilmastonmuutoksen sosiaalinen ulottuvuus tulisi ottaa huomioon torjuntatoimia suunnitellessa. Etenkin taloyhtiöissä tulisi kiinnittää enemmän huomiota yksittäisten toimijoiden, kuten isännöitsijöiden johtamiseen ja motivointiin. Kaupungin päättävällä tasolla tulisi varmistaa, että vaikka lyhyen aikavälin tavoitteet pakottavat nopeaan toimintaan, tulisi toimien todelliset ilmastovaikutukset ensin selvittää. Tutkimus osoittaa myös, etteivät kaupunkien nykyiset ilmastonmuutosstrategiat sovellu lyhyen tähtäimen tavoitteiden saavuttamiseen.

Tutkimuksen johtopäätös on, ettei yksikään toimija tai toimi ole yksinään riittävä ilmastonmuutoksen torjunnassa. Lisäksi vaikuttaa siltä, että esteet tehokkaalle torjunnalle liittyvät enemmän toimijoiden ja toimien ohjaamiseen, kuin teknologisiin rajoituksiin. Kaupunkiympäristön eri tasojen toimijat omaavat vaihtelevantasoista tietoa ja ilmasto-osaamista. Niin yksityistä kulutusta, isännöintikäytäntöjä kuin kaupunkitason päätöksentekoakin tulisi ohjata ilmastonmuutoksen kannalta kestävämpään suuntaan, esimerkiksi tarjoamalla luotettavaa tietoa eri toimien ilmastovaikutuksista helposti ymmärrettävässä muodossa.

Avainsanat hiilijalanjälki, elinkaarianalyysi, ilmastonmuutoksen hallinta, torjunta, asuminen

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As the climate negotiations in Doha have recently ended, with somewhat disappointing results, it is both exciting and a little depressing to realize you have touched such a topical global issue which is far from being solved. The climate change implications of urban housing deserve attention, and this research is but a small contribution to the field - albeit a huge personal project for myself.

It is safe to say I would not be writing this now if it was not for one of my dearest friends, Dr. Saija Toivonen, who recruited me to my first research project almost four years ago. Professor, Head of Department Kauko Viitanen was kind enough to hire me back then, and took me back under his wings last summer when my dissertation research came close to an end. I want to thank you both.

I am grateful to my pre-examiners, Associate Professors Thomas Olofsson, and Susanne Balselev Nielsen for their valuable comments, which greatly improved this dissertation summary. I also wish to thank Associate Professor Henrikke Baumann for first welcoming me to the industrial ecology research community, and now agreeing to act as my opponent.

Professor Seppo Junnila has been an encouraging supervisor, and, as a blessing to me, one who is genuinely enthusiastic about my research topic. As an ambitious and active publisher he has set an example for his entire team to pursue publications in quality journals and conferences. All research papers included in this dissertation have been prepared in excellent collaboration with other researchers in Professor Junnila's team. I am indebted to my hardworking co-authors Antti Säynäjoki, Jessica Karhu, and Dr. Matti Kuronen. Thanks are likewise due to Eeva Määttänen and Tuuli Luoma, not only for their professional help with my work, but for the friendship and emotional support I have experienced. In fact, all past and present colleagues at the department of Real Estate, Planning and Geoinformatics have always helped me with everything I have ever thought of asking, for which I am very grateful.

Of all my colleagues, however, the greatest amount of gratitude is directed at Dr. Jukka Heinonen, who has been my strongest ally, if also my biggest critic, in this whole process. I consider it a rare privilege having had the opportunity to work with someone who often knows what is on your mind merely by looking at you, and can finish your sentences for you – even though it can also be really annoying. Jukka, it would not have been possible to finish this work within this timeframe without our seamless collaboration and joint disregard for regular working hours, so thank you.

Without a doubt one of the most rewarding features in working at a research facility is the possibility to present your own work to the international research community - and of course the associated travel. As a self-proclaimed globetrotter I have felt particularly lucky when taking part in key conferences in different exotic locations around the world. Thanks are due to all my travel buddies, and people I have had the pleasure to meet. The travels have not only introduced me to my international colleagues, but to three new continents and six new countries, and created some of the greatest memories of my life. I have also made acquaintance with the respective beer cultures of the places I have visited, which has turned me into a microbrew enthusiast.

And with that awkward transition to brewing products, I have to say this: no matter how much you enjoy your work, you need something to balance it all out. I would like to jointly thank all my amazing friends, old and new, for bearing with me during this lengthy process, and reminding me to live, love, and laugh. And to dance, most of all, to dance!

I am grateful to and for my six beautiful godchildren, Ainuliina, Topi, Veini, Ville, Lilja and Veikka, who keep asking me the truly important questions in life (the answer is Team Jacob). My infinitely wise older sister Katja, besides giving me four of those precious godchildren, has always supported me, while still maintaining what big sisters do best: keeping me from thinking too highly of myself. As a psychologist she has readily provided diagnoses for all my quirky behavior, for which I am mildly appreciative. I am most grateful to my mother for being the only one in the family with any common sense. Thank you Mom, for always making sure the rest of us had food on our table, clothes on our back and a roof over our heads.

In the end, the person I owe the most with regard to this dissertation project is my father, Research Professor Esko Kyrö. His life's work with a global environmental problem has been an inspiration to my own research. What is more, spending time at those moldy research labs growing up has made me feel right at home at the moldy research labs at my own university. My father defended his dissertation thesis 32 years ago, almost to date, when I was only a few months old. Now, having recently retired from his research career, I hope he finds joy in witnessing one landmark in mine. It goes without saying this work is dedicated to you, Dad.

Home and far away
December 2012 - January 2013

Riikka

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List of appended papers

This dissertation of Doctor of Science in Technology comprises the following five scientific publications. The papers are referred to with Roman numerals (I-V) hereinafter.

Paper I: Heinonen, Jukka; Kyrö, Riikka; Junnila, Seppo (2011): Dense downtown living more carbon intense due to higher consumption: a case study of Helsinki, Environmental Research Letters, 6, 034034.

Paper II: Kyrö, Riikka, Heinonen, Jukka; Säynäjoki, Antti; Junnila, Seppo (2011): Occupants have little influence on the overall energy consumption in district heated apartment buildings, Energy and Buildings, 43, 3484–3490.

Paper III: Kyrö, Riikka, Heinonen, Jukka; Junnila, Seppo (2012): Housing managers key to reducing the climate impact of housing companies? A mixed method approach, Building and Environment, 56, 203-210.

Paper IV: Kyrö, Riikka; Karhu Jessica; Kuronen, Matti, Junnila, Seppo (2012): Generating low-energy alternatives for neighborhood-scale urban residential refurbishment through occupant involvement, Proceedings of the CIBW070 Conference, January 2012, Cape Town, South Africa.

Paper V: Kyrö, Riikka; Heinonen, Jukka; Säynäjoki, Antti; Junnila, Seppo (2012): Assessing the Potential of Climate Change Mitigation Actions in Three Different City Types in Finland, Sustainability, 4(7), 1510-1524.

Journal Impact Factors (2011)

Journal	ISI IF*	SCOPUS SJR/SNIP**
Environmental Research Letters	3.631	0.152/1.416
Energy and Buildings	2.386	0.080/3.105
Building and Environment	2.400	0.080/2.609
Sustainability	not listed	0.026/0.107

*IF: Journal Citation Report Impact Factor
**SNIP/SJR: SCImago Journal Rank / Source Normalized Impact per Paper

Author's contribution to the papers

The contribution of the author of this dissertation to the appended research papers I-V is outlined below.

Paper I: The author is mainly responsible for writing the paper. The first author initiated the paper, conducted the quantitative assessment, and contributed to writing parts of the paper.

Paper II: The author is responsible for initiating and writing the paper, and participated in conducting the quantitative assessment.

Paper III: The author is responsible for initiating and writing the paper, and participated in conducting the quantitative assessment.

Paper IV: The author is responsible for developing and writing the paper. The second and third author collected the data and contributed to writing portions of the paper.

Paper V: The author is responsible for writing the paper, and participated in conducting the quantitative assessments.

Table of contents

1. Introduction

> Unfortunately, humanity's behavior remains utterly inappropriate for dealing with the potentially lethal fallout from a combination of increasingly rapid technological evolution matched with very slow ethical-social evolution. The human ability to do has vastly outstripped the ability to understand.
> -Brundtland et al. 2012[1]

Anthropogenic climate change is one of the most severe environmental challenges facing the planet today, and it is certainly one of the most debated. Much of the debate is due to political and economic implications associated with climate change mitigation, which ultimately will require deserting the current fossil fuel dependency. Greenhouse gas (GHG) emissions, such as carbon dioxide (CO_2) derived from the burning of fossil fuels, are one of the main causes for climate change. While the detrimental impacts of human action on the environment have been a growing concern for the general public ever since Rachel Carson's Silent Spring was first published in 1962 (Carson 2002), climate change represents a new, globalized phase of environmental problems. Unlike many local environmental problems, greenhouse gas emissions are impossible to perceive with the naked eye, and this abstractness has likely contributed to the lack of concern and adequate action. From a strictly scientific perspective the issue is more straightforward, given that an enormous amount of evidence on the causes and consequences human induced global warming exist, along with evidence on the availability of potential solutions (e.g. (Rockström et al. 2009).

Urbanization brings along numerous challenges associated with the climate change. As cities strive to grow in population, and by increasing population density, severe problems with urban growth materialize. Cities are major consumption centers, and the built environment is one of the main sources of GHG emissions globally (UNEP 2012). It may well be

[1] From a recent Blue Planet Price awarded report entitled "Environment and Development Challenges: The Imperative to Act" dated February 2012.

argued that urban environments are at the very core of the climate change problem (Guy 2006). Consequently, cities and urban municipalities are also important actors in climate change mitigation. Local policy interventions are necessary to tackle the global challenge of climate change. Accordingly, many cities have already taken on the challenge by implementing ambitious mitigation strategies. Unfortunately, ambitious short term goals may lead to unwise decisions as rapid action needs to be taken and the effects of the actions are not always fully understood.

Carbon leakage through relocating GHG heavy industries outside national borders is a common phenomenon in the modern Western world. Besides being problematic from the environmental viewpoint due to less stringent legislation in developing countries, the issue can also be viewed as an ethical dilemma as it is essentially emissions import, and may lead to unjust allocation of global GHG emissions. A consumption perspective to GHG emissions allocates all life-cycle emissions to the actual consumer regardless of the geographical location of the emission source (Ramaswami et al. 2008; Sovacool & Brown 2010; Schulz 2010; Satterthwaite 2008). Emissions calculated using the consumption based approach often exceed emissions reported in traditional national GHG accounts in Western countries (Bin & Dowlatabadi 2005), demonstrating the importance of carbon leakage. Another, less recognized form of carbon leakage occurs within countries when locating heavy industries outside cities. To avoid bias caused by carbon leakage, all quantitative assessments included in this dissertation employ a holistic consumption based life cycle approach with a global perspective.

Sustainability is viewed as defined by the Brundtland commission in 1987 in Our Common Future (Brundtland 1987), as development that meets current needs without compromising the needs of future generations. The focus of research is on ecological sustainability, and within ecological sustainability, on energy use and climate change. Notwithstanding, social sustainability, when understood not in the sense of meeting the needs of humans, but rather in the sense that human actors and actions are included in the sustainability assessment, is also addressed.

Several scholars have argued the need for an actor perspective in conducting environmental assessments (e.g. Heiskanen 1999; Baumann ym. 2011), and this approach is supported by the findings of this dissertation. In fact, one of the main arguments of the dissertation is that the social constructiveness of the climate change issue should be considered in planning for urban mitigation action. *Actors* in this dissertation are the different stakeholders, acting in different roles in urban communities, while *action* refers to climate change mitigation measures. The dissertation

argues that more attention should be paid to management and motivation of individual actors, particularly on the housing manager or individual city dweller level. On the policy maker level, while ensuring prompt action, a vigorous attempt to establish the actual effects on GHG emissions resulting from the action should be maintained.

The study is positioned between a number of different research fields. The context of the dissertation is the built environment. More specifically, the research addresses place-based *urban communities* as defined by e.g. Heiskanen et al. (Heiskanen et al. 2010). The theoretical frameworks most relevant to the dissertation are life cycle assessment (LCA), and the social dimension of environmental assessments. The theoretical background for the dissertation is discussed in the following subchapter.

1.1 Theoretical background

Life-cycle assessment (LCA) is one of the most popular methods of environmental assessments. The SETAC LCA Code of Practice sees life cycle assessment as a tool to provide decision makers information on environmental implications of a certain product or process (Consoli et al. 1993). The benefits of LCAs over other means of environmental assessments include the holistic nature of the assessment (Crawford 2011) and the possibility to evaluate various impact categories over a longer period of time (Baumann 1998).

Certain forms of environmental LCA have been used since the 1960s; however, the approach only gained extensive popularity as late as in the 1990s. At that time, concern was expressed on the scientific validity of the approach. Hence, a desire to create a uniform standard for the assessments emerged (Heiskanen 2002). An international ISO standard was developed for LCA to provide a common global framework for the assessments. The current ISO standard 14040 dates from 1997 and serves as a framework for evaluating the environmental impacts from products, processes, and services throughout their life-cycle (Consoli et al. 1993).

LCAs can and have been applied for numerous different types of products and services. The scope and context in which the use of LCA is feasible has expanded over the years (Heiskanen 2002). Moreover, environmental impacts are no longer associated with only specific types of products, but every product, supply chain and service can be seen to have an environmental impact (Rosenblum et al. 2000), including buildings and other aspects of the built environment. In fact, LCA has been recognized as the best way to study the environmental impacts of buildings (Junnila 2004). Comparison of building materials is a common motivation for conducting building related LCAs (Crawford 2011). Two of the most typical

impact categories for building related LCAs are primary energy use and GHG emissions (Junnila 2004).

LCA studies of buildings and structures will inevitably differ from product LCAs. One obvious difference is that buildings have much longer life-cycles than most other products. While LCAs of buildings typically estimate the building life-cycle at around 50 years (Junnila 2004), buildings are well-known to outlive humans, expanding over several lifetimes. The longer life span brings along more uncertainties, as any unpredictable changes in the system will affect the results of the LCA. In particular, as the operational energy use forms the majority (an estimated 90%) of the life-cycle energy use and carbon footprint (Sartori & Hestnes 2007) derived from buildings, future changes in energy production modes brings along more uncertainties to LCAs of the built environment than for other types of products.

Accounting for the social, human dimension in sustainability assessments such as LCAs, has been identified essential by a number of researchers (Baumann 2004; Heiskanen 2002; Brunklaus 2008; Guy & Shove 2000; Jesper Ole Jensen 2012; Vermeulen 2006). An applied discipline addressing the issue has been referred to with such terms as, “sociology of nature” (Latour 2004) “sociology of technology, “sociology of buildings” (Guy & Shove 2000), “social construction of technology”, and “organizing and the environment” (Baumann 2004). The discipline emphasizes that science and technology, including and in particular environmental science and technology, is both socially and politically influenced. Flyvbjerg (Flyvbjerg 1992) views sustainability research more as practicing applied ethics than natural sciences. Bruno Latour argues that we cannot separate the social and political aspects of environmental problems from the “objective”, economic issues (Latour 2004). The energy-efficiency of buildings is a prime example of a practice shaped by social, political and commercial processes (Guy & Shove 2000).

Technology in general consists of material structures, physical artifacts, natural resources, organizations, and social structures (Jensen 2012). Consequently, environmental assessments, such as LCAs, have an inherent political aspect (Heiskanen 1997). Heiskanen (Heiskanen 1997) further suggests that environmental impacts are, in fact, “human constructs”. Therefore, also life-cycle assessments should be conducted using an actor’s perspective (Heiskanen 1997; Baumann et al. 2011). After all, environmental impacts are the result of human action, which should be managed (Brunklaus 2008). Guy (Guy 2006) suggests a paradigm of socio-technical research for studies of energy-efficiency, in which actors and their decision making are followed. Jensen et al. (Jensen 2012) call out the

current lack of connecting building users to the practice of sustainable buildings.

Contradictory to this widespread understanding within the research community, the social constructiveness of technology has traditionally been deemed insignificant (Shove 1998; Vermeulen 2006). The age-old difficulty in separating between the social and the natural world is accompanied with an inherent reluctance to cross boundaries (Guy 2006). This could be because the link between the techno-economical has been simpler to establish than the connection between technology and disciplines such as sociology or politics (Guy 2006). Current energy management strategies for example, are based on the technical elements, even though management should focus on changing human behavior. It is somehow trusted that calculating the cost savings of energy savings will be enough to lower energy consumption. The assumption expects rational, knowledgeable, and calculative behavior from building end-users. Vermeulen refers to this assumption as the "rational actor" assumption (Vermeulen 2006). However, attitudes and behavioral decisions are affected by more complex social processes (Guy 2006).

1.2 Structure of dissertation

The dissertation comprises this summary along with five appended research papers. The individual research papers of the dissertation all address and discuss the issue of climate change mitigation in an urban environment, but on different scales: individual city dwellers as consumers, neighborhoods with housing companies as the consuming entity, and cities. The papers are referred to in this summary with Roman numerals I-V, indicating both their chronological order and their place in the research process.

This summary is divided in to four sections. This first introductory section introduces the background for the research and provides insight into related research fields, which are used as a theoretical framework for this work. Furthermore, this section presents the research aims and along with the research process. The following Section 2 places the research within a methodological context and introduces the employed research methods. Section 3 then summarizes all five research Papers appended to this dissertation, with their main findings. The findings and contribution of the Papers are discussed further in Section 4, which also outlines the uncertainties and limitations related to the research. Finally, the last Section 5 concludes the dissertation with some final remarks and suggestions for future research.

1.3 Research aim

This dissertation addresses the topical problematic of climate change mitigation in urban communities. Among the goals of the research is establishing which urban activities contribute the most to city dwellers' carbon footprints, and identifying how much different commonly adopted mitigation actions actually influence the carbon footprint. The research also seeks to understand the role of different urban actors in climate change mitigation. **The overall research aim is to explore preferable means to mitigate climate change in an urban environment.** The research aim is divided into three separate, intertwined research questions (RQs) which tackle the problematic at three different scales of urban communities, with three different levels of decision making. First is the scale of an individual within a city; second, the scale of neighborhoods in the form of multi-family housing companies; and third, the scale of a larger urban community, a city. The subject of assessment can likewise be divided into three, based on the level of specificity: the overall carbon footprint, the more specific urban carbon footprint, and finally, energy consumption in urban housing.

The first research question is positioned on the scale of an individual city dweller. The RQ seeks to understand the magnitudes of urban consumption and is, as follows:

RQ1: How significantly do different urban consumption patterns contribute to the life-cycle carbon footprint?

The first research question explores the global carbon footprint of an average consumer from the city scale, and is addressed in Paper I. The first paper forms a foundation for the following two research questions so that the findings of Paper I act as a motivation for the next four Papers.

The second research question is in actuality the primary research question of the dissertation. It is positioned on the scale of urban housing, and reads:

RQ2: How do different actors influence the life-cycle carbon footprint of urban housing?

The second research question is explored in Papers II, III, and IV. Papers II and III assess quantitatively the annual carbon footprints of urban housing companies. The approach is considered relevant as nearly half of the Finnish population resides in housing organized as housing companies, the majority in urban areas. While all the activities of housing companies are included in the carbon footprint assessment, energy related activities, namely, heating and electricity, are taken into closer examination. Paper III also incorporates a qualitative assessment of housing management attitudes and practices. In fact, both Papers III and IV rely heavily on

qualitative data and methods in trying to understand the different roles of the different stakeholders in urban housing companies.

Having demonstrated the significance and challenges of efficient energy management on the housing company level, Paper V takes the issue back to the wider urban community level. As Paper IV makes clear that the role of city level policy makers is of importance in carbon management of urban housing, the third research question formulates into the following:

RQ3: How do common city promoted mitigation actions affect the life cycle carbon footprint of an average urban consumer?

The third research question is discussed in Paper V. Besides the differences in scale, Paper V addresses the problematic more from the action perspective, instead of an actor perspective.

The following table presents the research papers with their respective scales. Table I also denotes the research questions and indicates which papers have contributed to answering which research question.

TABLE I. PAPERS OF THE DISSERTATION WITH RESEARCH QUESTIONS

	Paper I	**Paper II**	**Paper III**	**Paper IV**	**Paper V**
Title	*Dense Downtown Living More Carbon Intense Due to Higher Consumption - Case Study of Helsinki*	*Occupants have little influence on the overall energy consumption in district heated apartment buildings*	*Housing managers key to reducing the climate impact of housing companies? A mixed method approach*	*Generating low-energy alternatives for neighborhood-scale urban residential refurbishment through occupant involvement*	*Assessing the Potential of Climate Change Mitigation Actions in Three Different City Types in Finland*
Focus of assessment	Individual within City	Housing Company	Housing Company	Housing Company	City
Addresses	RQ1	RQ2	RQ2	RQ2	RQ3

In summary, Paper I addresses the individual city dweller, while Papers II, III, and IV focuses on the housing company scale. Finally, the scale of larger urban communities, cities, is addressed Paper V. Despite the differences in scale, method, and data type, the papers all contribute to the general research aim described in the previous chapter. Summaries of all papers with the most significant findings are provided later in this summary in Section 4.

1.4 Research process

As indicated earlier, the dissertation is a compilation of peer-reviewed research papers which have been published in scientific publications. All papers benefit from the intense collaboration within the research group. The contribution of the author of this dissertation to each individual paper is outlined earlier on Page 3.

The research process was commenced in the summer of 2010, by gathering data and conducting quantitative carbon footprint assessments for the average consumer in Papers I, and several housing companies within the same neighborhood in Paper II. The process continued with a larger sample of housing companies for a quantitative assessment in Paper III during the summer of 2011. The housing manager interviews used as another major complimentary data source for Paper III took place in the fall months of 2011. Paper IV was initiated and written during late 2011, based both on previously collected data for Papers II and III, as well as ongoing occupant workshops. Finally, Paper V was initialized in late 2011 and completed in the spring of 2012. All in all, once the research process was started, it was carried out quite straightforwardly, albeit in various phases, within the course of little over two years from 2010 to 2012. The flow of the research process is depicted in Figure 1. The use of a flow chart captures the "inputs" and "outputs" of this dissertation in a descriptive manner, also demonstrating the timeline of the process, the connection between the different Papers, along with the emergence of the actor and action perspectives during the course of the study.

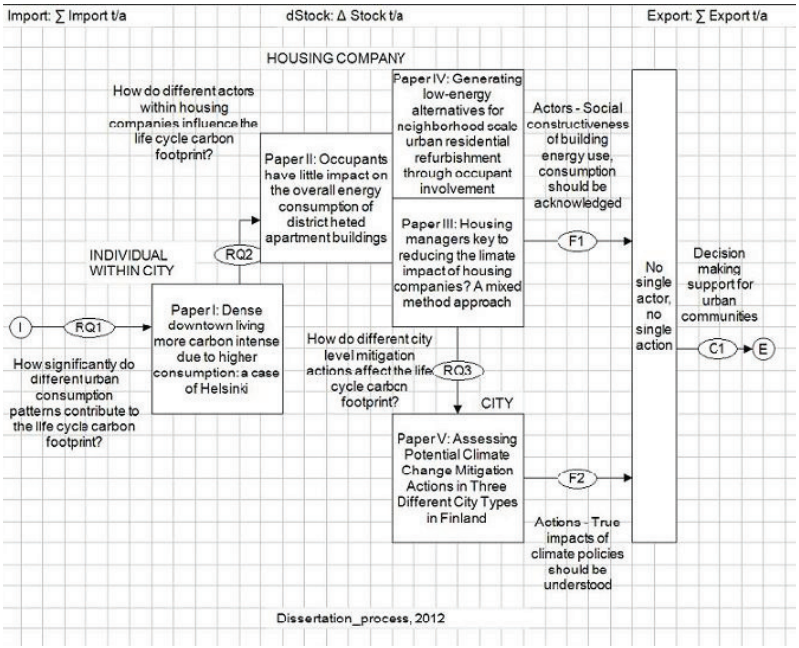

Figure 1. Research process flow

As illustrated in the research process flow, the research started out as a quantitative assessment of carbon footprints related to consumption - albeit with strong emphasis on qualitative interpretation of the results in Papers I and II. During the course of research it became obvious that a strictly techno-economical approach would not suffice, and research approaches

from social sciences and management studies were adopted. That said, to loosely quote Baumann in her 1998 dissertation (Baumann 1998): despite the best efforts to incorporate social sciences into this research, the work has been conducted in a school of engineering, by an engineer, and remains a technical assessment.

2. Research methodology and design

As the research questions address real-life phenomena, which are complex, uncertain, instable, unique and value-embedded (Creswell 2003, Schön 1983), a positivist research approach was not considered appropriate. The study is therefore conducted through the pragmatist worldview, following the epistemology of practice. Practice oriented research, which seeks to establish the consequences of action and more specifically, understanding and explaining the socially constructed phenomena under investigation (Creswell 2003), is in the core of this dissertation research. Context should never be ignored in practice based research, and both actor and structure should be considered (Flyvbjerg 1992).

Practical answers to the research problems and contributing to current practical knowledge were the main drivers for the research. Thus, in line with the pragmatist worldview, no theory or hypothesis was established for the study a priori, even though theoretical frameworks were used to locate the study within the relevant research realm. Furthermore, the conclusions made in the dissertation are not intended to form theories based on statistical generalization, but do provide analytic generalizations.

The chosen research methods reflect the pragmatist research approach, the related research frameworks, as well as the social constructiveness of the research problem. The interpretive paradigm is likewise supported by utilizing both qualitative and quantitative data, analysis and methods. The data and methods of assessment were mainly quantitative, while the interpretation of results was highly qualitative. According to Creswell (Creswell 2003), the pragmatist approach is well suited for using all available data, methods, and analysis. This dissertation is accordingly a combination of a qualitative and quantitative study, a so called hybrid or mixed method study.

2.1 Mixed method approach

A number of methodologists have suggested combining qualitative and quantitative methods to obtain a better understanding of the phenomenon

under study (Eisenhardt 1989; Miles & Huberman 1994; Yin 2003). Edmondson and McManus (Edmondson & Mcmanus 2007) introduce a contingency framework for promoting methodological fit (i.e. internal consistency of the research), particularly for management research. According to Edmondson and McManus methodological fit is best achieved by logical pairings of methods and the state of theory development. In other words, for a mature theory, quantitative testing is appropriate, while a nascent theory requires exploratory, qualitative research method and approach. For theories in their intermediate state, mixed methods are the preferred choice. The intermediate state can reasonably be attributed to the research subject of this dissertation. The use of solely quantitative methods would not have provided sufficient knowledge on the role of different actors while pure qualitative studies lack the reference point to actual GHG emissions that is essential in planning for mitigation action. The mixed method approach is most powerfully reflected in Paper III, which employs both the quantitative LCA and semi-constructed interviews.

While all of the research relies heavily on qualitative interpretation of the results, the bases for the findings of four of the five appended papers are based on a quantitative LCA assessment, and only Paper IV is a strictly qualitative study. The hybrid LCA model employed in the research papers is described in the following subchapter.

2.2 Hybrid LCA method

This dissertation employs an application of LCAs based on input-output-matrices. The input-output (IO) LCAs originate from economic IO assessments, first developed as early as the 1930s by Wassily Leontief (see e.g. Leontief 1986). The assessments were later expanded to cover issues beyond the economics, including environmental impacts, in the 1960s. Typical environmental impact categories included in the IO models comprise atmospheric emissions and energy use (Hendrickson et al. 2006).

The advantages of the consumption based IO LCA methods comprise allocation of emissions to the actual consumer of the service or product, independency of geographical location, and a wide system boundary with all upstream processes included in the assessment (e.g. (Suh et al. 2003; Hendrickson et al. 2006; Matthews et al. 2008; Crawford 2011). Furthermore, the IO LCA methods are generally easier and less time consuming to conduct than process based assessments, as they employ existing output tables (Lenzen 2000). The output tables have been calculated for different national economies. One distinctive deficiency of the method is that all products and production chains are assessed as if they were domestic (Bin & Dowlatabadi 2005). Another commonly

accepted weakness is the aggregation of the models due to the limited number of industry sectors included in the models (Lenzen 2000).

LCA studies of the built environment have successfully employed traditional process based LCAs (Junnila 2004). However, consumption based IO LCA models have proved especially suitable when assessing the environmental impact of the built environment (Crawford 2011). In particular, the comprehensiveness and extensive system boundaries allowed by IO LCAs complement the distinct nature of the built environment (Crawford 2011).

As indicated earlier, four of the five research papers in this dissertation tackle their respective research questions by employing a consumption-based, tiered hybrid IO LCA model for the assessment of carbon footprints. The IO LCA model used a basis for the employed models is the economic input-output LCA developed by the Carnegie-Mellon University (Hendrickson et al. 2006). Environmental impact categories included in the EIO-LCA comprise water use, energy use, GHG emissions and hazardous materials. For this study, a single impact category, namely, GHG emissions, was selected.

The EIO-LCA includes 428 industry sectors, making it the least aggregated IO model available. The low level of aggregation and availability were the two main reasons for selecting the North American model over a Finnish model (Seppälä et al. 2011), even though employing a model based on a foreign economy inevitably brings along uncertainties. The strengths and weaknesses of the employed EIO-LCA model are presented in the individual papers of the dissertation, as applicable.

The main data sources utilized for the quantitative assessment comprise the annual reports and financial statements of the housing companies from the year 2008, and a national consumer survey from 2005. In addition to the financial data, metric (kilowatt hour) consumption data and national data on GHG emission factors for energy production were utilized in the assessments. The first tier emissions (the production phase) for heating and electricity were replaced with this process based data in the output matrix. The remainder of the EIO-LCA matrix was left untouched to maintain full coverage of the model.

The development of the EIO-LCA based model into the hybrid models used in the assessments is described in Papers I and II. Papers I and V utilize a previously developed model for the assessment of the annual carbon footprint of cities, or rather average consumers within cities (see Heinonen 2012). Papers II and III in turn utilize an applied model specifically developed for the housing company level, assessing the annual carbon footprint of housing company occupants. The novel application

successfully incorporates hybrid LCA on the housing company scale and context.

2.3 Case study method

Another research approach well suited for the pragmatist worldview and practice based research is the case study approach. Flyvbjerg (Flyvbjerg 1992) even argues that practical rationality can only be understood through cases.

This dissertation comprises several different case studies with study subjects of different scales. In-depth case studies provide the best means to gain a holistic view on the subject of the study (Robson 2002). Case studies enable intensive analysis while maintaining the integrity of the research. Furthermore, the case study approach allows studying real-life phenomena in their real-life contexts, the boundaries between which are not always clear cut (Yin 2003). For the case study design, several methodologists suggest explorative "How?" questions instead of "What?" and "Why?" questions (Robson 2002). This research attempts to follow the suggestion with its research questions.

All individual papers of the dissertation address different study subjects, cases, within Finland. The cases and basis for their selection is explained in detail in the individual research papers, and listed only briefly here. Paper I addresses the largest city in Finland, Helsinki, divided into the downtown core and the suburban areas. Papers II, III, and IV share a case study subject, the neighborhood of Siltamäki in Helsinki. Siltamäki represents a 1960s-70s residential area with seven similar housing companies and altogether 44 buildings in need of refurbishment. The area hosts approx. 1,650 residents. The type of buildings included in the sample represent one third of the Finnish residential building stock and the poorest performers of the entire building stock with regard to energy efficiency. In Helsinki, the 1960s-70s buildings are estimated to consume roughly 20% more energy than those built before the 1950's or after 2000. A Danish study (Nielsen and Jensen 2010) found similar results for Copenhagen. Buildings from this era are also rapidly approaching heavy refurbishments, including energy retrofitting, and are therefore of high importance when planning for climate change mitigation measures. For Paper III, however, 18 additional housing companies from Helsinki Metropolitan Area (HMA), representing different types of housing from different eras, were included in the sample to expand the possibilities to generalize the results.

Finally, Paper V includes a city scale comparison of Helsinki, an adjacent smaller city Porvoo, and the third largest city in the country, Tampere. Despite the different scales and different cases used as samples for the study, Finland's capital metropolis, the HMA, is a common nominator for

all of the studied cases. Given the attempt to study climate change mitigation in urban communities, using the largest urban community in the country as a reference was considered appropriate.

Table II below outlines the method, data sources and cases for each individual study.

TABLE II. RESEARCH DATA AND METHODS

	Paper I	Paper II	Paper III	Paper IV	Paper V
Methods	Hybrid-LCA	Hybrid-LCA	Interviews Hybrid-LCA	Workshop Document review	Hybrid-LCA Document review
Primary Data Sources	Consumer Survey 2006 Emission data for local energy production	Annual reports of housing companies Energy use data for households and housing companies	Interview transcripts Annual reports of housing companies Energy use data for housing companies	Workshop Minutes from focus group meetings	Consumer Survey 2006 City level climate strategies Emission data for local energy production
Cases	The city of Helsinki (suburban vs. down town)	7 housing companies within the Siltamäki neighbor-hood in Helsinki	25 housing companies within the HMA (incl. Siltamäki)	7 housing companies within the Siltamäki neighbor-hood in Helsinki	The cities of Helsinki, Porvoo and Tampere

For all studies, the cases were selected using the theoretical sampling principle (Robson 2002). The sampling was also purposive in that certain characteristics were sought in choosing the case cities and housing companies. For the studied housing companies, the cases were considered representative of multi-family homes in urban communities. In other words, theoretical categories were used as factors guiding the choice of cases, as suggested by both Yin (Yin 2003) and Eisenhardt (Eisenhardt 1989).

The housing company assessments utilize the annual financial statements of the housing companies and annual energy consumption data as the primary data sources. For Paper III, however, equally important sources of data are interviews conducted with managers of the respective housing companies. Meanwhile, the city level assessments employ statistical data provided by the Statistics Finland, as well as other data sources, such as emission factors from local energy production, and information on building energy efficiencies. Exploiting different types of data, such as national surveys and census data, housing company records and interviews, further supports the choice of the multiple-case design.

3. Summaries of Papers

The five individual research papers that form this dissertation all address the issue of managing greenhouse gas emissions in urban communities. Three of the papers discuss the issue on the housing company scale, while the first paper focuses on the average city dweller, and the final paper addresses the wider city scale. Together the papers provide an understanding of the most significant urban activities generating GHG emissions, and the potential of different actions and actors to mitigate them.

The contribution of the individual research papers to the overall aim of the dissertation is summarized below in Table III. The table presents the key finding of each paper, along with the identified key actors on each of the three scales. Additionally, actions found to hold the most mitigation potential in the studied cases are outlined.

TABLE III. CONTRIBUTION OF THE INDIVIDUAL RESEARCH PAPERS

	Paper I	**Paper II**	**Paper III**	**Paper IV**	**Paper VI**
RQ	RQ1	RQ2	RQ2	RQ2	RQ3
Scale	Individual within City	Housing Company	Housing Company	Housing Company	City
Finding	Housing related emissions form the majority of an individual carbon footprint in urban context	Managers controlling the heating system may have a more crucial role in mitigating climate change than occupants	Different manager types exist and managers' attitudes and practices appear to have an impact on energy use, carbon footprint	Occupants prioritize individual preferences over energy-efficiency; housing management understands the whole	The reduction potential of currently preferred mitigation actions varies, based on the type of urban community
Influential Actor	City dweller	City dweller Manager	Manager	Manager Policy maker	Policy maker
Influential Action	Consumption	Energy consumption	Energy consumption	Energy consumption	Energy production

The following subchapters describe the individual papers and their results in more detail. The summaries place special emphasis on the conclusions most relevant for the general theme of this dissertation.

3.1 Paper I: Dense Downtown Living More Carbon Intense Due to Higher Consumption - A Case Study of Helsinki

The role of the first Paper is to estimate the share of different consumption categories in the carbon footprint of an average Helsinki inhabitant. The study was conducted using a consumption based hybrid LCA approach, in other words, the notion of consumer responsibility is embraced. The attempt is to allocate all carbon emissions associated with private consumption to the actual consumer. The primary input data for the study is extracted from the Finnish Consumer Survey conducted in 2006.

For the purpose of the study, the city of Helsinki was divided into two: the suburban areas and the densely populated downtown core. The results of the LCA show that the surrounding suburban areas with lower density generate a smaller per capita carbon footprint than the denser downtown area on an annual per capita level. The LCA outputs an annual carbon load of 14.7 ton CO2e per capita in downtown Helsinki compared to 12.0 ton CO2e in the suburban Helsinki. The results indicate that the socioeconomic standard of living in downtown Helsinki results in significantly higher per capita annual carbon footprint than in the suburban areas with a lower standard of living. Besides the affluence, the consumption orientated lifestyle is likely supported by easy access and availability to goods and services. Figure 2 depicts the results of the LCA.

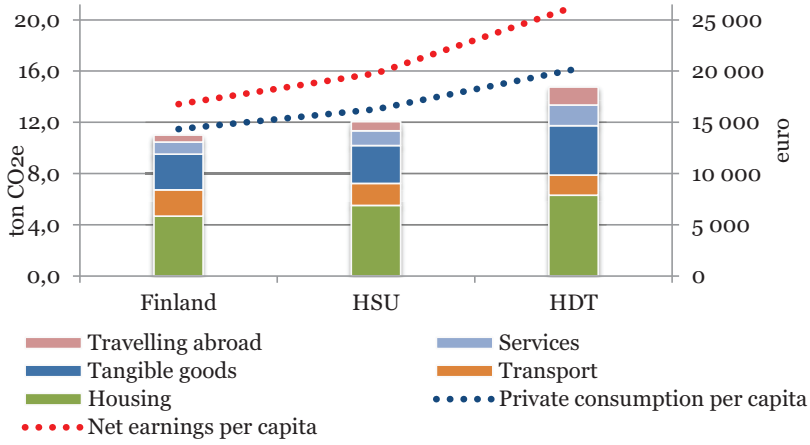

Figure 2. Annual net earnings, private consumption and carbon footprint (ton CO2e) per capita in Finland, Helsinki suburb (HSU) and Helsinki downtown (HDT) respectively (adapted from Paper I)

The main finding for this dissertation is, however, that the majority of an individual's annual carbon footprint, as much as 40%, is comprised of

housing related consumption and activities. All consumption generates GHG emission and is therefore detrimental for the climate. Promoting density in urban design in hopes of minimizing private driving is not an effective climate mitigation action as such. More emphasis should be placed on the energy consumption of buildings, on energy production and distribution modes, as well as on an individual city dweller's consumption patterns.

Identifying housing, and especially energy related to housing, as the most significant source of GHG emissions, as well as determining that city life is at the very core of the climate change challenge, gave reason to take the research to the scale of urban neighborhoods. The scale is addressed and examined from the perspective of Finnish housing companies, which are legal entities owned and managed by the residents in owner-occupied multi-family housing.

3.2 Paper II: Occupants have little influence on the overall energy consumption in district heated apartment buildings

The second paper aims at evaluating how occupant behavior causes variation in the carbon footprint and energy consumption of multi-family apartment buildings. The two main motivations for the research were to evaluate how occupant behavior in a neutral environment influences utility consumption and consequent carbon footprints of multi-family apartment buildings, and to identify which activities associated with housing generate the most GHG emissions. The subject of the study was a medium-sized residential area dating from the 1960-70s and located in the suburbs of Helsinki. The case area comprises 7 housing companies within the neighborhood of Siltamäki in Helsinki.

The study was conducted utilizing an applied hybrid LCA method. Hence, an additional aim of the study was to test the usability of an input–output-based LCA method within the context of housing companies. The practical goal was to provide housing companies with a simple calculation tool for the evaluation of their carbon footprints. The employed LCA model utilizes both economic and metric consumption data of different housing company activities. The private household electricity consumption of residents was included to make different housing companies in the study comparable, electricity and heat consumption being heavily interconnected. All life-cycle emissions of activities directly associated with housing could therefore be included into the assessment.

The research identified heating energy as the dominant activity by a margin, and electricity consumption as the second most significant (Figure 3). Perhaps surprisingly, water use, wastewater generation and waste management have a much smaller share on the GHG emissions, while other

activities have only negligible shares (Figure 3). Consequently, efforts aimed at mitigating the climate impact of housing should focus on energy management.

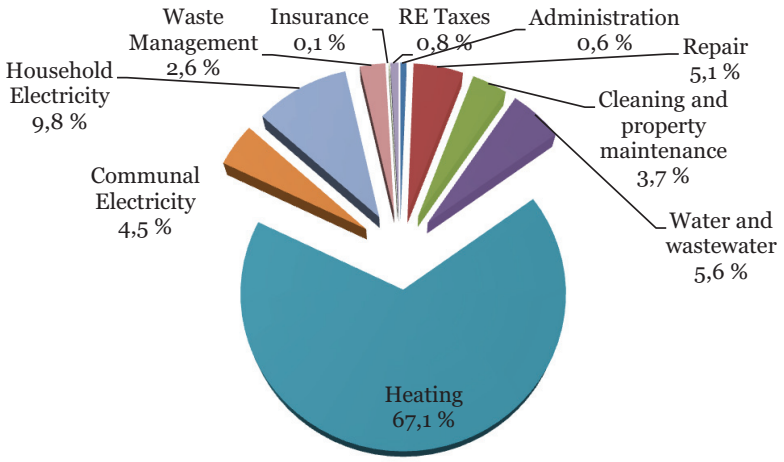

Figure 3. Percentage of CO2e emissions by activity (adapted from Paper II)

Table IV shows there is relatively little variation between the different housing companies. In other words, the assessment indicates that individual residents of multi-family apartment buildings have relatively little interest or control over the greenhouse gases their housing unit emits, once the choice of dwelling has been made and the technical systems are fixed. Given the results of Paper I, demonstrating that a significant portion of an individual's carbon footprint is derived from housing activities alone, this lack of influence may be considered problematic.

TABLE IV. ANNUAL CO2E (T) EMISSIONS BY ACTIVITY

	A	B	C	D	E	F	G	All
Property management and admin.	10.1	4.9	4.6	6.0	5.8	5.1	6.2	42.9
Cleaning and property maintenance	64.8	100.5	32.9	31.0	34.3	43.9	44.1	351.4
Repair	55.4	73.2	11.9	14.5	17.6	49.2	30.5	252.3
Water and wastewater	70.8	95.7	38.4	38.1	39.6	48.1	51.7	382.3
Heating	1028.0	1259.9	599.4	581.2	600.1	662.6	746.8	5478.2
Electricity	87.0	91.4	42.1	52.3	49.7	50.2	59.5	432.1
Waste Mgmt	37.4	46.5	16.6	16.1	17.8	21.7	24.1	180.2
Insurance	0.7	1.3	0.3	0.3	0.6	0.7	0.4	4.2
Real Estate Taxes	11.5	13.7	5.3	5.5	5.9	7.2	8.0	57.0
Total	1365.7	1687.1	751.5	744.9	771.5	888.7	971.3	7180.7
Emissions per resident	4.1	4.2	4.9	5.1	4.7	4.0	4.1	4.4
Emissions per sqm	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1

The results of the study gave reason to believe that more than individual occupants, maintenance policies and practices are influential. Housing managers, through their practices and policies, are known to have direct influence on environmental performance, including the heating energy consumption of buildings. To conclude, individual occupants in district heated apartment buildings have relatively little impact on their own carbon footprint, while managers who are controlling the heating system may have more impact.

A natural continuum for the dissertation research was to include the role of managers in the assessment, which was done employing a mixed method approach in Paper III. More housing companies from the Helsinki Metropolitan Area were also included in the multiple case study of Paper III.

3.3 Paper III: Housing managers key to reducing the climate impact of housing companies? A mixed method approach

Following Paper II, the purpose of the third paper is to examine the role and impact of managers and their practices on the carbon footprint and energy consumption of housing companies. More specifically, the paper

seeks to explore the role, impact potential and willingness to act of housing managers in the context of CO_2e performance of housing companies. A sample of 25 housing companies of a variety of types from the Helsinki Metropolitan Area, Finland was analyzed using mixed methods, that is, both quantitative and qualitative means.

Based on the LCA, heating energy was again identified as the most significant source of GHG emissions. Due to the significance of the category, metric energy consumption (kWh) without the influence of energy production technology was also included in the quantitative assessment. A rather large variation was found in both the emissions and energy consumption of the housing companies, yet expected variables such as building age provided no clear explanation to said variance.

The qualitative part of the study with semi-structured interviews, characterizes the housing managers in three different categories. The types are titled Uninformed, Professional, and Caring (Table V). The latter two of the identified categories have already been identified previously by Brunklaus (2008), while the Uninformed as the most adversarial was a new identified manager type.

TABLE V. HOUSING MANAGEMENT CHARACTERISTICS

	Uninformed	Professional	Caring
Managers	D	A, B, C, E, F	G
Sense of responsibility	*"…all this nonsense about the greenhouse gas emissions…it's the factories that emit gases, housing companies don't even consume that much energy!"*	*"The maintenance practices do have the most influence by adjusting the heating, only one centigrade means 5% energy savings… then again, we cannot help it if the residents keep opening the windows."*	*"The quickest means to cut consumption is through housing management and maintenance practices. It's much more difficult to affect the occupant behavior."*
Trust in the client's interest	*"People are only interested in their own comfort level."*	*"For now, only a Euro-based motive exists [for the clients] to save energy" maybe in the future this will change."*	*"If the results were illustrative enough, there would for sure be interest."*
Level of pro-activeness	*"What's the point? What would people do with the information on their CO2e emissions? Another useless measure, like those mandatory energy certificates"*	*"It's not that we don't care, but there's a profound, constant lack of time."*	*"I try to spread information on energy and water saving measures to the residents."*

While the Paper identifies three different types of housing managers (Table V), it finds an interesting connection between the manager types and the carbon footprints of the housing companies they manage. The best performing housing company is run by a manager who was typed as Caring, and the lowest performing housing company is managed by the Uninformed type. Majority of the housing companies are managed by Professional manager types, who are aware of the emission load but feel restricted by finances or time.

The study indicates that professional users, through their attitudes and practices have an impact on the CO2e performance of buildings. Identifying the different types of managers enables tailoring suggested measures for energy and water conservation to the different levels of motivation and knowledge, beyond national regulations.

The next phase of the research focused again on the original case neighborhood of Siltamäki addressed in Paper II, now with a qualitative approach to assessing a collaboration process associated with the retrofitting of the 1970s area.

3.4 Paper IV: Generating low-energy alternatives for neighborhood-scale urban residential refurbishment through occupant involvement

Paper IV describes a so called "4P" (Public- Private – People - Partnership) collaboration process, attempting to establish how the common aims between the different actors could be reached with the help of such process. Most interestingly for this dissertation, housing management acted as a representative of the "People", which allowed for further investigation into their attitudes and practices.

For this study, the research approach used was entirely qualitative. The data comprise minutes of focus group meetings, as well as recordings and statistics of occupant meetings. In this case, the subject neighborhood is shared with Papers II and III, the 7 housing companies within the neighborhood of Siltamäki in Helsinki.

The 4P collaboration generated an innovative way to finance low energy refurbishment by infill development in the neighborhood. However, based on occupant workshops organized after the results of the 4p collaboration were introduced, the individual occupants did not seem to be pleased with the innovation. In other words, the results of the occupant workshops revealed that employing representative democracy, i.e., using housing management as a representative of the People may be problematic. It appears that the goals of the housing companies as a whole, as represented by the housing management in the 4P collaboration process, differ quite significantly of the preferences of the individual occupant. Therefore,

referring to these two as one stakeholder, “People” is misleading. The similarities and differences in the hopes and needs of the different stakeholders and their relations to the others’ are depicted in Figure 4.

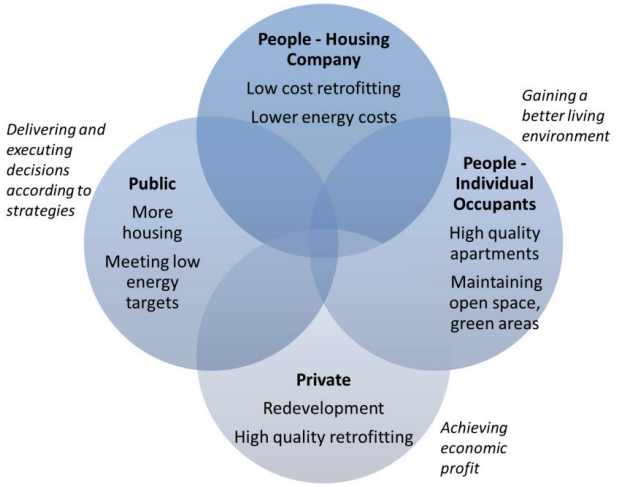

Figure 4. Stakeholders in the 4P collaboration model (adapted from Paper IV)

The study concludes that occupants, even owner-occupiers, tend to base their decision on financial issues and short-term individual preferences. Therefore, it appears that employing housing management as a representative of the People eases negotiations between the different actors. This finding supports the postulation that housing managers are in a key position.

In addition to the important role of housing managers, the role of the Public in the 4P partnership is crucial with regard to energy efficiency goals. The next paper takes a look into the role of the Public, i.e. the effect city level strategies have on the life-cycle carbon footprint of city dwellers.

3.5 Paper V: Assessing the Potential of Climate Change Mitigation Actions in Three Different City Types in Finland

The final and fifth paper included in the dissertation evaluates the effectiveness of commonly accepted strategies to achieve low-carbon urban communities. Three different city types in Finland, Helsinki, Porvoo and Tampere were assessed. The prevailing situation in each of the cities is depicted in Figure 5 below.

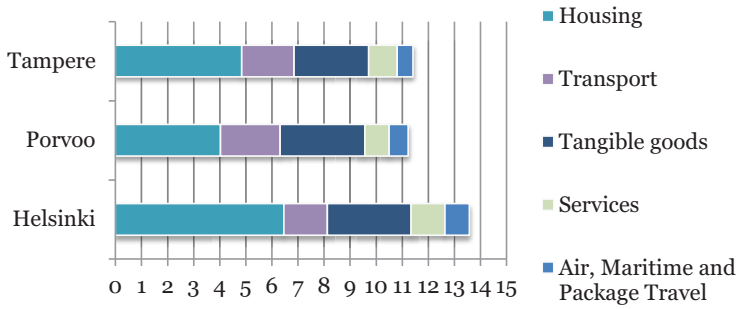

Figure 5. Carbon footprints of the case city residents (adapted from Paper V)

Based on outspoken climate strategies of the three case cities, four urban housing related mitigation actions (Higher density, Cleaner energy production, Low-energy residential construction, Improved energy-efficiency of existing buildings) were selected for assessment. It is considered particularly essential that the actions would be plausible with current technologies and best practice in Finland. Therefore two of the actions reflect prevailing situations in two of the case cities. Helsinki is considered the prime example for density and public transport in the country. Meanwhile the renewables based energy production in Porvoo represents the best practice of cleaner energy production on a city level. Additionally, the impact of low-energy new construction is assessed since it is stated as an important mitigation strategy by all three case cities. Finally, reducing the energy consumption of the existing building stock is likewise a common goal for the case cities and closely related to carbon footprint of housing companies, and is therefore included in the assessment.

In conclusion, the four mitigation actions selected for the assessment are, as follows:

1) Higher density, less VKmT;
2) Cleaner energy production;
3) Low-energy residential construction, and;
4) Improved energy-efficiency of the existing building stock.

Based on the findings, the type of urban community largely determines the mitigation potential of city level action. That said, the most effective climate change mitigation action is to significantly reduce the emission factor of the local energy production. Based on the assessment, increasing the share of renewable fuels to the level current best practice in the country, 70% would lower the annual per capita carbon footprint by as much as 2 and 2.3 tons CO_2e for the two cities currently relying heavily on fossil fuel based energy production.

The other three commonly employed mitigation strategies assessed are less effective. Attempting to reduce private driving with dense urban structure is a rather uncertain and unreliable strategy, with relatively weak

effect on the actual carbon emissions. It is worth noting nonetheless that, dense cities may have a number of other positive environmental, social and economic implications that were left outside the scope of the paper.

Paper V also finds that the carbon spike generated by current low-energy new construction is enough to overrule the benefits of the newly constructed low-energy buildings for decades. Given the accumulation of the carbon footprint into the atmosphere, this phenomenon is even more detrimental from the climate protection perspective, and by no means a viable strategy for reaching short term climate policy goals.

With regard to increasing energy efficiency of existing buildings, while the emission reductions were modest, the target is highly feasible even in short term, and in its current scale, even too modest. It should further be noted that, similar to energy production, the benefits from energy conservation penetrate most consumption categories, such as services or logistics, and are therefore not limited to only building energy use.

4. Discussion

The dissertation sought to find solutions for climate change mitigation in urban communities, and had one very general research aim: **to explore preferable means to mitigate climate change in an urban environment.** The dissertation argues that the social constructiveness of the climate change issue should be considered in planning for mitigation action. More attention should be paid to management and motivation of individuals, particularly on the housing manager or individual city dweller level. On the policy maker level, while ensuring prompt action, a vigorous attempt to establish the actual impacts on GHG emissions resulting from the action should be maintained. As a direct policy implication, the study suggests that significant changes are needed in city level climate strategies.

The *first research question (RQ1)* approached the issue from the perspective of an individual resident of a city. Paper I found that activities associated with the built environment, both with housing and a city's infrastructure comprise the vast majority of an individual's total annual carbon footprint.

Based on the findings of Paper I, the research went on to explore the role of different actors in the carbon emissions derived from urban housing companies, namely the role of occupants vs. that of housing managers. This *second, and primary, research question (RQ2)* was addressed in Papers II, III, and IV. Quite unexpectedly, it appears that occupant behavior had only limited influence on the overall energy consumption and consequent carbon footprint in the context of multi-family housing. Instead, attention was drawn to housing managers, who are responsible for the most significant source of GHG emissions, the heating system. On the housing company scale, building energy consumption was identified as the most important action.

Paper IV showed that policy makers also have an important impact on this scale, as they promote climate mitigation and encourage energy-efficient retrofits, for example. For this reason, the *third research question (RQ3)* was extended to the city level, attempting to determine the actual climate change impact of some commonly adopted mitigation action stated in a

number of city level strategies. Most of the assessed actions turned out to have only a modest impact on the carbon footprints of city dwellers.

4.1 Contribution of the dissertation

As stated throughout this dissertation summary, from a wider perspective, the research can been seen as a dialogue between management, engineering and environmental studies, a combination of social and natural sciences in the form of environmental assessments. The combination has been referred to with such terms as “sociology of nature” (Latour 2004), “sociology of technology, “sociology of buildings” (Guy & Shove 2000), “social construction of technology”, and “organizing and the environment” (Baumann 2004). Call it what you may, the discipline has gained momentum in recent years which, as this research also shows, is perfectly justifiable.

The discipline has been developed and explored in recent years by such Scandinavian scholars as Eva Heiskanen and Henrikke Baumann on the general product and supply chain level. On the building operations and energy use level Simon Guy, Elizabeth Shove, and Birgit Brunklaus have done research in the field. This dissertation strongly builds upon these scholars and their previous studies.

The findings of this dissertation support the postulation that technology alone, in particular one-dimensional technical solutions (Robèrt 2012), is not enough not solve what is perhaps the greatest environmental threat of our time, the climate change. As an example, a number of technological solutions within the field of the built environment exist, yet the means to implement the solutions are lacking (Guy 2006; Jesper Ole Jensen 2012). Scholars including Heiskanen (Heiskanen ym. 2009) and Lauridsen (Lauridsen & Jørgensen 2010) speak of problems with technology and sustainable transitions, pointing to hinders not in the technology itself, but elsewhere in the system: the actors (Brunklaus 2008).

Un-encouragingly enough, Flyvbjerg (Flyvbjerg 1992) saw power relations, on both global and local level, as the most problematic hurdle to effective implementation of sustainable technology already 20 years ago. Within the context of urban communities, it would be of essence to improve interaction between the three studied scales:

Individual - Housing Company - City

This would in turn require enhancing communication between the three identified decision makers acting on said scales:

City Dweller - Manager - Policy Maker

Methodologically the research contributes to assessing the significance of different actions by using LCA for the purpose of urban carbon management. The consumption based LCA approach was employed successfully throughout the dissertation on both the macro (city, or individuals within the city) and micro (housing company) scale. On the micro scale, a novel application of the hybrid LCA model was introduced and employed in Papers II and III. The model contributes to evaluating the life-cycle carbon footprints generated by urban housing companies and could well be adapted for use by professional building users, such as housing managers. However, the assessment model in itself does no equal policy support. As with all produced scientific knowledge, the assessment model still needs to be translated into policy-relevant information that is both practical and user-friendly. A good environmental assessment model should produce objective assessments of alternatives and their consequences, and thus help e.g. policy makers to see the actual impact of their action on the environment (Van Delden et al. 2011). It may be argued that the most important characteristic of an assessment model is that the intended users (in this case, the housing managers) are willing and able to use it. For example Lauridsen (Lauridsen & Jørgensen 2010) and van Delden (Van Delden et al. 2011) speak of transition management. Managing and implementing a novel technique requires time, training of potential users, as well as commitment from both sides.

4.2 Evaluation of the dissertation

All articles included in the study have been peer-reviewed and published in scientific publications. Accordingly, each paper includes a detailed description of the limitations associated with the paper in question. The following provides a brief overview on the general reliability and validity of this dissertation research.

Methodologically, the study subjects at different scales were researched with the same applied quantitative assessment model, which during the course of the research proved to be a fast and effective and reliable tool at the required level of accuracy. All analysis conducted were, however, qualitative, and in a few of the appended papers (Papers III and IV) qualitative data were also exploited. The use of mixed methods, i.e., multiple types of data, method and analysis brings with it the advantage of triangulation. Triangulation enhances the reliability of a research (Robson 2002) and can be applied to data, methods, interpretation of results, as well as to the researchers. All of these forms of triangulation were applied to this dissertation.

Reliability is a measure of research quality indicating the level of repeatability of the study (Yin 2003). For this research, fluctuations are mainly related to the data utilized in the studies, as the outputs of the hybrid LCA method are inherently constant and thus provide high repeatability. As for the data utilized, while the selection of the cases and attributes could have been done in a number of different ways, the selection criteria are well-established and the processes reported in detail to enhance reliability. Furthermore, utilizing the same LCA method repeatedly in the dissertation with similar results, and complementing the quantitative method with qualitative means, increases the reliability of the findings.

External validity (or generalizability) refers to whether the study can be generalized and is associated with sample quality and size (Robson 2002; Yin 2003). For the studies included in the dissertation, purposive sampling was utilized, despite the risk for potential researcher bias. Moreover, all results are context dependent and as such only applicable in Finland or countries with similar conditions (especially environmental and legislative conditions). Problems may also arise from the temporal limitedness, as only data from a single year is exploited in the studies. With further regard to the relatively small number of cases, the generalizations made in the individual studies may be considered analytic, rather than theoretic in nature. That said, the lack of theoretical generalizability is not to say the results lack value beyond their specific context (Flyvbjerg 2003) as they still provide strategic guidance.

Construct validity indicates whether the research studied what it sought out to study (Yin 2003). The use of multiple data sources and methods in this dissertation research provides a good basis for high construct validity. Internal validity is in turn is determined by how much the studied prevailing conditions actually contribute to the outcome (Yin 2003). A certain level of inaccurateness is inherently present in IO based LCA studies. In this case, the intent has never been to produce as precise estimates of carbon footprints or emission reductions as possible, but rather to place different GHG emission sources in order, and thus point to the right action.

The input data is considered relatively accurate based on data quality indicators for LCA studies defined by Weidema & Wesnaes (1996). The data is non-verified and partly based on estimates, indicating a level 3 reliability. The completeness of the data is on level 2 as it is representative but from a smaller number of sites and from short periods of time. The temporal and geographical correlation of the data is of the highest level, as it is less than three years old, and from the studied geographical area. The

technological correlation is yet again on a lower level as the data is only partly from the processes under study.

The accuracy of the results is diminished by a number of different factors, such as, the aggregation of the input data, asymmetries between the data and the LCA model, as well as potential errors in the output vectors of the model, aggregation of the output industry sectors. Despite this potential inaccurateness in numerical data, the overall validity of the conclusions and policy implications is considered high, as the results do place different activities in the right context even if only roughly estimating the GHG emissions.

It is further worth noting here that, the use of an IO based LCA model is always more problematic towards a smaller scale due to increased inaccuracy. A method that is based on averages is bound to work best for macro level assessments and with large sample sizes. However, to enhance the accuracy of the assessment, the IO model was complemented with process data in all studies. The potential problems associated with the housing company (micro) level assessments in Papers II and III are discussed in Paper II. Additionally, sensitivity testing with national data retrieved from Statistics Finland regarding the finances of housing companies was conducted, as reported in Paper III.

An additional note should be made on the use of the 50-year building life-cycle in the studies. The 50-year life span was adopted to emphasize the importance of the timing of the GHG emissions in the analyses. Generally all current global and local mitigation targets are set for the next 2 to 40 years period, creating a need to distinguish emissions based on their temporal allocation. Calculating all operational phase emissions for e.g. a 100-year building life-cycle could lead to biased policy implications with regard to the current GHG mitigation targets. Potential improvements in future energy production modes add to this potential bias. Moreover, typically all major building elements influencing the energy consumption of the building are renewed during the 50-year life-cycle, which further justifies the use of this shorter life span.

5. Conclusions

The main conclusion of the dissertation is simple and almost seems self-evident yet needs to be firmly outspoken: **no single action, no single actor will suffice in mitigating the climate change impact of urban communities**. The challenge appears to lie with the management of human action. Commonly adopted mitigation actions are accepted without full knowledge of their impacts on the actual global consumption-based life-cycle GHG emissions. Furthermore, whilst a lot of attention is paid on occupant behavior, not enough is placed on occupant preferences and ways to steer individual preferences and routines to a more environmentally sound direction. Occupant comfort, as an example, may conflict with attempts to lower the energy consumption (E. Shove 2003) of housing. Papers II, III and IV indicated that the practices and attitudes of housing managers are certainly one determinant factor in multi-family housing units. On the city level, Paper V shows how policy makers are in the decisive role. That said, as Paper I demonstrates, much of the GHG generating consumption is beyond the reach of city or housing company level strategies, and individual consumption should be managed as well. Adding to the challenge, the stakeholder-actors all act on different scales and possess more or less power, with varying levels of knowledge.

Rockström (Rockström 2012) calls it the paradox of climate change: of all the environmental threats facing the world today, climate change is the only one that is technologically rather simple and feasible to solve. We know and can calculate the parts per million (ppm) level of CO_2e to which we should strive for in order to prevent more than a 2 centigrade temperature rise globally (IPCC 2007). Second, substitutes for fossil fuels exist and have been extensively researched, and replacing fossil based energy systems is possible.

Climate change within the urban housing context may also be labeled a wicked problem as defined by Rittel and Weber (Rittel & Webber 1973), as there is meaning there is no simplistic solution to the challenge. Levin et al. even speak of a super wicked problem (Levin et al. 2012) based on four typical features identified in this dissertation as well: mitigation action needs to be immediate; every individual, including the people aiming at

mitigation action, are adding to the problem; no one can control all decisions related to mitigation action; and finally, the decisions made and policies implement are sometimes irrational.

In conclusion, climate change mitigation in urban housing may already be considered technologically feasible, and is today very much a political, economic and social dilemma. What is required is a paradigm shift significant enough, referred to as "thinking big" by Robert et al (Robèrt 2012). Besides the paradigm shift, a mind shift in individual city dwellers would also be welcomed.

5.1 Future research needs and final remarks

It should be kept in mind that, while urgent mitigation action is needed, the need for vigorous impact assessment remains, if one wishes to avoid any void action on any of the scales researched here. Environmental assessments can and should be used as decision making support. Modeling and quantitative assessments stimulate, facilitate and support discussion and knowledge building which are essential for effective urban climate management. A consumption based assessment model like the one employed here provides one solution for feasible, relatively fast and reliable impact assessments for both research purposes, and policy making - or possibly even individual city dwellers, as the general knowledge of GHG emissions and their relation to climate change continues to increase. That said, the developed hybrid LCA calculation tool needs further development into a usable interface. It is further worth noting that, particularly for non-professional building users, the use of the tool would require very detailed instructions for use and, more importantly, interpretation of the results.

One additional perspective when evaluating GHG emission reductions gained by increased energy efficiency is the rebound effect. For example Turner et al. (2009) demonstrate that the emissions may even increase when energy efficiency increases, as consumers spend the money saved on energy on activities generating potentially even more GHG emissions. Particularly due to this so called indirect rebound effect (Druckman et al 2011) improving the carbon intensity of energy production is all the more vital as a mitigation strategy. A detailed analysis of the rebound effect was left outside the scope of this dissertation but would certainly be of value and interest in future studies.

This dissertation focused on the very topical issue of climate change, within the context of urban communities. The environmental impacts of urban life and the built environment are, however, far from restricted to energy use and consequent carbon footprints of individuals. Means to assess other environmental impact categories, such as natural resource and water use, should be researched into as well.

Besides environmental assessment models and their implementation, further research into the management of humans is needed. Many of the GHG emissions generating activities and consumption categories are beyond the reach of policy makers. While the results of the studies included in this dissertation, much to the surprise of the author of this dissertation as well, show that in the current state, individual occupants living in urban environments lack the power or incentives to significantly impact the energy consumption of their dwellings, the research does not imply that this should or has to be the case. Moreover, professional building users clearly have an impact but lack incentives. Paper III of this dissertation found differences in housing manager's attitudes and a connection to the actual performance. Another study from Denmark (Nielsen et al. 2012) identified differences in the strategic decision making of housing managers between different management structures. According to the Danish study managers in social housing companies were more considerate of environmental issues than private housing managers, which could reflect the influence of public policies, which was also identified in Paper IV of this dissertation. Moreover, as recent research has pointed out (Heinonen 2012, Nielsen & Jensen 2012) urban structure is not in a decisive role in an individual's carbon footprint, but rather the overall consumption. To steer consumption into a more climate friendly direction, climate change research would benefit from the incorporation of social sciences. In the field of buildings and the built environment this would mean focusing more on the behavior and motivation of different actors, while maintaining a high standard of research on the technical potential of different action. This approach will undoubtedly be applied to any future research work by the author of this dissertation.

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Appended Papers I-V

Urban communities are at the very core of the climate change problem. This dissertation provides an understanding of the most significant urban activities generating greenhouse gas emissions, and the potential of different actors and actions to mitigate them. The research was conducted on three different scales (Individual – Housing Company – City) addressing the issue from the viewpoint of three identified decision makers (City Dweller – Manager – Policy Maker). It is argued that the social constructiveness of the climate change issue should be considered when planning for mitigation actions. More attention should be paid to the management and motivation of individuals, particularly of housing managers and individual city dwellers. On the policy maker level, while ensuring prompt action, an attempt to establish the actual climate change impact should be maintained. The research concludes that no single actor or action will suffice in mitigating the climate change impact of urban communities.

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