KTH Architecture and
the Built Environment

Smart Cities and Climate Targets

Reducing cities’ energy use with ICT and travel information

ANNA KRAMERS

DOCTORAL THESIS

in

Planning and Decision Analysis

with specialisation in

Environmental Strategic Analysis

Title: Smart Cities and Climate Targets. Reducing cities' energy use with ICT and travel information

Author: Anna Kramers

KTH Royal Institute of Technology
School of Architecture and the Built Environment
Department of Sustainable Development, Environmental Science and Engineering
Division of Environmental Strategies Research – fms
and
Centre for Sustainable Communications

TRITA-FMS-PHD 2014:01
ISBN 978-91-7595-265-9
Printed by US-AB in Stockholm, Sweden 2014

Abstract

This thesis examines use of ICT in helping to reduce energy use in cities, thereby contributing to sustainable development and achievement of cities' climate targets. It explores how targets can be developed in a consistent and transparent way, how to identify the main ICT 'hotspots' as regards reducing citizens' energy use and how they can be included in city planning. Implementation of mobility management principles and climate targets was tested in two existing solutions, a traveller information system and a flexible work hub solution.

Four key methodological considerations when setting climate targets for cities were identified. These concerned decisions on: target setting object, temporal scope, units and target range. A tool was developed for identifying promising ICT hotspots. The tool can also be used to monitor implementation of ICT solutions and the associated technological and socio-technical difficulties. In a case study in Greater Stockholm, the ICT hotspots identified were intelligent building heating systems, intelligent transport system and potential transformation of the physical environment (buildings and roads) enabled by ICT solutions.

Two aspects of planning identified as crucial for successful implementation of energy saving ICT solutions were studied in detail: i) Timing of ICT-related decisions in the planning process; and ii) the actor networks needed to implement the ICT solutions and their management. There are few decision points in the current planning process, so the municipality as property owner and its decision-making process are of crucial importance. Two collaborative approaches to govern, network governance and coordination through meta-governance as a way of indirect steering, are proposed.

An investigation of nine traveller information systems and a case study in Stockholm of flexible work hub solutions revealed that mobility management approaches to reduce transport demand and encourage environmentally friendly transport modes are poorly reflected in the implementation. To support mobility management approaches, traveller information systems should primarily offer, or be integrated with, other solutions that support the choices "no travel" and "shorter journey". Flexible work hubs should be located in local nodes closer to people's homes.

The main conclusions from this work were that ICT solutions can be modified to support achievement of cities' climate targets and that climate targets must be defined using transparent methodology that clarifies the target content, ensuring that the most promising energy saving ICT solutions are implemented.

Sammanfattning

Denna avhandling undersöker hur informations- och kommunikationsteknologi (IKT) kan användas till att bidra till minskning av energianvändning i städer och därmed bidra till att nå städers klimatmål. Den undersöker hur städers klimatmål kan utvecklas på ett konsekvent och transparent sätt, hur de mest lovande IKT-lösningarna kan identifieras när det gäller att minska invånarnas energianvändning och hur de kan ingå i stadsplanering. Genomförande av principer för mobility management samt samhälleliga mål testas i två befintliga lösningar, - ett resenärsinformationssystem och en flexibel arbetsplatslösning.

Fyra centrala metodologiska överväganden för att bestämma städers klimatmål identifieras. Dessa gäller: föremålet för målformuleringen, den tidsmässiga omfattningen, mätenheten och målets räckvidd. Ett verktyg togs fram för att identifiera de IKT-lösningarna som är mest lovande vad gäller att minska stadsbornas energianvändning. Verktyget kan också användas för att observera de identifierade IKT-lösningarnas utnyttjandegrad samt de tekniska och sociotekniska svårigheter som är förenade med införande. I en fallstudie i Storstockholmsområdet identifierades de IKT-lösningar som var mest lovande: intelligenta värmesystem för byggnader, intelligenta transportsystem samt den potentiella förändringen av den fysiska miljön (byggnader och vägar) som görs möjliggörs av IKT-lösningar.

Två aspekter av planering som identifierats som avgörande för ett framgångsrikt införande av energibesparande IKT-lösningar har studerats i detalj: i) Tidpunkten för IKT-relaterade beslut i planeringsprocessen; och ii) de aktörsnätverk som behövs för att införa och förvalta IKT-lösningarna. Det finns få beslutspunkter i den aktuella planeringen vilket gör att beslutsprocessen och kommunens roll som fastighetsägare är av avgörande betydelse. Två strategier för samarbete föreslås, styrning genom samordning i nätverk och samordning via metastyrning (indirekt styrning).

En undersökning av nio reseplanerare och en fallstudie i Stockholm av flexibla arbetsplatslösningar visade att mobility management metoder för att minska efterfrågan på transporter och uppmuntra miljövänliga transportsätt inte återspeglas tillräckligt i genomförandet. För att stödja mobility management-principer bör resenärsinformations-system främst erbjuda, eller integreras med andra lösningar som stödjer valen "ingen

resa" och "kortare resa". Hubbar för flexibla arbetsplatser bör placeras i lokala noder närmare bostäder.

De viktigaste slutsatserna i denna avhandling är att IKT-lösningar kan modifieras för att stödja städers klimatmål och att klimatmål måste definieras med hjälp av transparenta metoder för att säkerställa att de mest lovande IKT-lösningar för energiminskning införs.

Acknowledgements

I would first of all like to thank Professor Mattias Höjer and Doctor Åsa Svenfelt both at the Division of Environmental Strategies Research, and the former Adjunct Professor Anders Gullberg, at the Division of History of Science, Technology and Environment, for being such great supervisors and for all the support during my journey. Mattias, you are a very busy hardworking person who I am always able to count on when it really matters. I appreciate that a lot. I am eternally grateful that you invited me to do my post-graduate studies with you. It opened up a new world for me – the research world – where I now feel at home. Åsa, I'm very grateful for your advice regarding my scientific approach and for guidance in important strategic choices along the journey. You helped me bring the focus back onto things that were really important when I was rushing off in different directions. Anders, you were a great inspiration, especially for the parts on travel information. During the last year we had great fun when working together to raise funds for continuing the project.

I would like to specially thank a number of colleagues, all of whom contributed encouragement and support in different ways during the production of this doctoral thesis. These are Åsa Moberg for being such a great and encouraging manager, Göran Finnveden, who has taught me most of what I know about production and consumption perspectives and life cycle assessment, Örjan Svane who gave food for thought in the cross-disciplinary field of ICT and the built environment, Greger Henriksson who taught me about the importance of human habits, Jonas Åkerman for his support and knowledge about emissions from transportations, Arne Kaijser who introduced me to Jackie Klopp at Columbia University, Murial Beser Hugosson who helped me with the travel demand forecasting model Sampers and Marco Turpeinen EIT ICT Labs in Helsinki who gave strategic advice on the ICT parts in the early phases.

This thesis could not have been completed without the funding received from VINNOVA and partners at the Centre for Sustainable Communication, as well as partners at the TRACS project.

I would like to thank all partners who participated in my research projects. Nils Göransson, Ing-Marie Ahlstrand, Maria Lennartsson, Michael Erman, Christina Salmhofer, Johan Bergkwist, Malin Söderholm, from City of Stockholm; Per Andersson, Matilda Gennvi Gustavsson, Christer Törnevik, Nina Lövehagen, Pernilla Bergmark, Jens Malmodin, Michael Anneroth, Marcus Nyberg, Olle Isaksson and Craig Donovan from Ericsson; Petra Ranhem, Dag Lundén, Björn Hallare and Catherine Karagianni from TeliaSonera; Pernilla Wistrand, Joakim Barkman and Haval Davoody from Swedish Transport Authority; Elias Arnestrand and Åsa Edholm from Samtrafiken; Fredrik Meurman, Stockholm County Council; Gunnar Granberg, Spacetime; Pierre-Yves Fonjallaz, Swedish ICT Acreo; Ulf Ranhagen, Sweco; Karl Bergkvist, SL/Cybercom; Torbjörn Lundquist, Institute for Future Studies; Helene Wintzell, HS2020 and Cecilia Katzeff, Swedish ICT Interactive.

I would also like to thank Jackie Klopp and her team for showing such great hospitality during my time as a guest researcher at the Centre for Sustainable Urban Development, Earth Institute, Columbia University, New York.

Thanks to my co-authors Göran Finnveden, Josefin Wangel, Malin Söderholm, Marcus Nyberg, Mattias Höjer, Nils Brandt, Nina Lövehagen and Stefan Johansson.

Big hugs to all my colleagues at CESC and fms for good co-operation and interesting discussions during coffee and lunch breaks. Special thanks to Jorge Zapico, Malin Picha, Elina Eriksson, Daniel Pargman, and my roommates during the years: Bernhard Huber, Miriam Börjesson Rivera, Jacob von Oelreich, Wei Bai, Åsa Nyblom, Nils Brown, Stefan Johansson, Elisabeth Ekener Petersen, Mohammad Ahmadi Achachlouei, Annica Carlsson and Elisabeth Hochschorner.

Thanks to my quality reviewer Göran Cars for positive encouragement and to Mattias Höjer and Åsa Svenfelt for reading and providing many good comments and suggestions on the cover essay. Thanks also to Mary McAfee for professional language checking. Special thanks to Daniel Vare for invaluable help with the end-note system.

Finally, I would like to thank my family and friends. First of all I want to thank my beloved Michael for all his support and discussions about my research during all these years. When I sometimes thought I wouldn't make it, you encouraged me to continue. You have proofread manuscripts, contributed knowledge in social sciences and took on much of our joint work, especially when I was in New York. But you have also challenged me as a sparring partner, wondering if there would ever be any articles.

I would like to thank my dear children who after these years are now grown-ups. Thanks Sara for bringing in interesting new perspectives, such as pedagogics in childcare and criminology, and also for encouraging and challenging me in physical training. Thanks Jesper for inspirational talks about urban planning, sustainability and a new perspective on life from Lund.

Thanks to my parents, Kerstin and Lennart Boström, who always believed in my projects and also for their visit when I was at Columbia University. Finally, thanks to the rest of my extended Kramers Boström family and all my dear friends who have encouraged me and followed this work with interest.

List of papers

Paper I: Kramers A, Wangel J, Johansson S, Höjer M, Finnveden G, Brandt N (2013) Towards a comprehensive system of methodological considerations for cities' climate targets, Energy Policy 62: 1276-1287

Paper II: Kramers A, Höjer M, Lövehagen N, Wangel J (2014) Smart sustainable cities: Exploring ICT solutions for reduced energy use in cities, Environmental Modelling & Software 56: 52-62

Paper III: Kramers A, Wangel J, Höjer M (2014) Planning for smart sustainable cities: Decisions in the planning process and actor networks, In Höjer M, Lago P, Wangel J (Eds.) Proceedings of the 2014 conference ICT for Sustainability, Stockholm August 24-27, Atlantis Press ISBN (on-line): 978-94-62520-22-6

Paper IV: Kramers A (2014) Designing next generation multimodal traveler information systems to support sustainability-oriented decisions, Environmental Modelling & Software 56: 83-93

Paper V: Kramers A, Nyberg M, Höjer M, Söderholm M, Work hubs – Location considerations and opportunities for reduced travel, Submitted manuscript.

Comments on co-authored papers
Paper I: I am one of two main authors. Specifically I had main responsibility for 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 II: I am the main author. Specifically I had the initial idea for the tool and wrote the sections about smart cities and identifying ICT solutions for low-energy cities.
Paper III: I am one of two main authors. Specifically I had the main responsibility for the sections about the planning process and planning, timing and sequence of events, including Table 1.
Paper V: I am the main author. Specifically I had main responsibilities for all parts except the examples from Ericsson.

Contents

1. Introduction

The way cities is developed and managed is of fundamental importance for sustainable development (Egger 2006). Information and communication technology (ICT) can be used strategically to support achievement of a sustainable development and specifically cities' climate targets. However, ICT can be adopted in very different patterns (Benkler 2006) and there is no guarantee of success, although it has huge potential for use in reaching climate targets.

This thesis examined whether ICT solutions can be adjusted to support achievement of cities' climate targets. This can only be successful if the positive effects are greater than the ICT solutions' own impacts and possible rebound effects. Therefore there is a need to investigate how ICT is implemented and used today and how it could be improved to better fulfil cities' climate targets.

1.1 Background

1.1.1 Climate change connection to cities

The evidence on global warming of the climate system is unequivocal, according to the IPCC (2013). The atmosphere and oceans have warmed, sea level has risen and the concentration of greenhouse gases (GHG) has increased (IPCC 2013).

Many of the world's cities are vulnerable to climate change. The Stern Review (UK Government 2006) reported that many of the world's cities are at risk of flooding from coastal surges. Other impacts of climate change on cities are sea level rise, extreme weather events leading to breakdown of infrastructure such as electricity and water supply, landslides because of expected increases in the scale, intensity and frequency of rainfall, and heat waves and cold waves with intense episodes of thermal variability (IPCC 2014).

Even though only around half the world's population lives in urban areas, urban dwellers consume two-thirds of the world's energy and this figure is expected to grow to around three-quarters of world energy by 2030 (IEA 2008). This prediction is based on the assumption that demand in energy is closely correlated to per capita income and GDP growth (IEA 2008). Rising incomes continue to lead to increased demand for goods that require energy to produce and use. Examples of these products are cars, mobile communication devices, air conditioners etc. According to the International Energy Agency, the energy sector is responsible for two-thirds of global GHG emissions and is therefore pivotal in determining whether or not climate change targets are achieved ((IEA 2013), page 41). Combustion of fossil fuel is responsible for the majority of these energy-related emissions. According to IEA (2013), global energy demand will grow to 2035, leading to a 20% rise in energy-related CO_2 emissions, despite the strong rise of renewables.

Many cities in Europe have bold targets for energy and GHG reductions, and have adapted the Covenant of Mayor[1] target to exceed the EU target of reducing GHG by 20% from 1990 levels by 2020. In Sweden, Stockholm[2] has decided that the GHG emissions in 2015 must not exceed 3 ton CO_2e/capita and that all use of fossil fuels will be phased out by 2050. Malmö[3] has decided to reduce GHG by 40% by 2020.

Some believe that cities have the potential for more efficient use of resources (Williams 1999; Mindali et al. 2004; Dhakal and Shrestha 2010; Glaeser 2010), while others claim the opposite. The latter group argues that cities appear to be more resource-efficient as a result of inferior systems thinking and have a much larger carbon footprint than is typically accounted for (Hillman and Ramaswami 2010; Kennedy et al. 2010; Heinonen and Junnila 2011). This is because there are different ways of setting the system boundaries of a city, e.g. whether all energy used by the citizens is allocated to the city, irrespective of its origins, or whether only the energy used within the city is allocated to the city. Depending on how the allocation of energy use is made, the task of mitigating climate change in cities will be very different.

1.1.2 Transportation

One particular sector in the city with huge problems is transportation. The problems concern both the availability of the transport service and its energy use, which is mainly based on fossil fuels. Transportation infrastructure in cities over the world is crowded, with congestion during peak times when most people want to travel or commute. The transport sector uses 50% of global oil and nearly 20% of world energy use, of which approximately 40% is used in urban transport (OECD/IEA 2013). There are ambitious targets to reduce traffic and improve public transportation, while at the same time reducing energy use. The European Union (EU) target for the transport sector is to reduce emissions of GHG by at least 60% by 2050 compared with 1990 (EU 2011b).

The EU and its member states have set targets to move towards means of travel that use less energy. This involves provision of accessible travel information to allow change to a transport system that meets the requirements for optimisation of the transport network, efficient use of land, lower energy use and lower GHG emissions (EU 2011b).

1.1.3 Potential of ICT

According to Hilty et al. (2011), the ICT approaches that have emerged during the last two decades in the area of environmental sustainability can be divided into three themes: Environmental informatics, green information technology IT/ICT and sustainable human-computer interaction (HCI). Environmental informatics is the field of processing environmental information such as monitoring systems, databases and simulation models. Green information technology is divided into two areas: Green in IT/ICT and Green by IT/ICT. Green in IT/ICT is concerned with resource consumption and the sustainability impact of the ICT sector. Green by IT/ICT is an approach where ICT is viewed as an enabling technology to improve or substitute processes in other sectors. In the Sustainable HCI approach, the focus is on the relationship between humans and technology, where sustainability is considered to be as important a design criterion as usability. According to GeSI (2012), ICT has the potential to reduce GHG emissions and energy use by 16.5% of total global GHG emissions. However, other studies have reported significantly lower potential, e.g. a 4.6% decrease within EU-27 (Bio Intelligence Service 2008).

There are many ICT-related concepts for smart cities, but the unanswered question is how smartness is linked to sustainability issues such as GHG emissions and energy reductions. Questions can be asked about the types of ICT investments that provide the best benefits for the environment and society, and about the type of solutions that should be provided by the city or left to the market, where entrepreneurial firms decide on their existence. There are large uncertainties and disagreements on how ICT can contribute to reducing energy use in cities.

1.2 Aim & Scope

The main aim of this thesis was to explore how ICT can support achievement of cities' climate targets.

In order to achieve this aim, the following specific research questions were formulated and investigated:

- What methodological considerations are of importance when setting climate targets for cities? (Paper I)

- How can ICT solutions with the most promising capability to reduce urban citizens energy use be identified? What decisions in planning are of importance to capture these capabilities to reduce energy use? (Papers II & III)

- How are mobility management approaches to reduce transport demand and to optimise use of existing transport infrastructure reflected in solutions for multimodal traveller information and flexible workspaces? How can the solutions be adjusted to better fulfil mobility management approaches? (Papers IV & V)

In this work, ICT solutions were defined as both ICT solutions per se (for example a traveller information system) and ICT-enabled solutions (for example a service enabled by ICT such as a flexible work hub). The scope of the work extended to the positive environmental effects that can be achieved in urban areas, with the focus on the built environment and transportation infrastructure. The effects are thus energy reductions in all activities performed by citizens. The work presented in this thesis adopted the Green by ICT approach (Hilty et al. 2011), that ICT can reduce energy use and GHG emissions in other sectors.

In order to achieve positive effects from ICT solutions, a thorough analysis is needed to understand how the whole system of technology, institutions and individual behaviour interacts. Solving one problem can cause a new problem to arise in another area. To really achieve the desired effects, it is necessary to be aware of ICT's own impact on the environment (Berkhout and Hertin 2004; Malmodin et al. 2010) and of second order/rebound effects that can be the result of ICT (Berkhout and Hertin 2004;

Börjesson Rivera et al. 2014). There can also be positive and negative effects of ICT related to sustainable economic and social development, but these were beyond the scope of this thesis.

The remainder of the thesis is structured as follows: Section 2 describes the scientific context of the studies and section 3 the methods, research process and study objects. The results from Papers I-V are presented in sections 4-6, which correspond to the three research questions listed above. Section 7 provides a discussion of the results and section 8 presents the conclusions reached.

2. Scientific context

The research presented in this thesis is derived from real societal problems that urgently need to be solved. It is imperative to find solutions to reduce energy use and GHG emissions from cities and urban lifestyles. The thesis is therefore mainly of an instrumental orientation, i.e. it seeks to find solutions for societal problems by the implementation and development of various ICT solutions.

The research was performed within the scope of the technological sciences as defined by Hansson (2007). *First*, it was a study of human-made objects rather than the humans themselves. *Second*, it included the practice of engineering. *Third*, the study objects were defined in functional terms, where functionality can be seen as the affordances of technical solutions (Ng 2014). *Fourth,* the study objects were evaluated with category-specific value judgments (environmental/energy reduction). *Fifth,* it was impossible to employ far-reaching idealisations (no laboratory environment, since technology interacts with both nature and people). *Sixth*, the mathematical calculations used approximations, unlike natural science.

However, technological change can only be understood in the context of the social structure within which it takes place (Castells 1989), so parts of the social environment in which the technology will be adopted were also studied.

Since the characteristics of reality are complex and multifaceted, applied science cannot be described by only one discipline and will always require an interdisciplinary approach. 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 (ibid).

The work presented in this thesis falls mainly within sustainability research, computer science and planning. The theoretical base of these research areas, as used in the context of this thesis, is further described and defined in the following sections.

2.1 Sustainability

The '*Limits to Growth'* report released by the Club of Rome in 1972 explored how exponential growth interacts with finite resources (Meadows et al. 1972). The report's findings and recommendations stirred up public reactions, which was exactly what the Club of Rome intended (Bell 2003). The report claimed that the future depends on what we decide to do. If the global human society decides to restricts industrial growth, stop population growth, recycle, find substitutes for non-renewable resources, give priority to food production and make both production and consumption sustainable, a good, long life for all human beings can be achieved within a world system that is sustainable far into the future (Meadows et al. 1972).

The World Commission on Environment and Development (WCED), released its report '*Our Common Future*', also known as the '*Brundtland Report*, in 1987 (WCED 1987). The report includes the most widely cited definition of the term 'sustainable development', which states that "Sustainable development is the kind of development that meets the needs of the present without compromising the ability of future generations to meet their own needs". A key element in the definition is the unity of environment and development. The two are inseparable and they cannot or should not be distinguished as separate entities because the 'environment' is where we live and the 'development' is what we all do in attempting to improve our lives and wellbeing.

Owens (2003) uses the form of a journey to distinguish different definitions through four eras of sustainability. The journey starts in *pre-Brundtland* days, traces developments through initial *post-Brundtland* optimism to the situation in the *era of the millennium shift*, and finally takes a look into the *future*. According to Owen (ibid), prudent resource use and the aftermath of the *Limits to Growth* report characterised the pre-Brundtland days, while the initial post-Brundtland era was characterised by a promise that with sufficient human ingenuity, all of the world's population, now and in future, would be able to enjoy growth and prosperity. However, such a move towards sustainability would mean paying greater and more explicit attention to environmental protection and integrity, because economic and social development had for too long omitted these considerations. In the era of the millennium shift, Owens (2003) found that any attempt to move beyond Brundtland's consensual idea raised scientific questions and profound ethical and political dilemmas. For example, how should we decide which aspects of the environment are so valuable that they must be protected in all but exceptional circumstances? At the end of the journey, in the era of the future, Owens (2003) recognised an opportunity to make a comparison of sustainability with democracy, arguing that we have now moved towards stronger versions of our understanding and definitions about democracy, which raises hope for the future of the term sustainability.

A step towards that future understanding of sustainability is the definition of a safe operating space for humanity by setting up planetary boundaries for ecological sustainability, as proposed by Rockstrom et al. (2009). Their definition of the safe operating space is that our planetary state should remain in the Holocene, during which we have experienced environmental stability over the past 10 000 years. However, some believe that we have entered a new era starting in the industrial revolution, the Anthroposcene, in which human activities have become the main driver of global environmental change (Steffen et al. 2007). According to Rockstrom et al. (2009), the boundaries for three Earth system processes (climate change, rate of biodiversity and interference with the nitrogen cycle) have already been transgressed (Figure 1).
To remain in a safe operating space, the rise in global mean temperature should not exceed 2°C above the pre-industrial level (EU 2007). Rockstrom et al. (2009) also propose that human-induced changes in atmospheric CO_2 concentrations should not exceed 350 parts per million (ppm) by volume and that radiative forcing should not exceed 1 watt per square metre (W/m^2) above pre-industrial levels.

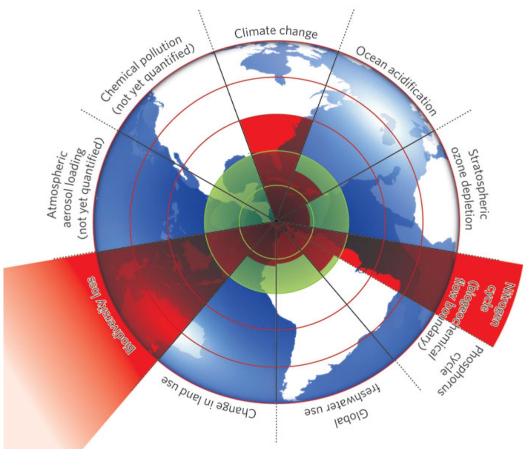

Figure 1. A safe operating space for humanity (Rockstrom et al. 2009).

The focus in this thesis work was on how to mitigate climate change with the support of ICT solutions in urban areas. In order to do so, there is a need to phase out fossil fuels and shift towards use of renewable energy sources, and to transform into a low-energy society. Hence the emphasis was on energy-reducing opportunities. The reason why it is not sufficient just to phase out fossil fuels is that energy is currently a scarce resource and needs to be distributed equally to all countries in the world. Certain countries have great renewable energy resources and others have not. For instance, Sweden has a good supply of renewable energy thanks to hydropower and bio-power.

2.2 Planning

The research in this thesis was mainly characterised by an interest in rational decision-making (Friedman and Hudson 1974; Raiffa et al. 2002), in particular decisions which public authorities, businesses and individuals can make to capture the energy-reducing effects of ICT. Some parts of the thesis (Papers III, IV, V) also examined the planning process (both urban and transport) and its role in producing the urban habitat (Hightower 1969; Friedmann 1998).

2.2.1 Decision making

Decisions in the planning of new city districts and the refurbishment or change of existing districts, traffic infrastructure etc. are preceded by negotiations and collaborations between many various stakeholders – private, public and non-profit organisations. The establishment of partnerships of different characters between these actors is crucial for successful implementations of decisions. The role of urban mangers has shifted to being more process management instead of drawing up plans that are then implemented.

The institutional planning system in Sweden consists of the following steps where decisions are made: 1) Idea, 2) planning, 3) public display, 4) public agency – adoption of plan and 5) building permit & implementation (Hedström and Lundström 2013).

The relative benefits of the current activity compared with other possible options increase over time (Pierson 2000). What happened at an earlier point of time will affect the possible outcomes of a sequence of events occurring at a later point in time. Earlier events matter more than later events and different sequences may produce different outcomes, which make history matter. These findings are important when considering

ICT in the planning process and the kinds of investments that should be made (Papers II & III). Path dependency means that once a country or region has started down a track, the costs for reversal are very high (Pierson 2000). Path dependency is used in Paper II when considering which ICT solutions are the real 'low-hanging fruit'.

The analysis of decision-making can be divided into decisions made by one individual or decisions made by a group, which can comprise as few as two people (Raiffa et al. 2002). Decisions made by the individual can be analysed from an approach that is:

- Descriptive (how decisions are made/behavioural, how and why individuals think and act like they do)
- Normative (how decisions should be made if they are to be rational and coherent)
- Prescriptive (how decisions could be made better, what modes of thought, novel perspectives, decision aids, conceptual schemes etc. are practically useful)

Decision-making where a group or several individuals are involved can be separate and interactive (*game theory*) or joint (*negotiation theory*) (Raiffa et al., 2002).

The decisions analysed in this thesis were transport choices that individuals make in order to perform activities in their daily life (Paper IV). The analytical approach used was normative (how decisions should be made to make favourable choices for the environment), since the results were used to define functionality to support environmentally friendly choices (Paper IV).

2.2.2 Mobility management & planning of transportation infrastructure

Mobility management approaches and the traffic hierarchy in Stockholm Royal Seaport were used to study how policies and guidelines that form part of the input to the planning of transport infrastructure are implemented in existing ICT solutions (Papers IV & V).

Mobility management is a demand-orientated approach to encourage the use of environmentally friendly means of travel. It is a concept to promote sustainable transport and manage the demand for car use by changing travellers' attitudes and behaviour. The

Four-Step Principle (FSP)[4] has been applied by the Swedish Transport Administration since 1997 when planning transport infrastructure. The FSP organises traffic measures in four phases: 1) Measures that reduce transport demand and transfer to efficient modes of transport; 2) measures for optimised use of the existing road network; 3) minor road improvements and upgrading of existing infrastructure; and 4) new investments and major road improvement. Mobility management measures coincide with FSP phases 1 and 2. To "reduce transport demand" (FSP stage 1), there is a need to find alternatives to travel. The measure "optimised use of existing road network" (FSP stage 2) can be achieved by choosing public transportation, multiple transport modes and also by ridesharing (Paper IV).

To encourage the use of environmental travel modes, the City of Stockholm is using a new *traffic hierarchy* that was first applied in the planning of the Stockholm Royal Seaport district and gradually also the whole inner city of Stockholm to achieve the vision '*Walk the city*' by 2030 (City of Stockholm 2010). This traffic hierarchy gives the highest priority to walking and cycling, followed by public transport/freight (eco-efficient vehicles), car-pooling (green cars, such as biogas and electric vehicles), and private cars (green cars). Values and norms about the mode of transport that are favourable are displayed by the physical infrastructure. It is more difficult to travel by private car and easier to walk and cycle. There are easily accessible racks for bicycles close to homes and workplaces.

2.3 ICT for sustainable development in cities

How to make use of ICT to transform cities and urban living towards more sustainable development has been discussed for a long time. With the launch of smartphones in 2009 and the emergence of mobile internet, several new opportunities have arisen that were not possible before. Other technological paradigms that have emerged during the last 5-10 years are cloud computing, internet of things, open data, crowdsourcing and social media technologies (Papers II & IV).

New information technologies have a fundamental impact on societies and therefore on cities and regions. Castells (1996) argues that the networked society is characterised by pervasiveness and penetration of technology to all domains of human activities, and therefore all processes of our existence are affected. The information technology paradigm is characterised by two features. The first is that it is focused on *information processing* and the second is that its raw material is *information*, and thus so is its outcome

(Castells 1989). The main outcome of innovation is process rather than products because the transformation of processes, unlike products, enters into all spheres of human activity and leads to modifications of the material basis of the way we live our lives (ibid).

Mitchell (2000) defines five main opportunities for how ICT can contribute to the reduction of energy use in cities. Four of these have direct effects and one has indirect effects on the reduction of energy use. The first opportunity, *dematerialisation*, involves lower accumulation of things and more flow of information where physical things have been replaced by virtual. Dematerialisation has the potential to decouple consumption from material resource use, something that has been put forward as a condition for sustainable development (UNEP 2011). Within the field of ICT, software represents the immaterial resources and the services provided represent the value that could become the paradigm for a decoupled economy (Hilty et al. 2011). 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. These principles can be applied to product design, architecture, urban design and planning at regional, national and global level (Mitchell 2000).

The Smarter2020 report (GeSI 2012) identifies ICT solutions by combining the abatement potential of ICT (called change levers) with economic end-use sectors. Somewhat similar to the opportunities put forward by Mitchell (2000) the change levers are: 1) Digitalisation and de-materialisation, 2) data collection and communication, 3) systems integration and 4) process, activity and functional optimisation. The economic end-use sectors are power, transportation, manufacturing, consumer & service, agriculture and land use and buildings. Based on a business-as-usual scenario in 2020, the Smarter2020 report (GeSI 2012) also calculated potential emissions savings from each of these sectors, resulting in an overall reduction potential of 16.5% of total global GHG emissions. Other studies have identified significantly lower potential, e.g. a 4.6% decrease within EU-27 (Bio Intelligence Service 2008).

With the aim of mapping out ICT solutions that have the potential to offer beneficial environmental effects, Hilty et al. (2004) (as cited in (Hilty et al. 2006)) used a combination of economic sectors and environmental indicators to compile a list of ICT solutions for sustainable development: e-business, virtual mobility (teleworking, teleshopping, virtual meetings), virtual goods (services partially replacing material goods), ICT in waste management, intelligent transportation systems, ICT in energy supply, ICT in facilities management and ICT in production process management.

In addition to this, The Climate Group et al. (2011) proposes a comprehensive list of possible ICT solutions that can be implemented, as well as setting out metrics in order to understand which solutions could be implemented to reach a specific city's targets. Other solutions proposed can be found in Schaffers et al. (2011) and Nam and Pardo (2011).

According to Deakin (2014) it was Mitchell (Mitchell 2000; Mitchell 2004) that first deployed ICT solutions, in the smart cities laboratory at MIT. There he sketched out how these solutions can make it possible for communities to network and use the embedded intelligence of smart cities. Further on Deakin (2014) argues that it is the work undertaken on the informational basis of the communication embedded in the technical systems (Castells 1996; Graham and Marvin 1996) that leads away from the technical aspects and towards an examination of the social capital to reveal the wider environmental and cultural role ICT solutions can play. The work in this thesis was mainly inspired by the work sketched out by Mitchell (Mitchell 2000; Mitchell 2004), which meant looking at the design and implementation of services and solutions that can be developed in order to reach climate targets in cities and not the cultural role ICT can play in this transition. The work presented here has its focus on how ICT can be seen as an enabling technology for improving or substituting processes in other sectors, as also proposed by Hilty et al. (2006).

3. Methods, research process and study objects

The research in this thesis was performed within the scope of technological sciences, with an interdisciplinary approach having its main emphasis on the sustainability research, planning and computer science. The methods used are derived from social sciences and adopt a qualitative approach. Studying ICT for supporting sustainable development in cities involves a lot of actors, different perspectives, different layers of information and different systems. This section explains the characteristics of the methods used, the research process and the study objects.

3.1 Methods

The research issues addressed concerned problems within society that can be solved partly by technical solutions (ICT) and partly by changed behaviours as a result of the new service. Hence the focus was on the socio-technical system. Literature reviews can provide many answers to the research questions posed here, while additional existing knowledge of how things are performed in real life can be obtained through questionnaires, interviews and workshops. The data used in this thesis were collected by performing: 1) Literature reviews, 2) a questionnaire study, 3) interviews and 4) workshops. Why and how these were performed are described in the following sections.

3.1.1 Literature reviews

In a review of the literature to search for methodologies that measure the GHG impact of cities, two groups of literature resources proved to be useful (Paper I). The first group comprised a number of GHG accounting protocols. Among those investigated were the ICLEI Community-Scale GHG Emissions Protocol (ICLEI 2011), the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2006) and the draft Corporate Value Chain (Scope 3) Accounting and Reporting Standard (WRI-WBCSD 2011). The second group comprised a selection of scientific papers reporting on accounting methodologies for cities.

In order to explore the extent to which sustainability is part of the definition of 'smart cities', a review was made of the commercial and scientific literature (Paper II). This included existing literature on smart cities[5] (Caragliu et al. 2009; Washburn and Sindhu 2010; Nam and Pardo 2011; Schaffers et al. 2011; The Climate Group et al. 2011; Townsend 2013), and a large number of other studies, including overarching and conceptual studies and studies of specific technologies and their potential to reduce energy or GHG (Mitchell 2000; Hilty et al. 2004; Fischer 2008; Hilty et al. 2011; UNEP 2011; GeSI 2012).

The literature on collaborative approaches to be used to govern the planning process was also reviewed (Paper III).

In Paper IV, scientific literature selected from a literature review made previously, where more than 100 articles published between 1996 and 2010 provided the basis for understanding society's motives and desired targets for travelling and transport, different perspectives of travellers' motives for travelling, travellers' choice of means of transport, user needs and different functionalities of traveller information systems.

Existing literature studies made by the telecommunications company Ericsson about the challenges faced by large cities in the world served as a baseline for further work on ICT solutions connected to flexible work places (Paper V). The results of these literature reviews are integrated into this thesis.

3.1.2 Questionnaire

A questionnaire was used to obtain information on how cities set their climate targets (Paper I). The questionnaire was sent by mail to climate coordinators in the eight cities listed in section 3.3.1 and covered questions regarding important system boundaries that the cities used when setting their climate targets. The questions were divided into five groups, covering: 1) The target and the baseline, 2) understanding and setting the context, 3) choosing the unit of measure, 4) defining and delimiting the activities and 5) other questions. Group (1) included questions about how the baseline was formulated, how the cities estimated the baseline, how the target was formulated and if there were any discrepancies between how the baseline was estimated and how the target was formulated and monitored. Group (2) included questions about which organisation(s) were involved in developing and setting the target, the timeframe for the target and why it was chosen. There were also questions about the reason for choosing this target and whether it was set according to other targets and how the area for the target was delimited geographically. Group (3) comprised questions about the unit of the target, i.e. CO_2, GHG and/or energy, and why this unit was chosen. Group (4) questions were about the activities that had been included and why. There were also questions about the definition and delimitation of the activities and how energy use had been allocated, i.e.

whether they used a consumer or producer perspective and whether they applied a life cycle perspective. Group (5) questions concerned any missing perspective/s in the questionnaire and the main strengths and weakness with the target.

3.1.3 Interviews

The interviews performed in Papers I and V were characterised as semi-structured, meaning that they were carried out following a predefined structure (Lundahl and Skärvad 1999). The interviews performed in Paper IV were unstructured, meaning that they followed a more conversational form (ibid).

By interviewing owners of selected flexible workplaces (see section 3.3.5), the aim was to explore what drivers and barriers there are to establishing a hub business in suburbs close to where people live, and also to get the owners' view on presenting their service offering in a travel planner (Paper V). The interview questions covered different predefined topics: The interviewee's role in the company, the characteristics of the business, the target group of the business and the company's booking system. The questions about the business were organised according to the Zachman framework (Swoa and Zachman 1992), asking WHY the business is conducted, WHAT kind of business is conducted, HOW the business is conducted, WHERE the business is conducted, WHEN the business is conducted and WHO is conducting the business. The semi-structured interviews lasted for one hour and were performed at the respective organisation's office.

A couple of interviews were also held with climate coordinators in the cities studied (Paper I). The interviews were semi-structured and held both in face-to-face meetings and via phone. The questions used during the interviews were the same as those in the questionnaire described in section 3.1.2.

Some interviews performed in an unstructured conversational form were held with ICT experts from Sweden and Germany (Paper IV). 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. The topics covered were the history of traveller information provision from automatic answering machines to the launch of smartphones, problem areas and future development.

3.1.4 Workshops

Planning in connection with ICT was discussed in a series of workshops. The participants in the workshops were representatives of the municipality of Stockholm with responsibilities for planning the new city district Stockholm Royal Seaport, dialogue with new citizens and implementation of climate targets in the district, together with representatives from telecom industries and academia. In one of the workshops, decisions in the planning process were walked through to identify which are of most importance in implementing the energy saving effects of ICT. Stockholm Royal Seaport was used as a case study. The questions dealt with during the workshop were: 1) When in the planning process should decisions related to ICT be made? 2) What decisions need to be taken, when and by whom in order for the various ICT solutions to be implemented? and 3) Are there solutions that affect the physical infrastructure and leading to new demands on the physical infrastructure? The results from the workshop are presented in Paper V.

3.2 Research process

Paper I developed a tool for setting climate targets for cities and for investigating how the eight cities included in the study set their climate targets. *First*, empirical observations were made on the system boundaries used for energy use and climate emissions in the eight selected cities, all of which were finalists in the European Green Capital award. *Second*, through the reading of scientific literature in the field, more knowledge was gathered. *Third*, the first tentative methodological considerations were tested in the eight cities. The guiding questions used to search for the main categories of system boundaries in order to clarify what a target implies were: Where (the target applies), when (the target should be reached), what (should be included) and how (target fulfilment should be calculated). *Fourth*, an interpretation was made regarding which of these system boundaries is the most important consideration to be used.

Paper II developed a tool to identify ICT hotspots for energy reduction that make it possible for cities with different needs to find their hotspots for ICT investments. *First,* the literature on smart cities and ICT with energy reduction potential was examined. *Second,* a framework was created in order to identify ICT hotspots by combining the energy use allocated to household activities with different ICT opportunities on a conceptual level (Table 3). *Third,* a tool with two different parts developed by Bocken et al. (2012) for rapid assessment of emission benefits (Part 1) and implementation difficulty (Part 2) was adapted (Figure 3). Part 1 of the tool, which is used to make a rapid assessment of emissions from ICT solutions, was deemed not meaningful in the context of Paper II and was therefore omitted. Instead, realisation of the different ICT opportunities was assessed. The ICT opportunities were divided into whether they contributed to direct energy reduction (de-materalisation, demobilisation, mass customisation and intelligent operation) or indirect energy reduction (soft transformation). The direct energy reduction opportunities were then characterised according to whether they were not exploited (0), exploited to some extent (1) or fully exploited (2) (Table 4). In Part 2, successful implementation as defined by Bocken et al. (2012) incorporates not only the launch of a product, but also its acceptance, domestication and dissemination. The model (Figure 2) consists of an evaluation of the implementation difficulty of a new product based on three different capabilities: the newness of 1) the technology, 2) the product concept, and 3) the extended supply chain, including consumer use and disposal. In each dimension, the newness of each capability is assessed as unchanged, new to the company or new to the world.

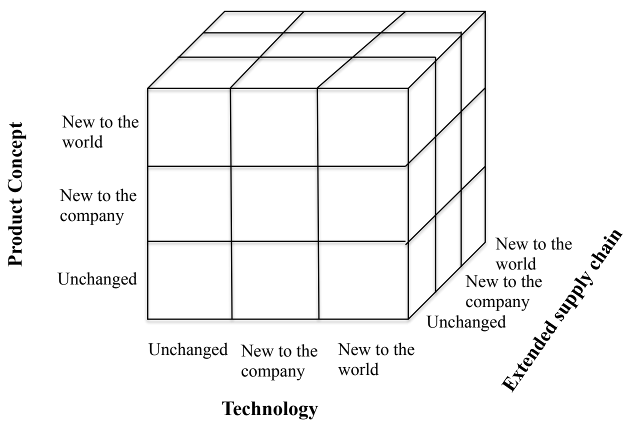

Figure 2. Model for measuring original implementation difficulty. Bocken et al. (2012)

Part 2 of the tool proved useful in Paper II once these three capabilities had been adapted. The technology capability was narrowed in scope to include only ICT, the product concept was expanded to include both services and products and the extended supply chain was redefined to focus on the use of individuals. Newness in Paper II indicated whether the ICT solution "*exists and is in use*" (value = 0) or whether it was "*new to households in the city*" (value = 1) (Figure 3).

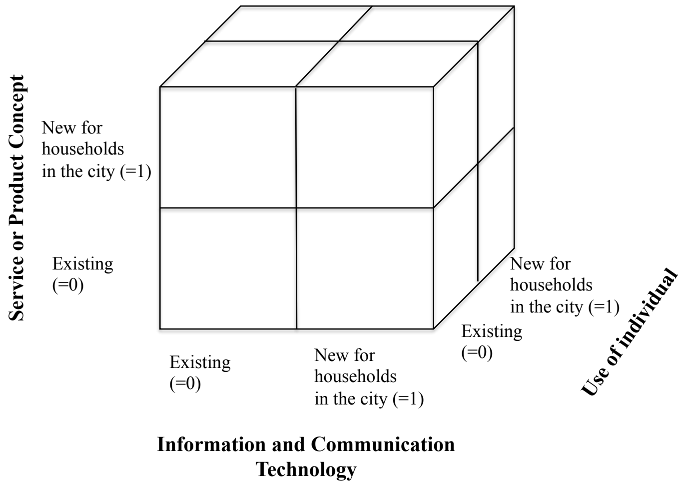

Figure 3. Model for measuring implementation difficulty of ICT solutions adapted from Bocken et al. (2012).

By combining the realisation of the opportunity with the implementation difficulty, the most promising ICT solutions, i.e. the 'low hanging fruit', were identified.

In a workshop with representatives from city planning departments, the telecom industry and academia (see section 3.1.4), formative moments in the planning process decisions were identified (Paper III). Stockholm Royal Seaport was used as a case study to concretise the planning process. Further input was gained from studying different planning documents used and produced by the city administration. In addition to this, a mapping was made where the environmental operational targets for Stockholm Royal Seaport were connected to physical impact and ICT or ICT-enabled solutions. A literature study was also made to identify different types of actor networks needed to implement the ICT solutions and how they can be managed or meta-governed.

In Paper IV, a new functionality for a traveller information system to encourage sustainability-orientated decisions was identified. The traveller's need for information and communication functionalities in order to make transport choices with the least environmental impact was analysed. Requirements on a traveller information system were identified for the different *phases of the journey* when individuals are more likely to change their travel behaviour (pre-, on- and post-trip) and then for the different alternatives in the model structure of *transport choices*. The model structure was made for individuals' alternative travel choices, based on the tool SAMPERS (Beser and Algers 2002) which is used to forecast transport needs, and different decision points were identified. To indicate whether the individual's choice led to lower energy use, lower transport demand and the use of efficient modes of transport, the *four-stage principle*[6] and the *traffic hierarchy* (City of Stockholm 2010) for City of Stockholm's new district Stockholm Royal Seaport is used. The identified requirements were then transferred into a proposal for functionalities in a travel information system. This list of proposed functionalities was used as an analytical framework to examine whether the functionality is implemented in the systems available today. This investigation resulted in a list of shortcomings of the available systems, which was used as a proposal for new and improved functionalities in next-generation travel information systems.

The research process in Paper V was characterised by three parallel activities. The first was an interview study with hub owners to investigate the business characteristics of flexible workplaces, the driving forces and potential barriers to establishing them in suburbs and their opinion about presenting their service offering in e.g. travel planners. The second activity was to estimate the energy saving potential from reduced commuting by having work hubs located in local nodes close to where people live.

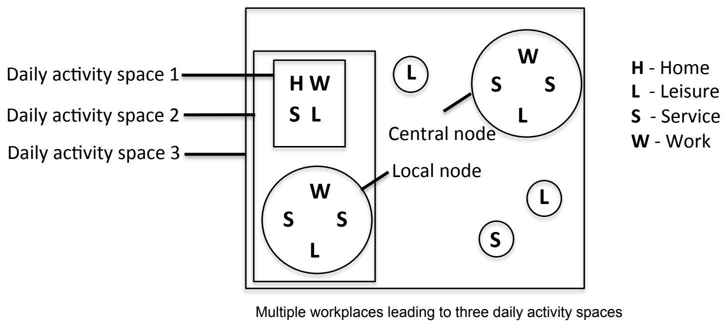

Figure 4. A new scenario for location of activities in an ICT society. Source: Paper V.

A 'multiple workplace scenario' was used (Figure 4), where the node definitions were taken from (Höjer 2002). A local node was defined as a centre with a mix of workplaces and housing and a central node as the whole Inner City of Stockholm. The potential reduction from shorter travel was estimated using figures for the Greater Stockholm area. The average distance travelled in Stockholm, one-way, per individual per journey is reported to be 12 km (Transport Analysis 2011). By using 12 km travel by car as a reference example (i.e. 120 km weekly commute), it was possible to estimate how much energy use could be reduced for a working week. In the example, one workplace was located at home, a second in the local node, in this example placed 3 km from home, and a third in the central node, in this example located 12 km from home. The third activity in

Paper V was a comprehensive review of results from a series of research projects performed at the telecommunications company Ericsson to investigate emerging technologies that can support cities within the transportation domain. The result of the Ericsson research were used together with the results from the interview studies with hub owners to exemplify a wider range of ICT opportunities when implementing hubs.

3.3 Study objects

The various empirical studies included in this thesis had different characteristics. Some investigated a multitude of objects, while others only used one specific case. The different study objects are presented in the following sections.

3.3.1 Eight cities with high environmental profiles

To explore how methodological considerations are handled in practice, eight European cities were selected in Paper I. These were: Copenhagen, Freiburg, Hamburg, Nantes, Malmö, Munster, Oslo and Stockholm. The reason for choosing these cities was that they were all finalists in the European Green Capital award[7] between 2010-2013. They were thus selected on the basis that they have all been officially recognised for their high environmental standard and for being committed to ambitious targets for further environmental improvements and sustainable development.

3.3.2 Case example – Greater Stockholm area

To find the ICT hotspots for energy reduction, information was needed on activities which require the greatest energy usage (Paper II). The Greater Stockholm area was used as a case example for a citizen-based energy consumption perspective. In a study by Höjer et al. (2011), energy usage was allocated to different household functions in the Greater Stockholm area, using data for the year 2001. This was a first attempt to divide energy use between the individual’s daily activities. The household functions to which energy use was allocated were: Personal (lifestyle markers such as leisure travel, cars, mobile phones, laptops etc.), housing (heating and other residential services), food (production, storage and cooking), care (education, social security and healthcare), common (safety and security) and support (work and commuting). The reason for choosing that study for the analysis in Paper II was that it provides such a comprehensive overview of the energy use from a consumption perspective. The system boundaries/methodological considerations used in the case example in Paper II were adopted from the same study (Höjer et al. 2011). The object for target setting was the

Greater Stockholm labour market, the geographical scope was Greater Stockholm, the target year was 2050 and the reference year was 2000. The unit of the target was set to MWh/capita per year and the range was a consumption-based citizens' perspective (no visitors included) and a life cycle perspective.

The Greater Stockholm area was also used as a case to exemplify to what extent potential opportunities to reduce energy use with different ICT solutions had been exploited before 2013 (Paper II).

3.3.3 Case example - Stockholm Royal Seaport

The environmental targets of Stockholm Royal Seaport (City of Stockholm 2010) were explored in order to understand how physical services can be replaced or changed by the use of ICT services to maintain the living standard (Paper III). When physical services are being reduced or changed in a city because of its environmental targets, there is an opportunity to instead make use of and plan for how ICT services should be implemented and maintained. The reason for selecting Stockholm Royal Seaport is that it is an area currently being planned and constructed, with ambitious environmental targets and a high interest in ICT solutions. Stockholm Royal Seaport has also implemented a new traffic hierarchy that was used as input in Paper IV.

3.3.4 Nine traveller information systems

To explore the kinds of services that are currently available in leading traveller information systems, nine systems were selected on the basis that they cover different geographical areas, include different combinations of modes of transport and have different ownership structures (Table 1) (Paper IV).

Table 1. The nine travel information systems studied in Paper IV

Travel information system	Abbr	Area covered	Owned by	Mode/s of transport
Deutsche Bahn Navigator[8]	DBN	Europe	Transport operator	Public transport
Google Transit [9]	GTR	Global	Internet service provider	Public transport, bicycle, walk, car
Munchner Verkehrs- und Tarifverbund[10]	MVV	Munich, Germany	Transport operator	Public transport
Res i STHLM[11]	RIS	Stockholm County, Sweden	App Developer	Public transport
ResRobot[12]	RRT	Sweden	Joint cooperation – transport operators	Public transport, car
Stockholm Public Transport Trip Planner[13]	SPT	Stockholm County, Sweden	Transport operator	Public transport
Trafiken.nu[14]	TNU	Stockholm, Gothenburg, Skåne, Sweden	Joint co-operation – city transport authority, transport operator	Public transport, bicycle, walk, car and comb. of public transport-car, public transport-bicycle
Transport Direct[15]	TDR	UK	Joint co-operation UK, Scottish and Welsh transport authorities	Public transport, car, walk
Transport for London, Journey planner[16]	TFL	London, England	Transport operator	Public transport, bicycle, walk

3.3.5 Five organisations offering flexible workplaces

In order to understand why the service offering 'flexible workplaces' is not available on a large scale in Greater Stockholm, close to where people live, a search was made to identify organisations that offer this service (Paper V). Among the relevant organisations identified, the following five were selected for further study: United Spaces[17], Hub Stockholm[18], Kolonien[19], Coffice[20] and Ekensbergs Church[21]. They were selected because: i) they are located at different places in Greater Stockholm, ii) their business concept included flexible working places and iii) their business concepts differ from each other.

4. Setting climate targets for cities (Paper I)

Paper I proposed some comprehensive methodological considerations to be used when setting climate targets for cities. The main categories identified were: object of target setting, temporal scope of target, units of target, and range of target. For each methodological consideration, different aspects were identified (Table 2).

Table 2. Methodological considerations when setting climate targets for cities as identified in Paper I

1. Object for target setting – where?
1.1. Defining and delimiting the spatial boundaries What are the geopolitical boundaries for the city or city district? 1.2. Defining and delimiting what activities to include Should all or a selection of the activities within the boundary be included or not?
2. Temporal scope of target – when?
2.1 Reference year Is the target absolute or set in relation to some reference year? 2.2 Time frame For what year is the target set?
3. Units of target – what?
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 – how?
4.1. Consumer or producer perspective? Should emissions from production or consumption within the geographical boundaries be the focus, or is a combination preferable? 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?

Object for target setting

In order to set a target for a city, the boundaries of the city, i.e. the object to which the target is applied, needs to be defined. The spatial boundaries can be defined by the geopolitical boundary or, for example, by a functional area, e.g. a commuter shed, which is the area in which the workforce commutes or the mass transit system serves. Among the eight cities investigated in Paper I, all employed the geopolitical boundary even if the data used covered other boundaries, such as local, regional and sometimes national boundaries. The next step is to decide which activities should be included, e.g. based on a service approach, where the function of the activity for the user is in focus (Lenzen et al. 2004; Lebel et al. 2007; Höjer et al. 2011), a sectoral perspective (IPCC 2006; Baynes et al. 2011), an organisational delimitation, i.e. the scope of influence (Kennedy et al. 2010; Sovacool and Brown 2010; ICLEI 2011; WRI-WBCSD 2011) or a combination of these. Among the cities studied, there are both similarities and differences in the activities included (Table 2 in Paper I).

Temporal scope of target

Targets for GHG emissions are often expressed as a reduction in emissions compared with a certain baseline or a reference year. By using a baseline, it is possible to calculate the scope and pace of change compared with the reference year. The cities studied in Paper I all used a reference year, but not the same year (Table 4 in Paper I). The time frame in which the target should be fulfilled gives an indication of the pace in which transformations need to take place. Shorter timeframes can force the formulation of more limited targets. Longer time frames, on the other hand, can lead to more challenging targets, but at the same time lose the sense of urgency and need for immediate action. The time frames for the targets chosen by the different cities studied varied (Table 5 in Paper I).

Units of target

A city's targets need to be related to the pressure the city places on the environment in terms of GHG emissions or, more indirectly, in terms of energy use. GHG emissions tend to be expressed as CO_2 equivalents (CO_2e). In addition to CO_2, the other major GHG emissions from cities are in the form of methane from landfill waste or industrial processes. The different cities studied had opted to use GHG emissions in their target setting, while energy use was omitted (Table 6 in Paper I). The target can be set either per capita or for an entire city. All cities included in Paper I calculate emissions in terms of total city emissions (ton CO_2/year) and some have also added the use in emissions per capita (ton CO_2/capita) (Table 7 in Paper I).

Range of target

The range concerns the perspective of the target, i.e. whether it uses a consumer or a producer perspective and whether it uses a life cycle perspective. The consumer perspective is based on accounting, which includes either consumption of products and services by the citizens living in the city, or the consumption within the defined boundaries of the city (Figure 5). In the first case, all consumption of a citizen is accounted for irrespective of where it occurs. In the second case only the consumption that occurs within the boundaries of the city is accounted for, irrespective of whether by citizens or tourists. An accounting based on the production perspective focuses on emissions from products and services produced within the city. The cities studied in Paper I did not include terms such as consumer or production perspective, but generally used a production perspective.

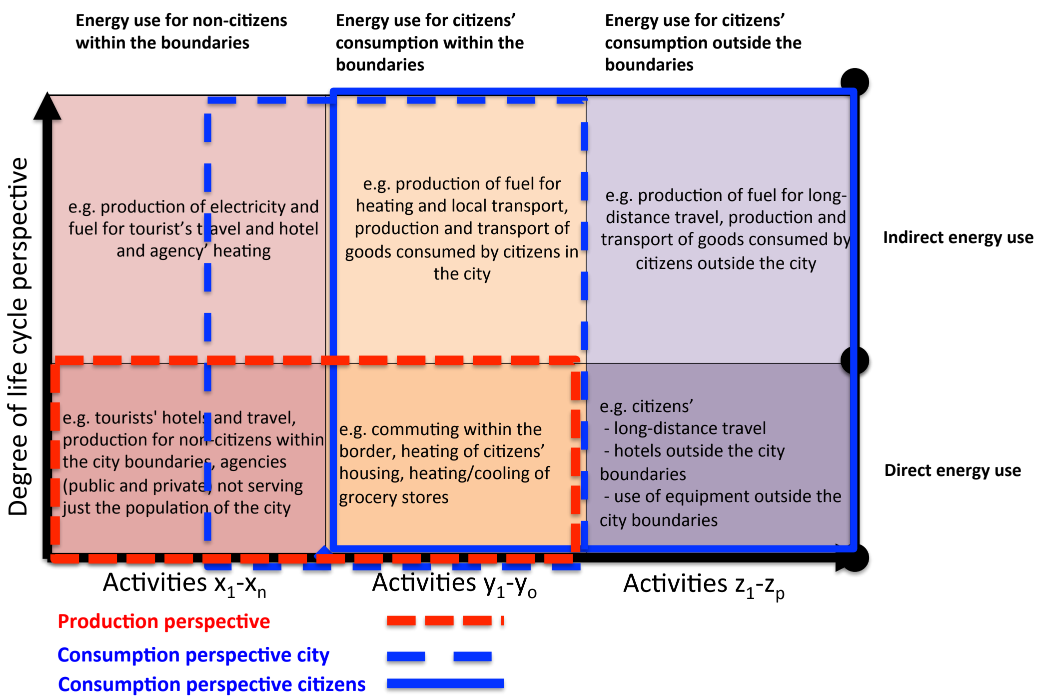

Figure 5 Relationship between activities, the consumption and production perspectives and the life cycle perspective. Source: Paper I.

The range also concerns whether a life cycle perspective is used or not. The question of using a life cycle perspective concerns whether the emissions from the whole life cycle, i.e. raw material acquisition, via production and use to waste management should be included in the calculations, even if they occur outside the city's boundaries. Only three of the cities studied in Paper I use a life cycle perspective (Table 8 in Paper I).

5. Smart sustainable cities (Papers II & III)

Cities with strong environmental ambitions and a telecommunication industry seek to understand how best to utilise ICT as an enabler to reduce energy use. The literature review in Paper II showed that there is a lack of connection between the term 'smart cities' and sustainability in the literature. However, there are a couple of exceptions where the connection is made (Mitchell 2000; Hilty et al. 2006; GeSI 2008; GeSI 2012).

Different cities have different needs because of their unique challenges (The Climate Group et al. 2011). It would therefore be beneficial if there were a methodology to identify the most promising ICT hotspots to reduce energy use for each unique city. A tool for that purpose is presented in section 5.1. Once the ICT hotspots are identified, cities need to understand how to capture the energy saving effects when planning the built infrastructure. How that can be done is discussed in section 5.2.

5.1 Tool to identify promising ICT solutions for energy reductions

The four-step tool developed in Paper II to identify ICT hotspots for energy reductions is described in detail below. To exemplify how it can be used, data from the Greater Stockholm area and ICT opportunities found in literature reviews are used.

In *Step 1,* ICT hotspots are identified using a matrix with household activities on the y-axis and ICT opportunities on the x-axis (Table 3). In *Step 2*, an analysis is made of the extent to which the energy reduction potential is captured today (Table 4). In *Step 3*, difficulties in implementation are analysed (Table 5). In *Step 4*, low-hanging fruit are identified by a combination of how well they capture the effect and their ease of implementation.

Step 1 – Identify ICT hotspots

The assumption in Paper II was that hotspots where citizens' most energy-demanding activities occur should be identified and then mitigation efforts should be concentrated on these hotspots.

The system boundaries for the city need to be defined first, using the methodological considerations developed in Paper I. The *object for target* setting in the case study was the geographical delimitation, comprising the 26 municipalities that comprise the Greater

Stockholm labour market. All activities in the city were included. For the *temporal scope of the target*, 2050 was used as the target year and 1990 as the reference year. Energy use in Mwh/capita was used as the *unit of target*. The *range of the target* was defined from a consumption perspective, where data on the energy use by citizens living in the city were taken from a study on citizens' energy use in Stockholm in 2000 (Höjer et al. 2011). That study was the first attempt to divide energy use between the daily activities of individuals and provides an illustration on how energy can be allocated using a household perspective.

To identify the most promising hotspots, a framework (Table 3) was created by combining the households' activities, including their energy use, with ICT opportunities on a conceptual level for energy reduction in cities defined by Mitchell (2000). The symbol (x) means that there is an opportunity to reduce energy use and (-) that there is no obvious opportunity identified.

Table 3. Opportunities for ICT to decrease energy use in different household activities. Source: Paper II

Energy use per household function	De-materialisation	De-mobilisation	Mass customisation	Intelligent operation	Soft transformation
Personal (35 %)	X	X	X	X	X
Housing (32 %)	-	-	X	X	X
Food (13 %)	-	-	X	X	X
Care (11 %)	-	X	X	X	X
Common (5 %)	-	X	X	X	X
Support (4 %)	-	X	X	X	X

The most energy demanding activities in households are travel, heating and consumption of food. The largest proportion of household energy use comprises the category *personal*. The largest proportion (50%) of the *personal* category is leisure travel, where car travel represents 30% and air travel 20% (Höjer et al. 2011). When commuting from the *support* category is added, it becomes obvious that travel is an important activity to mitigate. Another large energy consuming activity is the heating of residences within the *housing* category. Heating is also a large part of the *common* category, which is mainly heating of public buildings. The third large energy consuming activity is food production within the *food* category. The two main hotspots identified in our case example of Greater

Stockholm were intelligent operation and soft transformation of transport and heating of buildings by ICT.

Step 2 – Estimate implementation progress

To exemplify the kind of ICT solutions that could be useful, the most relevant solutions identified by different literature sources were chosen in Paper II, with the aim of mapping ICT solutions beneficial for the environment (Hilty et al. 2006; Nam and Pardo 2011; Schaffers et al. 2011; The Climate Group et al. 2011; GeSI 2012). The ICT opportunities were divided into solutions with direct energy reduction (demateralisation, demobilisation, mass-customisation and intelligent operation) and indirect energy reduction (soft transformation). A search was then made for ICT solutions with direct energy reduction effects in the Greater Stockholm area, in order to identify to what extent the opportunities have been exploited to date (Table 4). This was graded between 0 and 2, where 0 = not exploited at all, 1 = exploited in at least one case somewhere in Greater Stockholm and 2 = most of the energy saving potential is exploited.

Table 4. ICT solutions for direct energy reduction in the three household activities with the largest energy use and their current degree of realisation in Stockholm: Energy saving potential not exploited (0), exploited to some extent (1) or fully exploited (2). Source: Paper II

Household function (Activity)	**ICT solution**	**Realisation**	**Solution** (Example from Greater Stockholm area)
Personal & support (Leisure travel & commuting)	1. Public live-streamed events/concerts/games	1	Remote concert/theatre
	2. Extended road pricing (*i.e.* not only congestion charging)	0	n/a
	3. App for multimodal travel	1	Travel planner
	4. App for ridesharing	0	n/a
	5. Electronic payment and ticket	1	SMS payment & ticket
	6. E-shopping	1	Home delivery
	7. Virtual mobility	1	Videoconferencing, collaboration tools
	8. Flexible working place	1	Local co-working hub
Housing & common (Residential & public heating)	9. Visualisation of energy use	1	Flower lamp, LCD screen
	10. Sensors for demand management	1	Light sensors
	11. Advanced metering solutions	1	Remote monthly/hourly readings of electricity meters
	12. Pricing mechanism for energy supply	0	n/a
	13. Microgeneration - gateway to connect to energy grid	0	n/a
	14. Remote healthcare	1	ECG monitoring via mobile
	15. Distance education	1	Lectures online
Food (Food production)	16. App for information on energy use of different food products	0	n/a

Step 3 – Reflect on implementation difficulty

In order to be of good use in practice, there is also a need to reflect on the difficulty in implementing various ICT solutions, something that relates to issues of agency and the speed and scale of technology dissemination (Table 5).

The implementation difficulty was graded according to its newness. Newness in this case indicated whether the ICT solution "*exists and is in use*" (value = 0) or is "*new to households in the city*" (value = 1). The sum of the newness indicator from the three columns Information and Communication Technology, Service or Product Concept and Use of Individual gives the range of implementation difficulty, where the minimum is 0 (easiest) and the maximum is 3 (most difficult).

Table 5 Estimated implementation difficulty for identified ICT solutions with the potential to reduce energy use for travel, heating and the consumption of food (Paper II)

ICT solution	Information and Communication Technology	Service or Product Concept	Use of Individual	Sum (Imple-mentation difficulty)
1) Public live-streamed events/concerts/games	0	1	1	2
2) Extended road pricing	0	1	0	1
3) App for multimodal travel	0	1	0	1
4) App for ridesharing	0	1	0	1
5) Electronic payment and ticket	0	1	1	2
6) E-shopping	0	0	0	0
7) Virtual mobility	0	0	0	0
8) Flexible working place	0	1	1	2
9) Visualisation of energy use	0	1	1	2
10) Sensors for demand management	1	1	1	3
11) Advanced metering solutions	1	1	1	3
12) Pricing mechanism	1	1	1	3
13) Microgeneration - gateway to energy grid	1	1	1	3
14) Remote healthcare	1	1	1	3
15) Distance education	0	0	0	0
16) App for information on energy use of different food products	0	1	1	2

Step 4 – Identify most promising ICT solutions

The energy reduction potential of ICT has not yet been realised to any great extent. However, all the ICT solutions suggested above present opportunities to reduce energy use. By combining the exploitation of these opportunities with the implementation difficulty, the most promising ICT solutions can be identified. The low-hanging fruit in the case of Greater Stockholm that are easy to implement and already captured to some extent are e-shopping, virtual mobility, distance education and apps for multimodal travel. The other group of solutions that have not yet been exploited but are easy to implement are apps for ride-sharing and extended road pricing.

5.2 Physical transformation and ICT services

There are many opportunities to use ICT to reduce energy, as shown in the previous section. Many of these solutions have already been implemented and/or explored. Demateralisation of media and intelligent operation of energy, such as the smart grid, are examples of solutions that are already implemented or being explored. One of the opportunities, *soft transformation*, has not been explored as much as the others. The relationship between planning and ICT has been examined, but mainly focusing on how ICT can transform and improve planning practice itself, for example by visualisation of projects and also by improving public participation through communication and interaction (Dodgson and Gann 2011; Batty et al. 2012; Fernandez-Maldonado 2012; Houghton et al. 2014). In Paper III, the focus was on the *soft transformation* of the physical environment of infrastructure and the built environment, where the built environment (the atoms) is replaced by services enabled by ICT (bits) (Mitchell 2000; Mitchell 2004).

When ICT is introduced for energy reduction in cities, this might influence the spatial and institutional organisation of the city, but it might also achieve the reverse. Changes in the physical space can be improved or enhanced by ICT services. For example, fewer parking spaces for cars can be replaced by mobility services such as information systems for travel by other means than private car. By investigating the programme for environmental and sustainable city development for Stockholm Royal Seaport, it was possible to make suggestions on the physical impacts of the target influenced by the ICT solution and also on how ICT solutions can bridge the gap of lack of physical services (Paper III). Mapping of the operational targets for Stockholm Royal Seaport was connected to physical impacts and ICT solutions (Table 6).

Table 6. Connection between ICT or ICT-enabled solutions and physical impacts of operational targets for Stockholm Royal Seaport (City of Stockholm 2010). Translation of targets as in Paper III, but numbers refer to original numbering of targets (City of Stockholm 2010)

Area/Sector	Operational Targets	Physical impact and investment needed	ICT or ICT enabled solution
Energy	Smart energy grids shall be developed based on purchase and sale of renewable energy between the network & individual properties. (6.2.3)	Location of buildings, which share (purchase & sale) energy resources. Distribution of sensors for measuring the use, selling and purchasing of energy; Equipment of buildings with local renewable energy production facilities.	Smart grid; Smart meters
Energy	Regular measurement & visualization of energy use/climate impact. (6.2.5)	Distribution of sensors for measuring energy use; Places and technology for visualization in buildings, households, enterprises, transport and infrastructure.	Advanced metering for energy; Different devices for visualization
Energy	Individual properties shall generate its own electricity based on renewable energy and deliver the surplus to the smart grid. (6.2.7)	Location of buildings; Design of buildings; Equipment of buildings with local renewable energy production facilities;.	Micro-grid; Smart meters
Waste	Regular measuring and visualization of generated waste (7.2.9)	Distribution of sensors for measuring waste use; Places and technology for visualization in buildings, households, enterprises, transport and infrastructure.	Advanced metering of waste
Water/ Sewage	Regular measuring and visualization of water use shall be in real estate, homes and businesses. (8.2.6)	Distribution of sensors for measuring water use; Places and technology for visualization in buildings, households, enterprises, transport and infrastructure.	Advanced metering of water
Transport	Residents/workers should walk, cycle or use public transport to school/home/work. (9.2.1)	Pedestrian and bike paths; Public transport stops and stations; Premises for work and education integrated in the area.	Traveler information system; Flexible working place
Transport	Vehicular traffic is restricted and transit traffic is minimized. Priority should be given to walk, bicycling, and PT. (9.2.2)	Streets designed for restriction of vehicular traffic and minimized transit traffic	Navigation system for car drivers; Fleet management system
Transport	The no parking spaces will be set at a low level for residential/work. (9.2.7)	Reduced land use for parking spaces.	Traveler information system
Transport	The living/working in the area should be offered a personalized itinerary for sustainable travel options and to minimize their transportation. (9.2.10)	n/a	Traveler information system
Transport	A logistics center shall coordinate the internal transport of goods with green vehicles, linked to marine or rail transportation. (9.2.11)	Location of a logistics center.	Service via the logistics centers and transport plan; E-shopping
Transport	Advanced ICT with high performance should provide options for people living/working in the area to reduce/optimize travel. (9.2.12)	Reduced need for areas used for vehicle transportation.	General ICT infrastructure
Housing/ Premises	Housing/premises shall contain usually friendly system for individual measurement/visualization/reading/ control of energy/water/ waste. (10.2.8)	Places and technology for metering and visualization in buildings for residential or commercial use.	Advanced metering for energy, water, waste
Housing/ Premises	Advanced ICT with high performance should be installed in buildings to provide services to residents and businesses in area. (10.2.9)	Fiber in residential and commercial buildings.	General ICT infrastructure

The initial approach was to examine where in the different stages of the planning process decisions should be taken about ICT solutions to secure the energy saving effects. It emerged that the formal decision points in the planning process are quite few. Instead, it was found that the two different roles that the city plays in the planning process, as a public authority in the planning process and as a property owner in the exploitation process, are important. The phase in the life cycle of the city that is targeted is also important. The decisions for which the city is responsible cover the planning and construction phase of the city district, but have a more limited influence on the usage phase, during which citizens actually live and work there. While the city sets rules and regulations for the construction companies building a district, they have limited influence over the ICT companies. It is left to the market to decide the ICT solutions that should be provided. However, there are certain requirements that the city can set for the usage phase, such as the energy usage per square metre of buildings, the bandwidth on the wired communication network and who should deliver information and communication infrastructure to citizens.

Adding to the complexity of decisions concerning the fast moving ICT services are the way it should be governed to represent all actors and stakeholders in the city in a just and democratic way, while steering towards environmental targets that are sometimes not in favour of the market. In Paper III, two collaborative approaches were found: *Network governance* and *coordination through meta-governance*. To date, there has been substantial enforcement of the network character of governance (Arnstein 1969 ; Hajer and Wagenaar 2003; Pierre and Peters B. G. 2005; Treib et al. 2005; Cass 2006; Nyseth 2008; Sehested 2009). This represents a shift in governance deriving from different circumstances such as the global financial decline, a breaking of state autonomy, the rise of neo-liberalism and also the participative turn in policy and planning. Coordination through meta-governance is described as a way of indirect steering, or "regulation of self-regulation" (Lundqvist 2001; Throgmorton 2003; Nyseth 2008; Borgotti et al. 2009; Sehested 2009; Ernstson et al. 2010; Toikka 2010). Four meta-governing techniques were identified in the literature: Network framing, Network design, Network management and Network participation (Paper III).

6. Implementation of mobility management in ICT solutions (Paper IV & V)

There are environmental targets, planning principles and guiding rules for the planning and use of transport infrastructure. All are intended to lower energy use, lower transport demand and encourage the use of efficient modes of transport. The question is how well these targets and planning principles (used by the Swedish transport authority and City of Stockholm) are *implemented* in available ICT solutions and the *adjustments* needed to improve the energy reduction potentials/effects. Two solutions were investigated in Paper IV: an ICT solution, a multimodal traveller information system (section 6.1) and an ICT-enabled solution, a flexible workplace (section 6.2).

6.1 Traveller information system

Paper IV identified certain situations described in the literature where there is greater potential for a change to occur in travel behaviour. 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 (Nobis and Lenz 2009; Beige and Axhausen 2012). During the trip, *disruptions in the current mode* of travel can lead to a 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 (Lyons 2001; Chorus et al. 2006), it is likely that the traveller will be open to information about alternative travel modes that can lead to a change in travel mode in the next journey. In order to find functionalities to support these cases, in this thesis the journey was divided into three phases with different needs for functionality: Pre-Trip, On-Trip and Post-Trip (Figure 6). In the Pre-Trip phase (before starting the trip), the main need for functionality is planning. In the On-Trip phase (between the current position and the final destination), there is a need for optimising the current trip. In the Post-Trip phase (after the final destination has been reached), functionality for refinement of the usual trip is useful.

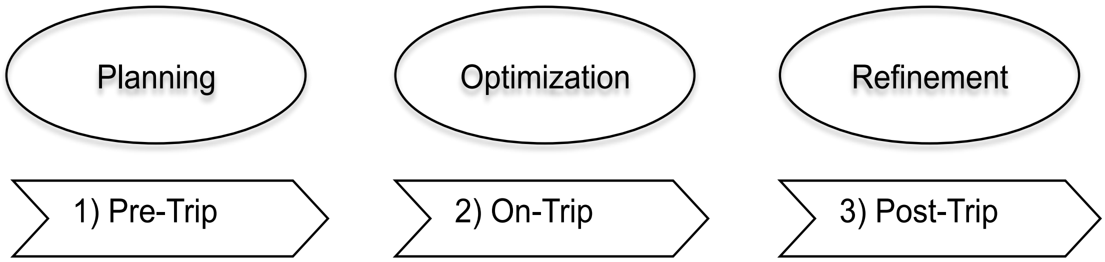

Figure 6 Main functionality in different phases of the journey. Source: Paper IV.

For the purpose of finding situations where individuals make choices about their daily activities, a model structure for choices that influence transportation, and hence energy, was created (Figure 7). Decisions are not linear and can happen in any sequence in the defined model structure. A choice leading to the right in the model structure (Figure 7) leads to less energy use.

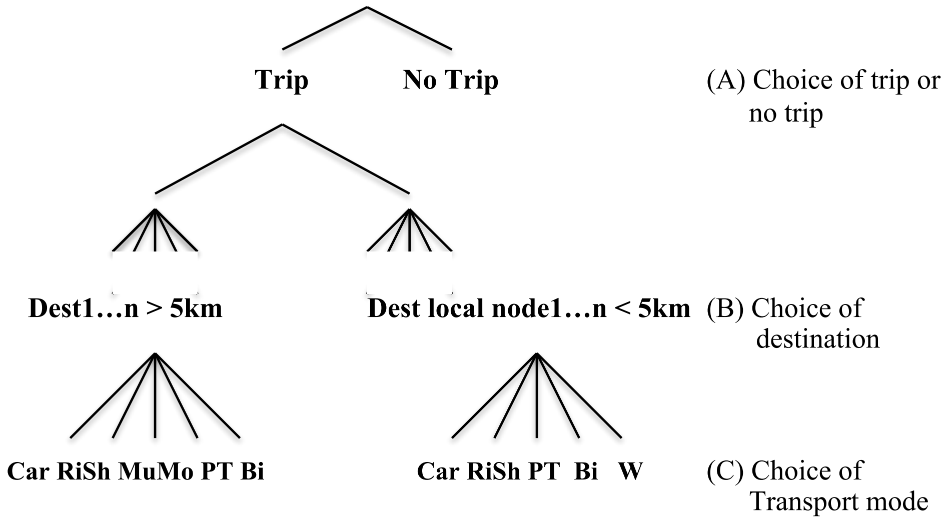

Figure 7. Model structure for transport choices. Source: Paper IV.

Paper IV showed that much of the functionality for traveller information systems to support mobility management principles is lacking. The systems studied mainly focused on the planning part of the journey, the Pre-trip phase, while functionalities for the On-trip and Post-trip phases were limited. Support for choices such as 'no-trip' or shorter journeys leading to less demand for transport infrastructure were lacking.

In order to encourage individuals to make decisions towards more sustainable choices, next-generation traveller information systems should include:

- Information about no-trip alternatives such as virtual meetings, e-shopping etc.
- Information about alternatives for shorter journeys
- Presentation of route alternatives with the lowest energy use
- Multimodal choices, where different modes are combined in the same view
- Ridesharing opportunities
- Easier access to payment mechanisms and tickets
- Information feedback to planning of infrastructure and traffic management and monitoring.

6.2 Destination local node – the flexible workplace

According to the calculations in Paper V, a more flexible way of working could reduce the total commuting distance per person living in the Greater Stockholm area by as much as 60 km, or 50%. Working from a local node (Figure 4) also provides the potential to change mode of transport to more energy efficient modes such as walking and cycling, giving a combined reduction of 60%.

Although there is clearly great energy saving potential in working from a place closer to home, there are few alternatives for this in the suburbs. The interview study with hub owners in Paper V showed that even if their businesses had adopted an environmental approach within their offices, they gave limited or no consideration to reducing transport demand when they located their hubs. However, they placed their hubs close to subway stations for the convenience of their customers, which might encourage the use of public transportation. The main driving forces for the hub owners were to increase returns and encourage innovation, new business opportunities, networking and knowledge sharing.

The interview study showed that there are opportunities to locate a hub business close to where people live. In order to establish a commercially viable, i.e. profitable, hub business, it is necessary to combine the business with some added value. Co-locating and combining the hub business with another profitable or publicly funded activity, e.g. café, restaurant, day-care, library, etc., would add value according to the hub owners interviewed. Another value that could be added is to offer access to a centrally located office as a complementary service. The members would then have access to a centrally located office where they could meet their customers and business partners etc., as well as their local hub for daily work. Another option would be to gather clusters of firms in the same sector or with additional specialisations in order to increase knowledge, networking, partnerships, etc.

There are also some obstacles to establishing hubs in suburbs. According to the hub owners interviewed, these include price pressure of the market, because leasing out overcapacity is possible for any company and their rental prices are low; the possible revenue from a hub business located in the suburbs is lower, since the rent for office spaces is significantly lower there; and the real estate industry requires long-term contracts that are not flexible. Other barriers are that starting a hub is a long and demanding process and that a culture needs to be created where people can interact and share knowledge with each other.

The interviews also revealed that the hub-owners viewed presenting their service offering in a traveller information system as an interesting opportunity. They saw this as a new marketing channel. They also thought that it would be good if competing businesses would be more visible.

The service offering provided by the hubs is today mainly aimed at members. The possibility for users to book a workplace via a system does not yet exist, since drop-in places are lacking and the internet-based reservation system for conference rooms is currently only available to members. By using a traveller information system in combination with a social media tool, the available workplaces would be more visible to the members. It could also facilitate a ride-sharing system for members to be able to share rides to the hub.

Paper V identified three groups of emergent ICT solutions that can be used to improve the service offering of a flexible workplace: 1) "Integration of fragmented information systems from different organisations", whereby in the flexible workplace context travel planners are integrated with other information systems, which can recommend relevant hub alternatives for the individual based on people's travel patterns, personal preferences and collective benefits; 2) "Mobility data for planning of hubs and transportation", where mobility data collected are made anonymous and analysed to understand where the flows of people through the city at different times of the day occur; and 3) "Flexible tools to support the workers at the hub"; an internet connection is often sufficient for workers visiting a hub, but sometimes there are specific needs for connectivity, secure cloud systems, communication services such as remote presence etc.

7. Discussion

7.1 Examining cities' climate targets

Many cities all over the world have set climate targets. An examination of how different cities in Europe set climate targets revealed that they do so in many different ways (Paper I). Therefore one city cannot easily be compared with another city because they use different system boundaries. All cities are unique and have different preconditions for their existence. Despite this, however, they could still make use of the same methodological considerations when they set climate targets and measure achievement of these targets. Another issue is that of transparency. Even if a city has specific reasons for having its own set of methodological considerations, it should as a minimum requirement report its standpoint on how it defined its climate targets. The available information about the delimitations is incomplete and there is generally a lack of data. There is also a need for standardised terminology and clearer application of the terminology to enable comparisons between different protocols and methodologies. There seems to be limited awareness among city administrations and councils about the delimitations and how they influence the targets. The methodological considerations presented in Table 2 (Section 4) can act as a starting point for work by municipal authorities to reduce the current ambiguity in cities' climate targets. By using these methodological considerations, a comprehensive picture of how a city has set its targets can be created.

7.2 Consumer perspective versus producer perspective

Analysis of the empirical material from the different European cities studied in Paper I revealed that it did not include terms such as consumer or producer perspective. Most of the activities included were delimited by the geographical boundaries and it could be argued that a production perspective was used. Moreover, the activities only covered a certain part of all climate impacts and there is therefore a risk that a large proportion of GHG emissions and energy use is being overlooked at the local level. In today's climate negotiations between countries[22], the principle employed is to allocate emissions based on the Kyoto Protocol, which uses a production perspective (UN 1998). Therefore the most common perspective used when allocating emissions at the national level is the producer perspective[23]. One can assume that cities have therefore adopted this same perspective.

When a production perspective is used, citizens do not have any incentive to reduce their consumption of products and services. Energy use and GHG emissions can easily be outsourced by locating an industry with high emissions outside the city boundaries, which leads to the city looking very successful from a GHG emissions perspective. A study by Stockholm Environmental Institute showed that changing perspective from producers to consumers would increase the carbon footprint of Stockholm from 2.91 to 15.68 tCO_2e/capita and year (SEI 2012). Similar results have been obtained in Singapore (Schulz 2010) and Sydney (Lenzen et al. 2004). Because the majority of the world's population and two-thirds of the population of Europe live in urban areas (EU 2011a) that is where the transformation to a low energy society must occur (Swedish Environmental Protection Agency 2012). Cities should start working towards including all impacts caused by their citizens. Consumption of goods, national transport services and production chain upstream processes are all unaccounted climate impacts that are currently omitted. Using a life cycle perspective and/or consumption-based accounts makes it possible to avoid moving emissions outside the city's geopolitical boundaries.

Paper II showed that by using a production-based perspective instead of a consumption-based perspective, a large proportion of energy use is not monitored. Therefore important ICT opportunities related to the personal consumption of goods and services might be missed. By using a consumption-based perspective when monitoring energy use, the complete energy use would be managed and connected to the origin of the energy demand. Investments might be made in new types of ICT solutions as a result.

7.3 Energy reduction and implementation progress

When trying to identify the most promising ICT solutions to mitigate climate change, Paper II focused on the people living in the city. People's needs and desires are the primary reason for why different services and products exist on the market (Ng, 2014). In order to find the most promising ICT opportunities to reduce energy use for a city, two categories of data source are needed: Information source about citizens' energy use and information about ICT solutions and their energy reduction effect. There is no easy way to find data from a consumption perspective in Sweden as yet, but work is underway (Swedish Environmental Protection Agency 2012). The literature on smart cities proved to have a weak connection to ecological or sustainable development. It can thus be concluded that the smart city concept is mainly used as a marketing tool to attract businesses, residents and tourists, instead of achieving climate targets. The literature search in Paper II revealed only a limited number of studies that have calculated the energy savings effect from ICT. This is probably because it is very difficult to estimate the potential for energy reductions in a meaningful way. ICT solutions are enabling technologies integrated into much larger socio-technical systems. There are other factors than the merely technical that are important for the results.

Paper II showed that many ICT solutions for direct energy reduction have been implemented, but the effects are only captured to some extent. It is rare for a transformation of the built environment to occur as a result of implementation of an ICT solution. One example is the reduced number of bank offices brought about by the use of internet banking. A reason for that can be that private companies have both the possibility to control their own business and much to gain if they can cut costs. Public authorities that provide services to citizens such as transport infrastructure have seldom the goal to cut costs, but rather to provide a high level of service to the citizens.

Paper II found that both technical and socio-economic factors are involved in the implementation difficulty of ICT solutions. The difficulty concerns the newness of the ICT solution, the actual service or product concept and its use by individuals. The sum of these three different aspects gives the level of implementation difficulty. It is possible that two solutions can have the same sum of implementation difficulty but the types of barriers and when they might occur can be very different. An aspect that is lacking in the model is a barrier of an institutional character, such as political barriers, values and norms. There are very different institutional conditions for implementing an extended road pricing system and a ride-sharing system.

7.4 From atoms to bits

The planning, construction and maintenance of the built infrastructure is very different from the planning, development and maintenance of ICT solutions. These two processes have different logistics. The physical infrastructure is shaped in the planning and construction phase and thereafter cannot be changed very much without relatively high expenses. The built environment will stand for a very long time in the future. Some maintenance is needed after the construction phase. In comparison with this built infrastructure, ICT solutions are very transient. It can be difficult to make them work so that people use them and they can quickly become obsolete. The depreciation period of ICT hardware products varies between no time at all and three years. Software is being updated almost instantly and new releases that involve major improvements of software platforms are often released every second year. The cost of maintaining the ICT solutions is therefore in the usage phase by a city. It is necessary to find sustainable business models that continue to work for a long time.

ICT solutions exist even if cities do not plan for them. However, as regards ICT solutions for environmental concerns such as energy reductions and climate targets, these should perhaps be planned/facilitated by municipalities or developed in collaborative forms. If no coordination takes place, there is a risk that different aims and goals will be counteractive for the fulfilment of climate targets.

When cities with high environmental targets are being planned, the built infrastructure is transformed to function in a different way, which can be viewed by some as a lowering of their standard of living. ICT solutions can be used as a replacement for these changed functionalities that were previously supplied by the built infrastructure. An example is that many see it as their right to have parking space for their car outside the house where they live. It might be possible to replace that physical functionality with information on how to travel without owning a car. Examples of these solutions are Ubigo[24] and Uber[25].

Therefore stakeholders that can deliver these ICT solutions should be invited to participate early in the planning process in order to enhance the knowledge of the community about what is possible and also to allow them to establish business models in an early phase. These solutions should be displayed during the public consultation phase of the new region/district etc. ICT providers should be treated equally to construction companies in the planning process. They should be invited to form win-win partnerships early in the process. The new information age that we are entering requires new ways of conducting business (Innes and Booher 2003) and new ways of incorporating ICT that can facilitate a low energy society.

To fully utilise the potential of ICT in sustainable cities, there is a need to reconsider the design and technical specification of buildings and infrastructures, and identify the actors who should be involved in the planning and management of the city. Given the large and increasing interest in ICT for sustainable cities[26] [27] (Townsend 2013), it is surprising that so little attention has been given to the capacity of urban planning to proactively plan for and implement ICT solutions.

7.5 Next-generation traveller information systems

Mobility management can be used to promote sustainable transportation and thereby change the use of private cars by changing attitudes and behaviours. This thesis showed that by using mobility management principles as a basis for the design of traveller information systems, it is possible to encourage individuals to reduce their need for transportation and change to more environmentally friendly modes of transportation. Paper IV showed that some available traveller information systems have untapped potential. Even if a traveller information system cannot contain information about all the choices an individual can make in their daily life, Paper V showed that it would at least be possible to connect the system with other systems that also support related choices or put them in the right context.

A multimodal system needs information from many different stakeholders. Paper IV showed that joint co-operation between public authorities, organisations and the public is essential. Furthermore, open data and standardisation (Jakobs 2006; Blind et al. 2010) are essential for these systems to work. The smartest technology can perhaps never describe the actual traffic conditions in all situations and should therefore be combined with parallel systems in which travellers provide reports.

A system aimed at supporting environmental goals should make use of environmental information to guide individuals towards options that use the least amount of energy. Today environmental information is quite hidden in the system and is only used to inform travellers about energy use and GHG emissions. Environmental data can be used to inform, advice/persuade or automate decisions (Loviscach 2011).

There are five main areas that need to be further explored and clarified as regards the whole existence of traveller information systems. This thesis touched upon some of these, but did not explore them in detail. The first is whether somebody should order the system and in that case *who*? Typically, no citizen wants to pay for these types of solutions, but they still exist. For the Greater Stockholm area, examples of available systems are Google Transit, Trafiken.nu, RESrobot, SL journey planner and ResiSTHL. The question is whether the requirements on such a system should be set by the public sector or the municipality to ensure that mobility management approaches, the new traffic hierarchy and climate targets are reached, or whether it should be left to market forces to develop these solutions. A second unexplored area relates to *planning* of the city and the ICT solution. Paper III revealed issues with *when* in the planning process these multimodal traveller information systems should be ordered and designed. In a city district such as Stockholm Royal Seaport, for instance, the possibility to park private cars is limited and physical parking space has been replaced by demands on mobility management services. This thesis indicates that a traveller information system should be one of the components in such a service which is planned specifically for local residents, rather than hoping that e.g. the developer of ResiSTHLM or a global company like Google does the job instead. This is something that needs to be analysed and discussed. The third area concerns *implementation* and how to get the service widely adopted by the citizens living in the city district. The fourth area concerns the *use* phase, where someone needs to be responsible for maintaining the service. Different business models can be discussed and there are several opportunities that need to be explored. Possible stakeholders are the municipal authority, the transport authority, a development firm or the housing association. Finally, the *fifth* area to be further explored is that information generated by the use of travel information system should fed back into the planning of new developments or the refurbishment of transport infrastructure and into traffic monitoring and management systems in order to optimise and enhance the use of infrastructure in urban areas and fulfil climate targets (Paper IV).

7.6 Work hubs in local nodes

Paper V showed that one opportunity to reduce transport demand is to reduce commuting and instead work at a work hub in a local node close to home. By working closer to home, it is also possible to change to travel modes that are more environmentally friendly, such as cycling and walking. At present there is no information site where different flexible workplace opportunities are presented, at least not for the Greater Stockholm area. In the "Amsterdam Smart City"[28] concept, such a solution, named W-Work[29], has been developed (Figure 8). By using this service, it is possible to book a videoconference, meeting room or just a work desk. This is an example of how flexible workplaces could be implemented in a travel information system to support the choice "shorter travel".

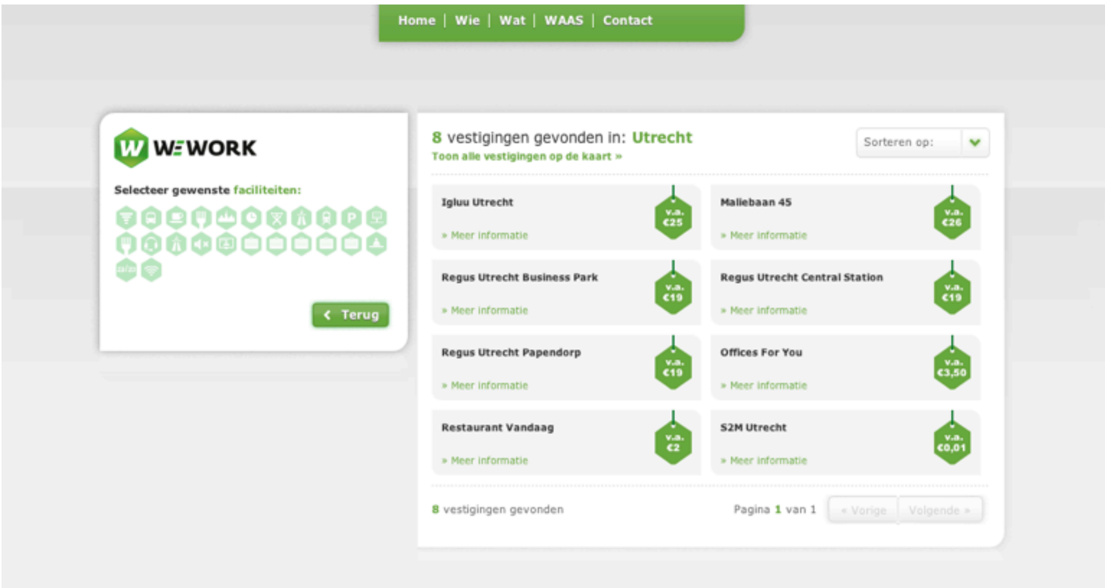

Figure 8. The W-Work webpage[30]

Instead of establishing hubs in local nodes, it is possible to make use of different places already in existence and offer workplaces in connection with those. Examples of existing places with opportunities to offer flexible workplaces are libraries, cafés and churches. In New York, for example, Starbucks has teamed up with Google to create free and fast WiFi access for all customers[31] and the public library offers free Wi-Fi, computers and a workplace for all citizens and visitors[32]. An information place like W-work can be used to inform about available and bookable workplaces.

Paper V only interviewed hub owners already established in Stockholm. To get better knowledge of whether it is possible to establish hubs in local nodes, it would be a good idea to also interview employees and firms that are potential users of the service. It would also be of interest to get an idea how municipalities think and what kind of possibilities and barriers they envisage.

7.7 Sustainability?

This thesis had a narrow environmental scope and only considered mitigation of climate change by lowering energy consumption through the use of ICT. However, as Rockström et al. (2009) point out, there are several other planetary boundaries that we should not transgress.

It is possible that the ICT solutions discussed in the thesis lead to second order effects (Berkhout and Hertin 2004) such as rematerialisation and induction, direct economic effects, indirect economic rebound effects, economy-wide rebound effects, time rebound and space rebound (Börjesson Rivera et al. 2014). These second order effects need to be analysed and considered when using the ICT solutions to reduce energy use in cities. It is important that the second order effects do not lead to increased environmental burdens larger than the possible reduction of energy by ICT. If the second order effects are larger, it might be possible to find solutions to restrict them. If it is not possible to limit the second order effects, the whole implementation of the ICT solution must be questioned.

The implementation of the solutions discussed in this thesis is mainly considered within a context where countries have democratically elected governments, where the social part of millennium development goals is fulfilled and where human rights are taken for granted. The implementation of these solutions can have negative impacts on social sustainability in other parts of the world (Ekener-Petersen and Finnveden 2013), unless all environmental and social consequences of ICT are considered.

This thesis did not directly assess the economic sustainability of the ICT solutions studied. However, the kinds of services that are enabled by information technology can lead to very different business models than used today. An example is the flexible workplaces provided for free by the church and the architects' firm in Paper V. Another example of a service provided free of charge is traveller information services, which are available to anyone who wants to use them. The app ResiSTHLM[33] was created by a developer based on micro-funding, while Google Transit[34] is based on income from advertisements on the internet.

8. Conclusions

This thesis examined how ICT can be used to reduce energy use in cities and thereby support sustainable development and achievement of cities' climate targets. It explored how cities' climate targets can be developed in a consistent and transparent way and developed a tool to identify the most promising ICT hotspots and how they can be connected to planning of cities. Finally, it studied whether mobility management principles and climate targets had been implemented in two existing solutions, a travel information system and a flexible work hub.

The conclusions were that the following points are recommendable to strive for when investigating how and if ICT can support achievement of cities' climate targets:

- The methodological considerations involved in definition of a city's climate targets are transparent
- The most promising solutions among the ICT hotspots are identified
- The ICT solutions are directed towards achieving climate targets
- ICT solutions are integrated early in the planning process

The thesis reveals gaps between cities' climate targets and implementation and usage of existing ICT solutions. It also shows how to identify the most promising ICT solutions to reduce energy use in cities. There is much to gain for society if future ICT solutions can induce reduced energy use in their functional specification. There might need to be an authority to "meta-govern" and carry out quality control to ensure that ICT solutions aiming to reduce energy are developed, implemented and maintained accordingly, meaning that their use leads to the desired effects. In future research it would be useful to explore how a meta-governance role for a public authority could be designed for maximum effect, e.g. how it could manage the path towards achievement of climate targets and at the same time encourage innovation, entrepreneurship and public participation.

In the transport sector there are possibilities to connect information on travel demand from travellers, with systems for traffic monitoring and management. It would be interesting to further explore what will happen if the different parts of the transport information and payment systems, such as travel planners, traffic monitoring and management, congestion charging systems, access cards etc., were to be connected.

9. References

Arnstein, S. R. (1969). "A ladder of citizen participation." Journal of the American Institute of Planners **35** (4): 216-224.

Batty, M., K. W. Axhausen, F. Giannotti, A. Pozdnoukhov, A. Bazzani, M. Wachowicz, G. Ouzounis and Y. Portugali (2012). "Smart cities of the future." European Physical Journal-Special Topics **214**(1): 481-518.

Baynes, T., M. Lenzen, J. Steinberger and X. Bai (2011). "Comparison of household consumption and regional production approache to assess urban energy use and implications for policy." Energy Policy **39**: 7298-7309.

Beige, S. and K. W. Axhausen (2012). "Interdependencies between turning points in life and long-term mobility decisions." Transportation **39**: 857-872.

Bell, W. (2003). Foundations of Future Studies: Human science for a new era. New Brunswick (USA) London (UK) Transaction Publishers.

Benkler, Y. (2006). The Wealth of Networks: How Social Production Transforms Markets and Freedom. New Haven and London, Yale University Press.

Berkhout, F. and J. Hertin (2004). "De-materialising and re-materialising: digital technologies and the environment." Futures **36**: 903-920.

Beser, M. and S. Algers (2002). SAMPERS - The new Swedish National Travel Demand Forecasting Tool; Advances in spatial planning. National Transport Models: Recent Developments and Prospects L. Lundqvist and L.-G. Mattsson. Berlin, Heidelberg, New York, Barcelona, Hong Kong, London, Milan, Paris, Tokyo, Springer.

Bio Intelligence Service (2008). Impacts of information and communication technologies on energy efficency, European Comission DG INFSO.

Blind, K., S. Gauch and R. Hawkins (2010). "How stakeholders view the impacts of international ICT standards." Telecommunications Policy **34**: 162-174.

Bocken, N. M. P., J. M. Allwood, A. R. Willey and J. M. H. King (2012). "Development of a tool for rapidly assessing the implementations difficulty and emissions benefit of innovations." Technovation **32**: 19-31.

Borgotti, S., A. Mehra, D. J. Brass and G. Labianca (2009). "Reviews: Network Analysis in Social Sciences." Science **323** (5916): 892-895

Börjesson Rivera, M., C. Håkansson, Å. Svenfelt and G. Finnveden (2014). "Including second order effects in environmental assessments of ICT." Environmental modelling and software **56**: 105-115.

Caragliu, A., C. del Bo and P. Nijkamp (2009). Smart cities in Europe. 3rd Central European Conference in Regional Science - CERS.

Cass, N. (2006). Participatory-Deliberative Engagement: a literature review. Manchester UK, School of Environment and Development, Manchester University.

Castells, M. (1989). The Informational City. Oxford, UK, Malden, Mass., USA, Blackwell Publishers Inc.

Castells, M. (1996). *The rise of the Network Society*, The Information Age: Economy, Society and Culture, Vol.I. Oxford, UK & Cambridge, Mass. USA Blackwell Publishers Inc.

Chorus, C. G., E. J. E. Molin and B. Van Wee (2006). "Use and Effects of Advanced Traveller Information Services (ATIS): A Review of the Literature." Transport Reviews **26**(2): 127-149.

City of Stockholm (2010). Action plan for environmental and sustainable urban development in the Stockholm Royal Seaport

Deakin, M. (2014). From intelligent to smart cities. Smart Cities, Governing, modelling and analysing the transition. M. Deakin. Abingdon; Oxon, UK, Routledge.

Dhakal, S. and R. M. Shrestha (2010). "Bridging the research gaps for carbon emissions and their management in cities." Energy Policy **38**(9): 4753-4755.
Dodgson, M. and D. Gann (2011). "Technological Innovation and Complex Systems in Cities." Journal of Urban Technology **18**(3): 99-111.
Egger, S. (2006). "Determining a sustainable city model." Environmental Modelling & Software **21**: 1235-1246.
Ekener-Petersen, E. and G. Finnveden (2013). "Potential hotspots identified by social LCA-part 1: a case study of a laptop computer." Int J Life Cycle Assess **18**(1): 127-143.
Ernstson, H., S. Barthel, E. Andersson and S. T. Borgström (2010). "Scale-crossing brokers and network governance of urban ecosystem services: The case of Stockholm." Ecology and Society **15** (4).
EU (2007). Limiting Global Climate Change to 2 degrees Celsius
The way ahead for 2020 and beyond. COMMISSION OF THE EUROPEAN COMMUNITIES, COM (2007) 2 final Brussels.
EU (2011a). Cities of tomorrow. Challanges, visions and ways forward, European Comission, Directorate General for Regional Policy.
EU (2011b). Roadmap to a Single European Transport Area - Towards a competitive and resources efficient transport system. COM(2011) 144 final. Brussel.
Fernandez-Maldonado, A. M. (2012). "ICT and Spatial planning in European Cities: Reviewing the New Charter of Athens. ." Built Environment **38**(4): 469-483.
Fischer, C. (2008). "Feedback on household electricity consumption: a tool for saving energy?" Energy Efficiency **1**(1): 79-104.
Friedman, J. and B. Hudson (1974). "Knowledge and Action: A guide to planning theory." Journal of the American Institute of Planners **40**(1): 2-16.
Friedmann, J. (1998). "Planning Theory Revisited." European Planning Studies **6**(3).
GeSI (2008). SMART 2020: Enabling the low carbon economy in the information age.
GeSI (2012). GeSI SMARTer 2020: The role of ICT in driving a sustainable future.
Glaeser, E. (2010). "The greenness of cities: Carbon dioxide emissions and urban development." Journal of Urban Economics **67**: 404-418.
Graham, S. and S. Marvin (1996). Telecommunications and the City. London Routledge.
Hajer, M. A. and H. Wagenaar (2003). Deliberative Policy Analysis: Understanding Governance in the Network Society. Cambridge, Cambridge University Press.
Hansson, S., O,. (2007). "What is technological science?" Studies in History and Philosophy of Science **38**: 523-527.
Hedström, R. T. and M. J. Lundström (2013). Swedish Land-use Planning Legislation. Planning and sustaianble urban development in Sweden. Lundström M.J., Fredriksson C. and J. Witzell. Stockholm, Swedish Society for Town & Country Planning.
Heinonen, J. and S. Junnila (2011). "Case study on the carbon consumption of two metropolitan cities." International Journal of Life Cycle Assessment **16**: 569-579.
Hightower, H. C. (1969). "Planning Theory in Contemporary Professional Education." Journal of the American Institute of Planners **35**(5).
Hillman, T. and A. Ramaswami (2010). "Greenhouse Gas Emission Footprints and Energy Use Benchmarks for Eight US Cities." Environmental Science & Technology **44**(6): 1902-1910.
Hilty, L., W. Lohmann and E. Huang (2011). "Sustainability and ICT - An overview of the field." notizie di POLITEIA **27**: 13-28.
Hilty, L. M., P. Arnfalk, L. Erdmann, J. Goodman, M. Lehmann and P. A. Wager (2006). "The relevance of information and communication technologies for

environmental sustainability - A prospective simulation study." Environmental Modelling & Software **21**(11): 1618-1629.
Hilty, L. M., P. Wäger, M. Lehmann, R. Hischier, T. Ruddy and M. Binswanger (2004). The future impact of ICT on environmental sustainability. Fourth Interim Report - Refinement and quantification. Sevilla, Institute for Prospective Technological Studies IPTS.
Höjer, M. (2002). "A hundred nodes in the Stockholm region: a simple calculation of the effects on commuting." Environment and Planning B-Planning & Design **29**(2): 197-217.
Höjer, M., A. Gullberg and R. Pettersson (2011). Images of the future City. Time and space for sustainable development. Dordrecht, Springer.
Höjer, M., A. Gullberg and Pettersson R. (2011). "Backcasting images of the future city-Time and space for sustainable development in Stockholm." Technological Forecasting & Social Change **78**: 819-834.
Houghton, K., E. Miller and M. Foth (2014). "Integrating ICT into the planning process: impacts, opportunities and challenges." Australian Planner **51**(1): 24-33.
ICLEI (2011). Community- Scale GHG Emissions Accounting and Reporting Protocol, International Council for Local Environmental Initiatives.
IEA (2008). World Energy Outlook 2008, International Energy Agency.
IEA (2013). World Energy Outlook 2013, International Energy Agency.
Innes, J. I. and D. E. Booher (2003). Collaborative policymaking: Governance through dialogue. Deliberative Policy Analysis. J. I. Innes and D. E. Booher. Cambridge, Cambridge University Press.
IPCC (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Intergovernmental Panel on Climate Change.
IPCC (2013). Summary for Policymakers. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. T. F. Stocker, D. Qin, G.-K. Plattneret al. Cambridge, United Kingdom and New York, NY, USA.
IPCC (2014). Climate Change 2014: Impacts, Adaptation, and Vulnerability, SUMMARY FOR POLICYMAKERS. WGII AR5 Phase I Report Launch, Intergovernmental Panel on Climate Change.
Jakobs, K. (2006). "Shaping user-side innovation through standardisation. The example of ICT." Technological Forecasting and Social Change **73**: 27-40.
Kennedy, C., J. Steinberger, B. Gasson, Y. Hansen, T. Hillman, M. Havranek, D. Pataki, A. Phdungsilp, A. Ramaswami and G. V. Mendez (2010). "Methodology for inventorying greenhouse gas emissions from global cities." Energy Policy **38**(9): 4828-4837.
Lebel, L., P. Garden, M. R. N. Banaticla, R. D. Lasco, A. Contreras, A. P. Mitra, C. Sharma, H. T. Nguyen, G. L. Ooi and A. Sari (2007). "Integrating carbon management into the development strategies of urbanizing regions in Asia - Implications of urban function, form, and role." Journal of Industrial Ecology **11**(2): 61-81.
Lenzen, M., C. Dey and B. Foran (2004). "Energy requirements of Sydney households." Ecological Economics **49**: 375-399.
Loviscach, J. (2011). "The Design Space of Personal Energy Conservation Assistants." PsychNology Journal **9**(1): 29-41.
Lundahl, U. and P. H. Skärvad (1999). Utredningsmetodik för samhällsvetare och ekonomer. Lund, Studentlitteratur.

Lundqvist, L. J. (2001). "Implementation from Above: The Ecology of Power in Sweden's Environmental Governance's Governance: ." An International Journal of Policy and Administration **14**(3): 319-337.
Lyons, G., D. (2001). "Towards integrated traveller information." Transport Reviews **21**(2): 217-235.
Malmodin, J., Å. Moberg, D. Lundén, G. Finnveden and N. Lövehagen (2010). "Greenhouse Gas Emissions and Operational Electricity Use in the ICT and Entertainment & Media Sectors." Journal of Industrial Ecology **14**(5): 770-790.
Meadows, D., D. Meadows, J. Randers and W. Behrens (1972). The Limits to growth, The Clube of Rome.
Mindali, O., A. Raceh and I. Salomon (2004). "Urban density and energy consumption: a new look on old statistics." Transportation reserach Part A: Policy and Practice **38**(2): 143-162.
Mitchell, W. J. (2000). E-topia, "Urban life, Jim - but not as we know it". Cambridge Mass., The MIT Press.
Mitchell, W. J. (2004). Me++ The cyborg self and the networked city. Cambridge, Massachusetts, USA & London, UK, The MIT Press.
Nam, T. and T. A. Pardo (2011). Conceptualiizing Smart City with Dimensions of Technology, People, and Institutions. 12th Annual International Conference on Digital Governmnet Research.
Ng, I. C. L. (2014). Creating New Markets in the Digital Economy, Value and Worth. Cambridge, New York, Cambridge.
Nobis, C. and B. Lenz (2009). "Communication and mobility behaviour – a trend and panel analysis of the correlation between mobile phone use and mobility. ." Journal of Transport Geography **17**: 93-103.
Nyseth, T. (2008). "Network Governance in Contested Urban Landscapes." Planning Theory & Practice **9**(4): 497-514.
OECD/IEA (2013). A Tale of Renewed Cities. Policy Pathway, Organisation for Economic Co-operation and Development/International Energy Agency.
Owens, S. (2003). "Is there a meaningful definition of sustainability?" Plant Genetic Resources **1**(1): 5-9.
Pierre, J. and Peters B. G. (2005). Governing Complex Societies: Trajectories and Scenarios Chippenhamn and Eastbourne, Palgrave Macmillan.
Pierson, P. (2000). "Increasing Returns, Path Dependence, and the Study of Politics." American Political Science Review **94**(2): 251-267.
Raiffa, H., J. Richardson and D. Metcalfe (2002). Negotiation Analysis. . USA Cambridge, The Belknap Press of Harvard University Press.
Robinson, J. (2008). "Being undisciplined: Transgressions and intersections in academia and beyond. ." Futures **40**(1): 70-86.
Rockstrom, J., W. Steffen, K. Noone, A. Persson, F. S. Chapin, E. F. Lambin, T. M. Lenton, M. Scheffer, C. Folke, H. J. Schellnhuber, B. Nykvist, C. A. de Wit, T. Hughes, S. van der Leeuw, H. Rodhe, S. Sorlin, P. K. Snyder, R. Costanza, U. Svedin, M. Falkenmark, et al. (2009). "A safe operating space for humanity." Nature **461**(7263): 472-475.
Schaffers, H., N. Komninos, M. Pallot and B. Trousse (2011). "Smart cities and the future internet: Towards cooperation frameworks for open innovation." Future Internet, Lecture Notes in Computer Science **6656**: 431-336.
Schulz, N. B. (2010). "Delving into the carbon footprints of Singapore-comparing direct and indirect greenhouse gas emissions of a small and open economic system." Energy Policy **38**(9): 4848-4855.

Sehested, K. (2009). "Urban Planners as Network Managers and Metagovenors." Planning Theory & Practice **10**(2): 245-263.
SEI (2012). Global miljöpåverkan och lokala fotavtryck - analys av fyra svenska kommuners totala konsumtion (Global Environmental Impact and Local Footprints - An analysis of the Total Consumption of Four Swedish Municipalities), Stockholm Environment Institute.
Sovacool, B. K. and M. A. Brown (2010). "Twelve metropolitan carbon footprints: A preliminary comparative global assessment." Energy Policy **38**(9): 4856-4869.
Steffen, W., P. J. Crutzen and J. R. McNeill (2007). "The Anthropocene: Are Humans Now Overwhelming the Great Forces of Nature." A Journal of the Human Environment **36**(8): 614-621.
Swedish Environmental Protection Agency (2012). Consumption-based environmental indicators. Basis for monitoring the generation goal. Report 6483.
Swoa, J. F. and J. A. Zachman (1992). "Extending and formalizing the framework for information systems architecture." IBM Systems journal **21**(3).
The Climate Group, ARUP, Accenture and Horizon (2011). Information Marketplaces: The New Economics of Cities.
Throgmorton, J. A. (2003). "Planning as Persuasive Storytelling in a Global-Scale Web of Relationships." Planning Theory & Practice **2** 125-151.
Toikka, A. (2010). "Exploring the composition of communication networks of governance - a case study on local environmental policy in Helsinki, Finland." Environmental Policy and Governance **20** (2): 135-145.
Townsend, A. (2013). Smart Cities; Big data, civic hackers, and the quest for a new utopia. New York, London, W.W. Norton & CompNy, Inc.
Transport Analysis (2011). Report 2011:3 Arbetspendling i storstadsregioner - en nulägesanalys, Trafikanalys.
Treib, O., H. Bähr and G. Falkner (2005). Modes of Governance: A Note Towards Conceptual Clarification" (EUROGOV) No. N-05-02, European Governance Papers
UK Government (2006). Stern Review: The Economics of Climate Change. London.
UN (1998). Kyoto Protocol to the United Nations framework convention on climate change
UNEP (2011). Decoupling natural resource use and environmental impacts from economic growth. A Report of the Working Group on Decoupling to the International Resource Panel. Fischer-Kowalski, M., Swilling, M., von Weizsäcker, E.U., Ren, Y., Moriguchi, Y., Crane, W., Krausmann, F., Eisenmenger, N., Giljum, S., Hennicke, P., Romero Lankao, p., Sibirian Manalang, A.,Sewerin, S., United Nations Environment Programme.
Washburn, D. and U. Sindhu (2010). Helping CIOs understand "smart city" initiatives, Forrester.
WCED (1987). Our Common Future. Oxford, World Commission on Environment and Development.
Williams, K. (1999). "Urban intensification policies in England: problems and contracdictions." Land Use Policy **16**(3): 167-178.
WRI-WBCSD (2011). Corporate Value Chain (Scope 3) Accounting and Reporting Standard, World Resources Institute (WRI) - World Business Council for Sustainable Development (WBCSD)

References for WEB pages and mobile applications

[1] Covenant of Mayor (2014) Retrieved 5/6 2014, from http://www.covenantofmayors.eu
[2] City of Stockholm (2013) "The city's environmental goals and work." Retrieved10/10, 2013,
from http://miljobarometern.stockholm.se
[3] City of Malmö (2014) Retrieved 24/5, 2014, from
http://www.malmo.se/Medborgare/Miljo--hallbarhet/Miljoarbetet-i-Malmo-stad/Miljoprogram-for-Malmo-stad/Sveriges-klimatsmartaste-stad.html
[4] Swedish Transport Administration (2012) "Four Stage Principle" Retrieved 28/6, 2012, from http://www.trafikverket.se/Foretag/Trafikera-och-transportera/Planera-persontransporter/Hallbart-resande/Fyrstegsprincipen
[5] Intelligent Community Forum (2012) Retrieved 25/5, 2012, from
http://www.intelligentcommunity.org
[6] Swedish Transport Administration (2012) "Four Stage Principle" Retrieved 28/6, 2012, from http://www.trafikverket.se/Foretag/Trafikera-och-transportera/Planera-persontransporter/Hallbart-resande/Fyrstegsprincipen
[7] European Green Capital Award (2014) Retrieved 13/5, 2014, from
http://www.europeangreencapital.eu
[8] Deutsche Bahn Navigator. (2012) Retrieved 20/1, 2012 from http://www.bahn.de,, Itunes appstore and Google Play
[9] Google (2012) Retrieved 20/1, 2012, from http://google.com/transit
[10]Munchner Verkehrs- und Tarifverbund (MVV) (2012) Retrieved, 20/1, 2012,
from http://www.mvv-muenchen.de, itunes appstore and Google Play
[11] Res i STHLM (2012) Retrieved 20/1, 2012 from Itunes app store, and Google Play
[12] Resrobot (2012) Retrieved 20/1, 2012, from http://reseplanerare.resrobot.se
[13] Stockholm Public Transport Trip Planner (2012) Retrieved 20/1, 2012,
from http://www.sl.se and http://mobil.sl.se
[14] Trafiken.nu (2012) Retrieved 20/1, 2012, from http;//reseplanerare.trafiken.nu and Itunes app
store.
[15] Transport Direct (2012) Retrieved 20/1 2012, from http://www.transportdirect.info
[16] Transport for London (2012) Retrieved 20/1, 2012, from http://www.tfl.gov.uk
[17] United Spaces (2013) Retrieved 7/3, 2013, from http://www.unitedspaces.se
[18] Hub Stockholm (2013) Retrieved 7/3, 2013, from http://stockholm.impacthub.net
[19] Kolonien (2013) Retrieved 26/3, 2013, from http://www.kolonien.se
[20] Coffice (2013) Retrieved 26/3, 2013, from http://www.coffice.coop
[21] Ekensbergskyrkan (2013) Retrieved 26/3, 2013, from
http://www.missionskyrkan.se/ekensbergskyrkan
[22] UNFCCC. (2014). "United Nations Framework Convention on Climate Change."
Retrieved 21/5, 2014, from http://unfccc.int/2860.php
[23] Government Offices of Sweden (2014) "National climate work: Objectives and Actions."
Retrieved 29/5, 2014,from http://www.regeringen.se/sb/d/8756/a/123033
[24] Ubigo (2014) "UbiGo - Ubiquitous Go." Retrieved 5/6, 2014, from
http://web.viktoria.se/ubigo
[25] Uber (2014) Retrieved 18/2 2014, from http://www.uber.com

[26] C40 & Siemens City (2014) "Clinton Climate Leadership Awards, Intelligent City Infrastructure." Retrieved 25/5, 2014, from http://cityclimateleadershipawards.com/tag/intelligent-city-infrastructure
[27] Ericsson (2014) "City Life." Retrieved 25/05, 2014, from http://www.ericsson.com/thinkingahead/networked_society/city-life
[28] City of Amsterdam (2014) "Amsterdam Smart City." Retrieved 4/6, 2014, from http://amsterdamsmartcity.com.
[29] W-work (2013) "W-work Netherlands." Retrieved 23/8, 2013, from http://www.w-work.nl/frontoffice/orientation
[30] W-work (2013) "W-work Netherlands." Retrieved 0823, 2013, from http://www.w-work.nl/frontoffice/orientation
[31] Starbucks (2014) "Starbucks free Wi-Fi (United States)." Retrieved 0704, 2014, from http://www.starbucks.com/coffeehouse/wireless-internet
[32] New York Public Library (2014) "New York Public Library, Computers, Internet and Wireless Access”
Retrieved 4/7, 2014, from http://www.nypl.org/help/computers-internet-and-wireless-access
[33] Res i STHLM (2012) Retrieved 20/1, 2012 from Itunes app store, Google Play
[34] Google (2012) Retrieved 20/1, 2012, from http://google.com/transit