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BUILDING AS ACTIVE ELEMENTS OF ENERGY SYSTEMS

Mehmet Börühan Bulut

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BUILDING AS ACTIVE ELEMENTS OF ENERGY SYSTEMS

Mehmet Börühan Bulut

Akademisk avhandling

som för avläggande av teknologie doktorsexamen i energi- och miljöteknik vid
Akademin för ekonomi, samhälle och teknik kommer att offentligen försvaras
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Abstract

Buildings account for approximately 40% of the energy demand and 33% of the total greenhouse gas emissions in the European Union. Accordingly, there are several efforts that target energy efficiency in buildings both at the European and Swedish levels. The role of buildings in climate change mitigation, however, is not limited to energy savings. Buildings are expected to become key elements of the future smart energy systems by supplying and using energy in a more flexible way. Reducing the energy demand in buildings effectively and shifting the role of buildings in energy systems from 'passive' consumers to 'active' prosumers, however, require close interaction and cooperation between the energy and buildings sectors.

Based on the data collected from interviews and a web survey, this doctoral thesis investigates the relationship between the energy and buildings sectors in Sweden at the inter-company level, presents key stakeholder views on smart energy features in buildings and investigates the opportunities and barriers for their adoption in Sweden and Hong Kong.

The results of this thesis suggest a potential for improving the cooperation between the Swedish energy and buildings sectors, which was identified to be influenced by the following factors: district heating monopolies; energy efficiency efforts in the buildings sector; unsuccessful technology-neutrality of the building regulations; self-generation systems in buildings; and energy use patterns. Shifting the focus from self-gains to mutual gains appears crucial to strengthen the inter-sectoral cooperation, as there are several opportunities for achieving mutually beneficial solutions for the two sectors. This would, however, require significant changes in current practices and business models as well as the introduction of new technologies, which would allow for a more flexible energy supply and use. Accordingly, technologies that target flexible energy use in buildings are considered the most important smart energy features in buildings. The current high costs of technologies, such as home automation and smart electrical appliances, however, create the strongest barrier to adoption. Therefore, the introduction of new business and ownership models and the elimination of the institutional and regulatory barriers are crucial to achieve a wide-scale development of smart energy features in buildings. The results from Hong Kong suggest that institutional and regulatory barriers can particularly create strong hinders to the adoption of technologies.

It is possible to achieve more sustainable energy systems, where buildings are active elements of networks that supply and use energy in a more flexible and 'smarter' way. Cooperation between the energy and buildings sectors can play a key role in the adoption of smart energy features in buildings and pave the way for the smart built environment of the future.

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To my family and friends

Summary

Improving the energy performance of buildings is one of the targets of the European climate policy, as buildings account for 40% of the total energy demand and 33% of the total greenhouse gas emissions originating in the European Union. The role of buildings in the combat with climate change, however, is not limited to energy savings; buildings are also expected to play a key role in the future energy systems by supplying and using energy in a 'smarter' way. Shifting the role of buildings in energy systems from 'passive' consumers to 'active' prosumers requires close interaction and cooperation between the energy and buildings sectors, which are considered two key sectors for the development and operation of smart energy systems.

Reporting on the results of interviews and a web survey, this thesis investigates the relationship between the energy and buildings sectors in Sweden, identifies barriers to cooperation between the two sectors and makes recommendations to strengthen the inter-sectoral cooperation. This thesis also presents the perspectives of the energy and buildings sectors on smart energy features in buildings, sheds a light on the barriers to their adoption as well as investigates the business and ownership models that can contribute to their wide-scale development. A comparative analysis of the smart home markets in Hong Kong and Sweden based on key stakeholder views is also included to study similarities and differences between the two jurisdictions and contribute further to the adoption of smart homes.

The findings suggest a potential for strengthening the levels of cooperation and mutual trust between the energy and buildings sectors. The identified factors to negatively impact the inter-sectoral cooperation were as the following: district heating monopolies; energy efficiency measures in the buildings sector; unsuccessful technology-neutrality of the national building regulations; self-generation systems; and energy use patterns in buildings. Shifting the focus of stakeholders from self-gains to mutual gains appears crucial to strengthen the inter-sectoral cooperation, although, this requires significant changes in current practices and business models as well as the introduction of new technologies, which would allow for a more flexible energy supply and use.

The results suggest that the technologies that target flexible energy demand in buildings are considered the most important smart energy features by the stakeholders. The high costs of technologies and the weak financial incentives in today's conditions were identified as the strongest barriers to the adoption

of smart energy features in buildings. Therefore, the introduction of new business models that reduce the costs and risks of investments is vital to encourage the development. The removal of the existing institutional and regulatory barriers, which were identified to particularly impact the development in Hong Kong, is, also crucial to create stronger incentives for buildings to supply and use energy in a more flexible and 'smarter' way, and eventually pave the way to the wide-scale adoption of smart energy features in buildings.

Sammanfattning

Byggnader står för 40 procent av energianvändningen och 33 procent av växthusgasutsläppen i Europeiska Unionen, vilket gör byggnaders energiprestanda till ett av de viktigaste målen för den europeiska klimatstrategin. Byggnaders roll i att bekämpa klimatförändringen är dock inte begränsad till energibesparingar. Byggnader förväntas också spela en nyckelroll i framtidens energisystem genom energiförsörjning och användning på ett 'smartare' sätt. Att transformera byggnaders roll i energisystem från 'passiva' konsumenter till 'aktiva' prosumenter kräver ett närmare samarbete mellan energi- och byggsektorerna, två nyckelsektorer för utvecklingen och driften av smarta energisystem.

Genom att presentera resultaten från intervjuer och en webbenkät, utforskar denna avhandling relationen mellan energi- och byggsektorerna på företagsnivå i Sverige, presenterar de faktorer som försvårar samarbete mellan intressenter och ger rekommendationer för att kunna minimera hinder för samverkan. Avhandlingen presenterar också energi- och byggsektorernas syn på smarta energilösningar i byggnader och hinder för implementering samt utforskar affärs- och ägarmodeller som kan bidra till utvecklingen av smarta energilösningar i byggnader i större skala. En jämförande analys av marknaderna för smarta hem i Hongkong och i Sverige, utifrån nyckelaktörernas syn, är också inkluderad för att studera likheter och skillnader mellan de två jurisdiktionerna och bidra till utvecklingen av smarta hem.

Resultaten i denna avhandling tyder på att nivåerna av samarbete och ömsesidigt förtroende mellan energi- och byggsektorerna i Sverige kan förbättras. De faktorer som påverkar samarbetet negativt är följande: fjärrvärmemonopol; energieffektiviseringsåtgärder i byggnader; bristande teknisk neutralitet i de nationella byggreglerna; egenproduktion av el; och energianvändningsmönster. Att byta fokus från egen vinning till gemensamma mål bedöms vara nödvändigt för att för att stärka samarbetet mellan energi- och byggsektorerna även om detta fodrar stora förändringar både i nuvarande verksamhet och i affärsmodellerna. Det krävs också en introducering av ny teknik som möjliggör flexiblare energiförsöjning och användning.

Resultaten visar också att teknologi som bidrar till flexiblare energianvändning ses som viktigast av de smarta energilösningarna i byggnader. Höga investeringskostnader och låga finansiella incitament verkar i dagsläget vara de största hindren för implementering av smarta energilösningar i byggnader. Introduceringen av nya affärsmodeller som minskar kostnader och risker med

investeringar är avgörande för att föra utvecklingen vidare. Avlägsnandet av institutionella och rättsliga hinder, som särskilt verkar påverka utvecklingen i Hongkong, är viktigt för att skapa starkare incitament för byggnader att försörja och använda energi på ett mer flexibelt och ’smart’ sätt och kommer framöver att bana väg för storskalig implementering av smarta energilösningar i byggnader.

List of Papers

This doctoral thesis is based on the following articles:

I. Bulut, M. B., Wallin, F., Stigson, P., & Vassileva, I. (2015). Cooperation for climate-friendly developments – an analysis of the relationship between the energy and buildings sectors in Sweden. *Energy Efficiency*, Volume 9, Issue 2, 353-370. http://doi.org/10.1007/s12053-015-9369-8

II. Bulut, M. B., Odlare, M., Stigson, P., Wallin, F., & Vassileva, I. (2015). Buildings in the future energy system – Perspectives of the Swedish energy and buildings sectors on current energy challenges. *Energy and Buildings*, *107*, 254–263. http://doi.org/10.1016/j.enbuild.2015.08.027

III. Bulut, M. B., Odlare, M., Stigson, P., Wallin, F., & Vassileva, I. (2016). Active buildings in smart grids − exploring the views of the Swedish energy and buildings sectors. *Energy and Buildings*, *117*, 185–198. http://doi.org/10.1016/j.enbuild.2016.02.017

IV. Bulut, M.B., Hills, P., Mah, D.N., Stigson, P., Wallin, F., A comparative study of key stakeholder views on smart homes in Hong Kong and Sweden. Manuscript for journal consideration.

Parts of the results in this doctoral thesis, including *Paper I* and *Paper II*, were published previously in a licentiate thesis entitled ‘An analysis of the relationship between the energy and buildings sectors in Sweden’.

Licentiate thesis:

Bulut, M.B., An analysis of the relationship between the energy and buildings sectors in Sweden. Mälardalen University Press, Licentiate thesis 215, ISBN 978-91-7485-222-6

Author’s contribution

I designed the interviews and the survey that were used in data collection and conducted the interviews. Dr. Monica Odlare performed the statistical analyses on the survey data and provided the text explaining the statistical methods in *Paper II* and *Paper III*. Excluding Dr. Odlare’s contribution, all papers were written by me under the supervision of Prof. Dr. Björn Karlsson, Dr. Fredrik Wallin, Dr. Peter Stigson and Dr. Iana Vassileva (excluding *Paper IV)* at Mälardalen University. Prof. Dr. Peter Hills from the University of Hong Kong and Dr. Daphne Mah from Hong Kong Baptist University provided supervision for the writing of *Paper IV*. Reprints of the papers were made with permission from the respective publishers.

List of Papers Not Included

I. Bulut, M. B., Wallin, F., & Karlsson, B. (2013). Barriers to development of the smart grid - perspectives of the building and energy sectors in Sweden. Presented at the 5th. International Conference on Applied Energy, July 2013, Pretoria, South Africa

II. Bulut, M.B., Wallin, F., (2013). The development of active buildings through renovation – Is it possible?. Presented at the YRSB13 - iiSBE Forum of Young Researchers in Sustainable Building 2013, June 2013, Prague, Czech Republic

III. Bulut, M.B., Wallin, F., (2014). Buildings as components of smart grids – perspectives of different stakeholders. Presented at the 6^{th} International Conference on Applied Energy, May 2014, Taipei, Taiwan (Conference paper published in Energy Procedia)

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Nomenclature

Abbreviations

ANOVA	Analysis of Variance
CHP	Combined Heat and Power
CLP	China Light and Power Company
CO_2	Carbon dioxide
C	Construction
ED	Electricity Distribution
EED	Energy Efficiency Directive
EM	Energy Management
EPBD	Energy Performance of Buildings Directive
ER	Electricity Retail
EU	European Union
ESCO	Energy Service Company
DH	District Heating
GHG	Greenhouse gas
GDP	Gross domestic product
GWh	Gigawatt hour
H	Housing
HEC	Hong Kong Electric Company
HSD	Honestly Significant Difference
IPCC	Intergovernmental Panel on Climate Change
$ktCO_2$-e	Kiloton carbon dioxide equivalent
kVA	Kilo-volt-ampere
kW	Kilowatt
kWh	Kilowatt hour
M	Municipality
MW	Megawatt
NZEB	Nearly Zero Energy Building
OECD	Organisation for Economic Cooperation and Development
PC	Principle Component
PCA	Principle Component Analysis
PV	Photovoltaic
R	Research
RES	Renewable Energy Sources

SAR	Special Administrative Region
SEK	Swedish Crowns
SCA	Scheme of control agreement
TWh	Terawatt hours
UK	The United Kingdom
UHK	Utility in Hong Kong
UNFCC	United Nations Framework Convention on Climate Change

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Introduction

1.1. Background

Increasing atmospheric concentrations of greenhouse gases (GHG) induce climate change, because of which the atmosphere, land and oceans have warmed, the global mean sea-levels have risen, ice and snow mass have been reduced, and the occurrence of weather anomalies has increased in frequency (IPCC 2014). In December 2015, world leaders reached an agreement at the 21st Conference of Parties of the United Nations Framework Convention on Climate Change (UNFCCC) in Paris to combat climate change and build a low-carbon global future. The Paris agreement targets at 'holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change' (UNFCCC 2015).

As the first major economy to submit its intended contribution, involving a GHG emission cut of at least 40% by 2030 from the 1990 levels, the European Union (EU) played an active role in the negotiations (European Commission 2015a). The European contribution was based on the EU's 2030 climate and energy framework, which, building on the 20/20/20[1] targets, sets the following targets to be achieved by 2030 (European Commission 2015b): i) at least 40% reduction in GHG emissions from 1990 levels; ii) achieving a renewable energy share of at least 27% in the final energy demand; iii) increasing energy efficiency by 27%[2]. The targets are binding, except the energy efficiency target, which is to be reviewed in 2020 with a 30% target in mind.

According to Lechtenböhmer and Schüring (2011), energy savings of up to 80% can be reached in European buildings by improving the energy efficiency of new and existing buildings. The role of buildings in the combat with climate change, however, is not only limited to energy savings; buildings can contribute further to the decarbonisation of the energy sector by using and supplying energy in a 'smarter' way. The following section discusses the role of buildings in the energy system and their rising role as 'smart' elements in networks.

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[1] The European 2020 Climate and Energy Package, introduced in 2009, aims to reach the following targets by the year 2020 (European Commission 2014): i) reducing the GHG emissions by 20% from 1990 levels; ii) increasing energy efficiency by 20%; iii) increasing the share of renewables in the final energy use by 20%.

[2] In reference to 2007 levels

1.1.1. Buildings and the energy system

The European climate policy primarily focuses on the emission reductions in the energy sector, which, including all emissions related to energy supply and use, emits 80% of the total GHG emissions in the EU (European Commission 2011). Buildings are a major contributor to the energy-related GHG emissions in the EU as they represent 40% of the total energy use, emitting one-third of the total GHG emissions (European Commission 2010a). Consequently, the buildings sector also plays an important role in fulfilling the European climate targets, as also acknowledged in the Energy Efficiency Directive (EED) which states that 'buildings are crucial to achieving the Union objective of reducing greenhouse gas emissions by 80-95 % by 2050 compared to 1990' (European Commission 2012). Accordingly, there are several EU directives[3] that address energy performance of buildings. The role of buildings in the EU climate and energy policy is not only limited to energy savings, buildings are also expected to become active elements in the future smart energy systems by allowing its occupants to supply, store, and use energy in a more flexible and smarter way (ACER 2014; Eurelectric 2015)

Traditional power systems operate on the principle of uni-directional flow of information and power from centralised large production plants to a large number of users that are often located further away from the point of generation, which not only results in overall inefficiencies due to mismatch between generation and demand, but also limits the amount of intermittent renewable generation that can be accommodated in the networks (Farhangi 2010; Güngör et al. 2011). Smart grids, on the other hand, have bi-directional flow of information and power, which yield higher demand flexibility and hence allow the accommodation of large amounts of intermittent renewable power generation in networks (Amin 2014; Farhangi 2010). The EU definition[4] of smart grids is 'electricity networks that can efficiently integrate the behavior and actions of

[3] The energy performance of European buildings is governed by the Energy Performance of Buildings Directive (EPBD), which imposes that by 2020 all new buildings in the EU are nearly zero-energy buildings (NZEB) with very low energy demand that is met by local or nearby renewable energy resources (European Commission 2010a). The EPBD also encourages the major renovation of existing buildings to become NZEB and imposes that all new buildings and buildings undergoing renovation to be fitted with smart meters. In addition to the EPBD, the Renewable Energy Sources (RES) Directive sets the minimum amounts of renewable energy that needs to be integrated into the electricity, heat, and cooling supply to both new buildings and buildings undergoing renovation (European Commission 2009a). Furthermore, the Energy Efficiency Directive (EED) requires the Member States to purchase and rent only very energy efficient buildings for governmental use, reduce energy use in existing governmental buildings by 3% per annum, and draw up renovation strategies to improve the energy performance of their building stock. Moreover, the EED imposes annual end-use energy savings of 1.5% on utilities, aiming to boost energy saving measures (European Commission 2012). Besides, the Eco-design of Energy Related Products Directive establishes the minimum energy efficiency levels for appliances that range from heat pumps to vacuum cleaners (European Commission 2009b).

[4] This definition was put forward by the European Commission Task Force for Smart Grids.

all users connected to it — generators, consumers and those that do both — in order to ensure an economically efficient, sustainable power system with low losses and high quality and security of supply and safety' (European Commission 2010b). Smart power grids can also be complemented with smart thermal networks to achieve fully renewable energy systems (Lund et al. 2012, 2014).

Parallel to the smart grid developments, smart buildings have emerged as a solution to optimise the benefits of smart grids for both consumers and power network operators by combining traditional buildings with technologies like manual and automatic energy management, self-generation of electricity, energy storage, demand flexibility, smart appliances, displays and decision support technologies to assist consumers in response to price and GHG emissions signals (Balta-Ozkan et al. 2013a; Bartusch et al. 2011; Gyamfi and Krumdieck 2011; Paetz et al. 2011; Rottondi et al. 2015; Sianaki et al. 2010). Given their energy storage capabilities, electric vehicles are also often associated with smart buildings (Erdinc 2014; Wi et al. 2013). Maximising the benefits of smart grid technologies and achieving the integration of smart homes in energy networks requires closer cooperation between the energy and buildings sectors, both at the end-user and inter-company levels, than there is today, as highlighted by Hashmi et al. (2011): 'Realizing smart grids' potential will require a new level of cooperation between industry players, advocacy groups, the public and especially the regulatory bodies that have such immediate influence over the direction the process will take.'.

1.1.2. Inter-sectoral cooperation

Despite the differences between them, the terms 'collaboration' and 'cooperation' are often used interchangeably in the literature for referring to alliances between organisations. Malone et al. (1994) explain that 'cooperation' refers to a set of shared goals between parties whereas 'collaboration' implies sharing workforce and intellectual efforts. Accordingly, the term 'cooperation' is used in this thesis for referring to a set of behaviours and efforts between organisations to achieve mutually beneficial outcomes and goals that cannot be achieved alone.

Cooperation between two organisations may lead to environmental and societal benefits, increase financial profits, encourage innovation, and result in other positive outcomes (Eriksson et al. 2008; Van Huijstee et al. 2007). Given the abovementioned interdependencies between the energy and buildings sectors, and the rising importance of buildings as active elements in smart energy systems, cooperation between these two key sectors would create both financial and environmental benefits and encourage innovation.

Below are some examples of cooperation between the energy and buildings sectors in Sweden that have resulted in positive outcomes. Municipal energy and housing companies have been actively involved in the development and execution of municipal energy and climate plans since many years. An example is the Eskilstuna Municipality, which aims to cut energy use in buildings owned by the municipality, including those that are operated by the municipal housing company, by 20% and achieve a 2.5 MW installed solar photovoltaic (PV) capacity by the year 2020, through joint efforts by the municipal housing and energy companies (Eskilstuna Municipality 2016). There are also cooperative smart grid pilot projects that included the development of smart homes. Stockholm Royal Seaport and Hyllie are the two well-known urban development projects that involved the integration of smart homes and electric vehicles into the grid, and set good examples of successful inter-sectoral cooperation (Hyllie 2014; Swedish Energy Agency 2011). Another key example is the Framtidsgränd (Future alley) smart home pilot that is developed cooperatively by the municipal housing and energy companies in the city of Västerås (Mimer 2014; Mälarenergi 2010).

A common feature of the abovementioned joint efforts between the energy and buildings sectors is that they are orchestrated by governmental authorities, such as municipalities, often at a pilot scale. It is, therefore, crucial to shift the level of inter-sectoral cooperation from such pilot projects to wider-scale common practices that focus on producing mutual benefits. This, however, may be challenging due to several barriers to cooperation between organisations that exist. These barriers can be organisational (lack of understanding, different agendas, cultural differences and short-sightedness), behavioural (lack of awareness or trust, risk, conservatism, miscommunication, bounded-rationality and self-interest), market related (lack of competition, inflexible business models, weak incentives, principal-agent problems and incomplete markets) or institutional (regulatory barriers, uncertain governmental policies, absence of platforms for dialogue, lack of involvement of stakeholders in decision making) (Barson et al. 2000; Eriksson et al. 2008; Humphries and Wilding 2003; Ingirige and Sexton 2006; Lendrum 1998; Mattessich et al. 2001; Murtishaw and Sathaye 2006; Ng et al. 2002; Rohdin and Thollander 2006; Sanstad and Howarth 1994).

This thesis identifies the barriers to cooperation between the Swedish energy and buildings sectors and presents key stakeholders' views on energy use in buildings and smart energy technologies with the aim to contribute to the inter-sectoral cooperation towards sustainable energy systems.

1.1.3. Energy and buildings sectors in Sweden

Sweden is an EU member state[5] located in Northern Europe, with a population of 9.8 million people distributed on an area of 438,574 km^2 (European Union 2014; Statistics Sweden 2016a). Sweden possesses a developed and export oriented economy that is dominated by the services sector, generating 72.6%

[5] Sweden accessed the EU in 1995

of its gross domestic product (GDP), followed by the industrial and the agriculture sectors with 26% and 1.4%, respectively (World Bank 2016).

Despite having a relatively high energy demand due to the energy intensive industries and the Nordic climate, the Swedish economy has the second lowest carbon-intensity (CO_2/GDP) among OECD countries (OECD 2014). The total primary energy supply in 2013 was 565 TWh, of which one third was provided by fossil fuels. Excluding losses and the use for non-energy purposes, the total energy demand in the same year was 375 TWh, of which 147 TWh (39%) was used by the residential and services sectors together, followed by the industrial and transport sectors with 144 TWh (38%) and 85 TWh (23%), respectively. The total energy demand by the residential and services sector and the industry has remained stable in the last two decades, while the demand by the transport sector has fallen slightly (Swedish Energy Agency 2015a).

Sweden has one of the highest per-capita power consumption rates in the world with 14,290 kWh/year (World Bank 2015). Nevertheless, the domestic power production relies primarily on fossil-free resources. In 2013, the total domestic power production was 149 TWh, of which 43% came from nuclear power, followed by 40% from hydropower, 10% from combustion based generation in combined heat and power (CHP) plants and the industry and 7% from wind power (Swedish Energy Agency 2015a).

As an EU Member State, Sweden's energy policy is largely influenced by that of the EU. Following the announcement of the 20/20/20 targets, Sweden introduced the national 2020 climate targets that aim at: i) cutting GHG emissions by 40% from 1990 levels; ii) reaching 50% share of renewables in the final energy use; and iii) increasing energy efficiency by 20% (Swedish Government Offices 2013a). Housing and services sectors account for approximately 40% of the total energy demand and 20% of the total GHG emissions in the country and hence play a key role in meeting the national climate targets (Larsson et al. 2008; Toller et al. 2009). Accordingly, buildings are central to reach the national target to achieve 20% improved energy efficiency by 2020[6] (Swedish Government Offices 2015a). Heat savings reportedly represent approximately two-thirds of the energy efficiency potential in buildings and are therefore at the focus of the measures to cut energy use (Chalmers Energy Centre 2005).

The Swedish efforts are, however, not only limited to achieve heat savings in buildings, but also involve the development of smart grids. Sweden was one of the first European countries achieve the universal roll-out of smart electricity meters (European Commission 2010b). Swedish consumers have been entitled to hourly metering of electricity free of charge since 2012 and a proposal has been put forward to also grant consumers free of charge access to hourly consumption data (Swedish Government Offices 2012, 2014a). In addition, several measures have been introduced to encourage electricity savings, such

[6] The reference year for the target is 2008.

as the mandatory billing of all dwellings in buildings and clearer energy bills (Swedish Government Offices 2013b).

Swedish consumers can receive investment subsidies for photovoltaic (PV) systems, in addition to tax reductions on the surplus electricity that is fed back into the grid (Swedish Energy Agency 2015b; Swedish Government Offices 2014b). The Swedish micro-generation market is dominated by solar PV technologies, with a 80 MW of installed capacity by the end of 2014, generating electricity that is enough to meet 0.06% of the total demand (Lindahl 2015). It can be, however, expected that this share increases in the future as a result of the tax reduction scheme, which came into force in 2015. In addition, the development of electric vehicles is supported by a premium and tax exemptions (Swedish Tax Authority 2016; Swedish Transport Administration 2016).

The Swedish electricity market was deregulated in 1996, which introduced competition to the generation and retail ends of the market. The deregulation, after which Sweden joined the Nordic power market Nordpool, has altered the structure of the domestic market fundamentally. Before 1996, ten state-owned companies supplied 90% of the power, while municipalities and small private generators supplied the rest (Kärrmark 2001). The state-owned Vattenfall owned and operated the transmission network until the state-owned Svenska Kraftnät[7] took over in 1992. Some 300 companies, of which the majority were municipal, owned the distribution networks and the tariffs were set on a cost-pricing basis with respect to the Local Government Act, which prevents municipalities from making profits (Kärrmark 2001). The transmission and distribution networks have remained as natural monopolies[8] after the deregulation. Several municipalities sold their energy companies due to financial and political reasons[9] (Andersson and Thörnqvist 2006). The internationalisation of the market and the mergers and acquisitions after 1996 have resulted in a higher concentration of ownership and capital in the market (Lundgren et al. 2013).

[7] Swedish National Grid in English

[8] In natural monopolies, the capital costs for the infrastructure are so high that only a single company can operate the network in the most cost-effective way (Posner 1969).

[9] Municipalities were no longer allowed to sell electricity on a cost-pricing principle.

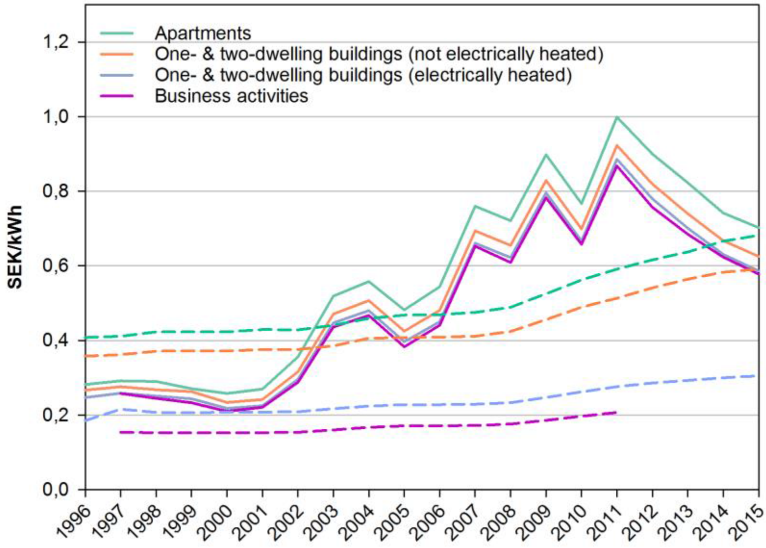

Figure 1. Price development of electricity between 1996 and 2015 for default rate. Continuous lines represent the retail prices and dashed lines represent the average distribution prices, both excluding taxes. The retail prices from 2007 and onwards include electricity certificates. The retail prices from 1 November 2011 and onwards are for the SE3 bidding area. Data source: (Statistics Sweden 2016b)

Despite the introduction of competition with the deregulation, the retail prices of electricity rose considerably between 1996 and 2011, as shown in Figure 1. After 2011, however, the retail prices have followed a downward trend. The average prices of electricity distribution, on the other hand, have steadily increased since 1996 and reached approximately 50% higher levels than the pre-deregulation prices levels for some users, as also shown in Figure 1. The kWh price of distributed electricity vary significantly between networks throughout Sweden, reaching more than twice the lowest price in the most expensive networks (Nils Holgerssongruppen 2015a). In addition, the applied pricing models by the network owners also vary, with tariff structures ranging from fully variable to fully fixed charges. The high fixed charges imposed by some network owners have received criticism for hampering the efforts for electricity savings (Nils Holgerssongruppen 2015b). The increasing electricity distribution costs combined with the dramatic price differences between different networks also resulted in allegations of opportunistic behaviour by the monopolists (Norran 2016; Skövde Nyheter 2016; SvD 2011; Swedish Property Federation 2013).

District heating is one of the pillars of the Swedish energy system; it dominates the national heating market, having supplied 46 TWh of heat in 2013 (Swedish Energy Agency 2014a). There is at least one district heating network in 263 municipalities out of 290 (Nils Holgerssongruppen 2014). District heating networks are natural monopolies, meaning that, despite interconnections between some networks, consumers purchase heat from the local district heating supplier. District heating generation in Sweden has low carbon-intensity due to the extensive use of biofuels (44%), followed by waste (21%), fossil fuels (including peat) (11%), flue-gas condensation (9%), electricity (8%), and industrial waste heat (7%) (Swedish District Heating Association 2014). Several district heating network owners operate Combined Heat and Power (CHP) plants that generate both electricity and heat, connecting some district heating networks to the electricity market. As a result of this connection, the deregulation of the electricity market has also introduced several changes to the district heating sector.

Municipalities operated the majority of the district heating networks before the deregulation in 1996 and sold heat on a cost-pricing basis with respect to the Local Government Act. Following the deregulation, the price regulations on district heating were lifted to prevent cross-subsidisation between electricity and heat, and district heating suppliers were instructed to charge customers the ‘market value’ for the heat. Similar to the electricity distribution networks, private companies acquired multiple networks around the country and created a higher concentration of ownership in the district heating market. (Söderholm and Wårell 2011)

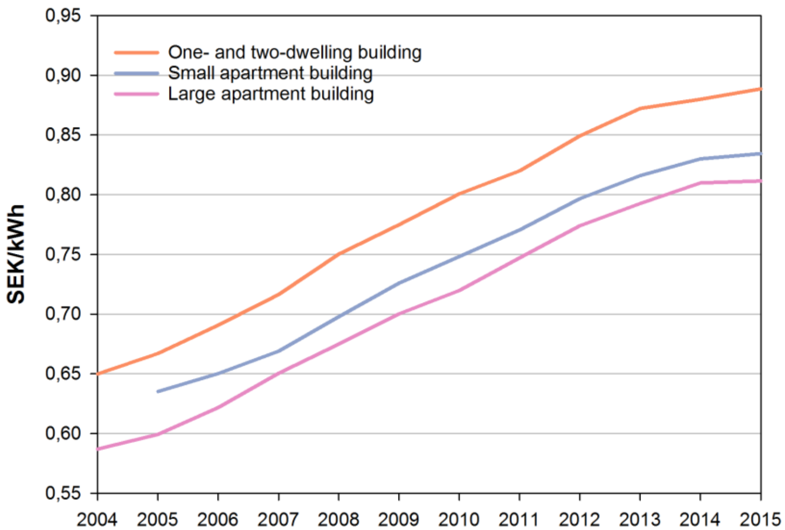

Figure 2. Average price development of district heating between 2004 and 2015. Data source: (Swedish District Heating Association 2016)

Following the deregulation, the average price of heat did not rise significantly until 2004. After 2004, however, the average prices of heat have increased for all consumer groups, as illustrated in Figure 2. It is important to point out that Figure 2 shows the average price development of heat and the price increases have been steeper in some networks. Prices of heat reportedly have increased more in networks owned by large companies than in those owned by smaller companies (Swedish Government Offices 2011a). The price differences between networks have also grown dramatically, reaching higher than twice the lowest price in the most expensive networks (Nils Holgerssongruppen 2015a). In the light of these factors, some monopolists have been accused of exercising opportunistic behaviour (NyTeknik 2013; Sveriges Radio 2010; SVT 2007). In response to the growing criticism, a governmental inquiry into third-party access, which would open district heating networks to competition similar to the electricity market, took place (Swedish Government Offices 2011b). The inquiry stirred debate and the proposal to introduce third-party access to district heating networks was shelved and later replaced with a so-called 'controlled access' to district heating networks, allowing external suppliers to sell heat to a district heating network even in cases where the supplier and network owner cannot reach an agreement (Swedish Government Offices 2014c). The controlled access aims to capture the waste heat potential from the industry and did not introduce competition to the retail end of district heating.

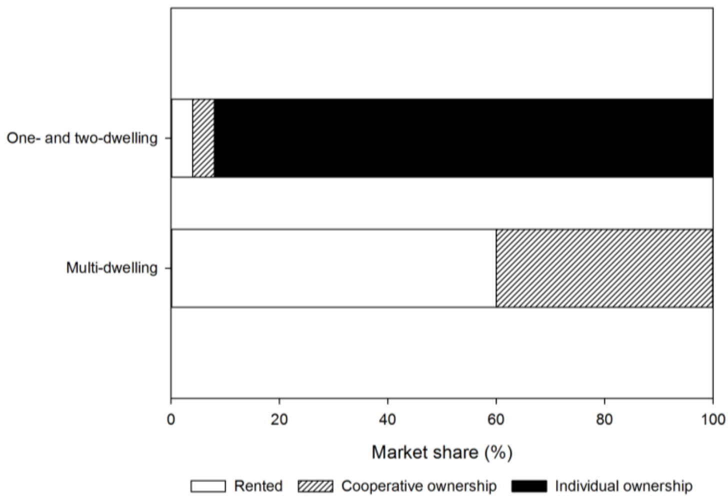

Figure 3. Ownership in the residential sector in Sweden. Data source: (Statistics Sweden 2013)

In this thesis, buildings are divided into two categories as residential and non-residential. Residential buildings are used for housing purposes whereas non-residential buildings, e.g., offices, schools, libraries, are used for all other purposes but for housing and industrial. Residential buildings are also categorised as multi-dwelling (block of flats) and one- and two-dwelling (villa). In Sweden, there are approximately four-and-a-half million households, of which two million are in multi-dwelling buildings and two-and-a-half million are in one- and two-dwelling buildings. The majority of households in the multi-dwelling sector are rented from housing companies, while private ownership dominates the one- and two-dwelling sector, as illustrated in Figure 3 (Statistics Sweden 2013). Cooperative ownership through housing cooperatives, i.e. economical associations that provide non-profit housing to its members, is also popular in the multi-dwelling building sector, where approximately 40% of the flats are owned cooperatively. The non-residential sector consists of 70,000 buildings that include offices, governmental organisations, libraries, schools swimming pools, among others (Swedish Energy Agency 2014b). State ownership, either through public authorities or state enterprises, is common for public buildings, while private ownership dominates the commercial sector, representing 80% of the commercial spaces (Swedish Government Offices 2011c; Swedish Property Federation 2014).

Public housing has traditionally been important in Sweden, where municipalities provide public housing through municipal housing companies. There are nearly 300 municipal housing companies in the country; there is virtually at least one in each municipality, ranging in size from a housing stock of 72 to 26,600 households (SABO 2013). Several changes were introduced to public housing in 2009 to comply with the EU rules on competition and state-aid, requiring housing companies owned by municipalities to adopt a ‘market approach’ while maintaining their public purpose (Swedish Government Offices 2010). The changes impose a clearer economic separation between municipalities and their housing companies, and also prevent municipalities from cross-subsidising public housing (Elsinga and Lind 2013; Pawson et al. 2012). Municipalities, however, may still maintain strong influence on these companies through owner’s directives.

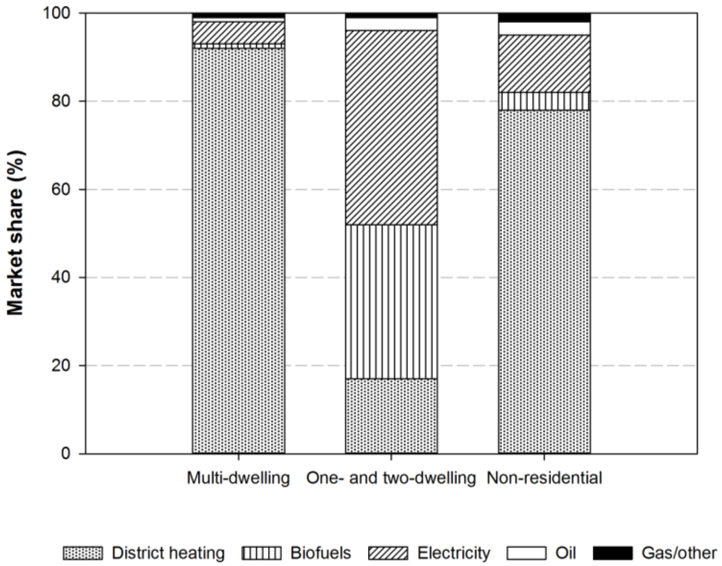

Figure 4. Heating in Swedish buildings. Data source: (Swedish Energy Agency 2013)

In 2013, residential and non-residential buildings used 133TWh[10] of energy, of which 76.1 TWh[11] was used for heating purposes (Swedish Energy Agency 2015a, 2015c). Including the electricity used for heating purposes, residential and non-residential buildings together created the largest demand for electricity among all sectors in 2013 with 70 TWh[12] (Swedish Energy Agency 2015a). District heating remains the most popular heating method for multi-dwelling and non-residential buildings in Sweden, while electric heating dominates the one- and two-dwelling buildings market, as shown in Figure 4. Electric heating in Swedish buildings is mainly provided through heat pumps, which have grown in popularity and reached a market size of 1.1 million devices in 2013, with 96% of the devices installed in one- and two-dwelling buildings (Swedish Energy Agency 2014a). Falling prices of electricity and the national building regulations that impose lower insulation requirements on buildings equipped with heat pumps expectedly have contributed to the rapidly growing market (Persson and Perman 2011). Air-source heat pump technologies have become particularly popular, with 90% of new one- and two-dwelling buildings were reported to use some type of air-source heat pump (Swedish Energy Agency 2009).

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[10] The total energy use by the residential and services sector was 147 TWh, of which approximately 90% was used by buildings.
[11] Excluding the energy extracted from the environment by heat pumps.
[12] As it is not specified in the statistics, it can be expected that this number covers both buildings and other uses that fall within the 'residential and services' sector.

1.1.4. Energy and buildings sectors in Hong Kong

Hong Kong is a special administrative region (SAR) in Southeast China with a population of 7.3 million people dispersed on an area of 1100 km^2 (Census and Statistics Department 2015a; Planning Department 2015). Since the British handover to China, Hong Kong exercises a relatively high autonomy under the 'one country, two systems' principle in executive, legislative, and judicial matters (Cooney 1997). The economy of Hong Kong relies heavily on the services sector, which generated 92.8% of its GDP in 2014 (Census and Statistics Department 2016). The contribution of the manufacturing sector has fallen to 1.3% of the GDP in 2014, as the production has moved across the border to Mainland China due to lower labour costs and the Chinese economic reforms (Census and Statistics Department 2016; Lee 2005).

Hong Kong, known for its traditional non-interventionist approach, follows a 'laissez-faire' energy policy, which has been challenged in the recent years due to the growing public concerns over air-pollution, climate change, nuclear safety and energy security (Mah et al. 2012). In 2012, Hong Kong emitted 43,100 $ktCO_2$-e of GHG, of which 68% came from fossil fuel combustion in power generation (Environmental Protection Department 2015). A large share of power supply (53%) in Hong Kong comes from coal combustion, followed by nuclear power imported from the Daya Bay plant across the border in Mainland China (23%), natural gas combustion (22%), and lastly oil and renewable energy resources (2%) (Hong Kong Environment Bureau 2014). The domestic power generation occurs in four large-scale fossil power plants and an onshore wind turbine (800 kW), accounting for a total capacity of 12,645 MW (Hong Kong Environment Bureau 2015a). In 2014, the annual power demand and the peak power demand were measured as 43.9 TWh and 9,962 MW, respectively, with the prior projected to increase annually by 1-2% (Census and Statistics Department 2015b; Hong Kong Environment Bureau 2014). Power supply in Hong Kong is among the most reliable in the world (99.99% availability in 2013), with an extremely low annual outage of around three minutes (Hong Kong Environment Bureau 2015a).

The power market in Hong Kong is regulated under the Scheme of Control (SCA) contracts that are signed between the Hong Kong Government and the two de facto geographical monopolies, the China Light and Power Company (CLP), which serves Kowloon, New Territories and the outlying islands, and the Hong Kong Electric Company (HEC), serving the Hong Kong and Lamma islands. The SCAs entitle the two companies a 9.99% rate of return on average net fixed assets and allow the recovery of increases in fuel costs through a fuel clause adjustment in the tariffs. The current SCAs expire in 2018, but they can be extended for 5 years. The government launched a public inquiry in 2015 to measure the opinions on modifications to the SCAs or an overall restructuring of the power market (Hong Kong Environment Bureau 2015a). The inquiry is partly a result of the growing criticism to the SCAs.

According to Luk (2005), the SCAs result in excess capacity and high prices and encourage demand growth. In fact, the reserve margins of the two companies are relatively high, 30% and 50% for CLP and HKE, respectively, although the proposals for capacity investments have been declined by the government in order to reduce the overall reserve margin to between 20 to 30% by 2018 (Hong Kong Environment Bureau 2014). The networks of the two companies are interconnected by a line with a very limited capacity at 132 kVA, which is reserved for only emergency purposes (HKSAR 1999). In addition, the SCAs are considered too generous for a relatively risk-free business, as the fuel risks are borne by the consumers through the fuel clause adjustment (Cheng and Lin 2014). It can also be argued that the SCAs do not sufficiently encourage renewable power generation, as the share of renewables in the total power supply in 2013 was only 0.23%, despite that the two power companies are entitled a slightly higher rate of return at 11% for renewable energy investments (IEA 2013). Nevertheless, Hong Kongers enjoy significantly lower electricity prices than consumers in other cities of similar size, e.g., Singapore, New York and London, with average residential tariffs of around 1HK$[13]/kWh (Hong Kong Environment Bureau 2014).

The government aims to cut the carbon intensity by 50-60% by 2020 and the energy intensity by 40% by 2025, taking 2005 as the reference year (Hong Kong Environment Bureau 2015b). In order to decarbonise the power supply, the partial replacement of coal with natural gas and increased nuclear imports from Mainland were proposed (Hong Kong Environment Bureau 2014). The renewable power generation in Hong Kong comes primarily from biofuels (89 GWh), followed by wind power (2 GWh) and solar PV (1 GWh) (IEA 2013). The contribution from small-scale generation, which is limited to a few initiatives, can be considered negligible. The share of renewables in the total energy demand is expected to reach to a mere 1% by 2023, provided that all the proposed waste-to-energy plants becomes operational by the same year (Hong Kong Environment Bureau 2014). Targeting to minimise roadside emissions, there are generous tax waivers and subsidies for electric vehicles for personal and commercial use (Environmental Protection Department 2016)

Hong Kong has an urban landscape dominated by a high-rise, high-density built environment and is one of the few countries in the world that are entirely urbanised (CIA 2016). Buildings account for 92% of the electricity demand, with the majority coming from the commercial sector with 65%, followed by the residential sector with 27% (Census and Statistics Department 2015b). The two sectors have experienced electricity demand growth in the recent decades, with a projected continuous growth as a result of climate change and economic growth (Census and Statistics Department 2015c; Ma and Wang 2009).

There are approximately 2.5 million households, of which just over the half are owner-occupied, nearly 16% owned through subsidised sales schemes for

[13] 1 HK$ = 1.086 SEK (17/08/2016)

low-income residents[14], and the rest are rented (Hong Kong Housing Authority 2016). The Hong Kong Housing Authority, a governmental organisation, and the Hong Kong Housing Society, a non-governmental non-profit organisation, provide public housing. Electricity use constitutes 66% of the total energy demand in the residential sector, primarily used for space conditioning purposes (EMSD 2015). The sub-tropical climate combined with the heat island effect from the high density, high-rise built environment create a large cooling demand, which peaks in summer mid-days (Giridharan et al. 2004). The rest of the energy use in the residential sector comes from the combustion of town gas and liquefied petroleum gas for cooking and water heating purposes. Taking the abovementioned factors into account, the Hong Kong Government has given a key role to buildings in its climate policy, as also reflected in the regulatory framework (Hong Kong Environment Bureau 2015c).

The Building (Energy Efficiency) Regulation governs the energy efficiency requirements on the building envelope of commercial buildings, while the energy performance of central services installations of all buildings, such as air-conditioners, lighting, lifts, escalators, among others, are regulated under the Building Energy Codes Ordinance (HKSAR 2012, 2013). For the energy performance of household electrical appliances, including air-conditioners, there is a labelling scheme that encourages the use of more energy efficient products (HKSAR 2009). The construction sector is also encouraged to integrate environmentally friendly technologies in new construction buildings through gross floor area concessions[15] for new construction buildings that integrate environmentally friendly technologies (Hong Kong Environment Bureau 2015c).

Although the Hong Kong Government mentioned smart meters as a tool to achieve energy savings in buildings in its Energy Saving Plan, there are currently no concrete roll-out plans and the deployment of smart meters has been limited to pilot projects (Hong Kong Environment Bureau 2015c). A pilot project conducted by CLP supplied 3000 residential and 1400 small and medium-sized enterprises with smart meters, along with the timely consumption data and energy saving advices. Different tariffs were also tested as part of the pilot project, which was reported to have resulted in energy savings and improved knowledge of energy use among the participants (CLP 2015). There is also a smaller scale smart meter pilot project under development by HKE[16].

Mah et al. (2012), presenting the results of a telephone survey, report positive consumer views on smart grids in Hong Kong, with strong public interest in dynamic electricity tariffs and self-generation of electricity with renewable energy technologies. In addition, more than 80% of respondents answered that

[14] Resale restrictions apply to subsidised flats.
[15] Gross floor area concessions allow developers to discount certain green and amenity features from the total gross floor area of the building.
[16] Personal communication.

they would voluntarily move their energy demand in response to varying electricity prices, suggesting a strong interest by respondents in demand response. Despite this positive public view on smart grids, however, there are regulatory barriers to the development of smart grids in Hong Kong, which are discussed in Section 3.3. of this thesis.

1.2. Previous research, motivation and research questions

Based on the seven research questions that are later stated in this section, this thesis is structured on three research themes: the relationship between the energy and buildings sectors in Sweden; the views of these two sectors on smart energy features on buildings; and, a comparison of the smart home markets in Sweden and Hong Kong.

The growing attention on climate change and concerns over energy security and affordability have shifted the policy focus on the relationship between the energy and buildings sectors. The emergence of buildings as a component in energy policy design was following the 1973 oil crisis, which prompted several countries to redesign their energy policy for reducing oil imports. Improving the energy efficiency of buildings, which mainly used oil for heating purposes, was considered as one of the most effective methods to cut the dependence on oil use, as several countries, including Sweden, introduced measures that target the energy performance of buildings (Smeds 2004). Although natural gas has emerged as an alternative fuel to oil for the buildings sector, the issues surrounding the security of supply, the price volatilities and the finite nature of fossil fuels have kept the policy focus on the energy use in buildings. In addition to these factors, climate change has added another environmental dimension to energy and put the relationship between the energy and buildings under the spotlight. This relationship can be expected to play a key role in the operation of the future smart energy systems, which would require closer interaction between buildings and the energy system.

There are a number of studies in the literature that highlight the importance of cooperation between the energy and buildings sectors. Arnbjerg-Nielsen et al. (2009) reported on experiences from workshops related to the deployment of climate change technologies, including those for sustainable buildings, and concluded that the 'rather fragrant collaboration between the relevant stakeholders' is a barrier to the roll-out of new technologies. Similarly, Williams (2010) pointed out that stakeholders from the energy and buildings sectors are important actors in the UK strategy of increasing the share of renewables in the energy system, arguing that some of the challenges that are experienced in the process can be resolved through cooperation between these two key sectors. According to Bakos et al. (2003), successful and efficient inter-sectoral cooperation contribute to the deployment of building-integrated PV applications, although, such cooperation can only be achieved after a long period of acquaintance and intensive collaboration between stakeholders. In the Swedish context, researchers focused on the interaction between the energy and buildings sectors by analysing the impacts of falling heat demand in buildings on district heating networks (Difs et al. 2010; Magnusson 2012; Truong et al. 2014; Åberg and Henning 2011; Åberg 2014), the impacts of district heating tariffs on energy efficiency measures in the buildings sector (Folkesson 2009; Högberg et al. 2009; Lind 2012), and the significance of feed-back mechanisms and demand response for residential power consumption (Bartusch et al. 2011; Vassileva et al. 2012, 2013). There is, however, a gap in the literature about a study that examines the relationship between the energy and buildings sectors at an inter-company level, investigates the views of stakeholders from the two sectors on energy use in buildings and discusses opportunities for improved inter-sectoral cooperation. This doctoral thesis addresses this research gap by answering the following research questions:

(Q1) What is the level of cooperation between the energy and buildings sectors in Sweden?
(Q2) What are the barriers to cooperation between the energy and buildings sectors?
(Q3) What are the opportunities to minimise these barriers and strengthen cooperation?

Buildings are expected to play a key role in smart energy systems, as discussed in detail in Section 1.1.1. of this thesis. Given the growing attention on smart grids, there are several researchers that investigated consumer views on buildings with smart energy features, such as Balta-Ozkan et al. (2013a, 2013b), Paetz et al. (2011), and Rihar et al. (2015). However, the relationship between the energy and buildings sectors may also be expected to play a key role, given the need for closer interaction and information-sharing between these two sectors in smart grids. Despite this, it was not possible to identify a study in the literature that present and compare the views of these two key sectors for the development on various smart grid features in buildings, barriers to their adoption, and ownership and business models for the wide-scale development. Reporting on the views of the energy and buildings sectors in Sweden, this thesis further contributes to the literature by answering the following research questions:

(Q4) What are the views of the Swedish energy and building sectors on smart energy features in buildings?
(Q5) What are the barriers to the adoption of smart energy features in Swedish buildings?

(Q6) Which ownership and business models are suitable for the development of smart energy buildings in Sweden?

Research by Balta-Ozkan et al. (2013a, 2013b), Paetz et al. (2011) and Rihar et al. (2015) suggest that various factors, such as culture, climate, socio-economic structures, characteristics of the built environment as well as local policies, law and regulations may create unique challenges and opportunities for the adoption of smart energy features in buildings. Accordingly, comparative research between jurisdictions may facilitate learning, highlight examples of good practice to overcome similar barriers that may exist for the adoption of technologies, and support technology transfer. Despite this, however, only few studies, such as Balta-Ozkan et al. (2014) and Jeong et al. (2010), compare and contrast smart home developments in different markets. This thesis contributes to the body of comparative research on buildings with smart grid features by comparing the Swedish and Hong Kong markets based on the results of expert interviews. Comparing the two markets is of interest due to following differences between Hong Kong and Sweden:

- Hong Kong has a high-density, high-rise built environment whereas Sweden has more one- and two-dwelling buildings than multi-dwelling buildings. Although, there is an increasing density of urban population in Sweden;
- Hong Kong homes use air-conditioners for cooling, while Swedish homes mostly use district heating or heat pumps for heating due to the large climatic differences;
- Swedish energy policy is progressive with a wide use of environmental taxes and charges, while the Hong Kong Government follows a more non-interventionist approach to energy issues;
- The Swedish power market is deregulated, while the Hong Kong power market is characterised by two privately-owned, vertically integrated monopolies;
- Sweden achieved universal access to smart meters by 2009, while in Hong Kong the deployment of smart meters has been limited to pilot projects.

This thesis, accordingly, compares and contrasts the Swedish and Hong Kong markets for smart grid technologies in the built environment by answering the following research question:

(Q7) What are the differences and similarities between the Swedish and Hong Kong markets for smart energy features in buildings?

1.3. Thesis contributions and structure

Corresponding to the appended papers, the main contributions of this doctoral thesis are illustrated in Figure 5 and explained in the bullet points below. The blue text in Figure 5 briefly explains how the research themes and the research questions in this thesis are connected.

- *Paper I* reports on the level of cooperation between the energy and buildings sectors in Sweden, presents the factors that negatively impact the cooperation and discusses opportunities to encourage and strengthen the cooperation. **(Q1, Q2, Q3)**

- *Paper II* presents the views of the energy and buildings sectors in Sweden on current energy-related challenges, the status of the inter-sectoral cooperation, and energy use in buildings. **(Q1, Q2, Q3)**

- *Paper III* presents the views of the energy and buildings sectors in Sweden on smart energy features in buildings, identifies the barriers to their adoption and presents the perceived ownership and business models by the two sectors for the successful dissemination of the technologies. **(Q4, Q5, Q6)**

- *Paper IV* compares and contrasts Sweden and Hong Kong for the deployment of smart energy features in buildings by presenting the views of key stakeholders on the technologies, barriers to their adoption as well as the suitable business and ownership models for the local developments. **(Q7)**

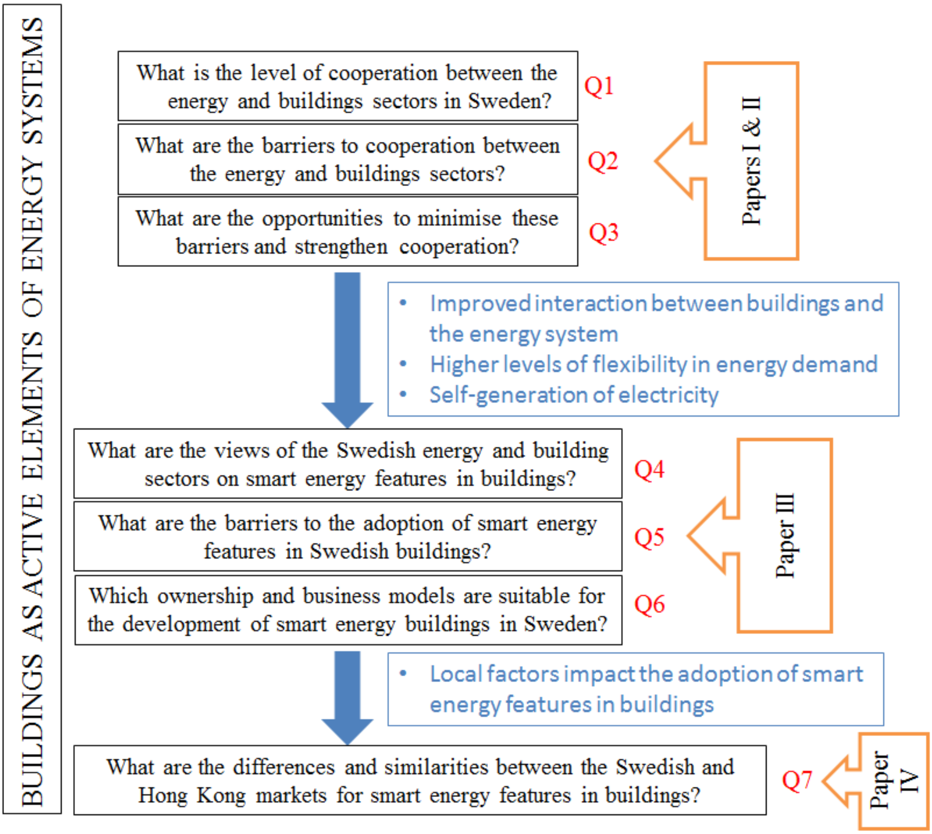

Figure 5. Thesis outline illustrating the relationship between the research questions and the appended papers

This thesis consists of the following chapters:

Chapter 1 *Introduction*
Introduces the background and presents the motivation and the research questions of this thesis. An outline of the thesis is also provided in this section.

Chapter 2 *Methodology*
Introduces the methodology and describes the used data collection methods in detail.

Chapter 3 *Results and discussions*
Summarises the findings that are reported in the appended papers and presents the main discussion points based on the findings.

Chapter 4 *Conclusions*
Presents the important findings in relation to the research questions of this thesis and highlights the specific recommendations and contributions based on these findings.

2. Methodology

This section outlines the methodology of this thesis and starts with a description of the research design, followed by the presentation of the data collection and analysis methods that were used.

The transition to smarter energy systems is a challenging task that requires the involvement of various stakeholders, such as energy companies, users, the industry, governmental and non-governmental organisations and many others. As a result of this, energy research has become increasingly inter-disciplinary by combining research methods from other fields of science to investigate energy-related issues holistically (Schmidt and Weigt 2015).

This thesis is based on a mixed-methods research methodology, also known as triangulation, which combines the qualitative and quantitative research approaches through the use of a web survey and semi-structured interviews as data collection methods. Combining the strengths of these two research approaches, mixed-methods research is deemed useful in discovering new insights into data by allowing researchers to study an issue from different angles (Bryman 2006; Olsen 2004). All quantitative data presented in this thesis was collected from the web survey, while the qualitative data was collected from both the interviews and the web survey.

Anonymous quotes from the respondents were used generously throughout this thesis to better interpret the quantitative data and to provide insights into the views of the stakeholders. Unless specified in the text, the quotes represent the identified general views of a stakeholder group, e.g., district heating companies, and do not only represent the views of a quoted respondent. The quoted respondents are denoted by an acronym, which signifies the background of the respondent, and a number (e.g. DH1): DH, district heating; ED, electricity distribution; ER, electricity retail; H, housing; C, construction; M, municipality; R, research; EM, energy management company; and, UHK, electricity utility in Hong Kong. The same acronyms are also used in tables and figures in the thesis due to space constraints. A list of the quoted respondents can be found in Annex C.

2.1. Data collection and analysis

2.1.1. Interviews

As part of the data collection for this thesis, thirty-six semi-structured interviews were conducted with key stakeholders from Sweden and Hong Kong. Semi-structured interviews combine close-ended questions with open-ended questions. Open-ended questions provide respondents with the freedom to discuss their opinions in detail, at the same time allowing researchers to discover other issues of interest that may not have been included in the interview guide (Bryman 2002; Dawood 2010; Sankar and Jones 2007). The presence of an interviewer, however, may produce social desirability bias, which occur when a respondent answers the questions according to what they believe is socially acceptable or desirable (Brace 2008; Huang et al. 1998; Zerbe and Paulhus 1987). In order to minimise the impacts of social desirability bias on this thesis, the interview data was combined with the data from a web survey, which is deemed as a data collection method that produces lower social desirability bias (Heerwegh 2009; Kreuter et al. 2008). This, however, was not possible for the study presented in *Paper IV,* for which only interviews could be used as the data collection method due to the difficulties in conducting survey research in Hong Kong, as explained in Section 2.1.2. of this thesis.

As part of the data collection in Sweden, a total of twenty-three interviews were conducted between November 2012 and June 2013. The majority of the respondents were from the energy and buildings sectors, although, additional respondents from municipalities and research institutes also contributed to this study. Sweden has a long tradition of local governance and municipalities play a key role in local energy developments both through local energy planning and the ownership of energy and housing companies (Nilsson and Mårtensson 2003). In addition, researchers whose area of specialisation is within the scope of this thesis contributed to this thesis with their expertise.

The distribution of the interview respondents from Sweden by stakeholders were as follows: three from construction companies; four from housing companies; four from electricity distribution companies; two from electricity retail companies; three from district heating companies; three from municipalities; and four from research institutes. Most respondents held executive positions at the time of conducting the interviews and hence were assumed to possess enough knowledge to answer the questions. An anonymised list of the interview respondents is provided in Annex D. The majority of the interviews (19) were face-to-face, except three interviews that were conducted on the telephone and one by video conference. Each interview took approximately one hour to complete and was documented through note-taking, except in two cases where the interviews were digitally recorded for later coding. Respondents were later provided with an interview report for checking in order to minimise errors. The interview guide that was used in Sweden, excluding the additional questions that were used for probing, can be found in Annex E.

A total of thirteen interviews were conducted with respondents from Hong Kong between December 2015 and April 2016. On two occasions, however, two respondents representing the same actor answered the interview together, meaning that fifteen respondents contributed to this study with their views. Given that there are two power companies in Hong Kong, a larger variety of actors, including non-governmental organisations, were included. An anonymised list of the respondents can be found in Annex F. The respondents were selected based on their knowledge of the studied issue and the majority of them held executive positions in their organisation. All interviews in Hong Kong were conducted face-to-face. Each interview took approximately forty minutes to be completed and was recorded digitally. Excluding the additional questions for probing, the interview guide that was used in Hong Kong is provided in Annex G in Annexes.

2.1.2. Survey

The data collection for this thesis also included the use of a self-administered web survey, whose results were reported in *Paper I*, *Paper II* and *Paper III*. Web surveys are a time- and resource-efficient data collection method that allows researchers to reach a large number of respondents. Respondents with time constraints may also prefer to answer web surveys over interviews as web surveys often require less time and planning from the respondent's side (Brace 2008). On the other hand, self-administered web surveys may create sampling risks if the person answering the survey does not belong to the target group or there are multiple answers (Wright 2005). In order to minimise sampling risks in this thesis, all recipients were contacted at their official business e-mail addresses and the returned surveys were checked for multiple answers.

The web survey was designed according to the recommendations by Brace (2008) and Iarossi (2006) and included open-ended, multiple-answer, yes/no, and 6-point Likert scale[17] questions to collect both quantitative and qualitative data. It included some of the interview questions as well as several additional questions that were created based on the identified issues from the interview results. A list of the survey questions can be found in Annex H.

With the aim to keep the focus on the perspectives of the energy and buildings sectors, the survey was only targeted at professionals that work for electricity distribution, electricity retail, district heating, housing, and construction

[17] The Likert scale used in the survey included a 'neither negative nor positive' answer to represent a neutral view, i.e., 'no impacts', and a 'don't know' answer to minimise the random selection of answers in cases where the respondent prefers not to answer the question or does not know the answer.

companies. As it is an uncommon practice in Hong Kong to publish the contact details of employees on the web-sites of companies, the web survey was only distributed in Sweden.

The web survey was administered on the online survey tool Netigate[18] and was sent to 884 recipients in May 2013. A total of 338 recipients answered the survey following three reminders, yielding an overall response rate of 40%. The specific response rates for the stakeholder groups were as follows: 40% for electricity distribution; 36% for electricity retail; 43% for district heating; 36% for construction; and 45% for housing companies. Figure 6 shows the breakdown of the number respondents by stakeholder groups.

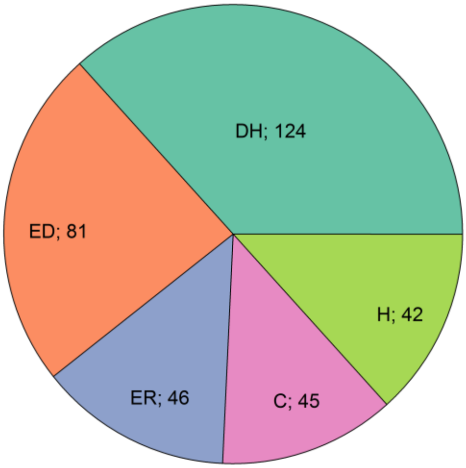

Figure 6. Breakdown of the number of respondents by stakeholder groups

In similarity with the interviews, the majority of respondents occupied executive positions at the time of sending the survey. All energy companies operating in Sweden at the time of sending the survey were contacted to accommodate possible differences that exist between networks and companies. Due to the large number of housing and construction companies, a representative group of housing companies from all regions of Sweden and large construction companies were contacted. Private owners of buildings and housing associations were excluded from data collection given that this thesis focuses on the views of companies. A map of Sweden illustrating the distribution of the survey respondents in the country is provided in Figure 7.

[18] www.netigate.net

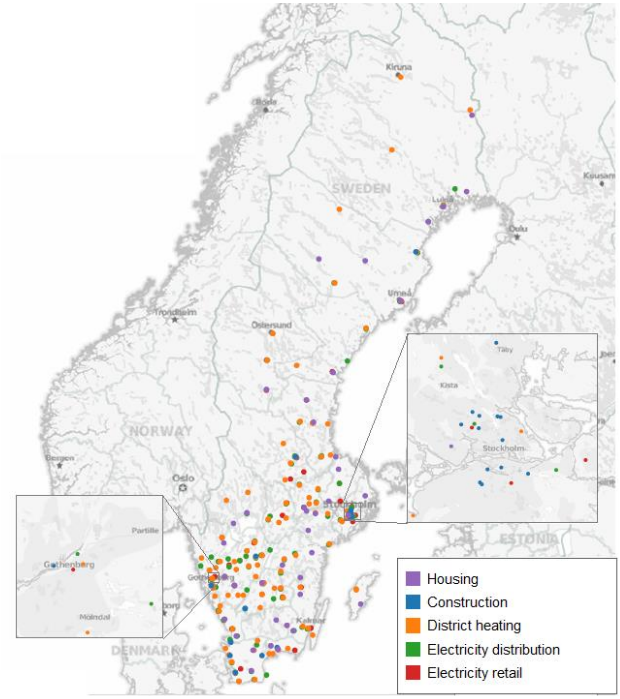

Figure 7. Map of Sweden illustrating the distribution of survey respondents. Overlapping dots are represented by a single colour. Figure created on Tableau (Tableau Software Inc., USA)

2.1.3. Data analysis methods

Descriptive statistics is used throughout this thesis to present the survey data. The survey data was also statistically analysed by a one-way Analysis of Variance (ANOVA) followed by a post-hoc test (Tukey's Honest Significant Difference (HSD) multiple comparison) as well as a Principle Component Analysis (PCA) to obtain further findings and discover new insights into the data. These statistical analysis methods were only applied on questions to which the responses were given on a scale where the size of the intervals match the differences in responses, i.e., a scale of 1-5 corresponding to disagree-agree.

The one-way ANOVA is a statistical analysis method that is used for comparing the means of three or more independent samples to determine whether there are significant differences between them. It involves computing the sums of squares and expected mean squares for all effects, which are then followed by a general linear model approach. The results are presented in a table, where statistically significant differences between the analysed samples are indicated by different letters or symbols. The software SPSS v. 22.0.0 (IBM SPSS Statistics Inc., Chicago, IL) was used to conduct the ANOVA in this thesis.

The survey data was also analysed by a multivariate approach to investigate the integrated effects by several different variables that may not be understood or noticed by analysing one variable at a time. PCA was the adopted multivariate approach in this thesis to visualise the relationships between the variables and samples with the aim to reveal patterns that may not be visible when looking at large data sets. PCA involves transforming a large data of possibly correlated variables to a smaller number of latent variables that are called Principal Components (PCs). The results are presented as scores, describing the data structure in terms of sample patterns, and loadings, describing the data structure in terms of variable contributions and correlations. The Unscrambler X v. 10.0.1 (CAMO Software AS, Norway) software was used to conduct the PCA in this study.

3. Results and discussion

In this chapter, the main findings from the papers appended in the end of this thesis are presented and discussed. First, the level of cooperation between the energy and buildings sectors in Sweden is examined then the identified barriers and opportunities to inter-sectoral cooperation are discussed. Following this, the views of these two sectors on smart energy features in Swedish buildings, the barriers to their adoption and the ownership and business models that are deemed for their wide-scale development are presented. Finally, the smart energy building markets in Sweden and Hong Kong are compared.

3.1. Inter-sectoral cooperation and trust

Given the strong interdependencies between the energy and buildings sectors, effective cooperation between these two key sectors is fundamental to achieve more sustainable energy systems and contribute to the climate change efforts. The findings of this thesis, however, suggest a potential for the improvement of the cooperation between the energy and buildings sectors, as also expressed by a respondent: 'We need to cooperate more than we actually do.'DH1.

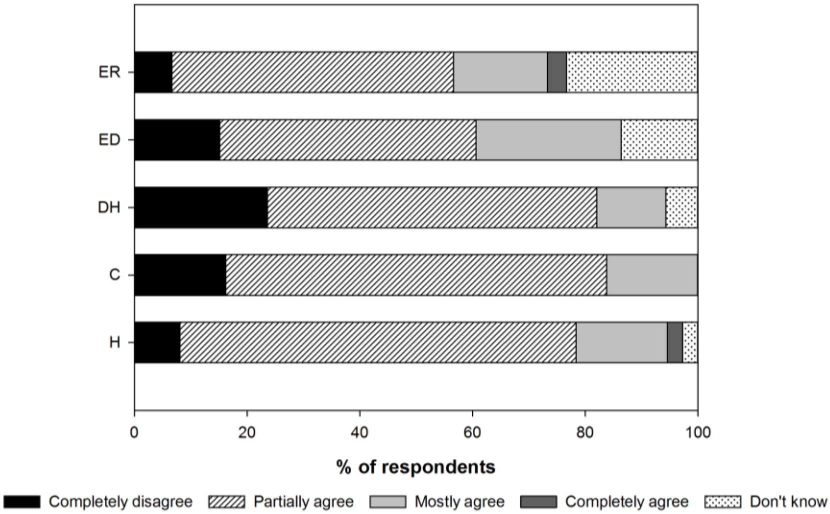

Figure 8. Answers to the statement 'There is very good cooperation between the energy and buildings sectors'

In order to investigate the perceived level of cooperation between the energy and buildings sectors by the stakeholder groups, the respondents were asked how they agreed with the statement 'There is very good cooperation between the energy and buildings sectors'. The results, presented in Figure 8, show that although many respondents agreed to some degree that there is very good cooperation between the energy and buildings sectors, the majority only partially agreed with the statement. It can be interpreted that the results confirm an ongoing cooperation between the energy and buildings sectors, albeit not at the desired levels. In addition, the open-ended answers also suggest an unrealised potential for higher levels of inter-sectoral cooperation. The shares of respondents that completely disagreed with the statement came out higher among construction, electricity distribution and district heating companies. In addition, none of the respondents from these three groups completely agreed with the provided statement, suggesting a lower level of cooperation between construction companies and these two stakeholder groups from the energy sector.

The results indicate that stakeholders representing the buildings sector, especially construction companies, are critical of monopolies in the energy sector: 'There is cooperation, but we are a little suspicious, because some of these monopolies used strategies that are not fair and predictable.'C1. Energy companies, on the other hand, argued that construction companies prioritise construction costs when designing buildings and do not take the impacts of buildings on the energy system into account: 'Users [housing companies] and energy companies are interested in low-cost and secure operation and maintenance, but construction companies are only interested in construction and installation costs'DH2. It appears that the emphasis on individual gains by the stakeholders impacts the trust between the members of the energy and buildings sectors.

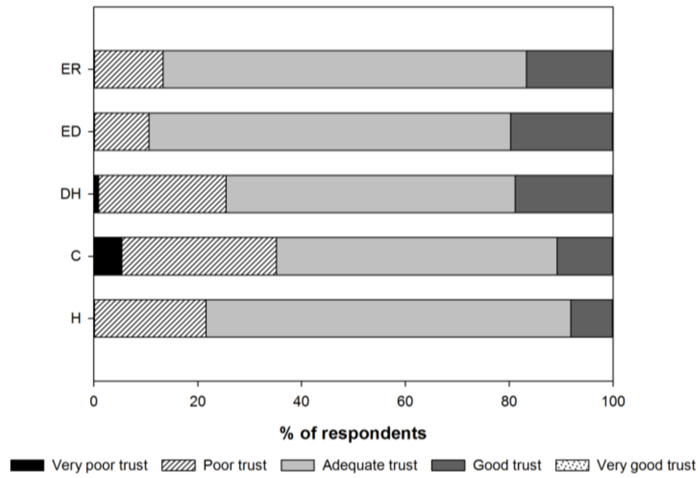

Figure 9. Answers to the question 'Which of the following describes the relationship between the energy and buildings sectors the best?'

Cooperation creates mutual dependencies between cooperating organisations, exposing them to risks of opportunistic act by other parties (Child et al. 2011). Accordingly, it is crucial that partners in cooperation trust that the other party focuses on mutual gains instead of self-gains. Several respondents cited trust issues between the energy and buildings sectors as an influential factor in inter-sectoral cooperation: 'There is always a mistrust between the energy and buildings sectors, "who is going to earn money from this?", "who is hiding something?"'C2.

The answers to the survey question 'Which of the following describes the relationship between energy and buildings sectors the best?', presented in Figure 9, also suggests that the level of mutual trust between the two sectors can be improved, as the majority of respondents from all stakeholder groups answered that the two sectors have adequate trust for each other and none of the respondents answered that they have very good mutual trust. The rates of respondents that selected 'poor trust' were higher among district heating, housing, and construction companies, suggesting deeper trust issues between the members of the buildings sector and district heating companies. A respondent argued that 'district heating is a big issue between the energy and buildings sectors and there is a big mistrust'R1. The results indicate that trust issues are especially evident between district heating and construction companies given that only respondents from these two stakeholder groups answered that there is very poor trust between the energy and buildings sectors. This is thought to be related to the growing use of heat pumps in new construction buildings, as addressed in Section 3.2.3. of this thesis.

In addition to trust issues, some respondents pointed out that the energy and buildings sectors 'lack knowledge about each other's business conditions and models'DH3, which they related to the inadequate communication between the two sectors. Some argued that 'there is no platform or common practice for stakeholders to establish dialogue'DH4 and called for joint initiatives, as a respondent from the energy sector suggested that 'the involvement of the energy sector in early stages of construction plans would contribute to cooperation between the two sectors'DH5. Respondents from the buildings sector also have a positive view on joint initiatives, but warn that monopolies may create hinders in the process due to previous history of conflicts.

The results suggest that the levels of cooperation and mutual trust are lower between the energy sector and construction companies compared to with housing companies. This is thought to be related to the ownership structure of companies, i.e. construction companies are privately owned whereas there are municipal housing companies which are expected to also have a social responsibility. Although the companies were not categorised and studied based on their ownership form in this thesis, municipally owned housing and energy companies can be generally expected be more open to inter-sectoral cooperation and dialogue compared to private companies due to their social mission. It can be of interest to investigate the role ownership structures on inter-sectoral cooperation and trust in a future study.

3.2. Factors that negatively impact cooperation

3.2.1. District heating monopolies

Achieving cooperation between actors within a monopoly environment can be particularly challenging due to risks of opportunistic behaviour by the monopolist, i.e., if the monopolist charges unfair prices in order to maximise its profits (Humphries and Wilding 2003, 2004). The results suggest that monopolies in the energy sector negatively impact the relationship, and hence cooperation between the energy and buildings sectors. Stakeholders representing the buildings sector are critical of the monopolists, although the criticism appears to be directly mainly at district heating companies than electricity distribution companies due to the following reasons: users buy heat entirely from one monopoly, while the electricity distribution fee only represent a part of the electricity bill, as users can buy electricity from a retailer of their choice; and, there are price regulations on electricity distribution in contrast to district heating.

Due to the lack of price regulations imposed on district heating, the buildings sector is concerned about the risks of opportunistic behaviour by district heating companies. In fact, a strong majority of survey respondents representing the buildings sector answered that district heating prices should be more transparent, as shown in Table 1. It is perceived that district heating companies are not only expected to publish their expenses to justify the price increases, but also create easier to understand tariffs, so the consumers do not feel 'gamed' into pay unfair prices. Another finding is that the majority of respondents from the energy sector, including even those from district heating companies, also agreed that district heating prices should be more transparent, suggesting that they consider increasing transparency of prices as a method to refute allegations of opportunistic behaviour. It may, however, also indicate concerns over the practices of some district heating companies. The growing criticism led the Swedish District Heating Association to introduce a number of initiatives to improve the consumer trust for district heating companies. One of these initiatives, Prisdialogen (the price dialogue), which requires the participating district heating companies to supply more information about price changes to its consumers at an early stage, have reportedly improved the customer trust, although, only 40% of the customers in Sweden are served by the companies that are part of the initiative (Swedish Energy Market Inspectorate 2015a).

Table 1. Answers (in %) to the question 'Do you agree with the following statements?'

		ER	ED	DH	H	C
Transparency of district heating price setting should be increased	Yes, I agree	**67**	**63**	**62**	**84**	**70**
	No, I don't agree	22	15	28	3	0
	Don't know	11	22	10	14	30
There should be more competition (third-party access) in district heating networks	Yes, I agree	22	31	23	**59**	**75**
	No, I don't agree	**63**	**57**	**68**	32	19
	Don't know	15	12	9	8	6
If there was more competition in district heating networks, there would be better cooperation between the energy and buildings sectors	Yes, I agree	22	22	19	**41**	**54**
	No, I don't agree	**52**	**51**	**63**	32	19
	Don't know	26	28	18	30	27

The other point of criticism raised by the respondents representing the buildings sector was low customer focus in the district heating sector, which is perceived as a result of the monopoly position of companies and significant customer lock-in. A respondent from a district heating companies acknowledged the alleged low customer focus and commented that 'the district heating sector has been more or less living in a "bubble"'DH6. The results also suggest that the argued low customer focus is also reflected in the limited variety of pricing schemes and business models that are currently being offered by district heating companies, as highlighted by a respondent from a housing company: 'District heating companies should adopt new business models. For instance, we have only one business model in our city and it is not suitable for all.'H1. Respondents argued that the current pricing and business models limit mutually beneficial cases between district heating companies and members of the buildings sector, hence negatively impacts the cooperation. In addition to financial aspects of district heating supply, there was also an identified demand by the buildings sector for 'products' with an environmental focus, i.e., selling heat that is only produced by biofuels.

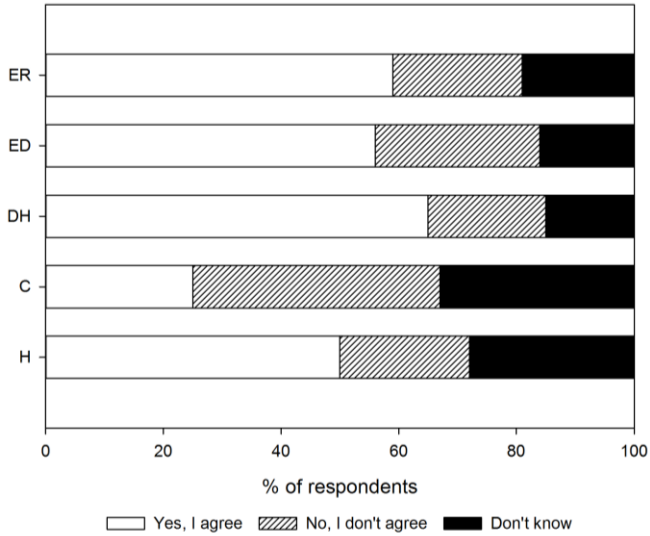

Figure 10. Answers to the question 'How do you agree with the following statements? – "The deregulation of district heating networks would result in higher prices"'

Some respondents from the buildings sector argued that opening district heating networks to competition in the form of third party access, in similarity to the deregulated electricity market, may result in increased customer focus and allow better use of resources as, according to them, competition would 'create new business set-ups'C2. Respondents representing the energy sector, on the other hand, pointed that there may not be sufficient number of suppliers in all networks to create competition and warned that 'opening district heating networks to competition risk higher prices'DH7 in many networks as a result of the additional administrative costs. The survey results, presented in Figure 10, show that the majority of respondents from all stakeholder groups, except construction companies, agreed that opening district heating networks would lead to higher prices, suggesting a stronger support for competition in district heating networks among construction companies. Respondents from construction companies argued that it is not financially feasible to connect new buildings, which require low amounts of energy, to district heating networks due to the high connection costs and the incompatible pricing models imposed by district heating companies. It is guessed that this, combined with the conflict between construction and district heating companies over the use of heat pumps in new construction buildings (see Section 3.2.3.), can be the reason that construction companies are supportive of competition of the deregulation of district heating networks and therefore answered that they do not think that it would result in higher prices.

The interview and survey results suggest that the energy and buildings sectors share opposing views on the competition in district heating networks. The survey results, presented in Table 1, confirm the conflicting views of the two sectors as the majority of respondents from housing (59%) and construction (75%) companies answered that they agree with the statement ‘There should be more competition (third-party access) in district heating networks’, while the majority of respondents from electricity distribution, electricity retail and district heating companies answered that they disagree (57%, 63% and 68%, respectively). It can be implied from the results that the majority of stakeholders from the energy sector would like to preserve its monopoly position in the district heating market, despite expectations of competition in the networks by the buildings sector. Opposing views on this issue are also visible in the answers to the statement ‘If there was more competition in district heating networks, there would be better cooperation between the energy and buildings sectors’ (Table 1), as the majority of respondents from housing and construction companies agreed with the statement (41% and 54% respectively), while the majority from electricity distribution, electricity retail and district heating companies disagreed (51%, 52% and 63% respectively). This further suggests that the two sectors have strongly opposing views on the introduction of competition to the district heating sector.

An interesting finding from the results is that some respondents from housing companies support competition in district heating networks even if it may result in higher prices of heat, suggesting that some housing companies think that monopolies should be abolished at any cost. The support for competition in district heating networks despite the risk of increasing prices is also apparent in the survey results, as 59% of respondents from housing companies answered that they support third-party access to district heating networks (Table 1), while 50% of respondents from the same stakeholder group also acknowledged that it would result in higher prices of heat (see Figure 10).

The results suggest that district heating monopolies create a strong barrier to cooperation between the energy and buildings sectors. Low customer focus, low variety in pricing and business models to cater to different customer profiles and needs, and the perceived risks of opportunistic behaviour by the monopolists are the strongest concerns of the buildings sector regarding district heating monopolies. Based on the results, it can be inferred that district heating companies may play a key role in re-establishing a mutual trust by adopting a more transparent pricing policy as well as increasing the customer focus, which would involve the creation of a stronger dialogue and the diversification of the current pricing methods to meet the needs of different customers.

3.2.2. Energy efficiency in buildings

The Swedish ambitions to cut energy use in buildings drastically threatens the energy sector, whose traditional business model is built on the volume of sold energy. Given that approximately two-thirds of the energy savings potential is in the form of heat savings, district heating companies can be expected to face the largest impacts from energy efficiency improvements in the buildings sector (Chalmers Energy Centre 2005). Energy efficiency improvements in buildings may, accordingly, create conflicts between the energy and the buildings sectors if companies in the energy sector, particularly district heating companies, cannot recover their financial losses.

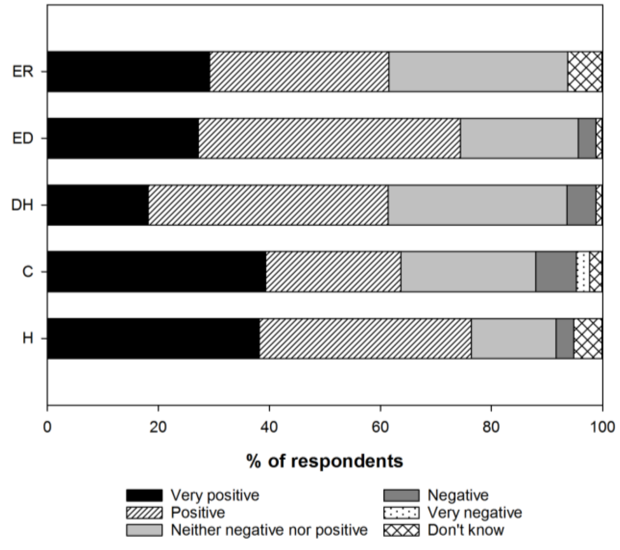

Figure 11. Answers to the question ‘How do you think the following trends in the buildings sector would impact the energy sector? – “Increased energy efficiency”’

The survey results, presented in Figure 11, however, show that most respondents from all stakeholder groups answered that increasing energy efficiency in buildings would have ‘positive’ to ‘very positive’ impacts on the energy sector. Although it can be argued that there may be social desirability bias - energy companies may think that a negative view on energy efficiency impacts their image - the answers to open-ended questions suggest that the energy sector considers energy efficiency as an opportunity to eliminate the use of fossil fuels in power and heat production. Despite this identified positive outlook in the energy sector, however, respondents representing the buildings sector argued that it is ‘challenging to reduce energy use in existing buildings in a cost-effective way’H2. Some respondents argued that the buildings sector is reluctant to conduct energy saving measures due to the risks of increasing energy prices or altered tariffs by energy companies to recover losses: ‘I hear many people in our sector say “what is the purpose of saving energy when they just increase the [energy] prices?”’C2. Similar concerns are also identified in a report by the Swedish Association of Public Housing Companies, which shows that 76% of housing companies in their study agreed, in varying degrees, with the statement ‘investments in energy efficiency are uncertain, because energy companies can raise the tariff if the energy use decreases’ (SABO 2011).

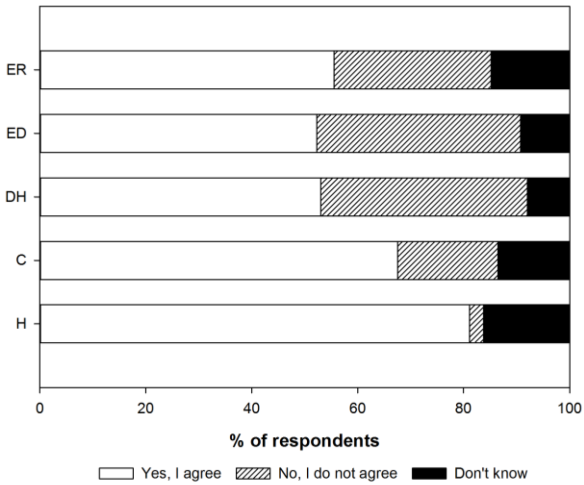

Figure 12. Answers to the question ‘How do you agree with the following statements? – “A fixed component in the energy tariff has negative impacts on energy efficiency measures”’

The survey results, presented in Figure 12, show that 81% of respondents from housing companies agreed that a fixed component in the energy tariff has negative impacts on energy efficiency measures. Given that individual billing of heat is uncommon for residents of multi-dwelling buildings in Sweden, housing companies are directly impacted by energy pricing policies of district heating companies. Interestingly, the negative impacts of fixed charges on energy efficiency were also acknowledged by all stakeholders from the energy sector, as shown in Figure 12. A respondent from a district heating company defended fixed charges with the comment: ‘Customers would like to have 100% variable tariffs, but we increase the fixed part to meet the actual production costs’DH7.

The results suggest that energy pricing models and uncertainties regarding the future development of prices create barriers to the adoption of energy saving measures in the buildings sectors. There are, however, also other financial barriers, such as lack of access to capital. Energy Service Companies (ESCO) has emerged as a market-oriented solution to remove some of the barriers and capture the energy efficiency potential of buildings. ESCOs provide technical, financial, and financial services, such as equipment installation, energy monitoring, funding, for energy efficiency projects (Marino et al. 2011; Painuly et al. 2003). Although energy companies played an important role in the development of ESCO markets around the world, their role in the Swedish market has been limited (Soroye and Nilsson 2010). According to the survey results, presented in Table 2, most respondents from all stakeholder groups agreed that the involvement of the energy sector in energy efficiency measures undertaken by the buildings sector would have 'positive' to 'very positive' impacts on the buildings sector. Indicating a strong support for the involvement of the energy sector in energy efficiency projects, nine out of ten respondents from housing companies consider such involvement to have 'positive' to 'very positive' impacts on them. This is especially of significance considering that housing companies are the primary actor in this thesis to undertake energy efficiency projects.

Table 2. Answers (in %) to the question 'How do you think the following trends in the energy sector would impact the buildings sector? – "Services for energy efficiency in buildings"'

		ER	ED	DH	H	C
Services for energy efficiency in Buildings	Very negative	0	0	0	0	0
	Negative	0	2	3	0	0
	Neither negative nor positive	17	15	21	5	22
	Positive	**53**	**62**	**51**	**45**	**43**
	Very positive	20	17	22	**45**	35
	Don't know	10	5	4	5	0

There is an identified demand by the buildings sectors for new energy services and business models to be offered by the energy sector, as also pointed out by a respondent with the comment: 'Are they [energy companies] innovative and flexible or do they just want to sell kWh?'C3. It is perceived that the buildings sector does not consider the pricing and business models applied by the energy sector to create satisfactory mutual benefits. An example of a mutually business model is the 'climate contract' offered by a district heating company in Gothenburg, which involves selling customers a guaranteed indoor temperature instead of kWh and providing operation and maintenance services for the district heating infrastructures in buildings. As the district heating company delivers the same 'temperature' to the customer, it has an incentive to fulfil its commitment in the most energy- and cost-effective way possible. It is claimed that the 'climate contract' has protected consumers from price shocks in colder periods and cut the delivered heat by 19% (Ehn and Schultz 2008; Göteborg Energi 2010). The survey results, presented in Table 3, suggest a positive view on new energy services, such as guaranteed indoor temperature, by all stakeholder groups. It appears that the buildings sector is open to alternative pricing schemes and business models in energy supply, which may encourage energy companies to introduce new practices in energy supply that can create mutual benefits for the two sectors.

Table 3. Answers (in %) to the question 'How do you think the following trends in the energy sector would impact the buildings sector? – "New energy services, e.g. guaranteed indoor temperature"'

		ER	ED	DH	H	C
New energy services, e.g. guaranteed indoor temperature	Very negative	0	0	4	3	3
	Negative	0	9	5	16	14
	Neither negative nor positive	33	**36**	28	24	30
	Positive	**40**	33	**42**	**34**	**35**
	Very positive	7	14	14	16	8
	Don't know	20	8	8	8	11

The results of this thesis suggest that energy efficiency improvements in buildings remain a controversial issue between the energy and buildings sectors in Sweden. Reduced energy demand by buildings will impact energy companies, whose traditional business model is built on the volume of sold energy. Given the significant potential for heat savings in Swedish buildings, district heating companies can be expected to be the primary actors to be impacted by energy savings. The results also suggest that the pricing schemes offered by the energy sector and the uncertainties about future prices, especially in district heating, result in weak incentives for energy efficiency improvements in the buildings sector. The involvement of the energy sector in energy efficiency projects through market based mechanisms, such as in the case of ESCOs, and the introduction of new pricing schemes and business models may create stronger incentives for the buildings sector to invest in energy efficiency measures and encourage cooperation between the two sectors.

3.2.3. Building regulations

The results suggest that the current national building regulations create strong conflicts between the energy and buildings sectors. Respondents from the energy sector argued that the regulations 'prioritise heat pumps [over other heating methods] and give a distorted view of energy efficiency'DH8. The regulations impose lower insulation requirements on buildings that use certain types of heat pumps for heating purposes (Perman 2011; Persson and Perman 2011).

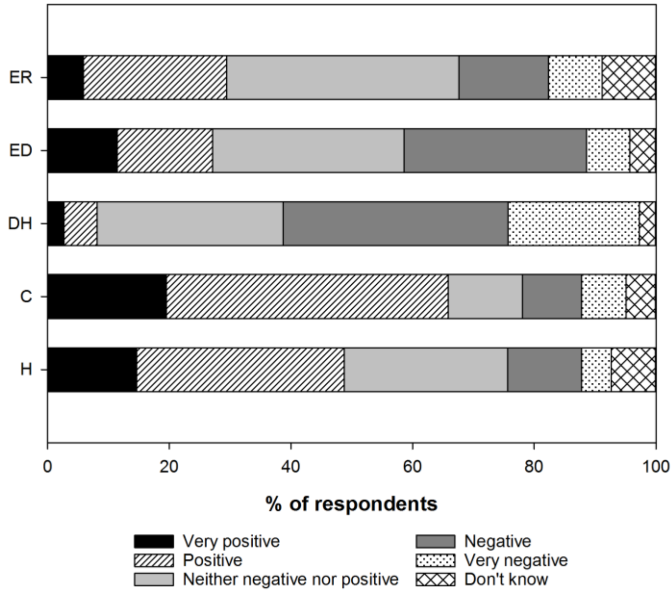

Figure 13. Answers to the question 'How do you think the following trends in the buildings sector would impact the energy sector? – "The use of alternative heating methods to district heating"'

The results suggest that the energy and buildings sector have opposing views on the use of alternative heating methods to district heating (Figure 13). Although the question does not specifically refer to heat pumps, both the fact that the competition in the heat market is mainly between heat pumps and district heating and the answers to open-ended questions suggest that the respondents consider heat pumps as the alternative technology to district heating. According to the respondents from the energy sector, from which several respondents consider the use of alternative heating to district heating to have 'negative' to 'very negative' impacts on the energy sector, replacing district heating with heat pumps in meeting the heat demand in buildings results in reduced electricity generation in CHP plants, increases the overall GHG emissions and requires capacity upgrades in local electricity distribution networks. Lower insulation requirements on buildings heated by heat pumps allow for lower construction costs for the buildings sector. However, the results also suggest that the buildings sector considers heat pumps as a means of gaining independence from district heating monopolies. In addition, some respondents representing the buildings sector argued that the pricing models and the connection costs imposed by district heating companies do not accommodate low-energy buildings, giving heat pumps economic advantages over district heating.

The negative view of district heating companies on heat pumps is likely to be a result of the competition between district heating and heat pumps. Electricity distribution companies are impacted by the further growth of the heat pumps market due to the peaking demand issues in colder periods, which require expensive grid upgrades. A respondent, however, explained that 'geothermal and water-source, not air-source, heat pumps usually create a base load and do not pose problems [of peak demand], except when they are used combined with direct electricity heating in peaking times'ER1. Another respondent added that 'electric heaters and air-source heat pumps are not desirable as they worsen the peak demand problem and cause disturbances in the grid'ED1. An interesting finding in the results in Figure 13 is that electricity retail companies appear to be more positive towards heat pumps, which may indicate that they expect increased electricity sales as a result of the growing use of heat pumps.

The results of this thesis suggest that the current building regulations create conflicts between the energy and buildings sectors. The regulations indirectly encourage the use of heat pumps in buildings over other heating technologies, as also acknowledged in a report by the Swedish Energy Agency (2015d). The Swedish National Board of Housing Building and Planning, which is in charge of the national building regulations, suggested changes to achieve technological neutrality in its recent proposal for the national definition of nearly zero-energy buildings (Boverket 2015). The proposal, however, received criticism from several stakeholders, which argued that the proposed regulations continued to encourage the use of heat pumps (Swedish District Heating Association 2015; Swedish Government Offices 2015b, 2015c).

The interest in heat pumps by the buildings sector can be expected to grow in the near future, especially given the falling electricity prices recently. Some of the argued negative impacts of heat pumps by the energy sector may be minimised or eliminated through cooperation between the energy and buildings sectors. Combining heat pumps with self-generation systems and demand response measures may reduce their impacts on energy systems during times of peak demand, allowing for improved integration into networks (B. Palm et al. 2010; Vanhoudt et al. 2014). Regarding district heating, it is clear that replacing district heating with electricity would reduce the amount of bought energy. However, an example in Stockholm shows that combining heat pumps with district heating can create mutual benefits for building owners and district heating companies. A housing company replaced oil boilers with geothermal heat pumps for heating, but continued to use oil combustion as the auxiliary heat source in colder periods when heat pumps could not deliver enough heat. Using district heating as an auxiliary heat source was not a financially viable option, as the pricing model offered by the district heating company would be too expensive for such intermittent and limited heat demand. As a result of the negotiations between the housing company and the district heating company, the housing company switched from oil combustion to district heating as the auxiliary heat source. Thanks to the inter-sectoral dialogue and cooperation, the district heating company gained a new customer and the housing company reduced its energy costs and GHG emissions.

3.2.4. Self-generation of electricity

Self-generation of electricity has increased in popularity in Sweden, where the total installed solar PV capacity doubled in 2014 (Lindahl 2015). Some of the prominent motivations among Swedish consumers to invest in self-generation equipment were identified in Palm and Tengvard (2011) as cutting energy expenses and gaining independence from energy suppliers. The results of this thesis suggest that the buildings sector is 'afraid of energy price uncertainties and it would like to gain a little independence from energy companies'R1 by investing in self-generation systems. Increasing amounts of self-generation, however, may create conflicts between the energy and buildings sectors, as it would impact the revenues of the energy sector, particularly when combined with the current policy emphasis on energy efficiency. In fact, a study by PWC (2013), reporting on the views of utilities from around the world, show that the energy sector expect revenues in the future as a result of the growing self-generation of electricity, although, the majority still consider self-generation of electricity as a business opportunity rather than a threat.

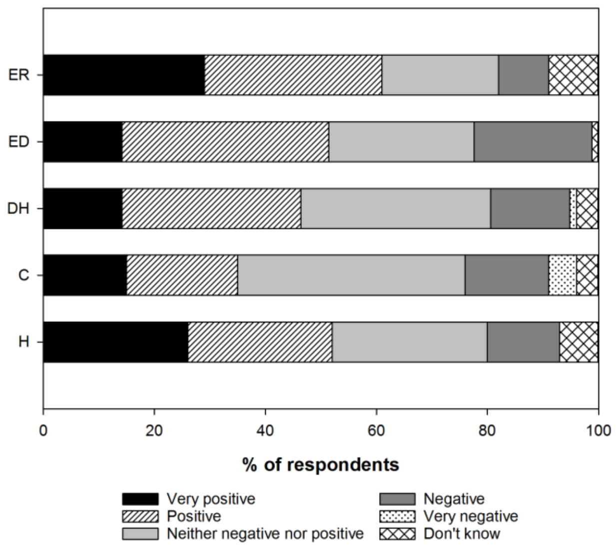

Figure 14. Answers to the question "How do you think the following trends in the buildings sector would impact the energy sector? – 'installation of self-generation systems'"

The gathered findings from both the interviews and the survey suggest that the energy sector, especially electricity distribution and electricity retail companies, think that self-generation of electricity is a positive development for the energy sector. Although the respondents acknowledged that the 'revenues will decrease with larger amounts of self-generation'ED1, they expressed that they did not consider self-generation of electricity as a threat to their business. In fact, the survey results, presented in Figure 14, also suggest that strong shares of respondents from both electricity distribution and retail companies consider self-generation to have 'positive' to 'very positive' impacts on the energy sector. The results are similar to those reported in the PWC (2013) study, suggesting that some of the challenges faced by the energy sector are of international character.

The results suggest, in further similarity to the PWC (2013) study, that electricity distribution and electricity retail companies consider self-generation of electricity as a business opportunity, which was identified as the reason behind their positive view. In fact, a strong majority of survey respondents from both electricity distribution and retail companies agreed with the statement 'Self-generation of electricity can create business opportunities for energy companies', reaching as high as 85% among respondents from electricity retail companies, as shown in Table 4. Some respondents argued that companies 'have to accept the trend of self-generation'ED2 and benefit from the developing market by providing services. Several energy companies have already started selling or renting PV packages, often involving installation and maintenance services. A. Palm (2016), reporting on the PV developments in various municipalities in Sweden, concluded that local electric utilities 'have a strong potential to elevate PV diffusion rates'.

Increasing amounts of self-generation in power networks may require expensive investments to upgrade grid capacity (Reiche and Bechberger 2004). This was perceived to be a concern among respondents from electricity distribution companies, which expressed that 'microgeneration could create [additional costs due to the need of increased grid capacity'ED2. The capacity issues, however, can be minimised both due to the fact that using self-generated electricity is more financially beneficial than selling it back to the grid in Sweden and also the development of smart grids would allow a more efficient integration of self-generation systems into the grid by demand response and storage capabilities (Thygesen and Karlsson 2016; Wissner 2011).

Table 4. Answers (in %) to the question 'Do you agree with the following statements? – "Self-generation of electricity can create business opportunities for energy companies"'

		ER	ED	DH	H	C
Self-generation of electricity can create business opportunities for energy Companies	Yes, I agree	**85**	**77**	**70**	**73**	**76**
	No, I don't agree	4	12	14	16	16
	Don't know	11	11	17	11	8

The results suggest that although increasing self-generation may create issues between the energy and buildings sectors due to reduced demand and the grid connection issues, it may also create business opportunities for the energy sector to benefit from. The positive view of self-generation systems from the two sectors is encouraging for both the wide-scale development of self-generation systems and achieving improved inter-sectoral cooperation for the installation, maintenance, and the integration of the systems.

3.2.5. Energy use patterns

The uni-directional flow of power and information in current power systems, as explained in Section 1.1.1., limits the penetration of renewable energy into the networks, leads to the use of carbon- and cost-intensive peaking generation plants, and requires costly network capacity upgrades (European Technology Platform 2010). Peaking demand is also a concern for district heating companies, as it may reduce overall efficiencies in CHP generation and increase the use of fossil fuels (Gadd and Werner 2013; Kensby et al. 2014). The results of this thesis also suggest that patterns of energy use in buildings are a matter of concern for the energy sector. The survey results show that 67% and 59% of respondents from district heating and electricity distribution companies, respectively, think that having active and flexible consumers would have 'positive' to 'very positive' impacts on the energy sector, as shown in Table 5. It is important to point out that district heating and electricity distribution companies are the two stakeholders in this study that are primarily impacted by peaking demand. Another important finding is that housing companies, which operate buildings, acknowledged the importance of active and flexible users for the energy sector, as 64% of respondents answered that they would have "positive" to "very positive" impacts on the energy sector (Table 5).

Table 5. Answers (in %) to the question "How do you think the following trends in the buildings sector would impact the energy sector? - 'Active and flexible customers' and 'Participation in demand response'"

		ER	**ED**	**DH**	**H**	**C**
Active and flexible customers	Very negative	0	0	0	0	2
	Negative	6	9	6	8	10
	Neither negative nor positive	29	31	23	23	**32**
	Positive	**32**	**39**	**51**	**38**	22
	Very positive	24	20	16	26	24
	Don't know	9	1	4	5	10
		ER	**ED**	**DH**	**H**	**C**
Participation in demand response	Very negative	0	0	0	3	0
	Negative	9	13	10	13	7
	Neither negative nor positive	**44**	**36**	**39**	23	29
	Positive	12	27	20	18	17
	Very positive	6	1	7	10	5
	Don't know	29	23	24	**33**	**41**

Demand response may create mutual benefits for the energy and buildings, as also pointed by a respondent representing an electricity distribution company: 'Demand response is a win-win situation [for the both sectors].'ED2. The demand response potential for housing companies, however, appears to be limited due to that households are billed for electricity separately and most multi-dwelling buildings use district heating for heating (SABO 2015). Although, this may change in the future if heat pumps achieve growth in the multi-dwelling building market. Nevertheless, both housing and construction companies play an important role in encouraging demand response at the end-user level by installing displays, sensors and thermostats, among other devices. In addition, tapping into the demand response potential in district heating may attract the interest of housing companies provided that there are suitable pricing models (Kensby et al. 2014; Lund et al. 2014).

The survey results, presented in Table 5, however, show that most respondents from the energy and buildings sectors answered 'neither negative nor positive' or 'Don't know' when asked how demand response in the buildings sector would impact the energy sector. The somehow low demand response potential for housing companies, as explained above, combined with the general weak incentives in Sweden for demand response, addressed in detail in Section 3.3.4., appear to be the reasons that demand response still remains an unexplored territory for the two sectors despite its perceived benefits.

3.3 Smart energy features in buildings

In the light of the results that are presented in the previous section, a clear need for closer interaction between buildings and the energy system was identified. In fact, the survey results, shown in Figure 15, suggest that 'smart grids and renewable energy integration' and 'achieving flexible energy use' are amongst the prominent energy challenges today, according to the respondents from the energy and buildings sectors. Buildings that incorporate technologies, such as local energy supply and storage, demand flexibility, among others, can allow the successful integration of buildings in smart grids (Eurelectric 2015). Accordingly, it is of interest to investigate the views of the energy and buildings sectors, which are considered two key sectors for the development, on smart energy features in buildings.

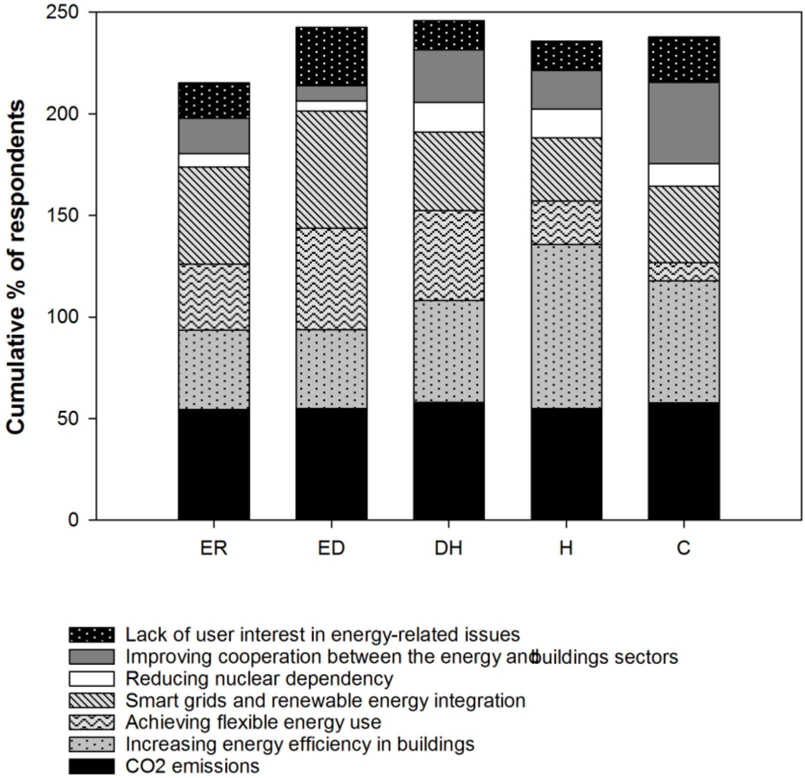

Figure 15. Stacked bar chart of the answers to the question 'What do you think are the current energy challenges in Sweden today?' presented as the cumulative shares of respondents by stakeholder groups

In the light of this, the survey respondents were asked 'Which of the following do you think of when you hear the words "active building"?' with the aim to investigate the views of the studied stakeholders on the smart grid integrated building concept. The results, shown in Figure 16, shows that the most prominent features of active buildings, according to the stakeholder groups, are 'automation of energy activities', 'interaction with the energy system', and 'flexible electricity use'. The results also suggest that the energy and buildings sectors share a similar understanding of the active building concept despite minor differences between responses. It is perceived that the respondents primarily associate active buildings with energy demand flexibility through automation, which would also allow for increased interaction between the building and the energy system, as explained by one of the respondents: 'An active building is not a building that operates on its own, but it communicates with other [active] buildings and the central [energy] system. The central system might tell the building to regulate the demand after the price and try to shift the load to times of low demand. These puzzle pieces [active buildings] communicate with each other and act collectively in times of low production and high demand. Certainly, an active building can also be a producer of electricity' DH1. The results, however, suggests that self-generation of electricity, as well as the accompanying technology of energy storage, do not appear to be considered as a prominent feature of active buildings by some stakeholder groups.

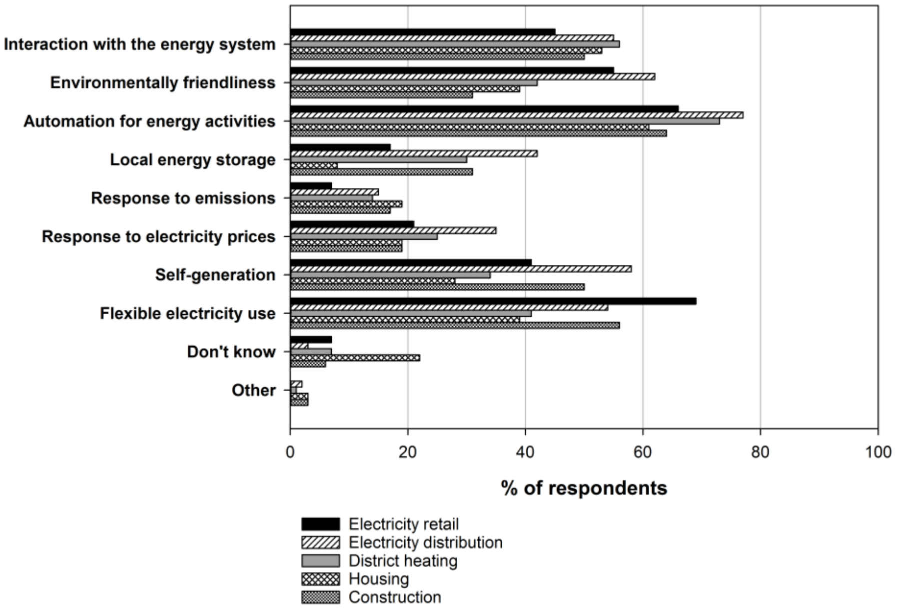

Figure 16. Answers to the question 'Which of the following do you think of when you hear the words "active building"?' by stakeholder groups.

In order to further investigate the views of the stakeholder groups, the survey respondents were asked to rate the provided smart energy features in buildings based on their importance. These smart energy features and the received responses from the stakeholder groups are presented in Table 6. The survey results were also analysed statistically by the PCA and ANOVA methods, whose results are shown in Annex A and Annex B, respectively. The following sections discuss the smart grid features in detail in the light of these findings and the interview results.

Table 6. Answers to the question 'How would you rate the importance of the following features for buildings to become more "active" in the energy system?'

		Construction (%)	***Housing (%)***	***Electricity distribution (%)***	***Electricity retail (%)***	***District heating (%)***
Smart systems that assist in energy-related decisions	**5 - highest**	**36**	31	24	26	30
	4	33	**47**	**54**	**33**	**51**
	3	25	8	14	22	11
	2	0	3	5	15	4
	1 - lowest	0	0	3	0	1
	Don't know	6	11	0	4	3
Automation of energy activities	**5 - highest**	28	28	31	37	23
	4	**36**	**42**	**49**	**52**	**48**
	3	25	17	12	4	20
	2	3	3	3	4	6
	1 - lowest	3	0	3	0	0
	Don't know	5	10	2	3	3
		Construction (%)	***Housing (%)***	***Electricity distribution (%)***	***Electricity retail (%)***	***District heating (%)***
Visualisation of energy use	**5 - highest**	33	28	28	26	22
	4	**36**	**42**	**38**	**41**	**53**
	3	25	14	22	26	16
	2	3	6	5	4	5
	1 - lowest	3	0	6	0	2
	Don't know	0	10	1	4	2
User response to electricity prices	**5 - highest**	33	25	22	7	20
	4	**56**	**36**	**38**	**56**	**47**
	3	11	22	29	22	19
	2	0	0	6	11	6
	1 - lowest	0	6	5	0	3
	Don't know	0	11	0	4	5

Table 6. (Cont.) Answers to the question 'How would you rate the importance of the following features for buildings to become more "active" in the energy system?'

		Construction (%)	***Housing (%)***	***Electricity distribution (%)***	***Electricity retail (%)***	***District heating (%)***
User response to GHG emissions	**5 - highest**	14	11	5	4	3
	4	28	25	15	15	**33**
	3	**31**	**36**	**31**	**44**	29
	2	25	8	31	33	18
	1 - lowest	0	3	15	0	12
	Don't know	2	17	3	4	5
Self-generation of electricity	**5 - highest**	28	17	20	**30**	13
	4	**36**	**33**	**41**	**30**	**30**
	3	19	22	25	**30**	25
	2	11	14	12	7	13
	1 - lowest	6	3	2	0	12
	Don't know	0	11	0	3	7
		Construction (%)	***Housing (%)***	***Electricity distribution (%)***	***Electricity retail (%)***	***District heating (%)***
Local energy sto-rage	**5 - highest**	17	6	9	22	11
	4	28	**42**	**37**	**26**	28
	3	**36**	22	23	22	**32**
	2	8	19	28	19	16
	1 - lowest	6	0	3	0	7
	Don't know	5	11	0	11	6
Electric vehicles for energy storage	**5 - highest**	6	11	9	7	13
	4	25	19	22	**45**	21
	3	**36**	**31**	**37**	33	24
	2	17	19	23	11	**25**
	1 - lowest	8	3	9	0	9
	Don't know	8	17	0	4	8

3.3.1 Smart systems that assist in energy-related decisions

Decision support system that provide consumers with necessary information and guidance to manage their energy activities can help optimise the benefits of smart grids and contribute to the efficiency of power systems (Sianaki et al. 2010). Consumers, however, lack sufficient information or necessary tools to manage their energy activities, which impacts their participation in, for example, demand response measures (Torriti et al. 2010). The results of the survey, presented in Table 6, suggest that smart systems that assist in energy-related decisions is considered the most important feature of active buildings, with the most positive stakeholders identified as housing, district heating and electricity distribution companies. It is important to note that these three stakeholder groups are impacted the most from peak energy use in buildings (Bulut, Odlare, et al. 2015; Bulut, Wallin, et al. 2015) and therefore the results can be suggested as support for increased flexibility in energy use patterns through increased knowledge. A respondent representing the energy sector highlighted the importance of receiving customised energy advices to consumers with the comment: 'Receiving [energy] advices is very important. Today, there are usually more general energy advices; they need to be tailor made for customers.'DH1. The loadings plot from the PCA, presented in Annex A, suggests that such tools may be combined with visualisation of energy use and GHG emission signals, as the three technologies are grouped together in the bottom left of the plot.

3.3.2 Automation of energy activities

Although the active engagement of consumers for household energy management is considered a crucial step towards the development of smart grids, automation technologies can maximise the economic benefits for consumers that respond to time-variable tariffs and contribute to the operational efficiency of smart grids (Rottondi et al. 2015). It is clear that automation of energy activities also improves the comfort of consumers. Paetz et al. (2011) reports positive consumer views on smart devices that operate when electricity prices are low. The survey results, presented in Table 6, suggests that automation of energy activities is the second most important smart grid feature in active buildings. It can be observed in the results that electricity retail companies are the most supportive of automation technologies whereas a relatively weaker support can be identified among construction companies.

Both the survey and the interview results suggest that construction companies are somehow reluctant towards automation technologies in buildings. The reason behind their reluctance appear to be concerns over technical difficulties that may arise in the operational phase of the automation technologies and the high costs of the systems, which adds up to the already high construction costs. In addition, there are risks of 'split incentives' if construction companies cannot recover the costs of the automation technologies when they sell the buildings, given that they do not operate the buildings and hence do not receive the operational economic benefits of the systems. A similar argument can be even made for housing companies, given that households are almost always billed for electricity individually: 'The costs are mostly on the housing companies and the benefits are generally on the tenant.'H3.

Some respondents argued that the customer interest in automation technologies remains weak due to the combination of low electricity prices and high costs of technologies, as also reported in the study by Paetz et al. (2011). Some also pointed that people may feel that they lose control over their home due to high levels of automation. Balta-Ozkan et al. (2013b) reported 'loss of control' as a social barrier to the adoption of smart homes in the UK.

3.3.3 Visualisation of energy use

Visualisation of energy use, via numerical or ambient and artistic visualisation methods, can influence energy behaviour in households (Rodgers and Bartram 2011; Vassileva et al. 2013). The survey results, presented in Table 6, suggest that visualisation of energy use is considered the third most important feature of active buildings by the stakeholder groups. No distinct differences could be identified between the answered by the stakeholder groups. Many respondents think that visualisation of energy use is a good method to create awareness by making energy 'visible' to consumers. Some respondents, however, expressed that the media used to communicate the information to consumers plays a key role in creating awareness and sustaining the consumer interest, with a number of respondents suggesting the use of mobile phone applications to capture the interest of consumers: 'Simple numeric visualisations are no longer interesting [for consumers], but mobile phone applications are'C2.

3.3.4 User response to electricity prices

Time-varying electricity prices create economic incentives for consumers to adjust their use either by cutting their demand or moving it in time, also known as demand response, on which Bartusch and Alvehag (2014), Bartusch et al. (2011) and Torstensson and Wallin (2014, 2015) have reported positive views among Swedish consumers. The survey results, presented in Table 6, suggest that user response to electricity prices is considered one of the important active building features by the respondents, despite varying responses between the stakeholder groups. Table 6 suggests that construction companies are the most positive stakeholder group towards user response to electricity prices as an active building feature, while electricity distribution companies appear to be the most negative, as also confirmed by the ANOVA results (Table F). It is interesting that the electricity distribution companies came out as the most negative stakeholder group towards user response to electricity prices, considering that they have the highest shares of respondents that selected ‘smart grids and renewable energy integration’ and ‘achieving flexible energy use’ as current energy challenges in Sweden today (Figure 15). This relatively negative view by electricity distribution companies can be related to the regulatory barriers which partially contributes to the current weak incentives for energy demand flexibility, as discussed in Section 3.4. of this thesis.

Several respondents argued that low electricity prices combined with daily price variations that ‘are not dynamic enough to create price differences and provide significant benefits’ED3 result in weak incentives for consumer participation in demand response. The survey results show that, more than 60% of respondents from all stakeholder groups agreed with the statement ‘the price of electricity varies too little over the day to create incentives for demand flexibility’, as illustrated in Figure 17. In fact, despite the free of charge availability of hourly metering since 2012, only 0.2% of consumers with a rating of up to 63 Amperes were reportedly have switched to hourly metering as of 2014 (Swedish Energy Market Inspectorate 2014). The weak incentives for demand response can be the reason that ‘user response to electricity prices’ is located further to the right from the features ‘visualisation of energy use’ and ‘smart systems that assist in energy-related decisions’ in the loadings plot (Annex A), suggesting that the respondents do not consider financial incentives to necessarily influence patterns of energy use.

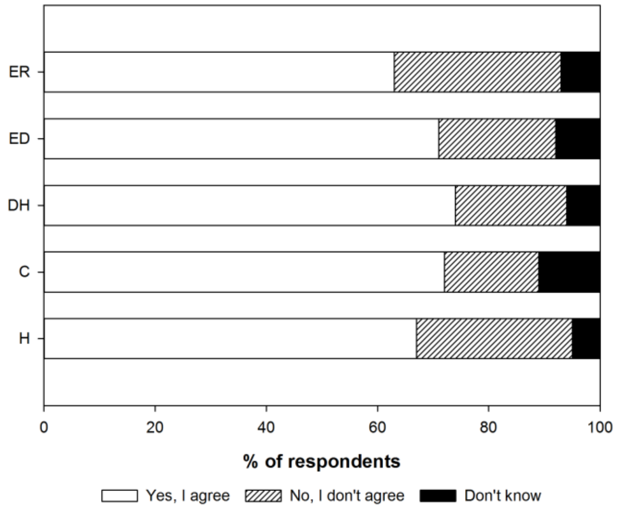

Figure 17. Answers to the question 'How do you agree with the following statements? – "The price of electricity varies too little over the day to create incentives for demand flexibility"'

3.3.5 User response to greenhouse gas emissions

Environmental concerns can create incentives for consumers to participate in demand response (Gyamfi and Krumdieck 2011). A study by Torstensson and Wallin (2015), presenting the results of a survey conducted with consumers in Eskilstuna, report that nearly one-third of respondents that live in multi-dwelling buildings consider environment as the major driver for demand response. However, the results of this thesis suggest that user response to GHG emissions is considered the least important feature of active buildings by the stakeholder groups. According to the results of the ANOVA, presented in Annex B, construction companies came out as the most positive stakeholder group towards user response to greenhouse gas emissions whereas a relatively more negative view was identified among respondents from electricity distribution and electricity retail companies. The findings may suggest that construction companies see a larger potential for user response to greenhouse gas emissions compared to the other stakeholder groups. The somehow negative view by the energy sector can be related to the perceived low level of interest by consumers in this smart energy feature as some respondents argued that despite the high awareness of climate change in the Swedish society, there is weak interest among consumers to adjust their consumption habits only based on GHG emission signals. Accordingly, some respondents suggested combining environmental and economic incentives in order to achieve greater energy demand flexibility: 'Although this [response to greenhouse gas emissions] is important for some people, it has to be combined with use response to electricity prices. There are a few people that are interested in emissions, but most people care more about prices. It is important to use both incentives'DH1. The abovementioned study by Torstensson and Wallin (2015) also report that more than half of respondents who live in one- or two-dwelling buildings and multi-dwelling buildings consider 'environment and prices combined' as the major driver for demand response.

3.3.6 Self-generation of electricity

Self-generation systems are expected to play a key role in the decentralisation of the current electricity networks to be upgraded to smart grids and therefore are considered as one of the key components of buildings with smart grid features (Paetz et al. 2011; Sianaki et al. 2010). However, the survey results, presented in Table 6, suggest that self-generation of electricity is not considered an important feature of active buildings by the stakeholder groups, in similarity to the results presented in Figure 16. It was perceived that stakeholders do not consider the systems to generate enough profits, due to the varying levels of solar irradiation throughout the country and the weak incentives on feeding the surplus electricity into the grid at the time of data collection. Due to that a tax reduction scheme came in force in 2015, it is important to follow up on the stakeholder views in a future study. Although, it can be guessed based on the results of this thesis that the reduction scheme may not have provided the desired security by the stakeholders, as the scheme does not guarantee payments for a pre-defined time period, like feed-in tariffs: 'There must be clear long-term political commitments. You can get subsidies for wind and solar energy [now], but then what will happen in the future when you make such long-term investments?'H4.

The survey (Table 6) and the ANOVA (Annex B) results suggest that electricity retail companies are the most positive stakeholder group towards self-generation of electricity as an active building feature whereas district heating companies came out as the most negative. The positive view of electricity retail companies can be related to that these companies see a business potential in the self-generation market, as also illustrated in Table 5. On the other hand, it is guessed that district heating companies are afraid that consumers would like to combine self-generation systems with heat pumps to further reduce energy costs and achieve higher levels of self-sufficiency, which would result in reduced heat demand.

3.3.7 Local energy storage and electric vehicles

Self-generation systems can be accompanied by local energy storage technologies, in the form of thermal and/or power storage, further contributing to the self-sufficiency and demand flexibility of households (Lamedica et al. 2015; Thygesen and Karlsson 2014). The results of this thesis suggest that, however, local energy storage is not considered an important active building feature by the stakeholder groups, although electricity retail and housing companies appear to be slightly more positive towards local energy storage, especially compared to district heating companies. A similar view was identified for electric vehicles, whose batteries can be used for energy storage, although, electricity retail companies again appear to be slightly more positive for this technology compared to other stakeholder groups.

It appears that the current low levels of self-generation and the weak incentives to participate in demand response are the two prominent reasons for the weak support among the stakeholder groups for local energy storage, which is also visible in the loadings plot in Annex A, where the features 'self-generation of electricity' and 'local energy storage' are grouped together in the top. It appears that besides the lifecycle environmental impacts, the limited capacity of batteries is also regarded as barriers to their adoption. Range issues and high costs are among the factors that were mentioned by the respondents as barriers to the adoption of electric vehicles. These factors are likely the reasons why 'electric vehicles for energy storage' is located further away from all features in the loadings plot in Annex A, including 'local energy storage': 'Electric vehicles would gain importance in the future if there is a huge development in terms of the expenses and batteries' DH1.

It is guessed that electricity retail companies consider both batteries (which they can sell to consumers) and electric vehicles (which would create an additional demand for electricity) as business opportunities. Electricity distribution companies, on the other hand, appear to be primarily concerned about the impacts of an increasing number of electric vehicles on the networks, which may need to be upgraded to accommodate the additional electricity demand. The relatively negative view by district heating companies may be related to the previously mentioned concerns over self-sufficiency by building owners, to which batteries contribute by storing energy for later use.

3.4 Barriers to the development of smart energy features in buildings

In order to investigate the barriers to the development of smart energy features in buildings, the survey respondents were asked 'Which of the following factors do you think that negatively impact the development of active buildings in Sweden?' and were provided with a set of pre-defined answers, from which they were allowed to make multiple selections. According to the results, illustrated in Figure 18, 'high investment costs', 'low energy prices', and 'regulatory framework' were identified as the strongest barriers to the development smart energy features in Sweden.

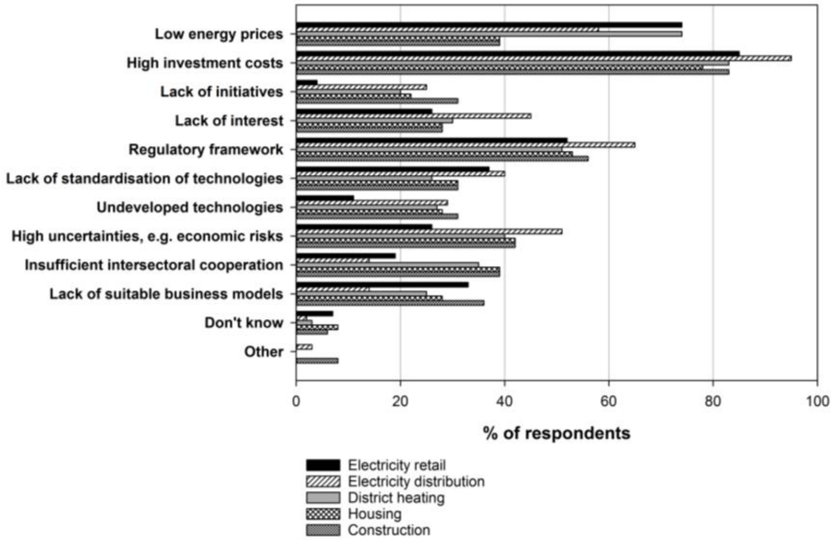

Figure 18. Answers to the question 'Which of the following factors do you think negatively impact the development of "active buildings" in Sweden?'

The results suggest that all stakeholder consider 'high investment costs' as the strongest barrier to the development of active buildings, reaching as high as 95% of respondents that answered such among electricity distribution companies. The high costs of the associated technologies result in high investment costs, which the respondents consider too high to achieve a wide-scale adoption. Some respondents cited the 'lack of standardisation of technologies' as one of the reasons behind the high costs of technologies, arguing that 'closed' technology suppliers try to 'monopolise' the market: 'A major problem in the development is that there is no standardisation and commercialisation of the components, which would reduce the prices and make these technologies more competitive and widely available'H2. In fact, more than a quarter of respondents from all stakeholder groups agreed that the 'lack of standardisation of technologies' is a barrier to the development of active buildings. High costs of technologies were also reported as a barrier to adoption in consumer studies (Balta-Ozkan et al. 2013b; Paetz et al. 2011).

According to the results 'low electricity prices' is another prominent barrier to the development of active buildings in Sweden. Although, Figure 18 shows that the shares of respondents that considered 'low electricity prices' a barrier are lower in the buildings sector, which may indicate that not many companies in the buildings sector find the energy prices low. Some respondents, however, argued that low prices of electricity combined with the high per-capita income in Sweden result in weak public interest in energy issues and hence in active buildings. Respondents also added that the low prices of electricity impact the economic feasibility of investments, resulting in long pay-back periods, which heightens uncertainties about their future profitability. In this regard, respondents pointed out that 'what levels of risks [that the investors of active buildings are subjected to] are one of the major factors to be taken into account'ED3, as higher risks result in weaker interest in the investments. In fact, many respondents consider 'high uncertainties' a barrier to the development of active buildings, as shown in Figure 18. Some respondents argued that new business models that involve other stakeholders, such as business models similar to energy performance contracts offered by ESCOs, may reduce the risks and financial burdens of the investments. In addition, the results suggest that many respondents, reaching as high as approximately 35% of respondents among construction companies, do not think that such business models exist now (Figure 18): 'I hope that the existing big actors, such as real estate and energy companies etc., also understand the opportunity here [with active buildings] and change their business models'C4.

The results suggest that there are regulatory barriers to the development of active buildings, as more than half of respondents from all stakeholder groups selected the answer 'regulatory framework' (Figure 18). Several respondents criticised the lack of a support scheme on self-generated electricity that is fed back into the grid, as the previously mentioned tax reduction scheme entered into force after the data collection. It is notable that a strong share of respondents, around 65%, from electricity distribution companies selected 'regulatory framework'. The reason behind this is the regulations that prevent the discrimination between consumers by imposing that consumers of the same category can only be offered uniform tariffs for electricity distribution (Swedish Energy Market Inspectorate 2015b). As a result of this, distribution companies are not allowed to offer special tariffs or demand response schemes to a specific group of consumers with a larger demand flexibility potential. Although companies are allowed to apply peak tariffs, as long as it is offered to all customers in the same category, they are argued to not create strong enough incentives for consumers to voluntarily move demand over time and hence invest in active buildings. Accordingly, some respondents argued that 'a more open way to test new tariffs could pave the way for the stronger development of active buildings'ED2.

Approximately one-third of respondents answered that 'undeveloped technologies' are a barrier to the development of active buildings, as illustrated in Figure 18. Some respondents argued that 'the technical solutions [that are used in active buildings] are quite immature, under development'ED2. Several technical difficulties that were experienced in one of the pilot projects in Sweden have been reported in the media (NyTeknik 2015).

The results of this thesis suggest there is potential for improving the cooperation between the energy and buildings sectors. The survey results in Figure 18 show that several respondents consider 'insufficient inter-sectoral cooperation' as a barrier to the development of active buildings. Some respondents highlighted the importance of inter-sectoral cooperation, particularly between the energy and buildings sectors, for the development of active buildings: 'If we do not work together, we will not see much development.'DH9.

Weak consumer interest in smart grids creates barriers to the adoption of smart energy features in buildings (Eisen 2013). Some respondents consider 'lack of interest' by consumers a barrier to the development of active buildings (Figure 18), arguing that many consumers lack knowledge regarding energy-related issues and their energy use, and hence would not be interested in active buildings. A respondent representing an electricity distribution company commented: 'A regular end-user does neither understand their energy use nor how the energy market functions. For example, it can be pretty hard for an end-user to know the difference between kW and kWh. I think the terms kW and kWh are not as easy to understand as a litre of gasoline. Therefore, it is hard for end-users to have an understanding of how much energy they use' ED2.

Finally, some respondents argued that 'lack of initiatives' is a barrier to the development of active buildings in Sweden, pointing that more 'pilot projects and research can be good for introducing the [active building] technologies'ER1. The survey results in Figure 18 suggest that construction companies especially consider lack of initiatives a barrier to the development, as selected by approximately one-third of respondents from this stakeholder group, which may be interpreted as a sign of interest for participating in collaborative smart grid initiatives.

3.5 Ownership models for the technologies

Given the high costs of technologies and long payback times of investments, effective ownership models play a key role in the development of smart energy features in buildings. Ownership issues are particularly relevant to the rental sector, as there are weak incentives for renters, who do not own the property, and housing companies, which do not pay the electricity bills, to make the investments. Accordingly, the survey respondents were asked who should invest in the infrastructure that supports more active buildings. The results suggest that houseowners and housing companies are the primarily perceived actors to undertake the investments, selected by nearly half of respondents from electricity distribution companies.

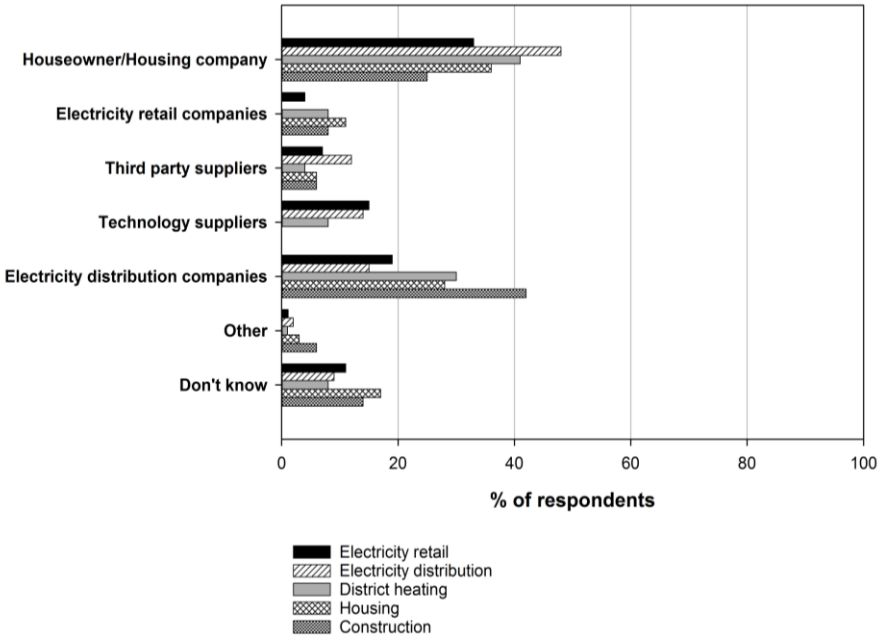

Figure 19. Answers to the question 'Who do you think should invest in the infrastructure that supports more active buildings?'

The findings, presented in Figure 19, suggest that the majority of respondents from housing companies answered that house owners and housing companies should invest in active buildings. A respondent from a housing company argued that it is the responsibility of housing companies to install the technologies in their buildings: ‘We, as the housing sector, have to provide them [active building features] and pay for the costs.’H3. Some respondents suggested that there should be an interoperable system, to which the consumers can add or subtract technologies, to minimise investment costs, pointing that housing companies can maybe provide the basic infrastructure and allow their tenants to purchase additional features of their choice: ‘There should be a simple system, where tenants can add desired applications and pay for the services that they wish to use, such as extra sensors. It is very hard for a person to buy the whole infrastructure.’C2.

Given that electricity distribution companies are regarded as one of the primary beneficiaries of smart grids, they are one of the expected actors to invest in active buildings, as shown in Figure 19. According to the results, more than 40% of respondents from construction companies think that electricity distribution should invest in active buildings. Even though, it appears that electricity distribution companies do not share the same opinion, given that only 15% of respondents answered such, accounting for the lowest share of respondents among all stakeholder groups.

The results presented in Figure 19 suggest that electricity retail companies are not considered a prominent actor to invest in active buildings, although a small number of respondents from electricity retail companies answered such. The transition towards smart grids is expected to lead to the emergence of new actors in the electricity market, such as aggregators and electricity service providers among others (Rahimi and Ipakchi 2010). The energy services market in Sweden, however, was reported to be quite limited (Swedish Energy Market Inspectorate 2014). Accordingly, the survey results (Figure 19) suggest that only small shares of respondents from the stakeholder groups consider 'technology suppliers' and 'third-party suppliers', such as aggregators, as the prominent actors to undertake the active building investments. According to some respondents, the current weak incentives to participate in demand response are the reason behind the limited energy services market: 'If you hire a company to reduce your energy use, it is hard to get your money back or payback in short time if you are a resident. It can take several years, or up to 20 years, to have it paid back" ED1.

3.6 Smart energy features in Swedish and Hong Kong buildings

The information presented in Sections 1.1.2. and 1.1.3. suggest both similarities and differences between Sweden and Hong Kong, which are also apparent in the results of this thesis. This section compares the Swedish and Hong Kong markets for smart homes, discusses the barriers to their adoption and presents the business and ownership models that are deemed suitable by the stakeholders for the development.

The results suggest that, despite the public support in the both jurisdictions, the respondents do not consider self-generation to be a prominent smart home feature in buildings. The relatively low residential electricity prices in Sweden and Hong Kong appear to be one of the factors that influence the views of the stakeholders, as several respondents argued that the low electricity prices negatively impact the financial performance of self-generation systems. However, the strongest barrier to the development in Hong Kong is the lack of regulatory framework that governs self-generation. The current SCAs only allow the two power companies to sell electricity and prosumers may only feed electricity into the grid if allowed by the local power company, as also highlighted by a respondent from an energy management company: 'Even PV is absolutely impossible to push in Hong Kong right now. We don't even know if it is legal, in fact. We don't even know where to go to start the conversation, there is no framework as such.'EM1. The lack of governmental support and the high-density, high-rise built environment that creates space and shading issues appear to further impact the adoption of self-generation systems in Hong Kong. Although Hong Kong may be considered an 'extreme' example of high-density, high-rise urban structure, growing urban density in Sweden may create similar challenges to the development of self-generation systems in the future.

The results suggest that respondents from Sweden and Hong Kong consider user response to electricity prices as a prominent smart energy feature in buildings. Despite the reportedly promising results from a Hong Kong pilot project, where time-varying tariffs were tested, the extremely low access to smart meters remains a strong barrier to achieve residential demand response in Hong Kong. In addition, several respondents pointed that the low electricity prices in Hong Kong would result in weak incentives to participate in demand response, especially considering the insignificant share of electricity bills in the household expenditure due to the high income levels. A similar view was identified among Swedish respondents, who argued that despite the universal access to smart meters and free of charge hourly metering the electricity prices and the intra-day price differences were too low to create incentives for residential demand response. In addition, the widespread use of district heating in multi-dwelling buildings in Sweden limits the flexible electricity load that can be used for demand response. Buildings that use heat pumps, however, offer a stronger potential for demand flexibility by using the building envelope as energy storage medium to move the electricity demand in time. In Hong Kong, however, the electricity demand by air-conditioners was argued to offer very little flexibility, particularly in the summer months. In addition, some respondents pointed out that the busy lifestyle of Hong Kong may create additional challenges for demand response, given that the amount of time spent at home could be limited, unless there are automation technologies to schedule the appliances.

According to several respondents from the both jurisdictions, cost savings create stronger incentives than environmental benefits for participating in demand response, with some respondents suggesting to combine both incentives to achieve wider participation. Additionally, they mentioned that despite the public awareness of climate change in Sweden and Hong Kong, as reported in Eurobarometer (2014) and Oxfam (2010), respectively, consumers may be reluctant to change consumption habits. Some respondents argued that displaying the amount of 'emitted kilograms of CO2' may be difficult to relate to by the public and suggested displaying a 'high environmental impact' warning or illustrate 'how many trees equivalent CO_2' can be offset by participating in demand response to facilitate understanding. Some respondents from Hong Kong suggested including local air pollution signals, which, according to these respondents, may create stronger incentives than greenhouses gas signals for some respondents: 'People may not be as responsive to hourly greenhouse gas emission signals as they are to price signals. This is a general statement, but if you also have climate change versus air quality, right now the issue in Hong Kong is air quality. […] Greenhouse gas emissions are more of a global issue.' UHK1.

The results of this thesis suggest that energy use visualisation is considered an important smart energy feature in buildings according to the respondents from Sweden and Hong Kong. The respondents think that energy use visualisation can contribute to the level of awareness of energy use among consumers, but expressed that the interest may fade away with time. Some respondents suggested the use of mobile applications, which they argued to be more effective than in-home displays. On the other hand, a number of respondents pointed out that the interest in energy use visualisation can only be sustained by linking visualisation to financial and/or environmental incentives: 'If you have an in-home display, you watch it the first day, the second day, the first week, and then afterwards it becomes just a decoration unless you link some interest to it, for example money.'UHK2. Decision support systems that help consumers manage their energy activities and maximise the benefits of smart grids are therefore considered an important technology by respondents from the two jurisdictions.

Several respondents from both Sweden and Hong Kong acknowledged that home automation technologies and smart appliances would facilitate the management of energy activities in households, also improving comfort. Some respondents from Sweden, however, argued that people may find home automation technologies intrusive whereas respondents from Hong Kong mentioned that it would not be the case for Hong Kongers, who may be more open to new technologies. On the other hand, some respondents pointed that Hong Kong homes are often very small and hence may not require high levels of automation, such as for lighting. The costs of automation technologies were perceived as the strongest barrier to the adoption, as several respondents from both Sweden and Hong Kong highlighted that the investment costs cannot be recovered only by energy cost savings. Thereby, some respondents suggested that home automation technologies also include other features, such as improved security and entertainment, to achieve a wider adoption rate.

The results suggest that respondents from Sweden and Hong Kong consider local energy storage to have low importance as a smart energy feature in buildings. Some shared concerns among the respondents from the both jurisdictions include high costs and the life-cycle environmental impacts of batteries as well as their short lifetime. Additionally, some respondents argued that the current low levels of self-generation and the small sizes of the self-generation systems do not create a strong need for local energy storage. The specific barriers to the adoption of local energy storage technologies in Hong Kong were identified as following: there are no time-varying prices to create incentives for storing electricity and feeding it into to the grid; the regulatory framework (SCAs) only allow the two power companies to sell electricity; and, space issues pose challenges for the installation of batteries in buildings. Additionally, the respondents from the two power companies argued that energy storage may not be needed in Hong Kong due to the high reliability of the electricity supply: 'Hong Kong Electric and China Light and Power, we supply very highly reliable electricity to our customers, almost among the top of the world. Our supply reliability is 99.999%, meaning that the average outage time is less than one minute per customer per year. For such highly reliable electricity supply, we do not see the need for energy storage.'UHK2. Despite the widespread use of electricity for cooling, it is perceived that thermal energy storage technologies have limited applicability in Hong Kong due to the hot and humid climate and the lack of insulation requirements imposed on residential buildings which impact the thermal storage potential of the building envelope.

It appears that, despite the attempts to encourage electric vehicle ownership in by the Swedish and Hong Kong governments, the respondents from the two jurisdictions pointed out several barriers to their adoption. Some of the shared barriers include the high costs of vehicles, limited distribution of charging stations, long charging times, the relatively short lifetime and the environmental impacts of batteries. Respondents pointed out that despite the short travel distances, the low car ownership rate and the limited parking spaces create specific barriers to the adoption of electric vehicles in Hong Kong. In Sweden, on the other hand, range anxiety and the required grid capacity upgrades are perceived as the specific barriers to the development.

According to the results, the high costs of smart energy technologies appear to be the strongest barrier to their deployment in both Sweden and Hong Kong. In addition to this, weak financial incentives in the both jurisdictions, primarily due to the low electricity prices, further impact the development given that they lead to increased uncertainty due to long payback times. In fact, although respondents acknowledge that there are consumers who may be interested in environmental benefits, 'business cases' with stronger financial incentives are deemed crucial to shift the development from pilot projects to a commercial level. Accordingly, the respondents argued that the standardisation of technologies may solve both interoperability issues between systems and push down the costs of technologies.

Weak user interest is considered a barrier to the development of smart energy features in buildings by respondents from both Sweden and Hong Kong. It was perceived that the user interest in Hong Kong may be weaker compared to Sweden. Respondents from the both jurisdictions, however, suggested that the government should adopt a more active approach in educating the public regarding the environmental impacts of energy use.

According to the results, there are strong institutional and regulatory barriers that negatively impact the adoption of smart energy features in Hong Kong buildings. The two monopoly structure of the power market significantly restricts the investments in renewable energy as well as limits the products and services that are available to consumers. The SCAs do not impose smart-meter roll-outs on the power companies, especially limiting the introduction of time-varying residential tariffs. In addition, the lack of a regulatory framework that govern grid connected self-generation systems requires the system owners to seek approval from their local monopoly and create uncertainties. Moreover, the Hong Kong government does not provide support schemes for self-generation, which, combined with the very low electricity prices, impacts the financial performance of the self-generation systems.

Several respondents argued that a deregulated market would encourage the development of smart grids by investments and the introduction of new business models, although, many expressed that a deregulation may be challenging for such a small market. In fact, these respondents suggested the revision of the SCAs to address issues of peak demand, decentralised power generation and energy efficiency. The two power companies, on the other hand, warned strictly against a deregulation and expressed that smart energy features can be developed even with the current monopoly structure, stressing the low price and high reliability of electricity in Hong Kong. Although critical of a deregulation, a respondent representing one of the power companies acknowledged that there need to be various tariff structures instead of the single residential tariff that is currently being offered to consumers: 'Deregulated markets have given customers more choice. In Hong Kong, customers do not have a choice between suppliers, which is true, but we have to ask 'are you looking for choice?'. Ultimately, you are looking for a low price and good services. I think the results have been mixed in deregulated markets [in terms of these factors]. You can give them [the users] choices under a regulated market. I do not think the regulated market hampers smart homes in that respect. What I do think that a regulated utility can do more is actually offer more flexible tariffs. Right now, we have one residential tariff for all users, no time of use [tariffs].' UHK1.

Another specific barrier to the development in Hong Kong is the small living spaces, which particularly impact the adoption of self-generation systems and batteries as well as limit the controllable load in households, such as lighting. Respondents also mentioned that Hong Kong people spend relatively less time at home, which they think also negatively influences the flexibility of the demand in the absence of automation technologies.

It was perceived that the expected actors to invest in smart energy features in buildings are building/flat owners, which can be consumers themselves, and construction and housing companies. Some respondents expressed that users should invest in smart home technologies of their choice, although, they also mentioned that not many may have enough knowledge and capital to make the investments. Due to the high costs, high-income consumers are considered, by some, the early adopters of smart energy features in buildings. It appears that, however, combining smart energy features with additional technologies, such as those target security, entertainment, among others, may be required to reach high-income consumers as financial incentives may not be sufficient to attract their interest.

Some respondents argued that housing companies should make the investments, although, the split incentive issues, which are discussed in Section 3.5., create barriers to the adoption in the rental sector. It was suggested that public housing companies, and semi-public housing companies in Sweden, lead the development and install smart energy technologies in new buildings and buildings undergoing renovation as part of their social responsibility. Some respondents also expressed that construction companies and real estate developers may introduce the technologies in new buildings, benefiting from the economies of scale and experience, provided they see a 'business potential'. Some pointed out, however, that particularly in Hong Kong, where real estate prices are among the highest in the world, construction companies would only make the investments if they are considered relatively low-risk, i.e., not negatively impacting the value or the 'sellability' of the property.

According to respondents from both Sweden and Hong Kong, some of the lower-cost technologies, such as in-home displays, can be adopted as the first step, to be later followed by home automation technologies and smart electric appliances, which involve larger investments. Given the perceived high costs and risks of investments, mutually beneficial business models that divide these burdens between different actors are perceived as necessary to achieve a wider penetration of these technologies into the market. Although many respondents think that such business models have not yet emerged, they expect new actors and business models to emerge provided that there are stronger financial incentives in the future.

Summarising the findings presented in this section, the high-density, high-rise built environment in Hong Kong create additional challenges for the adoption of smart energy features in buildings compared to Sweden. Accordingly, some smart energy features, such as self-generation systems and energy storage, find little applicability in Hong Kong. Given the increasing urban density, similar challenges can be expected to become relevant to the Swedish case in the future, albeit at a smaller scale. Although Hong Kong experiences peaking load issues due to the hot and humid weather, which results in extensive use of air-conditioners, the thermal storage potential can be considered lower than Sweden as the strict insulation requirements and the use of hydronic systems in Swedish buildings provide more opportunities for thermal heat storage, and hence demand flexibility. In addition, the small sizes of Hong Kong homes also limit the energy demand flexibility potential compared to Swedish homes. Regarding the electricity market structure, the fact that the Hong Kong market consists of two de-facto geographical monopolies greatly restricts the development of smart energy features in buildings, as only the two monopolists are entitled to sell electricity. The weaker policy focus in Hong Kong on renewables and smart meters compared to Sweden have resulted in more significant institutional and regulatory barriers against the development of smart energy features in buildings. As a result, there are much weaker incentives for Hong Kongers to generate electricity and participate in demand response through smart energy technologies compared to Swedes.

4. Conclusions

This thesis provides a snapshot of the current level of cooperation between the energy and buildings sectors in Sweden and presents the views of these two key sectors on smart energy features in buildings, the barriers to their adoption and the suitable ownership and business models for the development. In addition, this thesis compares the markets for smart energy features in buildings in Sweden and Hong Kong and highlights the different challenges and opportunities for the development of the associated technologies. Presented in relation to the research questions that are stated in Section 1.2., the conclusions of this thesis are as following:

What is the level of cooperation between the energy and buildings sectors? (Q1)

- The current level of cooperation between the energy and buildings sectors in Sweden can be improved, particularly between construction companies and electricity distribution and district heating companies (Paper I & II)
- There is also an identified potential to strengthen the level of mutual trust between the two sectors. Trust issues are especially apparent between the buildings sector and district heating companies. (Paper I & II)
- The emphasis on self-gains limits the dialogue and hence the cooperation between the two sectors (Paper I & II)

What are the barriers to cooperation between the energy and buildings sectors? (Q2)

- The following factors were identified to impact the inter-sectoral cooperation: district heating monopolies; energy efficiency measures in the buildings sector; unsuccessful technology-neutrality of the building regulations; self-generation systems; and energy use patterns in buildings. (Paper I & II)
- District heating monopolies create trust issues due to risks of opportunistic behaviour by the monopolists. Weak customer focus and the lack of variety in pricing and business models also negatively impact the cooperation. (Paper I & II)
- Energy efficiency measures create conflicts between the two sectors (especially between housing companies and district heating companies) due

to reduced energy demand. The alteration of tariffs in response to energy demand cuts jeopardises the economics of energy efficiency projects in the buildings sector. (Paper I & II)

- The criticised technology-neutrality of the building regulations, which led to an increasing use of heat pumps in the buildings sector, create conflicts between the energy and the buildings sectors. District heating companies are critical of heat pumps due to the falling amounts of sold heat whereas the buildings sector considers the use of heat pumps as a means to gain independence from district heating companies, citing issues surrounding the monopolies. The conflict is particularly strong between district heating suppliers and construction companies, which design and construct buildings. (Paper I & II)
- Self-generation of electricity may create conflicts between the energy and buildings sectors due to cut electricity demand and difficulties in accommodating large amounts of intermittent self-generated electricity in distribution networks. (Paper I & II)
- Current energy use patterns in buildings result in low operational flexibility in the energy sector and may create conflicts between the two sectors. The mismatch between energy use and supply patterns contribute to peaking electricity and heat demand, which prompts the use of cost- and carbon-intensive power and heat generation facilities and requires additional investments for increased distribution capacities. (Paper I & II)

What are the opportunities to minimise these barriers and strengthen cooperation? (Q3)

- Participating in collective initiatives that create mutual benefits is considered important to set good examples of inter-sectoral dialogue and cooperation. Shifting the focus from self-gains to mutual gains within the both sectors is deemed crucial to initiate cooperation. (Paper I)
- Increased transparency in the district heating sector may alleviate the suspicions of opportunistic behaviour and restore the inter-sectoral trust. Improved customer dialogue and the introduction of various pricing schemes and business models can minimise conflicts between district heating companies and the buildings sector. (Paper I)
- The buildings sector expects new energy services to be introduced by the energy sector. The involvement of energy companies in energy efficiency projects is deemed to create mutual benefits, reduce uncertainties and contribute to the inter-sectoral cooperation. (Paper I & II)
- Improved integration of heat pumps into electricity networks through demand flexibility and self-generation technologies can be expected to minimise the conflicts between the energy and buildings sectors regarding the use of heat pumps in buildings. Combining heat pump and district heating

technologies can further contribute to solving the conflict between the two sectors. (Paper I & II)

- The energy sector considers self-generation of electricity a business opportunity. The involvement of the energy sector in the PV market can create mutual benefits by supporting the development in the buildings sector and, at the same time, counteract revenue losses from reduced sales. (Paper I & II)
- Demand response may create mutual benefits for the energy and buildings sectors. The introduction of varying-price schemes in electricity distribution, supported by regulatory changes, may create stronger incentives for residential demand response. (Paper I & II)

What are the views of the Swedish energy and building sectors on smart energy features in buildings? (Q4)

- The energy and buildings sectors consider smart energy features in buildings to assist the energy sector in the operation of power networks by flexible energy use. (Paper III)
- Accordingly, smart energy features in buildings that specifically target energy demand flexibility, such as energy use visualisation and systems that assist in energy-related decisions, are considered important by the stakeholders. (Paper III & Paper IV)
- Self-generation of electricity is not considered a prominent smart energy feature in buildings. (Paper III & IV)

What are the barriers to the adoption of smart energy features in Swedish buildings? (Q5)

- The strongest barriers are financial, as a result of the low electricity prices and the high costs of technologies. Such financial barriers may be stronger for owners of one- and two dwelling buildings despite their higher potential for self-generation and energy demand flexibility. (Paper III & IV)
- Low intra-day electricity retail price differences combined with the regulations that prohibit distribution companies from offering tailor-made tariffs to consumers with a higher demand flexibility potential result in weak financial incentives to participate in demand response. (Paper III & IV)
- The standardisation of the technologies was suggested as a solution to interoperability problems and the current high costs of systems (Paper III & IV)

Which ownership and business models are suitable for the development of smart energy buildings in Sweden? (Q6)

- Housing companies and building owners/consumers are the expected actors to invest in smart energy buildings. (Paper III & IV)
- Split incentive issues in the rental sector and the lack of access to capital by companies and consumers, however, appear to create barriers for these actors to make the investments. (Paper III & IV)
- Business models that target the financial barriers are deemed necessary to encourage the adoption of smart energy features in buildings. (Paper III & IV)
- The dissemination of lower-cost technologies, such as those that visualise household energy use, prices and greenhouse gas emissions may pave the way for more advanced technologies, such as home automation and smart appliances. (Paper III & IV)

What are the differences and similarities between the Swedish and Hong Kong markets for smart energy features in buildings? (Q7)

- Similar to Sweden, technologies that target energy demand flexibility are considered more important than technologies that support self-generation for Hong Kong buildings. (Paper IV)
- The high-rise, high-density built environment strongly limits the adoption of smart energy features in buildings, i.e., space and shading issues result in weak technical and financial feasibility of PV systems. (Paper IV)
- Due to the climatic differences and the smaller sizes of Hong Kong homes, the energy demand flexibility potential appear to be higher in Sweden than in Hong Kong, especially for one- and two-dwelling buildings in Sweden (Paper IV)
- The institutional and regulatory barriers strongly impact the development of smart energy features in Hong Kong buildings, given that the access to smart meters remains extremely low and the SCAs prevent consumers to feed electricity into the grid. (Paper IV)
- Building owners/consumers are the expected actors to invest in smart energy features in buildings in both Hong Kong and Sweden. However, the high costs of technologies and the low electricity prices in the both jurisdictions create barriers to their adoption. The emergence of business models that targets these barriers may be more challenging in Hong Kong than in Sweden due to the current electricity market structure with two monopolies. (Paper IV)

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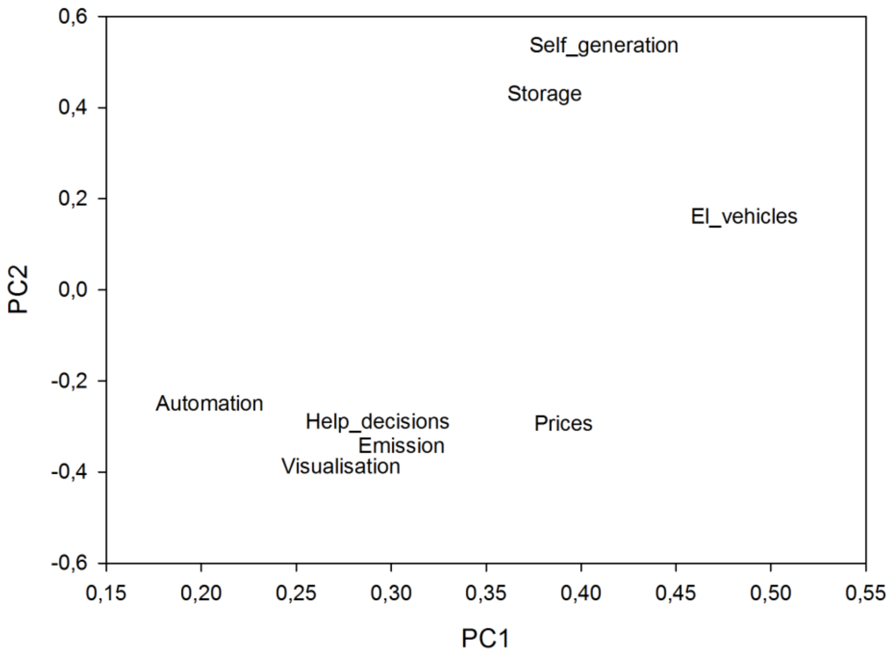
Annexes

Contents



Annex A. Loadings plot created by the Principle Component Analysis

Annex B. The results of one-way ANOVA with Tukey (p=0.10). The letters "a" and b" indicate statistically significant differences in responses between stakeholder groups.

	Housing	***Construct.***	***Electricity distrib.***	***Electricity retail***	***District heating***
Self-generation of electricity	3.5	3.7	3.6	3.8[b]	3.2[a]
Local energy storage	3.4	3.4	3.2	3.6	3.2
User response to electricity prices	3.4[b]	3.3[b]	2.6[a]	2.9	2.9
User response to GHG emissions	3.8	4.2[b]	3.7[a]	3.6[a]	3.8
Electric vehicles for energy storage	3.2	3.0	3.0	3.5	3.0
Automation of energy activities	4.1	3.9	4.0	4.3	3.9
Visualisation of energy use	4.0	4.0	3.8	3.9	3.9
Smart systems that assist in energy-related decisions	4.2	4.1	3.9	3.7	4.1

Annex C. List of respondents that were quoted in the text

Name	*Source*	*Background*	*Ownership*	*Position*	*Additional information*
ED1	Interview	Electricity distribution	Municipally owned	Market manager	1.75 TWh/year delivered electricity
ED2	Interview	Electricity distribution	Privately owned	Project manager	38 TWh/ year delivered electricity
ED3	Interview	Electricity distribution	Privately owned	Project manager	14.1 TWh/year delivered electricity
DH1	Interview	District heating	Municipally owned	Environ. manager	0.96 TWh/year delivered heat
DH2	Survey	District heating	Municipally owned	Chief Engineer	3.8 TWh/year delivered heat
DH3	Survey	District heating	Municipally owned	Depart. manager	1.6 TWh/year delivered heat
DH4	Survey	District heating	Municipally owned	Depart. manager	0.45 TWh/ year delivered heat
DH5	Survey	District heating	Municipally owned	Business manager	0.16 TWh/year delivered heat
DH6	Survey	District heating	Municipally owned	Business manager	0.25 TWh/year delivered heat
DH7	Interview	District heating	Municipally owned	Business manager	1.5 TWh/year delivered heat
DH8	Survey	District heating	Municipally owned	Depart. manager	0.17 TWh/year delivered heat
DH9	Interview	District heating	Municipally owned	Business manager	0.68 TWh/year sold heat
ER1	Interview	Electricity retail	State owned	Business developer	42 TWh/year sold electricity
C1	Interview	Construction	Privately owned	Technical manager	10,500 total number of employees
C2	Interview	Construction	Privately owned	Energy strategist	13,000 total number of employees
C3	Survey	Construction	Privately owned	Sustain. manager	13,000 total number of employees
C4	Interview	Construction	Privately owned	Technical manager	57 000 total number of employees
R1	Interview	Research	University	Professor	Real estate economy
H1	Interview	Housing	Municipally owned	Technical manager	115 total number of employees
H2	Interview	Housing	Municipally owned	Technical manager	406 total number of employees
H3	Survey	Housing	Municipally owned	CEO	12 total number of employees
H4	Interview	Housing	Municipally owned	Environ. manager	360 total number of employees
EM1	Interview	Energy management	Privately owned	Senior Consult.	Carbon reduction and sustainability projects
UHK1	Interview	Electricity utility	Privately owned	Senior proj. man.	35 TWh/year sold electricity
UHK2	Interview	Electricity utility	Municipally owned	Manager	10.9 TWh/year sold electricity

Annex D. List of interview respondents from Sweden

	Stakeholder group	*Background*	*Position*	*Additional information*
1	Electricity distribution	Municipally owned	Market manager	1.75 TWh/year delivered electricity
2	Electricity distribution	Privately owned	Project manager	38 TWh/ year delivered electricity
3	Electricity distribution	State owned	Development manager	71.9 TWh/year delivered electricity
4	Electricity distribution	Privately owned	Project manager	14.1 TWh/year delivered electricity
5	Electricity retail	State owned	Business developer	42 TWh/year sold electricity
6	Electricity retail	Municipally owned	Market manager	0.48 TWh/year sold electricity
7	District heating	Municipally owned	Business manager	1.5 TWh/year delivered heat
8	District heating	Municipally owned	Environmental manager	0.96 TWh/year delivered heat
9	District heating	Municipally owned	Business manager	0.68 TWh/ year delivered heat
10	Construction	Privately owned	Technical manager	57,000 total number of employees
11	Construction	Privately owned	Energy manager	2200 total number of employees
12	Construction	Privately owned	Energy strategist	13,000 total number of employees
13	Housing	Municipally owned	Environmental manager	360 total number of employees
14	Housing	Cooperative company	Sustainability manager	2300 total number of employees
15	Housing	Municipally owned	Technical manager	115 total number of employees
16	Housing	Municipally owned	Technical manager	406 total number of employees
17	Municipality	Medium sized city	Project leader	City population: 140,000
18	Municipality	Medium sized city	Environmental manager	City population: 65,000
19	Municipality	Large city	Project leader	City population: 1.4 million
20	Research	University	Professor	Smart grids
21	Research	Research Institute	Professor	Smart energy services
22	Research	University	Professor	Real estate economy
23	Research	National research centre	Project leader	Energy efficiency in buildings

Annex E. Interview guide used in Sweden

1. Would you like to be anonymous?
2. Could you please name the two most important energy challenges today?
3. Do you have any concerns regarding energy use in buildings?
4. Which developments in the buildings sector can positively impact the energy sector?
5. Which developments in the energy sector can positively impact the buildings sector?
6. Which developments in the building sector can generate extra costs/problems in the energy sector?
7. Which developments in the energy sector can generate extra costs/problems in the buildings sector?
8. Would third-party access to district heating networks promote competition? ☐ Yes ☐ No ☐ Don't know - (Yes) In which way do you think it would promote competition? - (No) Why do you think it would not promote competition?
9. The introduction of low energy buildings in the building stock will negatively affect district heating. ☐ 1 – I disagree ☐ 2 ☐ 3 ☐ 4 ☐ 5 – I agree -How do you think such impacts could be reduced?
10. Do you think district heating could be used for applications other than space heating and warm water?
11. There is enough cooperation between energy and building companies. ☐ 1 – I disagree ☐ 2 ☐ 3 ☐ 4 ☐ 5 – I agree - How do you think the cooperation could be improved?
13. What do you think of when you hear the words "active building"?
14. What are the factors that negatively impact the development of active buildings?
15. Can you please grade the following smart grid features in buildings based on their importance? *Self-generation of* electricity ☐ 1 – Unimportant ☐ 2 ☐ 3 ☐ 4 ☐ 5 - Important *Local energy storage* ☐ 1 – Unimportant ☐ 2 ☐ 3 ☐ 4 ☐ 5 - Important *User response to electricity prices* ☐ 1 – Unimportant ☐ 2 ☐ 3 ☐ 4 ☐ 5 - Important *User response to greenhouse gas emissions* ☐ 1 – Unimportant ☐ 2 ☐ 3 ☐ 4 ☐ 5 - Important *Electric vehicles* ☐ 1 – Unimportant ☐ 2 ☐ 3 ☐ 4 ☐ 5 - Important *Home automation* ☐ 1 – Unimportant ☐ 2 ☐ 3 ☐ 4 ☐ 5 - Important *Smart electrical appliances* ☐ 1 – Unimportant ☐ 2 ☐ 3 ☐ 4 ☐ 5 - Important *Visualisation of energy use* ☐ 1 – Unimportant ☐ 2 ☐ 3 ☐ 4 ☐ 5 – Important *Smart systems that assist in energy-related decisions* ☐ 1 – Unimportant ☐ 2 ☐ 3 ☐ 4 ☐ 5 – Important *Hourly metering of electricity* ☐ 1 – Unimportant ☐ 2 ☐ 3 ☐ 4 ☐ 5 – Important
16. Who do you think will undertake the investments for the infrastructure?
17. Do you expect collaborations between sectors or the emergence of new actors for the investments?

18. Do you think that the wider use of active building technologies will significantly change the energy market conditions and business models in the future? - (Yes) In what ways do you think that it will change?
19. Do you think that the regulatory framework in Sweden is suitable for the development of active buildings?
20. Do you think that end-users are ready for the changes that smart grids will bring? If not, what do you see as useful to change this condition?
21. Would it be possible to contact you in the future?

Annex F. List of interview respondents from Hong Kong

	Stakeholder group	*Background*	*Position*	*Additional information*
1	Electricity utility	Privately owned	Senior project manager	35 TWh/year sold electricity
2	Electricity utility	Privately owned	Manager Manager	10.9 TWh/year sold electricity
3	Architectural firm	Privately owned	Director	Green and sustainable building design
4	Construction	Privately owned	Managing director	4,000 employees
5	Housing	State owned	Senior architect Senior building services engineer	9,000 employees
7	Consultancy	Privately owned	Senior engineer	Energy management and technology supply
8	Property development	Privately owned	Senior project manager	640 employees
9	Energy management	Privately owned	Senior consultant	Carbon reduction and sustainability projects
10	Energy management	Privately owned	Founder	Smart meter and energy visualisation applications
11	NGO for sustainable construction	Non-profit	General manager	Sustainable and green buildings
12	NGO for green buildings	Non-profit	Head of department	Evaluation of green building certifications
13	Sectoral interest organisation	Non-profit	Officer	Interest organisation for the construction industry

Annex G. Interview guide used in Hong Kong

1. Would you like to be anonymous?
2. What comes to your mind when you hear the words 'smart home'?
3. Can you please grade the following features in smart homes based on their importance and briefly explain your answers? *Self-generation of electricity* ☐ 1 – Low importance ☐ 2 ☐ 3 ☐ 4 ☐ 5 – High importance *Local energy storage* ☐ 1 – Low importance ☐ 2 ☐ 3 ☐ 4 ☐ 5 – High importance *User response to electricity prices* ☐ 1 – Low importance ☐ 2 ☐ 3 ☐ 4 ☐ 5 – High importance *User response to GHG emissions* ☐ 1 – Low importance ☐ 2 ☐ 3 ☐ 4 ☐ 5 – High importance *Electric vehicles for energy storage* ☐ 1 – Low importance ☐ 2 ☐ 3 ☐ 4 ☐ 5 – High importance *Home automation for energy activities* ☐ 1 – Low importance ☐ 2 ☐ 3 ☐ 4 ☐ 5 - High importance *Smart electrical appliances* ☐ 1 – Low importance ☐ 2 ☐ 3 ☐ 4 ☐ 5 - High importance *Visualisation of energy use* ☐ 1 – Low importance ☐ 2 ☐ 3 ☐ 4 ☐ 5 – High importance *Smart systems that assist in energy-related decisions* ☐ 1 – Low importance ☐ 2 ☐ 3 ☐ 4 ☐ 5 – High importance *Hourly metering of electricity* ☐ 1 – Low importance ☐ 2 ☐ 3 ☐ 4 ☐ 5 – High importance
4. Can you please name the factors that negatively impact the development of smart homes in Hong Kong?
5. Which actor do you think should undertake the investments for smart homes?
6. Do you expect collaborations between different sectors or the emergence of new actors for the investments?
7. How do you consider the role of new business models for the development of smart homes? - Do you think that the demand for smart homes will change the market conditions?
8. Do you think that the regulatory framework in Hong Kong is suitable for the development of smart homes? - If not, what changes do you suggest?
9. Do you think that a deregulated electricity market in Hong Kong would have positive impacts on the development of smart homes?
10. Do you think that consumers are ready for the changes that smart grids will introduce? - If not, what do you see as useful to change this condition? - Which user groups/sectors in Hong Kong do you see as potential early adopters?

Annex H. The survey questions used in Sweden

1. What do you think are the current energy challenges in Sweden today?

- You can choose multiple answers.
  - ☐ Lack of user interest in energy-related issues
  - ☐ Improving cooperation between the energy and buildings sectors
  - ☐ Reducing nuclear dependency
  - ☐ Smart grids and renewable energy integration
  - ☐ Achieving flexible energy use
  - ☐ Increasing energy efficiency in buildings
  - ☐ CO_2 emissions

2. How do you think the following trends in the buildings sector would impact the energy sector?

Increased energy efficiency
☐ 1 – Very negative ☐ 2 ☐ 3 ☐ 4 ☐ 5 - Very positive ☐ Don't know
Active and flexible customers
☐ 1 – Very negative ☐ 2 ☐ 3 ☐ 4 ☐ 5 - Very positive ☐ Don't know
Installation of self-generation systems
☐ 1 – Very negative ☐ 2 ☐ 3 ☐ 4 ☐ 5 - Very positive ☐ Don't know
Participation in demand response
☐ 1 – Very negative ☐ 2 ☐ 3 ☐ 4 ☐ 5 - Very positive ☐ Don't know
The use of alternative heating methods to district heating
☐ 1 – Very negative ☐ 2 ☐ 3 ☐ 4 ☐ 5 - Very positive ☐ Don't know

2. Please name any trends that you think are important but not included in this question.

3. How do you think the following trends in the energy sector would impact the buildings sector?

New energy services, e.g. guaranteed indoor temperature
☐ 1 – Very negative ☐ 2 ☐ 3 ☐ 4 ☐ 5 - Very positive ☐ Don't know
Increased fixed charges in the energy tariff
☐ 1 – Very negative ☐ 2 ☐ 3 ☐ 4 ☐ 5 - Very positive ☐ Don't know
Services for energy efficiency in buildings
☐ 1 – Very negative ☐ 2 ☐ 3 ☐ 4 ☐ 5 - Very positive ☐ Don't know
Introduction of new pricing methods, e.g. hourly pricing, peak pricing
☐ 1 – Very negative ☐ 2 ☐ 3 ☐ 4 ☐ 5 - Very positive ☐ Don't know

4. Please name any trends that you think are important but not included in this question.

5. How do you agree with the statement 'There is very good cooperation between the energy and buildings sectors'?

- ☐ Completely disagree
- ☐ Partially agree
- ☐ Mostly agree
- ☐ Completely agree
- ☐ Don't know

6. How do you think that it could be improved?[20]

[20] Only the respondents that selected the answers 'Completely disagree', 'Partially agree' and 'Mostly agree' were asked this question.

7. Which of the following describes the relationship between the energy and buildings sectors the best?

- ☐ Very poor trust for each other
- ☐ Poor trust for each other
- ☐ Adequate trust for each other
- ☐ Good trust for each other
- ☐ Very good trust for each other

8. What do you think are the reasons behind the mistrust between the two sectors?[21]

9. Do you agree with the following statements?

Transparency of district heating price setting should be increased

☐ Yes ☐ No ☐ Don't know

There should be more competition (third-party access) in district heating networks

☐ Yes ☐ No ☐ Don't know

If there was more competition in district heating networks, there would be better cooperation between the energy and buildings sectors

☐ Yes ☐ No ☐ Don't know

The deregulation of district heating networks would result in higher prices

☐ Yes ☐ No ☐ Don't know

A fixed component in the energy tariff has negative impacts on energy efficiency measures.

☐ Yes ☐ No ☐ Don't know

Self-generation of electricity can create business opportunities for energy companies

☐ Yes ☐ No ☐ Don't know

The price of electricity varies too little over the day to create incentives for demand flexibility

☐ Yes ☐ No ☐ Don't know

10. Which of the following comes to your mind when you hear the words 'active building'?

- You can make multiple selections or specify a feature that is not listed by selecting 'Other' and answering the next question.
  - ☐ Interaction with the energy system
  - ☐ Environmentally friendliness
  - ☐ Automation of energy activities
  - ☐ Local energy storage
  - ☐ User response to emissions
  - ☐ User response to electricity prices
  - ☐ Self-generation
  - ☐ Flexible electricity use
  - ☐ Don't know
  - ☐ Other (Please specify in the next question)

11. Please specify the feature or features that come to your mind when you hear the words 'active building' but are not included in the list[22].

An active building participates in the efficient operation of the electricity network by energy demand flexibility, small-scale power production and storage. It provides real-time information about energy prices and related emissions as well as functions that allow manual or automatic energy management. Please continue the survey by clicking on the arrow below.

[21] Only the respondents that selected the answers 'Very poor trust', 'Poor trust' and 'Adequate trust' were asked this question.
[22] Only the respondents that selected 'Other' were asked this question.

12. How would you rate the importance of the following features for buildings to become more 'active' in the energy system?

- Please select your answer on a scale from 1 to 5, with 1 meaning the lowest importance and 5 meaning the highest importance.

Self-generation of electricity

☐ 1 – Lowest ☐ 2 ☐ 3 ☐ 4 ☐ 5 - Highest ☐ Don't know

Local energy storage

☐ 1 – Lowest ☐ 2 ☐ 3 ☐ 4 ☐ 5 - Highest ☐ Don't know

User response to electricity prices

☐ 1 – Lowest ☐ 2 ☐ 3 ☐ 4 ☐ 5 - Highest ☐ Don't know

User response to GHG emissions

☐ 1 – Lowest ☐ 2 ☐ 3 ☐ 4 ☐ 5 - Highest ☐ Don't know

Electric vehicles for energy storage

☐ 1 – Lowest ☐ 2 ☐ 3 ☐ 4 ☐ 5 - Highest ☐ Don't know

Automation of energy activities

☐ 1 – Lowest ☐ 2 ☐ 3 ☐ 4 ☐ 5 - Highest ☐ Don't know

Visualisation of energy use

☐ 1 – Lowest ☐ 2 ☐ 3 ☐ 4 ☐ 5 - Highest ☐ Don't know

Smart systems that assist in energy-related decisions

☐ 1 – Lowest ☐ 2 ☐ 3 ☐ 4 ☐ 5 - Highest ☐ Don't know

13. Which of the following factors do you think that negatively impact the development of 'active buildings' in Sweden?

- You can make multiple selections.

☐ Lack of suitable business models
☐ Insufficient inter-sectoral cooperation
☐ High uncertainties, e.g. economic risks
☐ Undeveloped technologies
☐ Lack of standardisation of technologies
☐ Regulatory framework
☐ Lack of interest
☐ Lack of initiatives
☐ High investment costs
☐ Low energy prices
☐ Don't know
☐ Other (Please specify in the next question)

14. Please specify the factors that negatively impact the development of "active buildings" in Sweden but are not included in the list[23].

15. Who do you think should invest in the infrastructure that supports active buildings?

- Please select one of the following actors or specify an actor that is not included in the list by selecting "Other" and answering the next question.

☐ Building owner/housing company
☐ Electricity retail companies
☐ Third party suppliers
☐ Technology suppliers
☐ Electricity distribution companies
☐ Don't know
☐ Other (Please specify in the next question)

[23] Only the respondents that selected 'Other' were asked this question.

16. Please specify the actors you think that should invest in the infrastructure that supports active buildings but are not included in the list[24].

[24] Only the respondents that selected ‘Other’ were asked this question.