Contribution of ICT to Climate Targets of Cities

Exploring the potential of Information and Communication Technologies in reducing emissions and energy use from buildings and travel

ANNA KRAMERS

KTH Architecture and the Built Environment

Licentiate thesis in
Planning and Decision Analysis
Stockholm, Sweden, 2012

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Abstract

This thesis examines how ICT solutions can assist in lowering energy use and greenhouse gas (GHG) emissions from buildings and travel in order to help cities meet their climate targets. It also provides an overview of relevant research intended to furnish new knowledge about the issues involved and to find solutions to social problems.

The first part of the thesis provides an analysis and compilation of critical system boundaries that need to be used for cities to set targets for energy use and GHG emissions. The climate targets of cities are dependent on setting system boundaries and establishing methods of calculations for monitoring whether the targets have been achieved. Today, there is no official standard for how the system boundaries must be set or what calculation methodologies to apply to evaluate the climate targets. Four main categories of system boundaries were identified: the temporal scope, the object of target setting, the unit of target setting, and the target range (e.g. consumer-producer and life-cycle perspective). Eight European cities were examined in relation to how they set climate targets. The examination showed that awareness of what is included in the targets is limited and that there is a need for standardised and consistent protocols and methods of setting climate targets for cities.

In the second part of the thesis, leading Advanced Traveller Information Systems (ATIS) and their functionalities were investigated. The relationship between individual decisions on different travel modes and functionalities of ATIS was investigated through a systematic investigation of the functionality of nine ATIS, mainly from Sweden, Germany, UK and USA. This allowed decisions that could lead to lower energy use and emissions of GHG to be identified. It also resulted in a proposal on requirements for new and improved functionality that could support a reduction in energy use and GHG emissions and a shift to renewable energy sources if implemented in next-generation ATIS.

In the third part of the thesis, ICT applications that can be used to reduce energy use and GHG emissions of buildings within the already built environment were identified. In addition, a brief analysis was made of how different actors such as the tenant, the building owner and the energy provider can reduce energy usage in buildings by means of ICT solutions.

The results of this thesis show that there is a potential to reduce energy use and GHG emissions in cities through the use of ICT solutions for buildings and travel.

Sammanfattning

I denna avhandling undersöks hur Informations och Kommunikations Teknologi (IKT) lösningar kan bidra till lägre energianvändning och utsläpp av växthusgaser från byggnader och resor för att hjälpa städer att nå sina klimatmål. Avhandlingen ger också en överblick över forskningen inom varje delområde som syftar till att skapa ny kunskap om forskningsobjekten och att hitta lösningar på samhällsproblem.

Den första delen av avhandlingen är en analys och sammanställning av viktiga systemgränser som behöver sättas för att städer skall kunna fastställa mål för energianvändning och utsläpp av växthusgaser. För att kunna sätta klimatmål är städerna beroende av att sätta systemgränser och bestämma beräkningsmetoder för att senare kunna följa upp om målen nåtts. Idag finns det ingen officiell standard för hur systemgränserna skall sättas eller vilka beräkningsmetoder som skall användas för städers klimatmål. Fyra huvudkategorier identifierades, den tidsmässiga omfattningen, det objekt som målet skall sättas för, den enhet i vilken målen skall sättas och för vilken omfattning (t.ex. konsument-producent perspektiv och livscykelperspektiv) målet skall definieras. Åtta europeiska städer undersöktes i relation till hur de sätter klimatmål. Undersökningen visade att medvetenheten om vad som ingår i målen är begränsad och att det finns behov av standardiserade och konsekventa protokoll och metoder för städers klimatmål.

Den andra delen av avhandlingen är en undersökning av ledande avancerade resenärs informationssystem (ATIS) och deras funktionalitet. Sambandet mellan individers beslut för val av olika resesätt och funktionaliteter i ATIS undersöktes genom en systematisk undersökning av funktionaliteten i nio ATIS främst från Sverige, Tyskland, Storbritannien och USA. Undersökningen resulterade i att beslut som kan leda till lägre energianvändning och utsläpp av GHG identifierades. Den resulterade också i förslag på förbättrad och ny funktionalitet som skulle kunna stödja beslut för transportsätt som minskar energianvändning och växthusgasutsläpp samt bidrar till en övergång till förnyelsebara energikällor om de implementerades i nästa generations ATIS.

I den tredje delen av avhandlingen identifieras IKT-tillämpningar som kan användas för att minska energianvändning och utsläppen av växthusgaser i byggnader i den redan byggda miljön. Dessutom redovisas en kortfattad analys av hur de olika aktörerna hyresgästen, byggherren och energiföretaget kan minska energianvändningen i byggnader med hjälp av IKT-lösningar.

Resultatet av denna avhandling visar att det finns en potential att minska energi och utsläpp av växthusgaser i städer genom att använda IKT lösningar för byggnader och resor.

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Preface

I started my PhD studies during spring 2010. Professor Mattias Höjer invited me to join the Centre for Sustainable Communication (CESC) and the postgraduate programme at the Division for Environmental Strategies Research (fms) to carry out my licentiate studies in the area of Information and Communication Technologies (ICT) and its contribution to environmental sustainable development of cities.

I would first and foremost like to thank Mattias Höjer, who was my main supervisor during the licentiate time, for inviting me to do postgraduate studies and for being such a great supervisor. You opened up a new world for me – the research world – that I really have appreciated being part of. It has given me a new dimension in life that I will enjoy for the rest of my life. I also would like to thank my co-supervisors Anders Gullberg, Stockholm City Museum and Division of History of Science, Technology and Environment, Marko Turpeinen, Department of Media Technology and Interactive Design and EIT ICT Labs Finland, and Åsa Svenfelt, Division of Environmental Strategies Research for engaging and stimulating discussion as well as constructive feedback that helped in the development of this licentiate thesis.

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List of Papers

Paper I

Kramers, A., Wangel, J., Johansson, S., Höjer, M., Finnveden, G. & Brandt, N. Elusive targets – methodological considerations for cities' climate targets. Submitted to Energy Policy.

Paper II

Kramers, A. Improving advanced travel information systems to reduce energy usage and GHG emissions in urban areas. Submitted to IEEE Transactions on Intelligent Transportation Systems.

Paper III

Kramers, A. & Svane, Ö. 2011. ICT applications for energy efficiency in buildings. ISSN: 1654-479X
TRITA-SUS 2011:3 Centre for Sustainable Communications, Stockholm.

Comments on co-authored papers

Paper I: I am main author together with Josefin Wangel. I wrote the main parts of the sections on reference year, unit of targets and range of target. I collected data from the majority of the cities and performed interviews with the cities' climate coordinators.

Paper III: I am main author. I wrote all sections of the paper and performed the literature review. Örjan Svane contributed the idea and the structure of the paper and also the different perspectives that were briefly analysed.

List of Abbreviations

ATIS	Advanced Traveller Information Systems
BIM	Building Information Modelling
BREEAM	Building Research Assessment Method
CASBEE	Comprehensive Assessment System for Built Environment Efficiency
ICT	Information and Communication Technology
ICLEI	International Council for Local Environmental Initiatives
IPCC	Intergovernmental Panel on Climate Change
ITS	Intelligent Transportation Systems
GHG	Greenhouse Gases
LEED-ND	Leadership in Energy and Environmental Design – Neighbourhood Development
MM	Mobility Management
REEB	The European Strategic Research Roadmap to ICT-enabled Energy Efficiency in Buildings and Construction
SRS	Stockholm Royal Seaport
TWh	Terawatt hour
UML	Unified Modelling Language

1. Introduction

More than half the world's population live in cities that account for just two per cent of the world's surface. Two-thirds of the world's energy is used in cities (IEA 2008) and the majority of all greenhouse gas emissions come from cities (Sovacool and Brown 2010). It is believed that cities have potential for more efficient use of resources. Therefore it is important to explore solutions that can contribute to the development of environmentally sustainable cites. This thesis examines the question of how Information and Communication Technologies (ICT) can contribute to sustainable development in cities. Sustainable development is defined by the Brundtland commission as "To meet the needs of the present without compromising the ability of future generations to meet their needs" (WCED 1987). Sustainability is often divided into an environmental, social and economic dimension. It is the contribution to the environmental dimension of sustainability that is discussed in this thesis.

There are currently many initiatives with plans and ideas about how to develop environmentally sustainable cities. However, the environmental plans and strategies of individual cities often lack details on how ICT can be utilised to contribute to more environmentally friendly development. ICT can be both an opportunity and a risk for the goal of achieving environmentally sustainable development. This thesis focuses on the opportunities for ICT to help society reach environmental targets, specifically the climate targets in cities.

In order to determine how ICT can help cities achieve their climate targets, it was first necessary to determine how cities set their climate targets. Therefore we examined the most important system boundaries to be used. We then needed to decide what functional areas of the city should be analysed. The choice was made to analyse buildings and travel, owing to the assumption that there is untapped potential for ICT to save a substantial part of the energy use in buildings in the already built environment and to facilitate the transformation of transport to fossil fuel-free modes.

This thesis consists of three parts. The first part is an analysis and compilation of methodological considerations used when cities set targets on energy usage and greenhouse gas (GHG) emissions. Each methodological consideration is presented and discussed. The second part is an investigation of leading Advanced Traveller Information Systems (ATIS) and their functions. Conclusions are made about new functionalities that could be included in the next generation to support a decrease in energy use and GHG emissions and a transition to renewable energy sources. The third part is an identification of ICT applications that could be used to reduce energy use and GHG emissions in buildings in the already built environment and a brief analysis of the actor perspective.

This cover essay provides a summary of the results presented in Papers I-III, which are appended at the end of the thesis. The background, the overall aim and the specific aims of each paper are presented in section 1 and the scientific context and methodology used are described in section 2. The results of the different papers are then presented in section 3. Section 4 draws conclusions, discusses whether the overall aim of the thesis was achieved, summarises the contribution of Papers I-III to meeting the overall aim and suggests some areas for future research.

1.1 Background

The world is changing under the development of ICT, creating many new possibilities. Castells (1996) argues that information technologies induce a pattern of discontinuity in the material basis of the economy, society and culture. A technological revolution is currently taking place, characterised by pervasiveness and penetration of technology to all domains of human activities, and therefore all processes of our existence are affected. Castells (1996) concludes that information is the raw material in the information technology paradigm and that it is now possible to implement network logic into all systems and processes.

At the beginning of the 21st century, information technology has merged with communication and media technologies. Information sources such as voice, sound and images can now be transferred into digital raw material and new opportunities are emerging. Money, keys, tickets, cameras, CD-players and navigation devices are all examples of material goods that have been dematerialised into digital raw material or have had their functionalities transferred into one single device – the mobile phone. In parallel, social network technologies have emerged and are now being employed by almost a billion users around the world (Facebook 2012). These technologies make the whole planet into a small village as far as communication and delivery of information are concerned, where everybody can communicate and share information almost immediately with everyone else, irrespective of where they are in the world.

There is emerging interest in how ICT can support the shift to a low carbon economy. This can be seen for instance in Sweden, in Stockholm's new city district Stockholm Royal Seaport, and in Masdar City in the United Arab Emirates, where there are ambitious targets on GHG emissions.
Mitchell (2000) argues that there are five main opportunities for ICT to support cities to become more environmentally sustainable. The first opportunity, *dematerialisation*, involves lower accumulation of things and more flow of information where physical things have been replaced by virtual. The second is *demobilisation*, where the dependency on connectivity is more important than geographical centrality and where travel is totally or partially replaced with telecommunications. The third opportunity is *mass customisation*, with less consumption of scarce resources through a move from mass production to intelligent adaptation or personalisation. The fourth opportunity, *intelligent operation*, involves putting more intelligence in operations of consumable resources that flow through pipes and wires, such as water, fuel and electric power. The fifth opportunity is *soft transformation*, where existing building stock, public spaces and transportation infrastructure are transformed to meet the new requirements from the information paradigm.

In spite of the opportunities relating to the information paradigm, very little has been changed in the physical environment. In the rich regions of the world we are still living in spacious houses, built infrastructure is increasing all over the world and we are commuting back and forth to our jobs every day as if the industrial society were still in place. Houses, infrastructures and vehicles have not yet been transformed or dematerialised because of the new information paradigm. The possibilities for more intelligent operation of water, fuel and electricity are not being utilised to their full potential and mass customisation is not widespread.

The European Commission (EU) has set out targets for where member states should be in the year 2020 regarding climate emissions and energy use (European Commission 2011). The member states have committed themselves to reduce GHG by 20%, increase the share of renewable energy sources in the EU's energy mix to 20%, and achieve a 20%

reduction in energy use compared with projected levels by 2020. The first two targets are on track, but the energy reduction target will not be met by 2020 unless further efforts are made (European Commission 2011). In order to keep the mean global temperature increase below 2ºC, the European Commission also reconfirmed in February 2011 the EU objective of reducing greenhouse gas emissions by 80-95% by 2050 compared with 1990 (European Commission 2011).

Global primary energy demand increased by 5% in 2010 and demand is expected to grow by one-third between 2010 and 2035 (IEA 2011). The total energy use in Sweden in 2010 was 411 TWh, according to the Swedish Energy Agency (SEA) (Swedish Energy Agency 2011). The residential and service sector was the largest user of energy, 40% of total energy production, which corresponded to 166 TWh. Residential houses, holiday homes and commercial premises apart from industrial facilities accounted for almost 90% of the sector's energy use. Industry is the second largest user of energy in Sweden, with a usage of 149 TWh in 2010, which corresponded to 36% of the total. The industry sector's use of energy increased by 13% during 2010 due to recovery from the economic recession. Transport of people and goods used 128 TWh and was the largest user of fossil fuel. Domestic transport used 96 TWh. The energy use in the transport sector is dominated by petrol and diesel, which are used in 87% of domestic transport.

The SMART 2020 report estimated the GHG reduction that can be achieved using ICT technology by the year 2020 compared with a business-as-usual (BAU) scenario (GeSI 2008). The report concluded that ICT technology can save 15% of total GHG emissions, which represents five times its own emissions. The SMART 2020 report put the focus on emissions reductions from four different sectors, namely buildings, transport, power and industry. It identified major opportunities for reducing GHG emissions and calculated potential emissions savings from each of these opportunities. The opportunities are dematerialisation, smart motors, smart logistics, smart buildings and smart grids. Dematerialisation is the replacement of high carbon products and activities with low carbon alternatives, for example replacing face-to-face meetings with videoconferencing or paper with e-billing (GeSI 2008). Smart motor systems are devices that convert electricity into mechanical power in industry. Smart logistics cover the logistics of transport of all sorts of goods. Smart buildings technologies are used to design, construct and operate buildings more efficiently, while smart grids are solutions that route power more efficiently, reduce the need for excess capacity and allow two-way real-time information exchange and real-time demand management.

There is currently no common standard for how to measure or set targets for climate emissions from cities. However, there are many initiatives underway in both academia and society to develop methodologies for setting and measuring climate targets in cities. The UN and EU are both leading initiatives initiated by the governments of their member countries and there are also some methodologies developed by different organisations such as LEED-ND, BREEAM-Community and CASBEE-City.

Advanced Traveller Information Systems (ATIS) for travellers, with public transportation, bicycle and multimodal journeys, is an area where there has been limited research to date. Furthermore, the research on Intelligent Transportation Systems (ITS) to date has mainly focused on the optimisation of traffic through better traffic flows and security. The development of new functionalities in ATIS is increasing rapidly through the new opportunities provided by social network technologies, applications in mobile phones and mobile broadband technology. However, research on how these systems can support the achievement of environmental goals and more optimised planning of traffic and essential infrastructure is still in its infancy.

A recent European research project made a comprehensive study of how ICT can be used to reduce energy use and GHG emissions from the building sector, covering the phases of design, production and usage (REEB 2010a; REEB 2010b). The project compiled a vision for how ICT can be used in buildings to reduce energy use and GHG emissions in a short, medium and long-term perspective. It also gathered examples of best practice and made a review of all research projects in the area. The conclusion from the REEB project was that the potential impacts of various technologies on energy reductions are still not sufficiently well known.

1.2 Aim and scope of the thesis

The overall aim of this thesis was to explore how information and communication technology (ICT) solutions can contribute to lower energy use and GHG emissions from buildings and travel and thus help cities reach their climate targets. An additional aim was to obtain an overview of the research front within each of the areas examined.

The specific research questions examined in Papers I-III were:

- WHAT methodological considerations are of importance when setting targets for energy use and GHG emissions by cities? This question is mainly explored in Paper I, where the aims were to:
    - *Identify, explore and present an overview of methodological considerations of importance in order to facilitate understanding, comparisons and setting of climate targets for cities.*
    - *Explore how these methodological considerations have been handled in practice.*

- HOW can Advanced Traveller Information Systems (ATIS) be improved to lower energy use and GHG emissions in urban areas? This question is discussed in Paper II, which aimed to:
    - *Identify and explore possible functionalities in ATIS that can support the traveller to choose travel modes that could lead to lower energy usage and GHG emissions*
    - *Make a systematic investigation of ATIS functionality, primarily in Sweden, Germany, the UK and US, to identify opportunities and challenges that can enable the next generation of ATIS to contribute to lower energy usage and GHG emissions*

- WHICH ICT applications can reduce energy use in buildings and by whom? Paper III handles this question by aiming to:
    - *Identify, list and describe ICT applications that can reduce energy use in buildings.*

2. Scientific and Methodological Approaches

The scientific approach adopted in Papers I-III was both theoretical and empirical and the aim of the research was both epistemologically and instrumentally orientated. It sought to create new knowledge of the research objects and to find solutions for societal problems and opportunities for development of commercial products.

Robinson (2008) argues that the field of sustainability or sustainable development can be characterised as issue-driven interdisciplinary research because of its inherently complex, multifaceted and problem-based focus. Issue-driven interdisciplinary operates in the borderland between academy and society as a whole and is typically characterised by partnerships with the external world (Robinson 2008). The research presented in this thesis had its origins in real societal problems, namely the need to reduce energy use and GHG emissions from cities. Since the characteristics of reality are complex and multifaceted, applied science cannot be described by only one discipline and will always be interdisciplinary.

The methodological approach in Paper I is characterised by induction and interpretation using a hermeneutic approach, while the empirical investigation is based on examination of eight European cities. The investigation sought to determine how the cities have set their climate targets, using data collected through a questionnaire and through interviews.

Paper II is an empirical study on the functionalities of nine different ATIS, which were tested through their internet and mobile phone applications. A decision tree model was used to analyse the data and derive requirements on functionality, which were presented in a use case model.

In Paper III, empirical observations from the EU project REEB (REEB 2010a; REEB 2010b) were used as they were recent and covered the field designated for study in this thesis.

The great scope of the topic studied in the thesis called for a variety of methods and approaches. A short account of the most important methods used is given below.

2.1 Literature reviews

In the literature review described in Paper I, a search was made for methodologies that measure the GHG impact of cities. Three groups of literature resources proved to be useful in this regard. The first group comprised a number of GHG accounting protocols. Among those investigated were the ICLEI Community-Scale GHG Emissions Protocol (ICLEI 2011), the draft International Standard for Determining Greenhouse Gas Emissions from Cities (IPCC 2010) and the draft Corporate Value Chain (Scope 3) Accounting and Reporting Standard (WRI-WBCSD 2011). The second group included major sustainable city frameworks, of which Paper I investigated BREAAM Communities (BRE 2011; BRE 2012), LEED-Neighbourhood Development (USBGC 2011) and CASBEE-City (JBSC 2011; Murakami et al. 2011). The third group comprised scientific papers reporting on accounting methodologies.

Since Gullberg (2010) had already made a comprehensive review of scientific literature in the field of ATIS, that review was used in Paper II to select articles for the purposes of the study. The articles listed by Gullberg (2010) covered different aspects of ATIS such as context, history, demand, owner's purpose, target groups, information characteristics, additional functions, impacts, future challenges. The articles selected for study in Paper II covered society's motives and desired goals for travelling and transport, different perspectives of travellers' motives for travelling, travellers' choice of means of transport, ATIS user needs and different functionalities of ATIS.

The literature review in Paper III mainly covered the scientific literature and was conducted with the aim of locating articles about buildings combined with energy, GHG and ICT. Approximately 70 articles were found and some 20 of these were selected for further study. The European Strategic Research Roadmap to ICT-enabled Energy Efficiency in Building and Construction (REEB) was identified as an interesting and relevant project to use as a basis for Paper III. The REEB project results consist of a review of scientific research projects and a list of best-practice solutions identified in the industry.

2.2 Questionnaire

In Paper I a questionnaire was drawn up in order to obtain information on how cities set their climate targets. The questionnaire was sent to eight cities, which were selected on the basis of having received an award for their high environmental standards and also for being committed to ambitious climate targets. The questionnaire covered questions regarding important system boundaries that the cities used when setting their climate targets.

2.3 Interviews

In Paper I, a number of interviews were held with some of the climate coordinators in the cities studied. These interviews can be characterised as semi-structured (Lundahl and Skärvad 1999) and were performed following the structure of the questionnaire. The interviews were held both in face-to-face meetings and via the telephone.

The interviews performed in Paper II were of an unstructured (Lundahl and Skärvad 1999) conversational form and were held with ITS experts from Sweden and Germany. The aim of these interviews was to obtain knowledge about how the information systems for travellers in public transport have evolved and also about future possible trends. The interviews were held in face-to-face meetings.

2.4 Induction and hermeneutic spiral

Williams and May (1996) define induction as the derivation of a general principle, which is inferred from specific observations. In Paper I the method of induction and hermeneutic spiral was used. First, theoretical and empirical observations were made on the system boundaries used for energy use and climate emissions in the eight selected cities by reading the scientific literature and testing the methodological considerations in these eight cities. An interpretation was then made regarding which of these system boundaries were the most important dimensions to be used. Mottier (2005) problematises interpretations by pointing out that researchers try to read the meaning of cultural text by writing their own text in turn and that issues of gender, class, race and the immediate contextual conditions also have an impact on the interpretation. The research group involved in Paper I had various theoretical prior knowledge of the topic and therefore the observations were not completely unbiased. We knew from the beginning that we were looking for certain dimensions such as producer or consumer perspective, life cycle perspective or not, all activities in the city or not, all environmental impacts or only a few.

2.5 Decision tree modelling

In Paper II a decision tree model was developed to identify and explore connections between travel decisions by individuals and different functions in ATIS. The decisions were selected by following the guiding principles from Mobility Management (MM) measures applied by the Swedish Transport Administration (STA) (Swedish Transport Administration 2010) and the traffic hierarchy applied in Stockholm Royal Seaport (SRS) (City of Stockholm 2010). The model was then used to demonstrate how different choices of travel modes for an individual's daily activities lead to different energy usage and GHG emissions and to find new requirements on functionality in an ATIS that can lead to lowered energy usage and GHG emissions.

2.6 Use case modelling

Unified Modelling Language (UML) is a standard language for modelling software systems starting with use case modelling to define the functional requirements and non-functional requirements (data characteristics, performance etc.) on a computer system (Booch et al. 1999). The use case model used in Paper II described travellers' specific usage of the system. The model was used to illustrate the requirements for functionality in potential use cases that would be needed if the ATIS were to support a more environmentally friendly journey.

3. Results

The major findings of this thesis can be classified into three different types of contributions. The first of these was an analysis of important system boundaries for cities' climate targets, resulting in the identification of the most important methodological considerations a city must make when setting climate targets for a city (Paper I). The second was identification of new and improved functionalities in an ATIS to support the individual's choice of travel modes, leading to decreased use of energy and GHG emissions (Paper II). The third contribution was a compilation of ICT applications that can be used in buildings to reduce energy use and GHG emissions (Paper III).

3.1 Paper I: 'Elusive targets – Methodological considerations for cities' climate targets'

The outcome from Paper I is a framework of methodological considerations (Table 1) that are of importance when setting climate targets for cities and an examination of how eight European cities set their climate targets.

In order to set climate targets for a city, it is necessary to decide what should be included in the target and what should be omitted. We sought out the main categories of system boundaries used for each study city's climate target and identified four main categories. The dimensions or methodological considerations identified as being of importance were the following: temporal scope, object for target setting, unit of target, and range of target. For each methodological consideration, different aspects were identified, as presented in Table 1. Each methodological consideration is discussed in more depth in Paper I in relation to climate targets for the eight cities.

Analysis of the results from the questionnaire showed that different cities use different system boundaries when setting climate targets. The information about delimitations made in the individual cites tends to be incomplete and there is generally a lack of data. City administrators and councils have limited knowledge about the delimitations made and how they influence the targets. The eight cities studied in Paper I only covered a certain part of all climate impacts. Consumption of goods, national transport services and production chain upstream processes are all unaccounted climate impacts that were omitted.

The multitude of differences in GHG accounting protocols, sustainable city frameworks, the different methods for calculating and the lack of data from the cities make it almost impossible to compare the cities' climate targets. Paper I concluded that there is a need for standardised use of common terminology in this field.

Table 1. *Methodological considerations when setting targets for cities. Source: Paper I*

1. Temporal scope of target
1.1. Reference year Is the target absolute or set in relation to some reference year? 1.2. Time frame For what year is the target set?
2. Object for target setting
2.1. Defining and delimiting the spatial boundaries What are the geopolitical boundaries for the city or city district? 2.2. Defining and delimiting what activities to include Should all or a selection of the activities within the boundary be included or not?
3. Units of target
3.1. Should the target be formulated in terms of GHG and/or energy use? 3.2. Should the target be set for the city or per person living in the city?
4. Range of target
4.1. Consumer or producer perspective? Should emissions from production or consumption within the geographical boundaries be the focus, or is a combination to be recommended? 4.2. Life cycle perspective or not? Should emissions from the whole life cycle of the product/service be included? Single process or production chain?

3.2 Paper II: 'Improving advanced travel information systems to reduce energy usage and GHG emissions in urban areas'

Paper II explored how the individual's choice of travel modes could lead to lowered energy usage and GHG emissions in urban regions by improved functionality in multimodal ATIS.

The literature review identified certain situations where there is higher potential for a change in travel behaviour to occur. Before the trip, *changes in 'life circumstances'* and *small changes in everyday life* that alter the normal course of life are potential situations in which a change of travel mode will occur. During the trip, *disruptions in the current mode* of travel can lead to change of travel mode when re-routing is needed. After the trip, if the *usual daily trip does not fulfil the individual's requirements* on cost, travel time, comfort, convenience and reliability, it is likely that the traveller will be adaptive to information about alternative travel modes that can lead to a change in travel mode in the next journey. On order to find functionalities to support these cases, the journey was divided into three phases: Pre-Trip, On-Trip and Post-Trip. Pre-Trip occurs before starting the trip, On-Trip occurs between the current position and the final destination and Post-Trip occurs after the final destination has been reached.

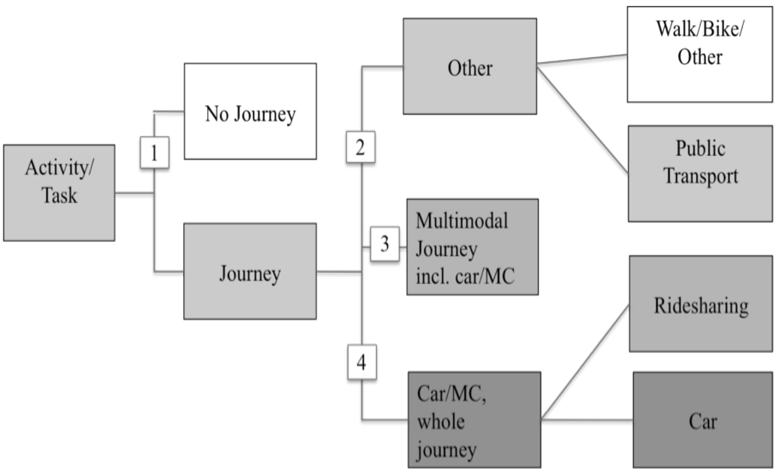

Figure 1. *Decision tree for different choices of travel modes, where the upward direction leads to less energy usage and GHG emissions. Source: Paper II.*

The decision tree model (Figure 1) was developed to demonstrate the travellers' choices of travel modes for different activities in their everyday life. When individuals choose a travel mode that is placed higher up in the decision tree, less energy is used and less GHG are emitted.

By examining current ATIS with the aim of finding functionality to support the different phases of the journey and for each choice of travel mode, new opportunities for functionalities can be found. A lack of functionality is identified and a proposition of new and improved functionalities is made, which could enable the next generation ATIS to contribute to lower energy usage and GHG emissions.

The results from Paper II show that there is a lack of functionality or a need for improved functionality in the following cases:

- Functionality to plan, book and perform activities for the choice "No Journey"
- On-trip and Post-Trip functionality.
- Booking, payment and ticket functionality.
- Environmental information used for automation or persuasion.
- Public transport information in car navigation systems
- Ridesharing functionality

The proposition for new and improved functionality resulted in the following use cases:

Pre-Trip: There is an opportunity to use environmental information to automatically select and present the journeys with the lowest environmental impact or to use different incentives or penalties to persuade the traveller to choose environmentally friendly travel modes.

On-Trip: When there is a disruption in traffic, the system has the opportunity to lead the private transport traveller to other alternatives, such as park-and-ride facilities for car drivers, or to lead the public transport traveller to alterative routes via two-way communication.

Post-Trip: When the usual trip does not fulfil the traveller's requirements, a feedback mechanism could give guidance on other modes of travel after the journey.

Choice (1) No Journey – To help travellers find *alternatives* to perform their daily activities, the system could provide information on other choices, such as videoconferencing, delivery of goods or virtual meetings with a doctor.

Choice (2) Walk, Bike, Public Transportation, Other – To encourage travellers that are already using environmentally friendly modes of travel to continue to do so, the system needs to be reliable and have accurate information on current conditions in the traffic system, as well as recent weather information.

Choice (3) Multi-modal journey/including car/MC – For travellers using several modes of travel, it would be convenient if the information were to be seamless and the system could follow the traveller in any mode of travel. Convenient handling of payment and tickets is particularly crucial for the multimodal traveller, since there are different tickets to handle such as parking tickets and public transport tickets.

Choice (4) Car/MC, whole journey – To make a car journey more environmentally friendly, sharing the journey with others is the best opportunity. Therefore there is an opportunity for ATIS to provide information about possible shared rides in the same system as the public transportation system.

In conclusion, the results from Paper II are:

- Division of the journey into three phases (Pre-Trip, On-Trip and Post-Trip) to identify functionalities
- Use of a decision tree model to illustrate how the choice of travel modes leads to different energy use and GHG emissions.
- An empirical investigation of the functionality of nine ATIS Internet and mobile applications
- A proposition for improved functionality in next generation ATIS to support more environmentally friendly travel.

3.3 Paper III: 'ICT applications to lower energy usage in the already built environment'

In Paper III, ICT applications that can be used for reduction of energy use and GHG emissions in buildings in the already built environment are identified (Table 2) through a compilation of literature. There is also a brief analysis of four different perspectives of ICT in buildings: The actor perspective, integrity questions, energy reduction potential, and synergies and conflicts between different objectives.

Table 2. *ICT application areas used for energy and GHG reductions in the already built environment*

ICT application area	**Functionality**
Intelligent and integrated control	Manages energy production and usage in buildings
User awareness and decision support	Visualises energy use and provides real-time pricing Measures and displays the building's performance by sensors
Energy management and trading	Makes it possible for the building to act as a node in the smart grid
Integration technologies	Enable different stakeholders to collaborate and share knowledge Enable different systems and tools to communicate with each other
Participatory sensing	Enables public and professional users to gather, analyse and share local knowledge
Social media technologies	Knowledge sharing and learning
Persuasive technologies[1]	Used to influence the attitudes or behaviour of users through persuasion or social influence, but without coercion
Cloud computing	Enables on-demand network access to a shared pool of configurable computing resources
Energy management without smart meters	Monitors and controls residential energy use without the use of smart meters using existing nodes in the home network infrastructure.

[1] Persuasive technology is not comparable with the other application areas in table 2. It is rather a collection of principles being used to use ICT as an enabler to persuade the users.

4. Concluding discussion

The main conclusions of the research presented in Papers I-III are summarised below, with a discussion on whether the overall aim of the thesis was achieved and a reflection on the contribution of each paper to that aim. Finally, some areas for future research are suggested.

4.1 Was the overall aim of this thesis achieved?

The overall aim of this thesis was to explore how ICT can contribute to lower energy use and GHG emissions and thus help cities reach their climate targets.
The climate targets of cities address the need for a reduction in GHG emissions and in energy use. The thesis identified ICT solutions for both the travel and residential sectors in urban areas that have potential to reduce GHG emissions and energy use. However, the potential savings derived from ICT systems and the climate emission and energy use of the ICTs themselves need to be further examined (Jens Malmodin et al. 2010). Different rebound effects derived from ICT, such as increased car travel due to solutions that make traffic flow more efficiently, need to be taken into account. There are also aspects to consider regarding the individuals intended to make use of the systems. Just because the systems exist, there are no guarantees that individuals will use them or that the use of the systems will lead to the expected outcomes.

In the following sections, there is a reflection on the contribution of Papers I-III to the overall aim.

4.1.1. WHAT methodological considerations are of importance when setting targets for energy use and GHG emissions by cities?

Paper I contributes to the overall aim of the thesis by identifying how climate targets are set today in cities and how different protocols and methodologies are measuring energy use and GHG emissions from cities. When going through the multitude of proposals for how accounting could be done, it becomes obvious that there is a need for standardisation and a common terminology. Paper I identifies important system boundaries to be considered when setting climate targets in cities. These system boundaries must be borne in mind while finding solutions for reductions in energy use and GHG emissions in cities.

In order to make realistic calculations of the contribution of ICT to climate targets, it is necessary to have comprehensive and consistent accounting protocols and methodologies in place, developed especially for the climate targets of cities. ICT solutions that reduce a certain amount of GHG emissions and energy use in one city will not lead to the same result in another city if the system boundaries used are different, even if everything else is equal. Cities are therefore difficult to compare and it is difficult to know how efficient different ICT solutions are in different environments. Paper I shows that cities only cover a certain part of all climate impacts, which means that the majority of all GHG emissions and energy use risk not being recognised at the local level. Even if ICT solutions can give substantial support for reductions in energy use and GHG emissions that are not part of calculations, there is a risk that these ICT solutions will not be developed since the need for them will not be identified owing to their contribution not appearing in any calculations.

4.1.2. HOW can Advanced Traveller Information Systems (ATIS) be improved to lower energy use and GHG emissions in urban areas?

Paper II contributes to the overall aim by making a connection between societal goals and functionalities in ATIS. By studying society's desired and expected effects on transportation, the connection between the individual's choice of travel mode/s and the environmental effects of different travel modes was established. An examination of some of the world's leading ATIS for multimodal travel revealed that it was possible to identify functionalities that are currently lacking or could be improved to support the individual to choose more environmentally friendly travel modes.

ATIS can support travellers with information so they can make choices both to reduce energy usage and shift to transport modes using renewable energy sources. ATIS can support the reduction in energy usage by providing functionalities for the choice to forego the journey and instead use virtual possibilities such as videoconferencing or telephone meetings. The system provides functionalities for demobilisation in this case, where connectivity is more important than centrality (Mitchell 2000). By providing reliable information on bicycle paths, ATIS might be able to encourage individuals to shift to travel modes that only require physical energy sources instead of energy from the grid or other sources. Ridesharing is another opportunity for energy reduction that can be supported by the system. ATIS can also support the transformation from travel modes using fossil fuel to modes that use renewable energy sources.

4.1.3 WHICH ICT applications can reduce energy use in buildings and by whom?

Paper III contributes to the overall aim by providing an overview of ICT applications that can be employed during the usage phase of buildings to reduce energy use and carbon emissions. The main focus in that overview is on ICT applications that reduce electricity use. Each of the ICT applications can be seen as an object that could have an impact on energy use and GHG emissions. These objects will not have any impact if there are no actors there to buy, install and use them. Paper III contributes a brief examination of the actors that could be the owner of the system and those that would use it.

4.2 Proposals for future research

To acquire deeper knowledge and a better understanding of how ICT solutions can support the transformation to lower use of energy and GHG emissions and allow cities to reach their climate targets, more research is needed.

The methodological considerations developed in Paper I need to be further elaborated. In order to make calculations for different activities in cities, it is important to know how to define and delimit different activities. Since ICT is characterised by its pervasiveness and penetration of all domains of human activities (Castells 1996), there are almost unlimited ways to define and delimit activities depending on the perspectives used. Further research is needed on the methodological considerations for each activity. In this thesis a sector approach was used to subdivide the activities examined. However, it is possible that there are other perspectives and layers that could be used to divide the city and allow identification of ICT solutions that are better suited to the support of climate targets.

This thesis examined travel and the residential sector in urban areas. In order to account for emissions from travel in an urban area, a number of issues need to be considered. The most important is the spatial borders of the city. Vehicles and travellers pass over the borders of the city several times per day, which makes it difficult to know what emissions and energy use to allocate to the city. There are also unresolved issues regarding the range of travel that should be included in accounting. Should only the fuel be considered, or should the entire production of the vehicle and infrastructure be included as well? How should the fuel be calculated – from fuel sales data within the geopolitical border, or for a car that is registered within the city? Regarding public transportation, there are issues on how passenger data should be calculated. Accounting for emissions and energy use in the residential sector is slightly easier, since buildings remain in a fixed place. For the residential sector there is also a question of what activities should be allocated to the building – all household electricity, or only the heating and cooling energy use.

Traffic planners and traffic monitors are currently not using the information about travellers and their demand for transportation from the use of ATIS. Functionalities during the trip can be combined with traffic planning and traffic monitoring requirements in order to optimise and enhance the use of infrastructure in urban areas. The system could be used to gather information on how individuals travel, to be used when planning for new infrastructure in the city. It could also be used for traffic monitoring to support travellers on their journey.

In Paper II the real travel behaviour of individuals was not considered and instead a theoretical way of finding possible new functionalities was used. In ethnographic field studies, researchers closely observe and investigate decision-making, habits and changes of travel through interviews and travel planning diaries. This provides real-life details and mechanisms of thinking ahead, planning and preparing for travel; or, in short, an understanding of everyday travel planning in practice. To further strengthen the system or devise a better system suited for the real travel behaviour of individuals, it would be good if studies such as those reported in Paper II could be combined with studies of real travel behaviour in order to determine the extent to which ATIS can influence travellers' choice of travel mode.

The ATIS investigated in Paper II and the ICT systems for energy efficiency in buildings investigated in Paper III are both dependent on many organisations on order to function well. There are many different stakeholders, providers of data and functionality, different

users and usages. Therefore, joint co-operation between public authorities, organisations and the public is necessary. Open data and standardised interfaces are also necessary for these kinds of systems to function well.
Business models need to be developed to examine sustainable co-operation.

ICT solutions have very short life cycles, which are not easily combined with long-term targets such as the climate targets of cities. Solutions that are brand new today will soon be obsolete. Exploring new ways or business models to handle the upgrading and transformation of solutions into future needs is another subject for further research.

Finally, in Paper III we initiated a brief study on the actor perspective, the possible energy savings, personal integrity questions and synergies and conflicts between different types of objectives. In future research it would be interesting to make a more thorough analysis of these perspectives.

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