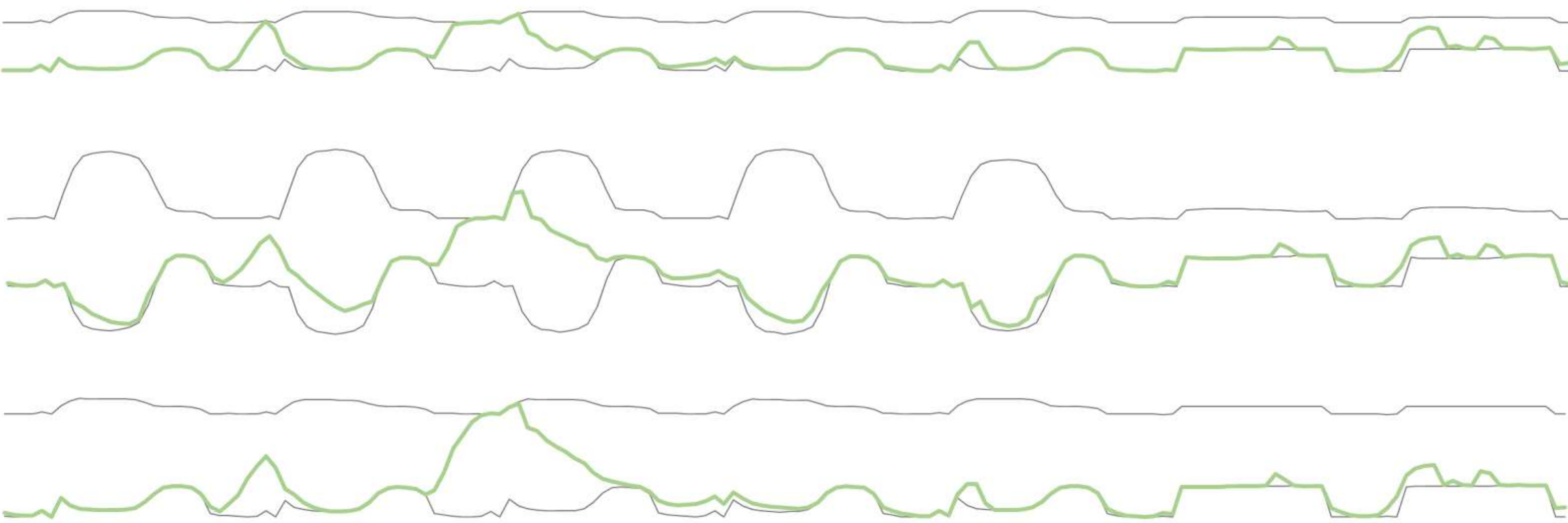
CHALMERS UNIVERSITY OF TECHNOLOGY | UNIVERSITY OF GOTHENBURG

Behavioural Roots and System Effects of Residential Electric Heating DSM

Household Willingness and Potential to Participate in Electric Heating Demand Side Management and its Significance for Balancing Wind Intermittency

Master's Thesis in Industrial Ecology



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Cover:
[Weekly temperature variations for the different participation scenarios, see report section 5.2.3.]

Abstract

In a wind dominated future electricity system, consequences of intermittency can be reduced through residential demand side management (DSM), but studies on this subject generally lack understanding of resident behaviour. This work is an interdisciplinary master's thesis, aiming to bridge the gap between behavioural studies and electricity systems modelling. The work is carried out at the Department of Energy and Environment at Chalmers University of Technology, in cooperation with the research group of Environmental Psychology at Gothenburg University, and relates to previous electricity system research on DSM of electric heating in Swedish single family dwellings (SFDs) in a future scenario of a north European wind dominated electricity system.

A survey is sent out and answered by 338 E.ON customers living in SFDs. The survey answers are used to model the potential for Swedish electric heated SFDs to reduce costs and emissions in a wind dominated northern European electricity system by accepting variations in their indoor temperatures. The outcome shows that there is potential to reduce electricity demand by around 1.6TWh/year, costs by around 120M€ and CO_2 emissions by around 870 tonnes by applying DSM in all Swedish SFDs with electric heating.

If it is desired to stimulate additional DSM efforts in SFDs it is found that system benefits are larger when making the household’s accept a slight increase in variations all time, rather than allowing for a significant increase in temperature variations at times when no one is home. It is found that people are overall willing to participate in the DSM-scheme and that they are mainly motivated by the environmental benefits, regarding DSM as mitigating the social dilemma of climate change. The main factor explaining the participation level is found to be the respondents awareness of the connection between electricity use and climate change.

Further research is suggested for residential DSM in other system contexts, such as countries without hydropower which can be expected to be more affected by wind intermittency. Future pilot studies investigating actual, rather than theoretical, household participation and experiences of temperature variations are also suggested.

Keywords:
Demand Side Management, Demand Response, Wind Intermittency,
Temperature Regulation, Willingness to Participate, Goal Framing Theory,
Household Behaviour, Electricity System Modelling, Climate Change

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Yrsa Dahlman and Hanna Gerhardsson
Gothenburg, May 2017

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List of Abbreviations

AC	Awareness of Consequences
AR	Ascription of Responsibility
BP	Barrier for Participation
CCS	Carbon Capture and Storage
DR	Demand Response
DSM	Demand Side Management
EC	Environmental Concern
GAG	Gain Goal Accessibility
GAH	Hedonic Goal Accessibility
GAN	Normative Goal Accessibility
PTP	Potential to Participate
SC	Subjective Comfort
SE	Subjective Economy
SFD	Single Family Dwelling
WTP	Willingness to Participate

1 Introduction

During the last 11 700 years our earth has stayed in a relatively stable state, *the Holocene epoch*, the only state in which we are ensured that our earth can support contemporary human societies. A high degree of change in our climate would likely, by its own, be enough to push the Earth system out of the Holocene state. To avoid this, the EU has restricted the maximum allowable increase of the global mean temperature to 2°C above preindustrial temperature. Unfortunately, human activities causing the climate to change are ongoing, like emitting CO_2 through burning of fossil fuels to receive energy (Steffen et al 2015). Ever since the industrial revolution, people in developed countries have not needed to adapt themselves to nature and its rhythms to achieve electric power. Our problem of leaving the current *carbon lock-in* reflects how this has shaped our expectation on power supply and natural systems (Klein 2014).

Even though people in general do consider climate change as an important problem, we do not engage in enough mitigation behaviour to stem the increasing flow of greenhouse gases risen by our current societies. This is partly due to structural issues, like how our societal infrastructure is built up, but also relates to psychological factors like lack of awareness of consequences or the feeling that someone else is responsible for taking care of the problem (Gifford 2011).

Electricity, supplying a fifth of the global total energy demand (IEA 2016), and powering an increasing variety of human activities, has the potential of being a clean and convenient energy carrier, but unfortunately todays production of electricity often entails huge environmental, social and political problems. Overall, electricity production calls for a radical transformation away from fossil sources of power. This could be achieved either through nuclear, CCS technologies, renewable power sources, or through a combination of these. However, one big question problematizing a transition to renewables is how supply and demand of electricity can be balanced when large amount of intermittent power sources, such as wind energy, is connected to the grid (Sandén 2014). A tool that can be used to handle these challenges is Demand Side Management (DSM); a variation management strategy where the consumers of electricity adapt to the production of electricity, rather than, as traditionally, the production adapting to consumer demand. In colder parts of the world, such as Sweden, residential electric space heating constitutes a significant part of the electricity load, and has previously been shown to be well suited for DSM (Nyholm 2016).

An interdisciplinary research, studying both the hard values of the electricity system and the softer values of how electricity consumers use, and view, electricity, is required to increase the understanding of the possibilities of DSM, both in the transition to a more sustainable electricity system, and in the resetting of power relations between us and the planet we depend on.

1.1 Aim

The aim of this thesis is to help bridge the knowledge gap between the technical and behavioural aspects of the residential sector electric heating DSM potential to manage wind intermittency. This is done by building on previous work on electric space heated single family dwellings (SFDs) in Sweden and its electricity system effects. A survey is used to investigate household's potential and willingness to take part in an DSM-scheme. Survey results are translated and used to model the household potential to participate and its effects on a north European wind dominated system. Conclusions are drawn regarding the psychological roots of the household willingness and potential to take part in electric heating DSM. Further, system effects of altering the participation level are investigated.

1.2 Research Questions

Question 1:
What are Swedish SFD residents willingness and potential to participate in DSM of electric heating?

Question 2:
What psychological aspects are guiding the willingness to participate?

Question 3:
What electricity system effects could be expected by implementing a DSM-scheme, in a wind dominated system, based on the household's potential to participate?

Question 4:
To what extent are these electricity system effects altered by a changed participation level, rooted in the need for private investments, slighter comfort sacrifices, or a focus on technology development?

1.3 Limitations

This work is limited to investigating DSM theoretically using a survey and models in order to describe residential heating DSM and household participation. It is further limited in looking at DSM in a specific sector, in a specific country and in a specific system, which means the conclusions from the work relate to DSM in a specific context rather than to DSM in general. This specific context is residential heating DSM for Swedish electric heated SFDs in a wind dominated system. This limits the conclusions since Sweden is characterised by a high amount of hydro power and a cold climate, affecting the outcome of the work. The results are also restricted to the building stock model, which specifically describe the Swedish building stock.

Limiting the investigation of DSM to one sector in one country entails limited overall system effects, and the work does not investigate what would happen if residential heating would be applied more extensively throughout the system, or in a different country. Furthermore, since the study relates to DSM in a system where the wind power penetration levels lies on 47%, the potential for DSM in other types of production systems such as solar dominated or thermal systems are not covered by this work.

The modelling is constrained in terms of using a cost optimized model, implying that there may be more environmentally beneficial outcomes. There might also be benefits of DSM on both shorter and longer timescales than investigated in this thesis. The system technology investments are further fixed, meaning that all effects of the DSM-scheme that can be found, and laborated with, are within one specific investment scenario.

The central behavioural limitation of the work is that household residents habits and actions are searched through a theoretical survey, rather than observed in practical situations.

2 Swedish Electricity System

In this chapter the constitution of the Swedish electricity system is introduced in terms of production, consumption and trade with surrounding countries. In a global perspective the Swedish electricity production is clean: it has the third least amount of CO_2 emissions related to each unit of electricity produced in the country, after Iceland and Norway (Swedenergy 2016). Still Sweden is not isolated from the rest of the electricity system: if electricity use in Sweden is managed properly clean energy produced in Sweden can be traded and reduce fossil energy otherwise produced somewhere else. The last couple of years Swedish electricity production has exceeded the Swedish electricity demand, resulting in a net export of electricity from Sweden to other countries (Swedenergy 2016).

2.1 Swedish Electricity Production

In 2015 the Swedish electricity production amounted to 158.5TWh, with about 47% produced from hydropower, 35% from nuclear power, 10% from wind power and the rest from conventional thermal plants using mostly biofuels as an energy source. In all, around 98% of the electricity produced in Sweden is produced from non-fossil energy sources (SEA 2016, Swedenergy 2016). While still constituting a fairly small fraction of the total production, wind power is the power technology related to most of the new capacity investments in Sweden today. The Swedish wind turbine capacity has increased by around 40% between 2014 and 2015, while the two largest production technology capacities, nuclear and hydro, have more or less stabilized (figure 2.1) (Swedenergy 2016).

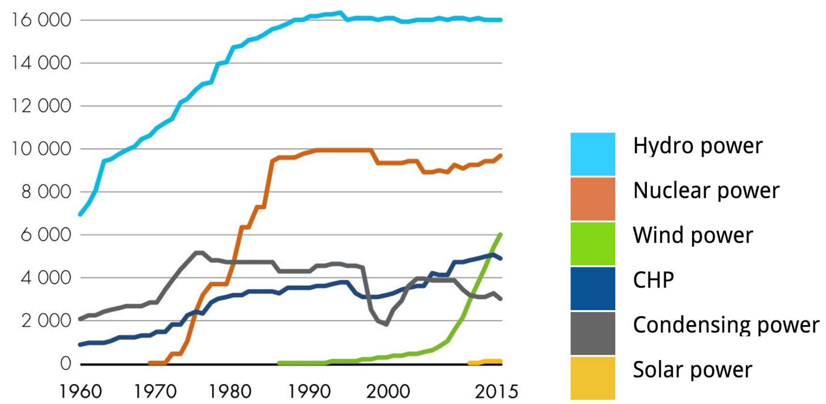


Figure 2.1. Development of power technologies in Sweden over time [MW] (Swedenergy 2016, p. 28 diagram 19).

The fact that the Swedish electricity production causes little CO_2 emissions is mainly due to the naturally suitable environment for hydropower, in combination with a long tradition of nuclear power. While the northern half of the country contains over 80% of the Swedish hydropower capacity and has an overall electricity production surplus, the southern half of the country contains all Swedish nuclear reactors and is characterised by an overall electricity production deficit (Swedenergy 2016, Elområden 2011).

Hydropower is the main contributor to the Swedish electricity production and is a very useful technology from a system perspective since it has low running costs and start up costs. This means the energy can be stored and used when most needed, reducing system production costs and helping to balance system variations. Although hydropower is a renewable energy source with a high value from a system perspective, its capacity is unlikely to increase significantly in the future, due to that it is a mature technology limited by both environmental and societal factors (Sandén 2014, Sandén et al 2014).

Nuclear power has been produced in Sweden since the 1970's, and has over the years been the subject for a continual political debate. Today, six of the twelve Swedish reactors either have already been shut down or are planned to shut down (SRSA 2017).

2.2 Swedish Electricity Consumption

In Sweden about one third of the energy we consume every year is in the form of electricity (SEA 2016). 2015 the Swedish electricity consumption amounted to 135.9TWh, with the remaining 22.6TWh of the Swedish production being exported to other countries. About 37% of this electricity demand is consumed by the industry, 30% by the residential sector, 26% by the service sector and the rest (7%) being lost through transmission (Swedenergy 2016).

Since a significant part of the Swedish electricity consumption, in all sectors, is related to heating, the seasonal demand pattern depends largely on outdoor temperatures, with demand rising as outdoor temperature decreases and vice versa (figure 2.2). When it comes to diurnal demand variations, weekday electricity demand has a largely recurring pattern, with demand peaks around 8am in the morning and 5pm in the evening (Swedenergy 2016).

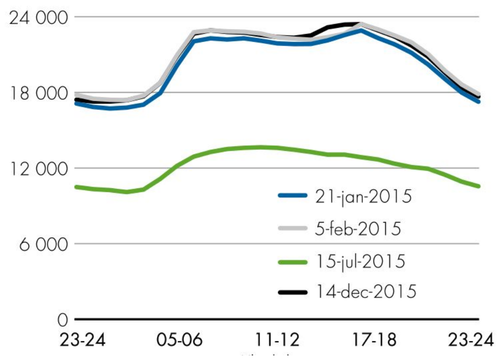
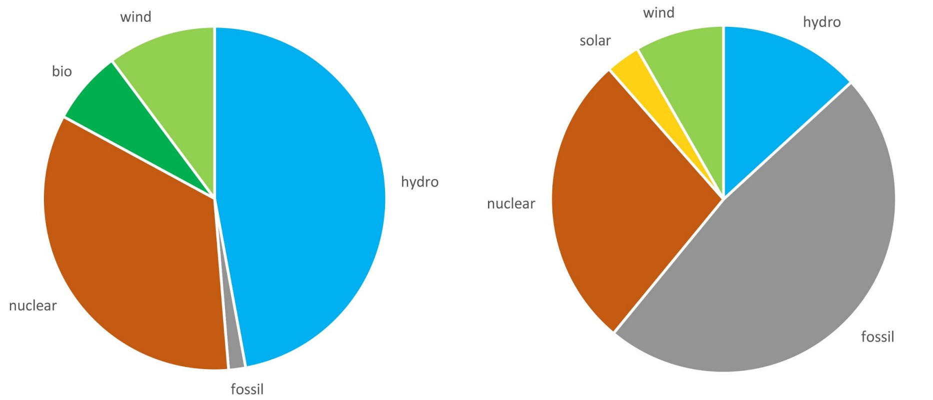


Figure 2.2. Diurnal electricity demand profile in Sweden 2015 for different times of year [MWh/h] (Swedenergy 2016, p. 40 diagram 37).

2.3 European Electricity Trade

In order to cover the Swedish electricity demand and achieve balance at every instant, the Swedish system is dependent on transmission and trade within the country as well as with surrounding European countries. By importing and exporting electricity, the varying technology characteristics and production conditions in the different countries and regions can be utilized in order to balance the system and avoid electricity price peaks. Due to the possibilities of trade, the electricity consumed in Sweden is not necessarily the electricity produced in Sweden, and vice versa. Hence, limiting the viewpoint to the national boundaries is deceptive in this context, since changes in Swedish electricity production or consumption have effects on the production and consumption in many other countries. When expanding the viewpoint to Europe, the average electricity production looks vastly different from the carbon-neutral picture of Swedish production (figure 2.3a), with almost half of the produced electricity originating from fossil fuels, and just about one fourth from renewable resources (figure 2.3b) (Eurostat 2016). Since Sweden today has transmission connections with several European countries, the Swedish production and consumption is closely linked to the production and consumption also in these countries.



Figures 2.3a-b. Electricity production 2015 in Sweden (a) (SEA 2016) and EU-28 (b) (Eurostat 2016) [%TWh].

3 Theoretical Background

In this chapter, following the introduction to the swedish electricity system given in chapter 2, the reader is given the background knowledge needed to follow the work carried out. In section 3.1 characteristics of a future system with high levels of wind penetration are described, ways to handle wind variations are discussed and DSM is introduced as a potential tool manage electricity in the residential sector. In section 3.2 previous research emphasizing the interdisciplinary nature of DSM, and the need of behavioural studies when investigating residential electricity consumption is presented. The third section, 3.3, introduces previous behavioural research relating to the psychology behind behavioural change and acceptance of new technology and pro-environmental schemes.

3.1 Wind Variation Management

In the challenge of leaving the fossil era and developing a global electricity system based on renewable energy, wind, together with solar, energy are predicted to play a significant role (Sandén 2014). Wind power availability for a specific time is largely unpredictable on the longer time horizon, e.g. a month or year beforehand, and does not follow a clear pattern (Steen et al 2014, Carlson et al 2014). Due to the high level of variations related to wind, variation management is important if the share of wind power in the system is to be increased.

3.1.1 System Aspects of Wind Intermittency

Though it is widely agreed that expanding the global utilization of wind energy is required in order to reduce CO_2 emissions, introducing large fractions of this technology into today's system changes and challenges the system in many ways. This is because in an electricity system with significant amount of intermittent supply the supply technologies are not fully adaptable to the electricity demand, since also the intermittent power supply varies over time (Ehnberg et al 2014).

Wind Variation Characteristics

While demand variations are quite predictable and follow a certain pattern, wind supply variations can be quite problematic from a systems perspective, since the wind power availability for a specific hour, day, week or month is largely unpredictable on longer time frames, and does not follow a clear pattern. However, on a yearly level a slight pattern of increased availability in winter time can be noted in northern Europe (figure 3.1), which correlates well with Swedish yearly demand variations with higher demand related to winter time heating (Steen et al 2014, Carlson et al 2014).

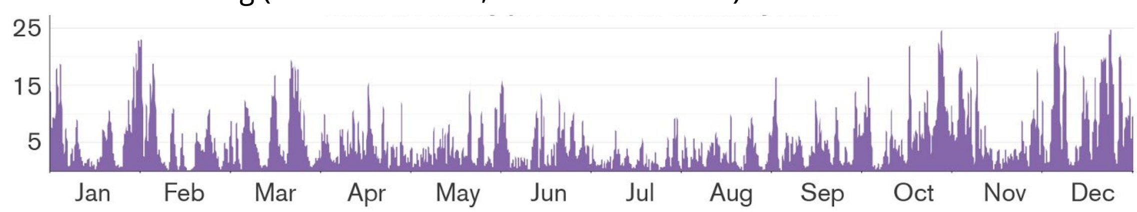


Figure 3.1. Yearly wind production variability for Germany 2013 [GWh] (Carlson et al 2014, p. 35 figure 4.3).

In order to analyse the system implications of introducing intermittency it is commonly talked about the *net load,* which usually means the load to be supplied from non-intermittent power sources. Figure 3.2 shows a weekly electricity load and net load in Denmark, a country with a high wind penetration in their electricity system. As can be seen, both size and irregularities of the load variations increases when intermittent wind power production is accounted for (Göransson 2014).

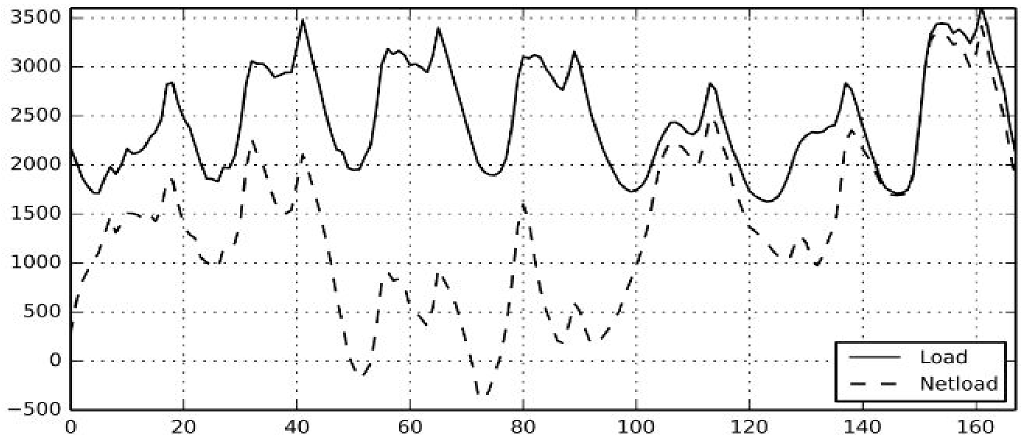


Figure 3.2. Load and net load excluding wind production for the first week of January 2013 in western Denmark [MWh] (Göransson 2014, p. 19 figure 1).

System Costs

Another important characteristic of wind power production is its extremely low running costs, once the initial capacity investment has been made (Kåberger 2014). This means that whenever the conditions are good, the wind turbines will, more or less, be used to supply electricity. Some other system technology will then be forced to reduce its production temporarily, while standing by to start producing again when the conditions for the wind power are no longer favorable. This creates problem in a system with high amounts of inflexible base load technologies, as is evident for the case of the Swedish nuclear, where an increased penetration of wind power production has forced the plants to run inefficiently, vastly reducing their profits (Göransson 2014, Swedenergy 2016). Introducing large fractions of intermittent wind generation also means introducing the possibility to sometimes have large amount of power available, while at others (e.g. a calm day) have none. When no renewable energy is available, there has to be enough non-intermittent power capacity to meet demand. This implies that a system with a large fraction of intermittent supply needs to build a larger supply capacity than a traditional system in order to meet the same level of demand (Göransson 2014).

Variation Management

The concept of variation management is commonly talked about as a means of efficiently solving the problems related to intermittency. The concept is a mix of different types of strategies to manage the variations caused by system intermittency or demand variations. Basically it boils down to whether to balance the system using other production technologies, by adapting electricity demand, or by storing the electricity until it is needed

(Ehnberg et al 2014). The different strategies have different qualities, work differently in different types of system, and could complement each other by playing different roles in a future system.

As mentioned in Chapter 2, both hydropower and trade can be used to manage the variations caused by wind production, with the hydropower working as a type of storage. By having the possibility to trade, the intermittent aspects of wind power production can be reduced, due to the likelihood of wind power being available at any given time, somewhere in the system (Göransson & Lundberg 2014).

Another way to manage production variations is by curtailing some of the wind energy, which is different than other management strategies in the sense that it can only help to reduce production, and is not a strategy to enable a more efficient use of production (Nyholm 2016). To what extent wind is curtailed depends on the surrounding production system; in a system with a lot of inflexible power technologies the costs of decreasing production are high, while in a system with a lot of flexible production and other variation management strategies, curtailment can, to a great extent, be avoided (Göransson 2014).

3.1.2 Demand Side Management

The variation management strategy called Demand Side Management (DSM) basically means making electricity demand more flexible both in time and in size. It entails a new, more active role for the electricity consumers who have historically been seen largely as passive in their demand (Nyholm 2016). DSM can be used similarly to other variation management strategies, and as with other variation management strategies, its role and potential depends largely on the surrounding system costs and variabilities. It is to a large part a decentralized variation management strategy in the sense that the often small consumer loads available to manage the variations are spread out in the system. Its current deployment is tightly linked to the simultaneous development of smart technology; smart grids and smart meters (Nyholm 2016). With DSM developing alongside these smart technologies, the possibilities to collect and transfer information between the decentralised consumers and the electricity production are expected to increase. This would allow the system to act with higher speed and accuracy on the available information, and adapt demand to production when there are incentives to do so, making DSM a much more valuable and efficient way to manage variations (Nyholm 2016).

Energy Conservation and Demand Response

The possibilities to apply DSM on electricity demand depends largely on the type of load which is to be managed. One way to manage electricity demand is to decrease the total amount of electricity consumed by behavioural or technical system changes, a strategy referred to as *energy conservation* or *load shedding* (figure 3.3a). Another way to manage electricity demand is by shifting the load in time, in order to better utilize the supply system and decrease the system costs and emissions. This concept is referred to as *demand response* (DR) or *load shifting* (figure 3.3b).

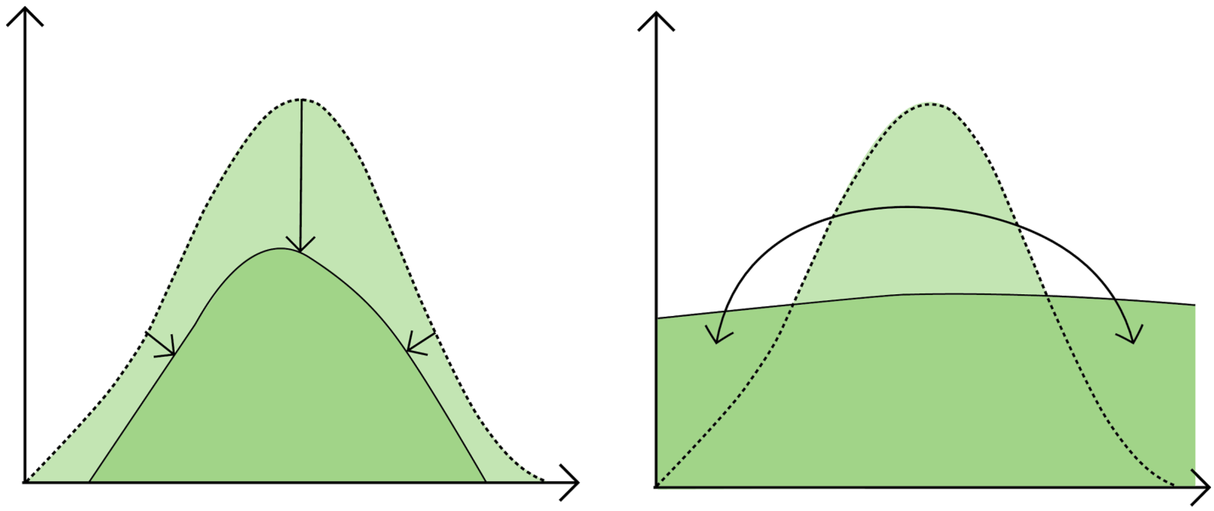


Figure 3.3a-b. Effects on electricity demand from energy conservation (a) and demand response (b).

DSM in Different Electricity Systems

When it comes to DSM, DR is the management strategy most affected by the production technology composition. By simply decreasing the total amount of production, energy conservation decreases the need for new investments as well as the total system cost, regardless of system composition. For DR, however, its ability to manage system variations makes its role very different depending on the production composition in the system it is applied in. The potential value of DR in a given system depends on aspects such as fuel prices, transmission characteristics, demand and supply variations and flexibility of the non-intermittent production (Tuohy et al 2014).

Traditionally, DR has been used mainly to reduce load variations, in order to decrease the need for production flexibility. This is done by decreasing demand at high production cost peak hours (peak clipping, figure 3.4a) while increasing demand when production is cheaper (valley filling, figure 3.4b). Since diurnal demand variations are pronounced and predictable, DR is usually used to shift demand from the daily peaks toward a nighttime consumption (Nyholm & Steen 2014). By doing this, a larger portion of the production can be supplied by base load plants, reducing the total system costs.

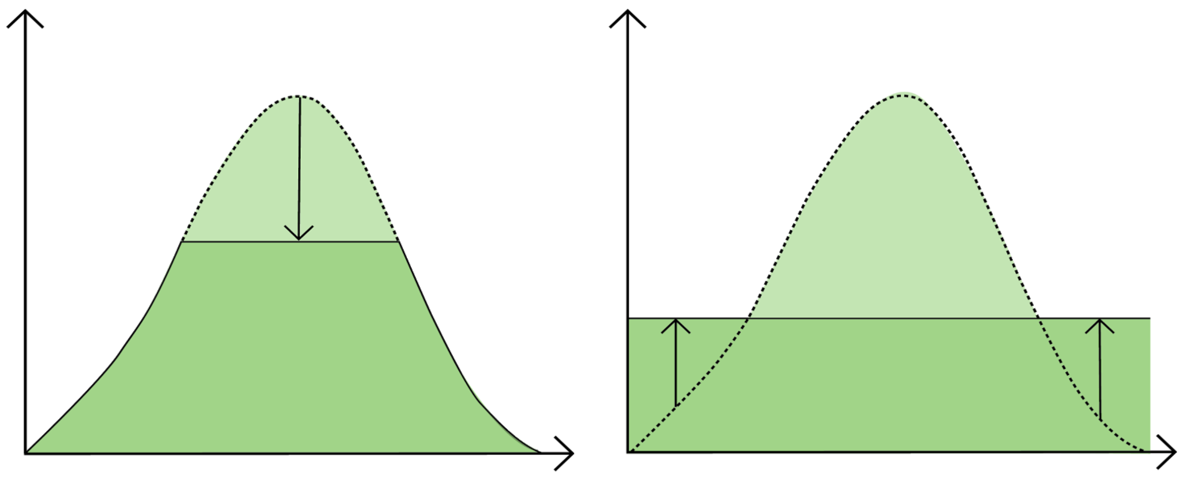


Figure 3.4a-b. Traditional DSM use through peak clipping (a) and valley filling (b).

In a system with a high penetration of intermittent supply, the value of DR can be high, since the need for any type of variation management to balance the intermittency is huge. In this type of system, DR is used in order to manage the net load variations. This means that from a systems perspective, it could be beneficial to increase, rather than decrease, the variability of demand, in order to better match the intermittent supply (figure 3.5b) (Nyholm 2016). Overall, increasing the demand to high levels when the winds are blowing, and to low levels when they are not, helps reduce curtailment and non-renewable electricity production. However, it is widely recognized that the main potential for DR in relation to intermittency is at a shorter time frame, while any longer demand shifts are seen as improbable (Nyholm & Steen 2014). This means that while DR may be useful to make the electricity system adaptive to wind variations on an hourly or daily basis, large long term variations (stormy periods and periods of completely wind absens), can exceed the flexible space created through DR.

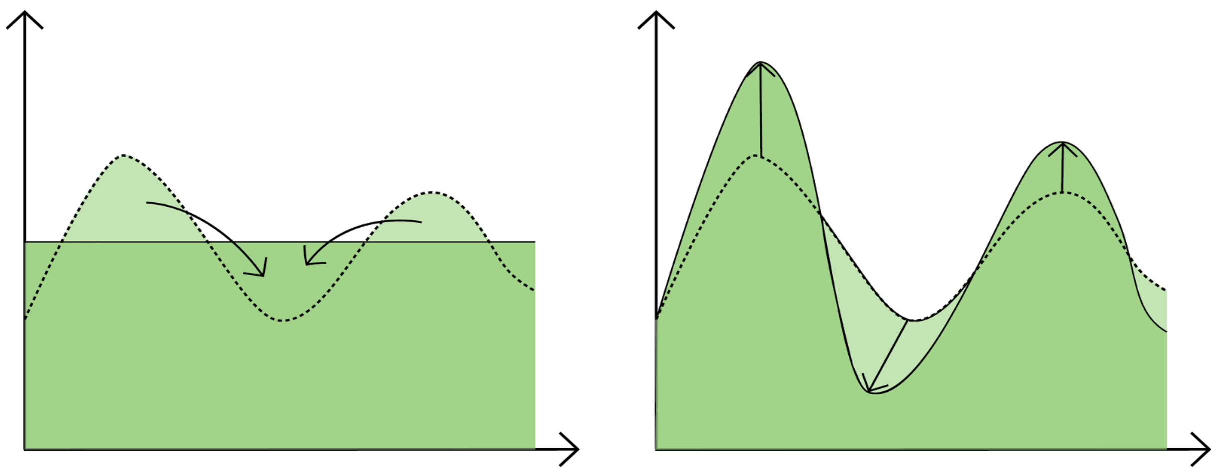


Figure 3.5a-b. DR impact on demand variations in a thermal system (a) and an intermittent system (b).

3.1.3 Residential Sector DSM

DSM can be utilized in different sectors, for example by stopping or shifting production in the industrial sector or by managing air heating or cooling in the commercial or residential sector (Nyholm & Steen 2014). The total Swedish residential electricity demand is a significant load, constituting 30% of the total Swedish electricity demand, which makes it an interesting option for reducing demand by energy conservation, as well as for helping to balance system variations through DR. The residential electricity demand, however, is not a homogenous load, but consists of several loads with very different characteristics and suitability for DSM (Tuohy et al 2014).

Residential Loads

To analyse the potentials of the different residential loads, Seebach et al (2009) has classified four different load qualities important for its value for DR. The first quality relates to how big the load is, the second to how often the load is available for shifting, the third to for how long the load can be shifted and the last quality relates to how convenient or inconvenient the shifting would be for the consumer. Based on these factors Seebach et al conclude that the residential loads with the overall highest DR potential are the loads of electric heating and water heating (table 3.1). This is to a high extent due to the fact that heating is a large load - electric heating constituting about 50% of Swedish residential electricity demand - which due to the thermal storage capacity of the building mass can be relatively easily shifted for a couple of hours without significant losses in comfort or temperature. Dishwashers and washing machines represent big loads but are only available for shifting short periods of the day and its shifting represent inconvenience for the consumer, while refrigerators and freezes represent a small load and can be shifted only over short time spans. Studies also show that electric heating, apart from being a large residential load, is among the loads with the higher consumer acceptance for its DR use (Seebach et al 2009). The load is also interesting for energy conservation, since the service of comfortable indoor temperatures is today usually not reserved for the times when residents are at home, but rather constantly active, even when the service is not used.

Table 3.1. Residential electricity loads and their suitability for DR (Nyholm 2016, Table 1. p. 12, adopted from Seebach et al. 2009).

	Washing Machines and Dishwashers	**Freezers and Refrigerators**	**Electric Heating**
Load Size	high	low	very high
Availability	low	high	moderate
Flexibility	moderate	low	high
Convenience	low	high	high

In the context of residential electric heating DSM, single family dwellings (SFDs) are of highest interest, since most Swedish multi family dwellings are heated by district heating, while about 1.3 million of Sweden's 2 million SFD's are heated by some type of electric heating (Nyholm 2016).

DSM of Electric Heating in Swedish SFDs

DSM of electric heating in Swedish SFDs has previously been researched by Nyholm (2016), using a building-stock model to describe the heating demand of the dwellings, and creating a sub-model simulating an electric heating DR-scheme. The simulations made in the study are based on the assumption of homogenous routines and preferences among all households, as well as a 100% willingness to participate in the scheme. The study investigates different production composition contexts and shows that the system value of residential heating DR is considerably higher in a system with a high penetration of wind power. The value of DR in this type of system is seen to consist mostly of reducing the need for cycling of the inflexible thermal plants, as well as decreasing the need to run high cost peak load power plants. DR is found to change the diurnal load pattern by decreasing daytime demand and increasing nighttime demand. Nyholm found the monetary savings for the households taking part in the scheme to be rather low (1-200€/year), and varying significantly between households, highly dependent on building characteristics.

3.2 Interdisciplinary Nature of DSM

Even though the residential sector is a huge consumer of electric power, there are far fewer works about applications of DSM programs in the residential sector than in industrial and commercial sectors (Sharifi et al 2017). Because DSM today is rarely profitable, the research is in general limited to modellings and assumptions (Tuohy et al 2014). The residential sector is particularly hard to model due to the fact that occupant behaviour varies widely, while at the same time playing a crucial role for the consumption level (Swan & Ugursal 2008).

However, in a future electricity system with high levels of intermittent power supply and an increased deployment of smart technology, the value of DSM is expected to increase significantly (O'Connell et al 2014), also increasing the importance of understanding the potential of DSM of residential electricity consumption. This potential can not be found without an interdisciplinary approach, combining the fields of behavioural studies and electricity systems.

3.2.1 DSM Potential

Nyholm (2016) discusses three different types of potential for DSM. The *technical potential* is the actual load available for DSM, and the maximum time it could be shifted when it comes to DR. The *economic potential* is the part of the technical potential for which it makes economical sense to use the load for DSM in order to increase profits or decrease costs. The *achievable potential* is the part of the economic potential for which DSM actually takes place, which is largely dependent upon behavioural aspects, and is the main limiting factor for a large part of residential DSM (Nyholm 2016).

3.2.2 Potential of Residential Heating DSM

The load available for residential electric heating DSM is relatively big. However, how large part of the load that can be shifted through DR, and how far, depends on behavioural factors such as consumer habits and attitudes toward changing temperatures (Nyholm & Steen 2014). Since behavioural analysis has classically fallen outside the scope of natural science focused system modelling, the achievable potential of DSM in residential sector has not been investigated properly. Still, factors such as how consumers feel about potential inconveniences and savings related to DSM has been acknowledged, within the research area of system modelling, as important for identifying measures needed to close the gap between the achievable and economic potentials (Nyholm 2016). The unpredictability and heterogeneity of household resident behaviour and reactions to different incentives have been recognized as one of the most important issues to be investigated, in the context of residential DSM (Sharifi et al 2017).

Household Participation

Research is needed to achieve a better understanding of to what extent, and why, consumers are willing to participate, since the effects of a DSM-scheme can be strongly hindered by consumer reservations. To understand why consumers are willing to participate in a scheme or not, it is important to investigate consumer attitudes towards the scheme, what *motives* are strongest in making consumers accept the scheme, and what *psychological barriers* that might block their acceptance. Todays assumption of full social acceptance of the technology, will not do in the search for a reasonable, instead of a highly overestimated, potential of the schemes (Ellabban & Abu-Rub 2016).

When investigating DSM in the residential space heating context, behavioural research on how people's lives are scheduled, and on what temperature variations people find acceptable, is also necessary, in order to help mapping the households actual potential to contribute to the scheme.

3.3 What Precedes Behaviour

Even though people in general do consider climate change to be an important issue, people do not engage in enough mitigation to suppress the increasing flow of greenhouse gases risen by engagement in high-greenhouse-gas-emitting behaviour. The explanation for this attitude-behaviour gap partly lies is structural barriers, such as a climate-averse infrastructure, but this is not exhaustive, and removal of structural barriers is unlikely to be sufficient to make people drop out of high-greenhouse-gas-emitting behaviour. What is often missed by technical experts is that psychological barriers also impede behavioural choices that would facilitate environmentally sustainable behaviours. Participation in environmentally beneficial behaviour can be hindered e.g. by lack of trust in authorities advocating the behaviour or by worldviews such as overconfidence in technology efficiency and its promise of alone bringing the final solution, or the conviction that we should let mother earth take care of herself (Gifford 2011).

3.3.1 Technology Acceptance Model

When a behaviour implies acceptance of new technology, such as a heat regulating DSM-scheme, the *Technology Acceptance Model* (TAM) has been proposed for understanding people's behaviour. TAM highlights that *perceived ease of use, perceived usefulness* and *perceived risk* determine a person's intention to participate, or not to participate, in the behaviour and Ellabban and Abu-Rub (2016) have pointed out three aspects of *perceived usefulness* that need to be considered when trying to make people participate in a scheme that relies on smart technology (figure 3.6).

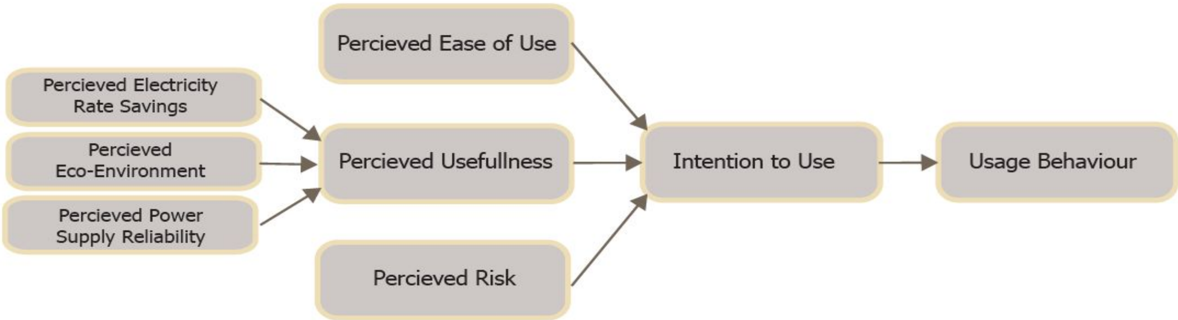


Figure 3.6. TAM with external variables of Perceived Usefulness, relating to acceptance of smart technology.

The components of the perceived usefulness corresponds to three claimed motivations for participating in a DSM-scheme, supposedly dominating in different groups of people; decrease of the electricity bill, decreases of the environmental load from the house heating, and the improvement of the indoor climate (Ellabban & Abu-Rub 2016).

3.3.2 Goal Framing Theory

The three motivations presented above, antecedent of perceived usefulness, also correspond to the main goals in the *Goal Framing Theory*; *gain goals*, *hedonic goals* and *normative goals.* The Goal Framing Theory postulates that the way a person behaves in a specific situation depends on what goals are activated. The goals, if activated, help "frame" what knowledge and what attitudes that are cognitively accessible for a person in a specific situation (figure 3.7). Through this, the goals determine how a person interprets a situation, and consequently behaves. This implies that when confronted with a DSM-scheme a person will be attracted by different incentives depending on the constitution of her/his goal frame (Lindenberg & Steg 2007).

Figure 3.7. Goal Framing theory: Situational factors shape the goal frame, which determines the receptivity to situational cues.

Gain goals seek to manage, guard and improve personal resources, which is clearly the dominating motive when a person participates in the DSM-scheme in order to decrease the household's electricity bill. *Hedonic goals* strives for pleasures and to improve feelings, and thereby correspond well to the motive of improved indoor climate for the case of participating in the DSM-scheme. *Normative goals* aims for appropriate behaviour and for doing *the right thing*, which is the case when the motive behind participation in the DSM-scheme is to decrease the environmental load from the household's electric heating (Lindenberg & Steg 2007).

An important implication of normative goals is that when the goal of acting appropriately guides a person, that person will search memory and environment for cues on what behaviour that would be appropriate in the situation at hand. In situations where norms are quite abstract, it is hard to understand which behaviour is actually appropriate. When people do want to do *the right thing*, but do not know what *the right thing* is, the normative guidance will likely fade away. In the managing of environmental problems this is frequently the case: it is hard for people to see what consequences follow a specific behaviour, e.g. how the electricity use of a household contributes to climate change. Environmental norms therefore often need strong support to keep of from being pushed into the background by gain goals or hedonic goals. In situations where the will of *doing the right thing* is already in place, it is not "moral training" but rather practical, concrete, situation-specific tools supporting the sustainable behaviour that is needed to hinder people from giving up and go with more selfish motives (Lindenberg & Steg 2007).

3.3.3 Behaviour Change Tools

Awareness of the complexity of why people chose to act the way they do is of high importance to manage an effective DSM-scheme. In simple terms the *benefits* people associate with accepting the scheme must exceed the *barriers* they face if the scheme is to be effectively implemented (figure 3.8). If the barriers are extensive, it is often pointless to emphasize the motivation (the sum of the benefits), unless this is done in parallel with a barrier-cutting. In cases where the motivations almost exceeds the barriers, on the other hand, increasing the motivation is the best way to foster a behavioural change (McKenzie-Mohr & Schultz 2014).

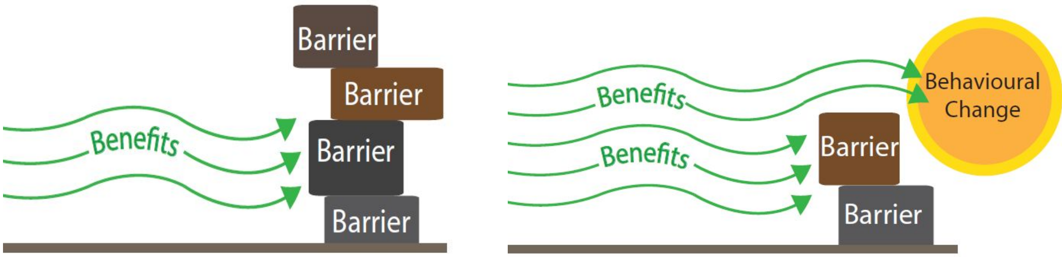


Figure 3.8. Behaviour change will not occur until benefits exceed barriers. Extensive barrier must be handled before an increase of benefits is an effective strategy.

Two effective behaviour change tools, that are natural parts of the DSM-context, but that might be utilized in a stronger way through deeper understanding of potential barriers blocking participation, are *convenience* and *incentives*. *Convenience* is an important tool since even though barriers can take a variety of forms, they are typically associated with an increased degree of difficulty. If the target behaviour is much more difficult to execute than the status quo, then an increase in convenience is necessary to achieve a behaviour change. If the target behaviour approaches the status quo in terms of convenience, then it is time to emphasize and increase the benefits of the target behaviour. If the target behaviour actually overtakes the status quo in terms of convenience, then the desirable behaviour change will occur naturally. *Incentives* can be an effective tool to use to reduce the difficulty of a target behaviour for which some kind of cost constitutes a big barrier. Incentives can appear in different forms, but they generally involve desirable consequences, rebates or other rewards, following the target behaviour, or undesirable consequences, taxes or other punishments, accompanying the deselection of the target behaviour (McKenzie-Mohr & Schultz 2014).

3.3.4 Value Orientation

Values function as stable guiding principles in people's lives, reflecting which overarching goals and means that are most important to them in general (Steg et al 2014). When several compatible values are clustered, they constitute a value orientation (Hansla et al 2008a). Typically a discrimination between *egoistic* (e.g. personal success), *social-altruistic* (e.g. helpfulness) and *biospheric* (e.g. protecting nature) values is made. An *egoistic* value orientation implies focusing on the maximizing of individual outcomes, a *social-altruistic* value orientation reflects concern for the welfare of other human beings, and a *biospheric* value orientation entails concern with life in general; the whole biosphere. Egoistic values are often referred to as *self-enhancing*, while both social-altruistic and biospheric values are referred to as *self-transcending* (Schwartz 1992).

When a person gets engaged in an environmental issue it is likely that this environmental issue has threatening consequences for some object that the person values. Hansla et al (2008a) have shown that depending on if the person primary values egoistic, social-altruistic, or biospheric objects, she/he will strongly perceive consequences of either egoistic, social-altruistic, or biospheric kind, respectively, and experience motivation, and responsibility, to act improving upon these perceived consequences.

It has been found that general values do not have strong direct effects on behaviour, but that they do have an indirect effect, via various factors (described below). The more self-transcendent values an individual holds, the more likely she/he is to engage in pro-environmental behaviour. The opposite holds for self-enhancing values; the likeliness that a person will engage in pro-environmental behaviour decreases, in general, the stronger self-enhancing values she/he holds (Steg et al 2005).

Awareness of Consequences and Ascription of Responsibility

Studies emphasizing the role of moral obligations to act in favour of the common good usually apply the *Norm-Activation Model* (Schwartz 1977); claiming a person's behaviours depends on if she/he is aware of adverse consequences (*Awareness of Consequences*, AC) related to the situation, and if she/he feels that she/he has a responsibility to do something about these consequences (*Ascription of Responsibility*, AR) (Steg et al 2005).

Problem Awareness in Electrical Issues

When a person is unaware of a problem, in terms of lack of AC or lack of AR, she/he is unlikely to try to solve it. One aspect that has been found as important for a person's problem awareness is if she/he feels that performing the behaviour lies within her/his power, because humans in general do not engage in behaviours they expect they will not manage (Ajzen 1991).

Yang and Solgaard (2015) have acknowledged that it is complicated to achieve the necessary public problem awareness about electricity consumption, and related CO_2

emissions. This is strongly due to that the emissions are not visible to the consumers, since they take place primarily during the production process, and the electricity seems clean at the use phase (Yang & Solgaard 2015).

3.3.5 Social Dilemmas

Social dilemmas refer to situations that require people to trade-off between private interests and collective interests, structured in such a way that most of the people confronting the situation will end up worse off if many of them act out of purely selfish interests than if many of them act out of collective interests (Dawes 1980). When we refrain from stopping climate change, we inevitably impose an unreliable future on all humans and the whole biosphere (De Groot & Steg 2008), presenting us with a social dilemma.

A few reoccurring roots of the choice of defection in social dilemmas are found to go in line with low problem awareness. First: the collective benefits from cooperation may be hidden or disbelieved. Second; one may be convinced that enough others will cooperate to bring the desired collective benefits. Third; one may be convinced that too few will cooperate to reach those benefits, so that personal sacrifices will just be in vain (Attari et al 2014).

Electricity Use as a Social Dilemma

Attari et al (2014) have studied people's (US citizens) intention to, and reason for, cooperating or defecting when confronted with two real-world social dilemmas related to electricity usage: energy conservation and purchasing of green electricity. The level of cooperation differs widely between these two dilemmas; 92% of the respondents state that they do conserve energy in their home by energy efficient technologies and behaviour change, while only 8% say that they do buy green electricity from their energy supplier (Attari et al 2014).

While the level of engagement in energy conservation was high, the majority of the respondents did not regard energy conservation as a social dilemma: the main reason for engagement lay in economical savings, not in environmental care. In the green electricity dilemma the opposite was found; a low current engagement level was followed by a common view of fossil based electricity as a social dilemma where the main reason for acting for a green transition was to save the earth and cause less pollution (Attari et al 2014).

In the case of purchasing green electricity, care for the environment was not sufficient for engaging in pro-environmental behaviour, since the respondents were, to a high degree, unaware of the possibility to purchase green electricity (Attari et al 2014). While likely needed in such a case, information-intensive marketing has unfortunately shown not to be sufficient to encourage pro-environmental behaviour, as other barriers often show up when the lack of information is handled. One example of this is found in a Danish study where the majority of the respondents revealed a low level of AR in contributing to expand green electricity, as they mainly felt it was the government's, and not the consumers, responsibility (Yang & Solgaard 2015).

Still, self-transcendent values and care for the environment seem to have positive effects in the case of purchasing green electricity, on the condition that people know that they can purchase it, and that they know the environmental benefits of it. Self-transcendent values further increases people’s receptivity to this kind of information (Hansla et al 2008b).

3.3.6 Acceptance Studies

An unclear level of public acceptance and support is a recurring issue when studying potential alternatives to mitigate climate change. Steg et al (2005) have confirmed that a range of the factors discussed above are of importance for the level of acceptance of policies aimed to reduce CO_2 emissions, such as people’s values, general environmental awareness, awareness of the problems and responsibility for the problems (Steg et al 2005).

Willingness to Pay

Hansla et al (2008b) have studied swedish household’s willingness to pay for green electricity and shown that this willingness increases with a positive attitude towards green electricity, and that it decreases with increased electricity costs. The results verified the hypotheses that a person's attitude towards green electricity is derived from her/his value orientation, awareness of consequences and environmental concerns. Hansla et al (2008b) found self-transcendent value orientation to be positively related to willingness while a more egoistic value orientation showed to be negatively related. This corresponds to the more general idea that the stronger self-transcendent values a person holds, the more likely she/he is to engage in pro-environmental behaviour (Steg 2005). Due to the effect of electricity costs, the willingness to pay showed not to coincide with the attitude towards green electricity, indicating that stated willingness to pay is a more appropriate measure than attitude to predict actual purchase of green electricity (Hansla et al 2008b).

Yang and Solgaard (2015) have found strong public support, in terms of willingness to pay, from residential energy consumers in Denmark to offset their CO_2 emissions from electricity consumption, which is one of many proposed instruments to reduce CO_2 emissions. The study revealed the primary motivation factors for participation to be perceived moral obligations and feeling of self-responsibility to mitigate environmental problems. The more a participant felt that her/his participation in carbon offsetting contributed to environmental gains, the more likely she/he was to pay extra. These findings corresponds clearly with the normative goal frame in the Goal Framing Theory and also goes in line with the findings by Attari et al (2014) concerning roots of behaviour choices in social dilemmas.

Consumer Acceptance of Demand Side Management

In line with Theory of Planned Behavior (Ajzen 1991), perceived control is assumed to be of importance to consumer acceptance of new technologies and technical services, such as smart meters and related DSM. Fell et al (2014) have studied consumer acceptance of electricity demand response in the residential sector and their results confirm that people are unfond of adapting their home electricity use and heating when they perceive it as related to loss of personal control. Costs, comfort, flexibility and autonomy were found to be main issues. Effort requiring DSM, e.g. if the consumer needs to regulate the indoor temperature manually, and lack of trust in third parties or in technology, showed to strongly enhance people's perceived loss of control. High level of simplicity, predictability and familiarity of a residential DSM program, on the other hand, showed to reduce the perceived loss of control following (Fell et al 2014).

Furthermore, Lund et al (2015) state that because electricity costs often constitute a fairly small part of people’s economy, economically incentives are often an ineffective way to attract consumers to participate in a DSM-scheme. They also conclude that the participation rate will be low as long as consumers are to pay for needed technology devices, and installations, themselves.

4 Method

In this chapter the methods used for this thesis are described. The first part of the work consisted of literature studies, literature seminars and a stakeholder interview with Björn Berg, the CEO of Ngenic (a company working with autonomous heat regulation). This part guided in scoping the work and in selecting relevant questions for the survey. The next part of the process, described in sections 4.1-4.2, was the construction of a survey with the aim to collect data on household attitudes, values and routines, as well as the managing of the survey results. The behavioural aspects of the survey were analysed in terms of their effects on household participation, as described in section 4.3. Based on the survey results, new modelling inputs were further created, enabling modelling based on respondents answers. This was followed by an analysis of the DSM-scheme effects on system level, which is described in section 4.4.

Due to the interdisciplinary approach of the thesis, supervision was received from both research areas: from one supervisor at Environmental Psychology, Gothenburg University: André Hansla, and from two supervisors at the department of Energy and Environment, Chalmers University of Technology: Lisa Göransson and Emil Nyholm. André Hansla was the main supervisor when designing the survey and analysing the household behaviours and attitudes, while Lisa Göransson and Emil Nyholm guided in constructing survey questions relevant from an electricity system modelling point of view, as well as in analysing the DSM modelling output.

4.1 Construction of Survey

A survey was constructed, with the goal of answering questions directly related to assumptions made in the model as well as questions related to respondent's values and behaviours, which are important factors in determining household willingness to participate in DSM, and thus the achievable potential of DSM in reality.

Before the survey was sent to the respondents, the questions were piloted to a smaller group of people. This way, potential errors in the survey, e.g. technical problems, questions and texts that were confusing, overly complicated or simply boring, could be detected and taken care of. One way to make a survey easy to handle for the respondents is to use a recurring pattern of question formulation and answer requirements. This approach was embraced by using the *Likert-scale* throughout, having the respondent answer to what extent she/he agreed with a statement on a 1-to-7 scale.

The survey was designed in the program Qualtrics, and sent out to the respondents as a link via email. The survey, which was sent out in Swedish, can be found in its entirety in Appendix I.

4.1.1 Participants and Procedure

In order to ensure a high quality survey results, it was important to have a large number of respondents answering the survey. It was also important that the respondents answering the survey had a high similarity to the group for which the DSM-scheme was intended.

The target group for the DSM-scheme are Swedish electric heating SFD residents. In order to reach an appropriate sample of respondents, questions were sent out to various Swedish electricity companies, as well as to Villaägarnas Riksförbund (the national Swedish Association for house owners). Due to Chalmers ongoing cooperation with the electricity company E.ON, the company agreed to provide email addresses for 2500 of their electricity clients. The client respondents were chosen by E.ON to show a high resemblance to the target group. In addition to this, some survey questions were designed in order to check how well the respondents actually resemble the target group. By using this approach, a random sample was not achieved, since the respondents were likely the E.ON customers most interested in the subject and thereby willing to answer the survey. It should also be mentioned that since the respondents were contacted in the role of energy consumers, the representative for every household was the person registered as "energy bill payer", which might affect the representativeness of the respondents.

The survey was sent out on the 13 of march 2017, and a reminder was sent out ten days later. It was sent out to 2500 households, with the goal of reaching 100-300 responses. In total, 338 E.ON customers answered the survey, but since not all respondents that started the survey finished it, the analysis and modelling were based on 216 adequately answered surveys.

4.1.2 Survey Questions

The survey was designed to guide both the search for behavioural causes of the participation level and the modelling of its effects on the electricity system. Part of the survey questions were constructed to help improve some inputs and outputs in the existing models, while others were constructed to capture how consumers relate to this type of DSM-scheme. In order to fulfill this double purpose, a mixture of both qualitative and quantitative questions was required.

At the end of the survey the respondents were confronted with an open ended question, offering the possibility to express additional information not addressed in the earlier questions. They were also asked to write down their email-address if they would like to take part of the results.

Questions on Household Demography

In the survey, some basic demographics and questions on household constellation were asked in order to show how well the survey respondent households corresponded to the model sample households, which were picked out of a set of buildings representing the entire Swedish building stock in a study conducted by the Swedish National Board of Housing, Building and Planning (Tolstoy 2011). This information was used in the weighting of the survey answers, as well as in an analysis of connections between household behaviour and attitudes and different household demographics.

Geographic Location

Question GL1 (table 4.1) related to the geographic location of the household, and was answered by marking one of three alternatives in terms of which part of the country the respondent lived in (Götaland/Svealand/Norrland).

Table 4.1. Survey question related to respondent's geographic location.

Question GL1	In which part of the country do you live?

Household Residents

In addition to helping indicate respondent representability, Questions HR1-HR3 (table 4.2) were used to analyse to what degree household behaviour and preferences are connected to factors like age, gender or if the people living in the house e.g. are retired or have small children.

Table 4.2. Survey questions related to the respondent and household.

Question HR1	Gender (of respondent).
Question HR2	Age (of respondent).
Question HR3	How many persons, of different age spans, are living in your household (incl. you)?
Question HR4	Experienced household income as *low* to *high*.
Question HR5	Experienced household income as *insufficient to sufficient*.

Questions HR4-HR5 were asked to help indicate how attractive monetary savings would be for the household. The questions were formulated to ask for respondents subjective income rather than for their objective income (e.g. monthly salary) since the residents experienced economy was judged to be higher important for their interest in monetary savings than the actual income. Questions on objective income, occupation etc. were not asked since these questions, to the extent they were interesting for the analysis of the study, were judged to already be covered by other survey questions.

Building Characteristics

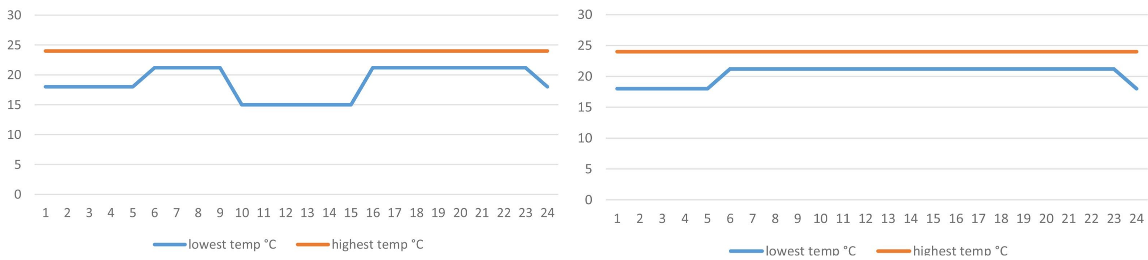
Question BC1 (table 4.3) was asked to make sure all the responses in the survey were actually from people living in a single family dwelling. If a respondent answered no on this question, she/he was immediately directed to the end of the survey, without answering any more questions. Questions BC2-BC4 were asked in order to investigate possible connections between building characteristics and household behaviour and preferences.

Table 4.3. Survey questions related to building characteristics.

Question BC1	Do you live in a single family dwelling?
Question BC2	Which year was your house built?
Question BC3	How big is your house?
Question BC4	Which type of heating system does your house have?

Questions on Routines and Temperature Preferences

In previous work by Nyholm et al (2016) it was assumed that all people are away from home between 9am and 3pm on weekdays, and that it is acceptable for the indoor temperature to vary between 15 and 24°C during these hours (figures 4.1a-b). It was also assumed that all people are asleep between 23pm and 5am, both weekdays and weekends, and that it is acceptable for the indoor temperature to vary between 18 and 24°C during these hours. The rest of the time (weekends, weekday mornings and weekday nights) household residents are assumed to be at home, accepting the indoor temperature to vary between 21.2 and 24°C . This assumed comfortable temperature interval was based on the measured average indoor temperature in SFDs (21.2°C) together with the idea that a slight temperature increase is perceived as unproblematic, while a temperature decrease is unwelcome (Nyholm 2016).



Figures 4.1a-b. Indoor temperature variations assumed by Nyholm (2016) to be acceptable for the households for 24 hours at weekdays (a) and weekends (b) [°C].

To model the actual DSM acceptance, a temperature profile had to be created for each household,: stating the maximum and minimum temperature accepted, for every hour over an entire year. The behavioural assumptions constituting Nyholms temperature profiles related both to the household weekly routines and to the household prefered and acceptable indoor temperatures for different circumstances. As a result, survey questions were constructed in an attempt to cover these aspects, and to check the temperature profile assumptions.

Weekly Household Routines

In order to evaluate the modelling assumptions related to the weekly household routines the respondents were asked a combination of quantitative questions on their daily and weekly schedule, together with more qualitative questions on the perceived regularity of the stated schedule. Questions MR1-MR2 (table 4.4) were asked in order to get new inputs to the model in terms of which hours of the day the household residents can be assumed to be asleep, at work, or at home and awake. Question MR3 was similarly used to create a new modelling input in terms of which days of the week household residents are actually away at work.

Table 4.4. Survey questions related to the household’s weekly schedule.

Question MR1	Mark the household approximate mutual sleeping hours (when everyone in the household is asleep).
Question MR2	Mark the household approximate mutual working hours (when no one in the household is at home).
Question MR3	State the days of the week for which these mutual working hours are valid.

Questions RR1-RR3 (table 4.5) were asked in order to capture the regularity of the stated working and sleeping hours of questions MR1-MR3. The questions were asked to give an indication to the certainty of the modelling inputs of MR1-MR3.

Table 4.5. Survey questions related to the regularity of the household’s weekly schedule.

Question RR1	There is a high degree of regularity in the household’s mutual sleeping hours.
Question RR2	There is a high degree of regularity in the household’s mutual working hours.
Question RR3	The household weekday and weekend sleeping hours are clearly differing.

Preferred and Acceptable Indoor Temperatures

In order to evaluate assumptions related to indoor temperatures, the survey included questions related to preferred as well as acceptable temperature intervals for different occasions of the week. Question PT1 (table 4.6) was asked in order to get a new input to the model in terms of which temperature span the household should stay within at hours when no temperature variations are accepted by the residents. The question was answered by marking one or several out of 9 temperature alternatives (17-25°C). The resolution was set to whole °C, since this was assumed to be the highest resolution for which the respondents could actually give trustworthy answers.

Table 4.6. Survey question related to prefered indoor temperatures.

Question PT1	What indoor temperatures do you experience as pleasant?

Questions AT1-AT3 (table 4.7) were asked in order to get a new input to the model in terms of which temperature increases and decreases are acceptable for the household residents for different occasions of the week. The questions related to question PT1 above in the sense that the respondent was asked to use the previously answered temperature preference as starting point when stating the acceptable variations.

Table 4.7. Survey questions related to acceptable indoor temperatures at different occasions.

Question AT1	Which indoor temperature increase versus decrease do you feel is acceptable at the hours of day when everyone in the household are asleep?
Question AT2	Which indoor temperature increase versus decrease do you feel is acceptable at the hours of day when no one in the household is at home?
Question AT3	Which indoor temperature increase versus decrease do you feel is acceptable at the hours of day when someone in the household is awake and at home?

Questions on Knowledge and Attitudes

In order to capture the household's awareness of and attitudes towards electricity consumption and climate change, the first eight questions of the survey investigated four aspects of the respondent's attitude and knowledge which were judged to be of importance for this specific case. The aspects chosen were barriers for participation, awareness of consequences, ascription of responsibility and environmental concern.

Barriers for Participation in Electric Heating DSM

Questions BP1-BP3 (table 4.8) were asked in order to investigate to which extent the survey respondents experience some of three barriers, commonly assumed to be problematic in the application and success of residential electric heating DSM.

Table 4.8. Survey questions related to potential barriers for participation in the DSM-scheme.

Question BP1	I have good knowledge about technical possibilities to control my indoor temperature and reduce my heating costs.
Question BP2	I have good knowledge about how the electricity I consume is produced.
Question BP3	I trust my power company and that the electricity prices I pay are reasonable.

Questions BP1-2 related to barriers regarding the level of knowledge concerning how the DSM-scheme would work. Question BP1 examined respondent's degree of knowledge in technologies available to control and change residential indoor temperatures possibilities. It was assumed that lack of this knowledge would be a barrier for willingness to participate.

Question BP2 examined the respondent's degree of knowledge in the production of the electricity the respondent is consuming. It is a common conception that consuming electricity in Sweden is not related to environmental problems. In line with this, it was viewed to be possible that respondents experience that they have the knowledge asked about in BP2, but regards this knowledge as reducing the motivation to participate. Both having and lacking the knowledge addressed in BP2 could therefore potentially block respondents willingness to participate.

Question BP3 related to the barrier of lack of trust, in examining to which degree the respondent trust their power company and the fairness of their electricity prices. A lack of trust in these senses was assumed to possibly extend to a lack of trust also in information and propositions from the power companies to the households, and to the feeling of power companies withholding information or using the residents to gain economical benefits.

Awareness of Consequences of Climate Change and Electricity Consumption

Questions AC1-AC2 (table 4.9) were asked in order to investigate to what extent the respondents are aware of some consequences of electricity consumption. As described in section 3.3.4 the respondent's awareness of consequences has been assumed to affect her/his attitude towards a DSM-scheme, and further her/his likeliness to participate.

Table 4.9. Survey questions related to respondent’s awareness of consequences.

Question AC1	Climate change is a problem for society.
Question AC2	Electricity savings help reduce climate change.

The nature of the two questions differed in the sense that while AC1 was related to consequences on a very general level, AC2 referred to a much more specific area of consequences. This was done based on the assumption that a respondent can experience climate change as a societal problem, without seeing electricity savings as having a role in mitigating it. The design of the questions were inspired by two questions on awareness of consequences developed in the context of household acceptance of different CO_2 emissions reducing energy policies by Steg et al (2005). Steg et al combined six questions as a measurement on the respondent’s awareness of consequences. However, in this study, to keep the size of the survey down, two questions were assumed to give an good enough estimate of the respondent’s overall awareness of climate consequences of electricity consumption.

Ascription of Responsibility for Climate Change

Questions AR1-AR2 (table 4.10) were asked in order to investigate to what extent the respondent ascribe herself/himself responsibility for the consequences of electricity consumption and climate change. As described in section 3.3.4 the respondent’s ascription of responsibility has been assumed to affect her/his attitude towards a DSM-scheme, and further her/his likelihood to participate.

Table 4.10. Survey questions related to respondent’s ascription of responsibility.

Question AR1	In principle, individuals on their own are not responsible to combat climate change through management of their electricity consumption.
Question AR2	The contribution to climate change through my electricity consumption is negligible.

Also these questions (AR1-2) were inspired by two questions from the study by Steg et al (2005). As with awareness of consequences, while Steg et al used in total six questions to measure respondent ascription of responsibility, this study used only two questions in order to estimate the same. Question AR1 was designed to indicate the respondent principal standpoint in terms of individual responsibility for making electricity consumption changes in order to combat climate change. Question AR2 was designed to indicate to what extent the respondent experience that they themselves are actually responsible for contributing to climate change by their electricity consumption.

Environmental Concern

Question EC1 (table 4.11) was asked in order to investigate if the respondent holds a more self-transcending or a more self-enhancing value orientation. As presented in section 3.3.4, the relationship between holding a self-transcending value orientation and being concerned about the environment has been widely established through previous research. Therefore one question was assumed to be enough to estimate the respondent’s value orientation.

Table 4.11. Survey question related to respondent's environmental concern.

Question EC1	I am generally concerned about environmental problems.

Questions on Temperature Management

A number of survey questions were asked in order to increase understanding of how the household residents felt about their indoor temperatures and the possibilities of temperature management.

Experience of Indoor Temperature

Questions ET1-ET3 (table 4.12) were asked in order to indicate the household's indoor temperature experience of today. The questions were asked to indicate if there exists significant comfort incentives for the respondents to take part in the DSM-scheme.

Table 4.12. Survey questions related to experience of current indoor temperature.

Question ET1	Experience of today's indoor temperature as *unsatisfactory* to *satisfactory.*
Question ET2	Experience of today's indoor temperature as *cold* to *warm.*
Question ET3	Experience of today's indoor temperature as *unstable* to *stable.*

Spontaneous Attitude Toward Temperature Regulation

Questions SP1-SP3 (table 4.13) related to the respondents spontaneous attitude toward temperature regulation, and were introduced by a short text with information for the respondent to take into account when answering the questions. This approach had the benefit of allowing the respondents to relate to important aspects of electric heating DSM regardless of not having any previous knowledge. However, the answers to the questions were also obviously sensitive to which information had been presented and how. When developing the information text, there was a trade-off between accuracy and brevity of the information. The information text in its entirety can be found in Appendix I.

Table 4.13. Survey questions related to respondent's attitude toward heating DSM.

Question SP1	Are you spontaneously positive to this type of heat regulation?
Question SP2	Would you consider investing in this type of heat regulation, if it would pay off in the long term?
Question SP3	Do you feel like this type of heat regulation would involve data collection that would be threatening to personal integrity?

Question SP1 was asked to get a sense of the respondents spontaneous attitude to the setup after being presented with the information. Question SP2 was asked to get a sense of to what degree the respondents saw the setup as valuable enough to actively invest money in it. Question SP3 was asked to get a sense of to which degree the respondent was worried about the setup collecting information about the households living patterns.

Temperature Management Scenario

After the survey section related to attitude toward temperature regulation in general came a more specific scenario presenting which concrete benefits (in terms of saved money, comfort increase and reduced CO_2 emissions) the respondent could expect if taking part in the DSM-scheme. The text can be found in Appendix I, and the underlying calculations it is based on can be found in Appendix II.

Questions SC1-SC3 (table 4.14) were formulated to relate to the Goal Framing Theory (presented in section 3.3.2), in terms of economic incentives (gain goal), comfort incentives (hedonic goal) and environmental incentives (normative goal). The answers were to show what kind of incentives that strongest motivated the respondent to to take part in the scheme, thereby indicating what type of goals that are more easily activated in her/him. What should be highlighted related to this part of the survey is that the respondents goals are not permanent. Even if gain goals (economical benefits) has most strongly motivated a respondent to take part in the scheme under the circumstances presented in the scenario, gain goals do not have to be the main motivation for this person in all situations of behaviour choice. It should also be mentioned that the exact level of benefits presented are of importance; a person may usually be driven by economical goals, but consider the sum presented in the scenario too low to motivate her/him.

Table 4.14. Survey questions related to respondent's attitude toward a specific DSM scenario.

Question SC1	I am positive toward this case of automatic heat regulation since it would save money and be economically advantageous.
Question SC2	I am positive toward this case of automatic heat regulation since it would contribute to decreased carbon dioxide emissions and reduced climate change.
Question SC3	I am positive toward this case of automatic heat regulation since it would help avoid unpleasant changes in indoor temperature.

4.2 Managing Survey Results

When a sufficient amount of survey responses had been collected, the process of interpreting the survey answers, translating them into a form more suitable for modelling, and analysing the respondent answers and their connections, started off.

4.2.1 Interpreting Respondent Answers

To be able to interpret respondent answers or lack thereof, some methodological choices had to be made.

Open Ended Questions

Comments left in open ended questions helped in explaining ambiguities in answers due to a non optimal survey design, e.g. if no answer alternative matched what the respondent wanted to answer, or if the respondent felt some important question or information was missing from the survey. When possible, the comments given in the open ended questions were used to guide interpretations of answers and imputations in cases of lacking answers.

Failure to Answer

In order to be able to take into account as many as possible of the survey responses, a strategy for the handling of failures to answer was developed. It is not perforce to have values on every studied parameter for every household to investigate relationships between parameters or to group the households. Still, it simplifies the work to have an as exhaustive rate of answers as possible. To as great extent as possible, missing answers were imputed based on well underpinned assumptions. The assumptions and their resulting imputations are presented in Appendix III.

4.2.2 Translating Survey Responses into Modelling Inputs

Due to a number of fragmentary answers among the 338 survey respondents, only 216 of the answers were used in analysis and creation of temperature profiles. The 216 respondents were chosen since their answers were sufficient enough to be able to draw fairly good conclusions.

Household Routines

Respondent answers on sleeping hours and working hours, together with their answers on working days (questions MR1-MR3), enabled a weekly household schedule to be assigned through a categorization of each hour of the week into one of three modes (*work*, *sleep* or *home*). For each of these modes acceptable temperature span was set, creating a temperature profile showing the maximum and minimum accepted temperature for each hour during one week.

The profiles were extended to one year, starting on a sunday, and stretching over 8784 hours, to match the year of 2012 (a leap year) run by the model. This created two vectors (length 8784) for every respondent household; one for the maximum and one for the minimum allowed indoor temperature for each hour of the year.

Household Temperature Acceptance

In the survey the respondent was asked to state how much of a temperature increase/ decrease she/he would find acceptable during different circumstances (questions PT1, AT1-AT3). Since the respondent was allowed to state more than a single degree as a pleasant temperature, an interpretation strategy was needed when translating the respondent answers into modelling inputs. The model has previously been seen to almost always choose the minimum temperature constraint as indoor temperature, since this can be seen as a form of energy conservation, which is almost always an attractive action from a system perspective. In order to avoid an overestimation of the respondent willingness and its effects, the lowest prefered temperature when no variations are accepted was set to the mean value of the temperature span marked as pleasant by the respondent, rather than the minimum value. When temperature variations are accepted, however, the increases and decreases in temperature were calculated starting from the maximum and minimum degrees marked as pleasant by the respondent. Formulas for calculating the prefered temperature constraints for different circumstances can be found in Appendix IV.

Creating the Modelling Temperature Profile

Through the method described above, 216 pairs of temperature vectors, giving the maximum and minimum allowed indoor temperature for each over of the year in each of the 216 respondent households, could be created. In order to translate these vector pairs to represent the entire Swedish SFD stock, a single pair of temperature vectors was created as an input to the model.

Household Type Weighting

In the attempt to weight and scale the respondent answers to better match the entire Swedish SFD stock, the respondents were separated into different demographic groups for which the temperature profiles were expected to be similar within the group, while different between the groups. The respondents were grouped in two levels, firstly based on the constellation of inhabitants in the households, and secondly, within the group, based on the gender of the respondent.

Senior households were distinguished into one group, based on the hypothesis that this group does not have the same level of regular working hours than the rest of the respondents. Families with children were distinguished into one group, based on the hypothesis that the group may have a quite high extent of overlapping working hours. Single person households were distinguished as one group, based on the hypothesis that these households may have a higher potential to participate since only the routines of one person have to be considered as a limiting factor. The households fitting into several of the groups (senior and family, or senior and single), based on the definitions in table 4.15, were modelled as part of the senior group. This was based on the assumption that this demography is the one property impacting the respondents temperature profiles the most. The households not fitting into any of the groups were distributed into one joint group with no specific demographics assumed to be of relevance for their temperature profiles. The statistical percentages used for the weighting were calculated using data from Statistics Sweden (SCB). The data and calculations can be found in Appendix V.

Table 4.15. Definitions used to divide the respondent households into categories.

Demography Grouping	Definition of household type
Seniors	Household containing at least one person over 65 years.
Families with children	Household containing at least one person under 18 years (and no person over 65).
Single	Household containing only one person (who is under 65 years).
Other	Household not meeting any of the three definitions above.

After the respondents were distributed into four groups, as described above, each group was divided into two subgroups based on respondent gender. This was done based on the fact that the respondent gender distribution was found to differ significantly from the statistical gender distribution in Swedish SFDs, together with the hypothesis that the gender of the respondent would have an impact on their survey answers used to create the household temperature profile.

Because of the linear nature of the model, the single temperature profile vector could be created by calculating mean temperature profiles for each of the eight sub-groups pair. This was done by weighting of the eight temperature profiles to match the actual gender disposition of each group, as well as the actual distribution between household types in Swedish SFDs.

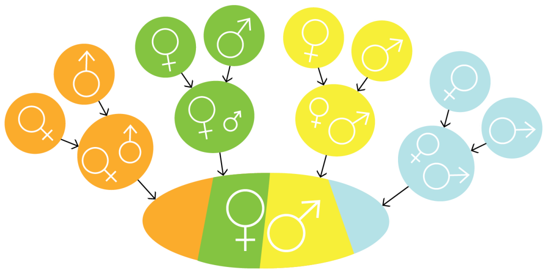


Figure 4.2. Conceptualisation of the process of combining the eight sub-groups into a common, representative temperature profile.

Checking of Weighting Method

While the household types were hypothesized to have an effect on the respondent temperature profiles, weighting based on household resident parameters fails to take into account more technical differences between the households that may be of relevance, such as building year or heating system. An alternative grouping based on instances of these parameters which showed a high difference between respondent and statistics distribution may have a significant impact on the resulting weighted temperature profile. Due to this, another grouping and weighting approach was tested, based on the size of the respondents house, as a kind of validation of the initial grouping method. The building size grouping was chosen due to a significant mismatch of house size between respondents and statistics, in parallel to that the temperature profiles were found to differ between the house size groups. Since the differences in outcome of modelling based on house size grouping and household type grouping was found to be negligible, the robustness of the initial grouping method was validated, and was continued to be used for further temperature profile creation. The house size calculations can be followed in Appendix VI.

Participation Scenarios

In the initial modelling the focus was to translate the survey results into modelling inputs, while the stated participation levels were left unmodified, assuming all households participate in the DSM-scheme with the temperature profiles created from their survey answers. For further investigation, three scenarios, with different participation levels, were designed and modelled. The purpose of the scenarios has been to explore the effects we can expect without further participation incentives, as well as the effects we could achieve through some extra effective incentives. These scenarios were chosen because the outcome could be of relevance for policymaking, since the different approaches of focusing either on technological fixes or behavioural mind-set changes has been emphasised.

No Subsidy Scenario

Since people generally are found to show resistance to change, it was assumed that respondents have to be clearly motivated, not just neutral, in order to actually participate in the DSM-scheme. Unless the technical smart meters and the installation of these are to be completely subsidized, there would be an investment cost related to the participation. This cost was regarded as a divide, separating people who actually would participate from those who would need some additional motivation, and was used in the design of a first scenario. In this scenario, only respondents who had answered positively (>4 of 7) on the question if they would invest in the DSM-scheme (question SP2) were considered as participating, while the temperature profiles of the rest were substituted with a steady 20.8°C setpoint every hour, equivalent to no DSM (figure 4.3).

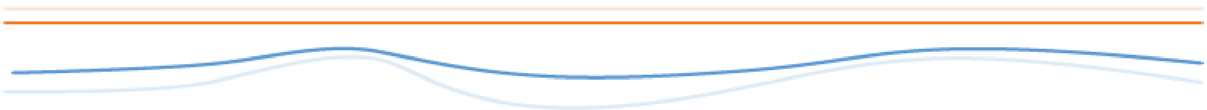


Figure 4.3. Conceptualization of allowed temperatures for one day in no subsidy scenario in relation to base case scenario.

Technical Fix Scenario

The first of two explorative scenarios were designed to investigate the effects of DSM if all respondents accept a quite big temperature span when they are not at home (working hours) (figure 4.4), while the temperature profiles are to be kept as the preferences given by the respondents for hours when they are at home (awake or asleep). The point of this scenario was to look at the potential of DSM in terms of making people accept and trust the technology fully, without accepting a noticeable lifestyle-change. The new maximum and minimum temperature, used for all the respondent during their respective working hours, was calculated using the average temperature of the 5 highest accepted temperatures as new maximum, and the average temperature of the 5 lowest accepted temperatures as new minimum.

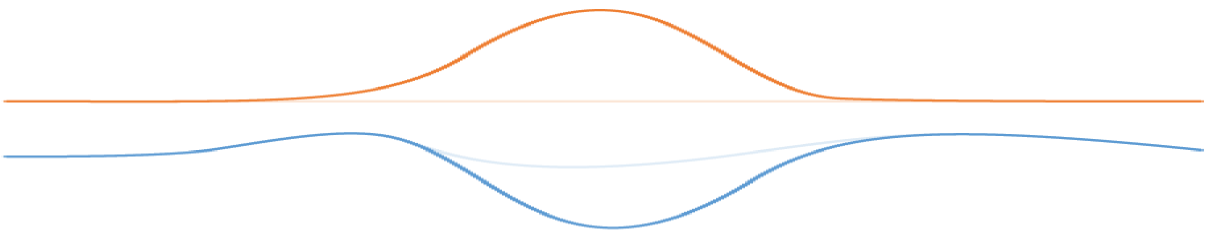


Figure 4.4. Conceptualization of allowed temperatures for one day in technical fix scenario in relation to base case scenario.

Lifestyle Change Scenario

The second explorative scenario was designed to investigate the effects of DSM if all the respondents would engage slightly more than their temperature profiles proposes and accept some noticeable changes. More precisely, increasing their maximum accepted temperature with one degree, and decreasing their minimum accepted temperature with one degree, at every hour of the year (figure 4.5). The point of this scenario was to look at the potential effect of making people accept the idea of compromising the comfort a little bit each, in order to make a big difference together.

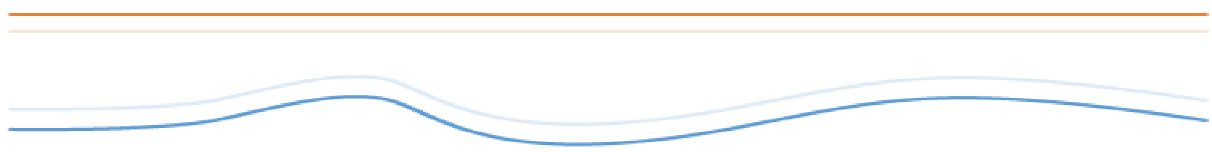


Figure 4.5. Conceptualization of allowed temperatures for one day in lifestyle change scenario in relation to base case scenario.

4.3 Behavioural Analysis

When the survey results were received, they were thoroughly investigated both in purpose of supporting both the modelling and as main material for the behaviour analysis.

4.3.1 Intention to Participate

The household participation was investigated in two ways. The first one, henceforth referred to as *Willingness to Participate (WTP,* not to be confused with the term willingness to pay*)*, related to the respondents attitude towards the presented type of heat regulation (question SP1). The second one, hereafter referred to as *Potential to Participate* (PTP), regarded the temperature profile that the respondent has accepted, and is influenced of aspects such as habits and routines, rather than simply the respondent attitude toward heat regulation. No high correlation was assumed between these two factors, but a high level of both WTP and PTP was strongly assumed to predict a strong *Intention to Participate*, which was assumed to be directly related to the resulting household behaviour (figure 4.6)*.* In the modelling (see section 4.4.2) the intention to participate was not distinguished from the potential to participate in the base case DSM, while in the no subsidy scenario, the respondents intention to participate was restrained due to investment costs.

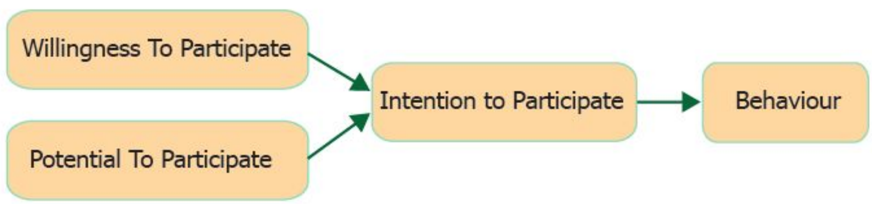


Figure 4.6. WTP and PTP affecting the intention to participate preceding behaviour.

A value for each respondent's PTP was calculated as the aggregation of her/his accepted temperature span for each 168 hours of the week, according to equation 4.1. The respondent's WTP was assigned as her/his answer on question SP1.

Equation 4.1. $$PTP = \sum_{t=1}^{168} (Tmax(t) - Tmin(t))$$

4.3.2 Correlation Analysis

The survey questions regarding the respondent's general and scenario specific attitudes and behaviour intentions were investigated in relation to each other through a *correlation analysis*, in order to explore how well the trend in the answers of different questions followed each other. The *p-value* of each correlation was calculated, in order to measure the probability that the correlation had occurred completely at random, and that there was no *real* correlation between the two variables. A low p-value means that there is most likely a real, significant, correlation between the variables. The mean value and standard deviation were also calculated for each question. Figure 4.7 shows how the several aspects investigated through the survey were supposed to underlie the willingness to participate and the potential to participate.

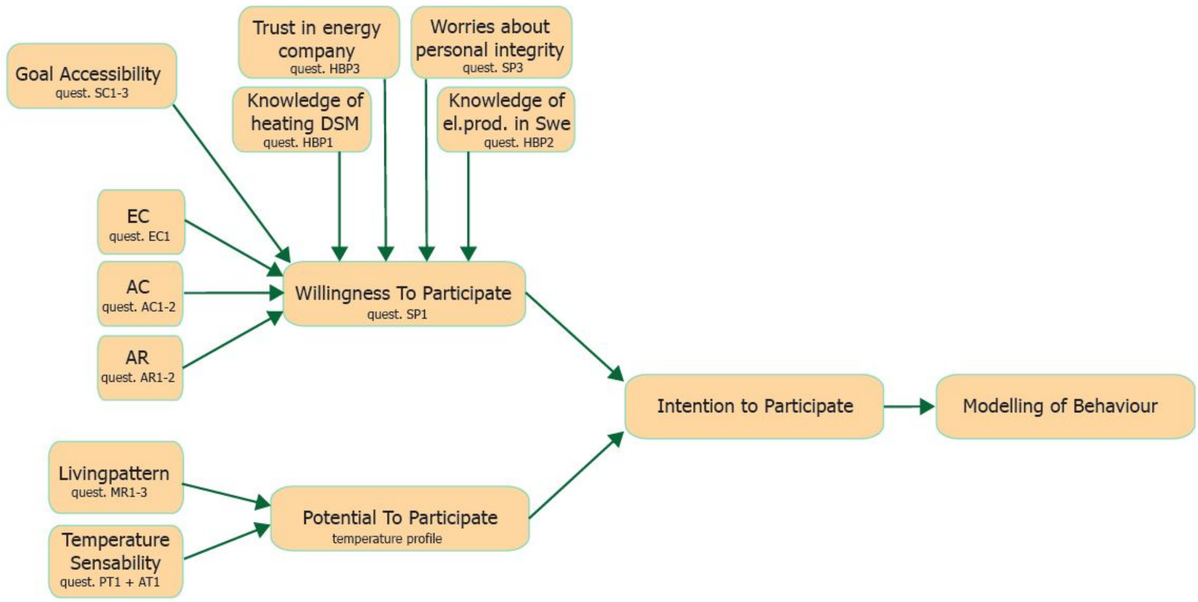


Figure 4.7. Model of expected relations between WTP and PTP with several factors, regarded in the survey.

Correlation Analysis Preparations

Before a correlation analysis could be performed, the survey answers to questions covering the same area had to be evaluated and possibly transformed into indices. For questions that were negatively formulated (SP3, AR1-AR2), the respondent answers were translated so that a positive correlation value always marks a positive correlation between the aspects.

Subjective Economy Index

For the correlation analysis, the aspect of *subjective economy* was assumed to be captured by the questions on experienced income in terms of low-high and insufficient-sufficient (questions HR4-HR5). Since these factors were found to show a high correlation (see Appendix VII), their average was calculated and used as an index for the respondents subjective economy (SE).

Subjective Comfort Index

Subjective comfort was assumed to be captured by the questions on experienced indoor climate in terms of unsatisfying-satisfying and unstable-stable (questions ET1 and ET3). These factors were found to show a high correlation (see Appendix VII), and their average was calculated and used as an index for the respondents subjective comfort (SC).

Ascription of Responsibility

The two questions related to the respondents ascription of responsibility (questions AR1-AR2) showed a high correlation (see results) and the average of the two was used for correlation as an AR-index (AR).

Awareness of Consequences

The two questions related to the respondents awareness of consequences (questions AC1-AC2) were not consistent in that they deal with different generality levels of AC - one relating to the global problem of climate change while the other to the much more niched and small scale issue of electricity savings - and they were not found to show a high correlation (see results). Thus, the judgement was made that the AC of a respondent is better grasped if the two AC-questions were not aggregated into an index, but looked at separately in order to capture different aspects of consequence awareness.

4.3.3 Partial Correlation of Goal Frames and Problem Focus

Based on the Goal Framing Theory (see section 3.3.2), it was assumed that a person's problem focus - what kind of problem she/he experiences - would determine what kind of benefits from DSM-participation that attracts the person (figure 4.8). If she/he would find her/his indoor climate as unpleasant, she/he would be in a hedonic goal frame, and thereby primarily have eyes for hedonic goals, such as increased indoor comfort. A person experiencing a problematic economical situation, was assumed to primarily have eyes for gain goals, such as economical savings. When a person experienced worries for the environment, she/he was assumed to primarily be accessible for normative goals, such as climate change mitigation.

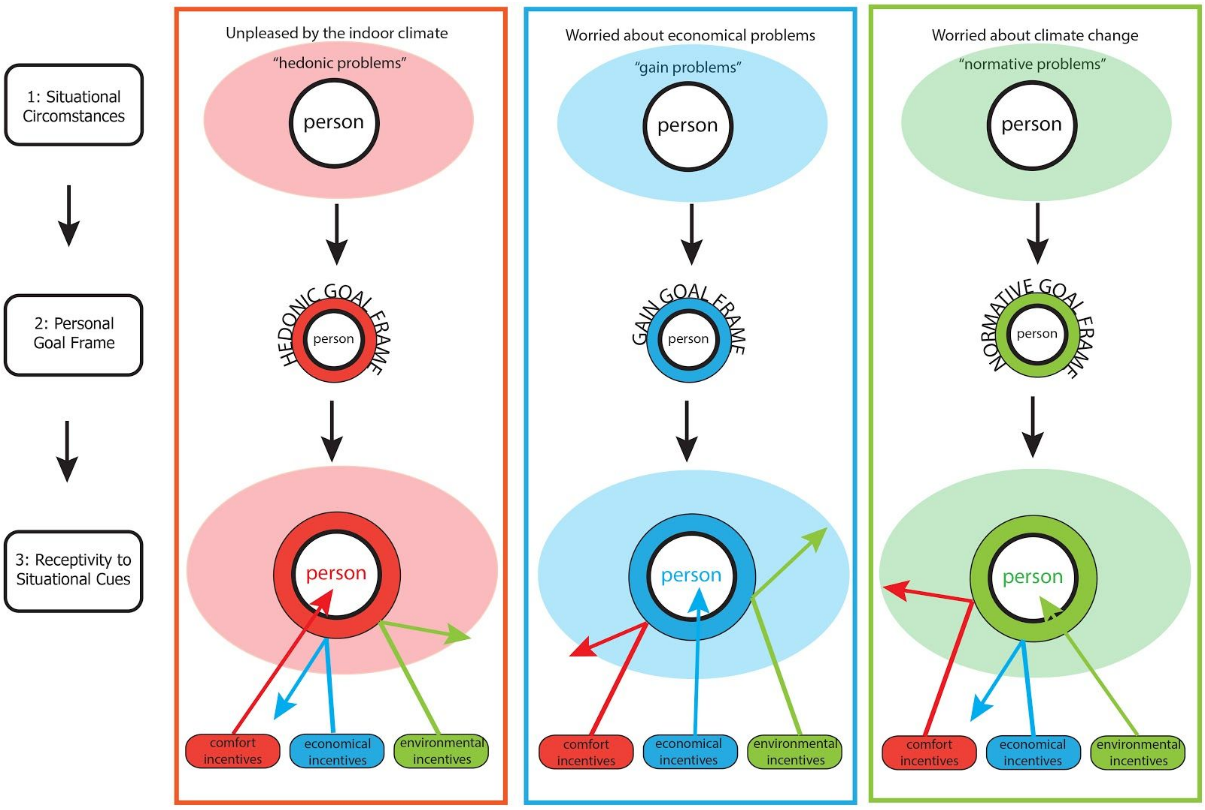


Figure 4.8. A person's situational circumstances, or problem focus, frames what kind of incentives she/he is receptive to.

Respondents problem foci were measured according to the *subjective comfort index* (hedonic) and *subjective economy index* (gain) described in section 4.3.2, together with the *environmental concern question EC1* (normative). The respondents accessibility for different kinds of goals was measured by the three scenario specific questions (question SP1-3), asking for willingness to participate due to comfort, cost savings and decrease of CO_2 emissions respectively.

An initial hypotheses for the analysis was that a person experiencing a certain type of problem would be more receptive toward DSM-scheme benefits corresponding to the experienced type of problem than to other types of benefits. When investigating this hypothesis, it had to be highlighted that the questions measuring the respondent's problem focus do not operate in the same generality level for the different types of problems. While *subjective economy* and *subjective comfort* were captured through specific questions relating to household level problems, the question regarding *environmental concern* was asked in a much more general way.

A partial correlation was carried out to further analyse the roots of the correlations found between problem foci and goal accessibilities (see results). Since the three different goal accessibilities showed a high internal correlation, it was of interest to see what would happen if the different accessibilities were investigated separately. Partial correlation allows for calculating the correlation between two variables while a third variable, potentially disguising or over enhancing the correlation between 1 and 2, is held constant.

The partial correlation (r) between variable 1 and 2 (variable 3 held constant), was calculated according to equation 4.2.

Equation 4.2. $$r_{12.3} = \frac{r_{12} - r_{13} r_{23}}{\sqrt{(1-r^2)_{13}(1-r^2)_{23}}}$$

Two hypotheses were tested through partial correlation, based on the unexpected correlation results (see section 5.1.3) that economic incentives of DSM did not especially attract people who experienced their income as insufficient, and that comfort incentives did not especially attract people who were unhappy with their indoor climate. Further, it was assumed that people who regard climate change as a problem are more attracted by all kinds of benefits of DSM (economy, comfort, environment), than others.

The first hypothesis was that the apparent, but unexpected, strong correlation between *hedonic* and *gain goal accessibility* on one hand, and *environmental concerns* on the other, was caused by the strong, and expected, correlation between *normative goal accessibility* and *environmental concerns* in combination with the strong correlation between the three goal accessibilities. The second hypothesis was that an unobserved, but expected, correlation between *hedonic goal accessibility* and *hedonic problem focus,* and between *gain goal accessibility* and *gain problem focus,* was hidden due to the same intercorrelation between the three *goal accessibilities.* To test the first hypothesis *normative gain accessibility* was held constant. To test the second hypothesis, also the *hedonic goal accessibility* and the *gain goal accessibility* were held constant one at the time.

4.4 Modelling Analysis

The system analysis was carried out through output studies in GAMS and Excel. The studied outputs gave numerical results for a whole year, while, for simplicity, the month of january and its first week were chosen to illustrate the results. The patterns seen in the selected time frames were then checked against yearly patterns in order to assess the representability of the patterns. However, since January is a winter month, system demand, as well as the production from chp plants are relatively high at that part of the year.

4.4.1 Models and Scenarios

Figure 4.9 illustrates how the survey functions in relation to the models used for the work, enabling modelling and analysis of the system effects of the survey respondents stated participation rate.

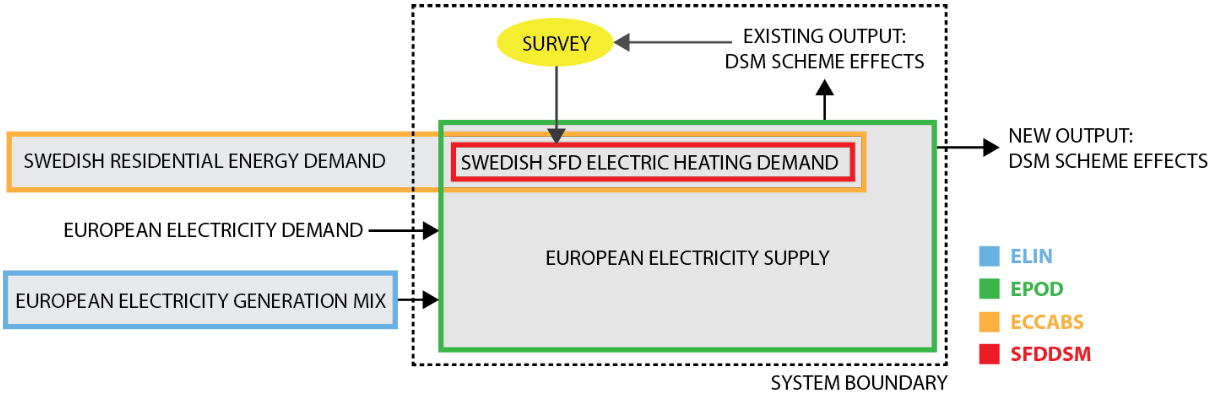


Figure 4.9. Relation between used system models and the survey.

Modelling Demand

The ECCABS (Energy, Carbon and Cost Assessment for Building Stocks) model (figure 4.9), developed by Mata et al (2013), is a bottom-up simulation model built to assess possible energy and CO_2 savings for different residential sector energy savings measures. The model uses an hourly heat balance to estimate the energy demand for the households under study over one year.

The model for SFD electric heating DSM (SFDDSM in figure 4.9) was developed by Nyholm (2016) as an optimization sub-model for ECCABS. It builds on the ECCABS fraction of energy demand for SFD electric heating, and allows the household residents to cost-minimize, by shifting their heating consumption to hours when electricity price is low, or simply allowing for indoor temperatures to decrease at times (Nyholm 2016).

Modelling Supply

The ELIN (Electricity Investment) model (figure 4.9) is a bottom-up, long-term investment cost-minimizing model. Since the model is built to minimize investments and generation costs to meet electricity demand under a number of constraints, it lends itself well to investigate different possible pathway of the European electricity system development (Nyholm 2016).

The EPOD (European Power Dispatch) model (figure 4.9) is a bottom-up, dispatch optimization model, in the sense that it minimizes the costs of power production within a given generation composition and within some given constraints (Göransson 2014). It is often used as an extension to the ELIN investment model, and is built to, with an hourly resolution, cost-minimize the electricity generation dispatch over one year, with the year and generation composition in question often derived from a ELIN pathway scenario (Nyholm 2016).

Green Policy Scenario

To study, and try to draw conclusions around, the future is a somewhat complex and uncertain task, but nonetheless a necessary one when planning for a sustainable transition of the electricity system. Through the use of scenarios, it is possible to investigate imagined futures which are judged to be interesting to look at.

In the (ELIN) pathways for the European electricity system, different scenarios, building on different constraints, develop different types of electricity production technology compositions to reduce the European electricity sector emissions with 95-99% from 1990 to 2050 (Nyholm 2016). This involves pathways with no increase in demand, slight increase in demand and a high increase in demand. It also involves pathways with caps on CO_2 emissions, targets on renewable electricity, and bans on new investments in nuclear and CCS (carbon capture and storage) starting from 2050 (Nyholm 2016).

For the scenario worked with in this thesis, often referred to as the *green policy* (GP) scenario, the system composition by 2050 is dominated by wind power production (figure 4.10).

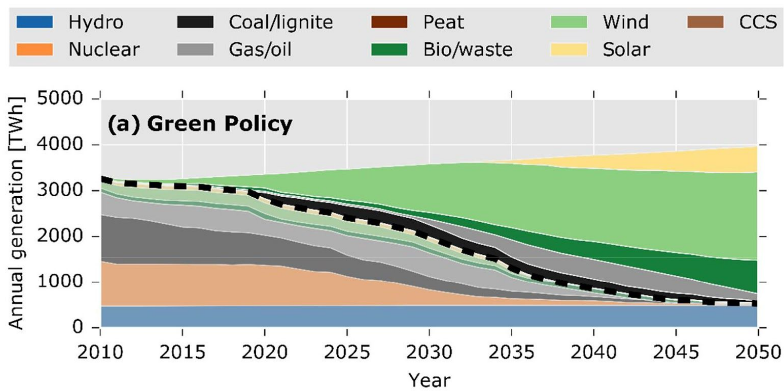


Figure 4.10. The development of the European electricity generation under the Green Policy scenario [TWh] (Nyholm 2016, p. 42 figure 8(c)).

When comparing the capacity distribution for the year 2032 in the GP scenario with the Swedish power capacity distribution of today the penetration of wind has increased from 10 to 52%, while the base load nuclear plants has been completely phased out. The capacity of fossil peak power plants has increased significantly, as a result of the increased need for flexible non-intermittent generation to balance the wind production.

4.4.2 System without DSM

In order to distinguish the effects of applying DSM in the system, the system was first modelled and investigated without any DSM. Important aspects to note were the system net load and available variation management strategies. Also the Swedish load, net load and variation management strategies were an important basis of comparison for investigating the effects of DSM. The net load was looked at as the load after subtracting intermittent supply and variation management through hydro, electricity trade and wind curtailment. When the modelling was carried out, the electricity system, governed by the green policy scenario, was investigated in terms of existing wind variation management, and need for additional management through DR. Vast amounts of wind power in the multiregional system, and large amounts of hydropower in Sweden and Norway were highlighted as supposedly affecting this suitability, and were captured by looking at the net load. Also congestion between regions were investigated. These system characteristics were found by the GAMS-variables describing the different aspects, and investigated in excel, mainly by visually analysing and comparing plotted graphs of the variables.

4.4.3 Comparing DSM to no DSM

The modelling package was first run with the temperature profile input for the DSM participation base case. This was done in order to be able to roughly single out the effects of DSM by comparing the output from the DSM base case to the output for the scenario with no DSM. The system effects in terms of demand were looked at through changes of the net load, which should ideally be smoothened by DR. In terms of system production, effects were looked for in four relevant areas. The first one was how well the system manages curtailment, the second was if the system shows a switch from peak load technologies to base load technologies, the third was the level of cycling costs in the system, and the fourth was the effectiveness in the trade between regions. Regions that at first sight showed unexpected behaviours in terms of production or curtailment were further investigated to reveal potential congestion in the transmission grid.

System Demand

The energy conserving qualities of the scheme were investigated by examining the DSM impact on the yearly load, with the yearly load reduction being equal to the DSM energy conservation. The DR qualities, however, were more complex to grasp, since they did not imply any yearly change in the load, but rather a switch from one time to another. Hence, the scheme's DR qualities were looked upon mainly visually through graphs of Swedish demand variations before and after the scheme was applied. Since the DSM takes place at a fairly small scale in Sweden, most load investigations related to the Swedish load, rather to the overall system load, for which the differences from applying would be very small and hard to grasp visually. Lastly, the root of the demand changes - the SFD indoor temperature changes - were investigated. A visual analysis of the temperatures chosen by the model was carried out, as well as a comparison to system aspects which were assumed to could have impacted these chosen temperatures.

Congestion

In order to investigate congestion, the yearly trade pattern between specific regions were analyzed and compared to the maximum transmission capacity. The congestion situation in the system was measured as the yearly average of hourly difference in marginal cost (mc) between regions (r1, r2), using Equation 4.3. This is done since large differences in marginal costs over time, and between regions, imply that the electricity has not been efficiently allocated throughout the system.

Equation 4.3.
$$congestion = \frac{\sum_{t=1}^{8784} \left| mc_{r1} - mc_{r2} \right|}{8784}$$

By comparing the congestion situation in the system before and after the DSM, it was investigated to what extent the DSM in Sweden reduced congestion problematics in the system.

System Costs and Emissions

System emissions before and after DSM were investigated in order to increase understanding of possible environmental aspects of the scheme. The system costs that were investigated were marginal costs, running costs and cycling costs. Since production and transmission investments were applied as inputs, and did not change for different scenarios, their costs were not seen as part of the system costs. While the running costs relate to different plants and are not affected by how they are run, cycling costs relate to how efficiently the plants are run and how often they are forced to cycle. Thus, a reduction of cycling costs may be a sign of efficient DR while a reduction of running costs may be a result of either DR or energy conservation.

4.4.4 Comparing Scenarios

After the general system impacts of applying DSM were examined, the modelling package was run with the different temperature profile inputs relating to the different participation scenarios. The difference between the scenarios was compared in terms of demand, indoor temperatures and system costs and emissions. The effects of the different scenarios were compared to each other, to emphasize the value of different approaches and participation levels. To visualise how the system utilized the allowed temperature span in the different scenarios, their average temperature profiles were plotted.

5 Results & Analysis

In this chapter, the results of the work, as well as the analysis of these results, are presented in two parts. The first part, section 5.1, describes the behavioural results and analysis, presenting the outcome of the survey, and an analysis of the correlation between different survey answers. The second part, section 5.2, describes the outcome of the modelling in terms of system impacts of DSM and compares the effects of the different DSM participation scenarios. The main points of the stakeholder interview with Björn Berg from Ngenic can be found in Appendix VIII.

5.1 Survey Results

Generally, the survey results show that the respondents are pleased with their current indoor temperatures. The regularity in routines is found to be quite high for daily sleeping hours (question PP1), while lower for daily working hours (question PP2).

5.1.1 Willingness To Participate and Potential To Participate

In all groups a high WTP-mean value (measured on a 1-7 scale) is seen (table 5.1). The highest willingness to participate is found in households including children. Other demographic groups found to significantly distinguish themselves as having a high willingness to participate are women and respondents from the northern part of Sweden (Norrland).

In the interview with Björn Berg (see Appendix VIII), it is hypothesized that early adopters for technical heat regulation are mainly young families and middle aged men. The survey findings of a high WTP among households including children confirms the theory of young families as early adopters. However, the survey outcome show no particularly high WTP for middle aged men, meaning the hypothesis of this group as early adopters finds to support in the result. The survey also indicates that household income does not seem to have a significant impact on WTP. Further, the WTP for senior households is found to be lower than for the other groups. This is likely due to the fact that many seniors, as expressed in the survey's open ended question, see heat regulation as difficult and pointless for people who are not working.

The potential to participate is also highest for the households including children (table 5.1 on next page). This result is unexpected, since these households were expected to have fewer and less regular working hours than others, resulting in a lower than average PTP. The high PTP for these households can rather be seen as acceptance of wide temperature variations also when they are at home. Senior households show the lowest PTP, which is expected due to the limited amount of working hours.

Table 5.1. Willingness and potential to participate presented as a mean value for different household types.

	WTP mean (attitude)	PTP mean (1 week)
All 216 households	5.49	602
Single households	5.75	612
Senior households	5.11	503
Households with children	5.86	669
Other households	5.57	607

5.1.2 Open Ended Answers

In the section at the end of the survey allowing for open ended comments about issues the respondents felt were not covered sufficiently in the survey, 57 answers were received. The individual answers can be found in Appendix IX.

Lack of Potential to Participate

13 of the comments relate to confusion and frustration regarding how households with retired residents can relate to the survey and the scheme. Some indicate that they found the survey questions on working hours hard to answer due to this. Some show an interest in knowing more about how they, having no regular working hours, could participate in DSM. An additional 6 comments relate to other cases of lack of regular working hours, some indicating that they work from home, some that they work in shifts and some that they are unemployed. These groups also found it hard to answer the questions on working hours.

Experienced Barriers

Some comments relate to barriers. One respondent experience that the electric utilities increase the electricity prices in order to ensure large profits, while at the same time politicians are increasing the electricity tax. The respondent further states that they have already made huge efforts to decrease costs for electric heating by isolating the house and changing to new doors and windows, but that it has not had an effect on the electricity bill. Another respondent states that due to the households relatively small living area, they perceive the economic savings from heating DSM to be small. A respondent living in an old house express the concern that changes in heating will make the indoor temperature far to unstable, since the temperature in the old house is fast to respond to heating changes.

Environmental Impact of Electricity Use

Some respondents experience electricity use as being related to low emissions levels, and that climate change mitigation efforts would be better directed at for example reducing air plane travel. A frustration is also expressed regarding that the national Swedish emissions are insignificant on a global scale, so that we can not solve climate change with Swedish DSM.

Several comments relate to the Swedish production of nuclear power, and its role in sustainable development. One respondent expresses the attitude that nuclear waste, rather than CO_2 emissions, is the main environmental issue that is to be addressed regarding Swedish electricity use. Another respondent state, on the contrary, that Swedish electricity use is environmentally unproblematic as a result of nuclear.

When it comes to the transition to a sustainable electricity system, several respondents display a sustainability vision based on solar energy, with e.g. standards for solar panels on all roofs. Some of these respondents view the scheme, as it is described, as an attempt to push a real, well needed system change into the future. Another respondent states that the future of electricity will be based on decentralized electricity production and that this will make the DSM-scheme redundant.

Indoor Temperatures and Heating Methods

A few of the comments relate to experience of temperatures. Some state that the different household residents prefer different indoor temperatures. One respondent explains that the residents joint disease prevents her/him from decreasing the temperature, which needs to be held higher than in other households.

Some comments indicate that the households regularly use complementing heating options, such as woodstoves, to avoid using too much electricity. Others comment that they have chosen district heating instead of electric heating due to electricity being too expensive.

5.1.3 Correlation Analysis

An investigation of correlations between household values, attitudes and potential barriers, increases the understanding of why people chose to engage or not in heating DSM.

Behind the Intention to Participate

In table 5.2 on the next page different colours mark different strengths of correlation; gray marking the instances of no significant correlation, yellow the instances of slight correlation, light green the instances of moderate correlation and bright green the instances of high correlation between the variables. The table also states level of significance (*p-value)* for the different correlations, as well as a mean value and standard deviation for the investigated variables.

The correlations in table 5.2 show that the respondents are positive in terms of all three potential motivations asked about (comfort, economy, environment), but that the environmental benefits are perceived as the strongest motivation. The three goal accessibility variables correlate strongly to each other, and all of them correlate strongly with WTP. This could indicate that people either see the DSM-scheme as generally good, and then they embrace all motivations, or they are generally sceptical towards the scheme, and then are not tempted by any of the specific motivation.

Table 5.2. Correlation between psychological factors. EC = environmental concern, AR = ascription of responsibility, AC1&2 = awareness of consequences, SE = subjective economy, SC = subjective comfort, BP1 = knowledge of DR, BP2 = knowledge of electricity production, BP3 = trust in power company, SP3 = trust in handling of personal data, GAG = goal accessibility gain (SC1), GAH = goal accessibility hedonic (SC3), GAN = goal accessibility normative (SC2), WTP = willingness to participate (SP1)

	EC	AR	AC1	AC2	SE	SC	BP1	BP2	BP3	SP3	GAG	GAH	GAN	WTP
AR	0.21 **	1												
AC1	0.48 ***	0.36 ***	1											
AC2	0.29 ***	0.35 ***	0.42 ***	1										
SE	0.00	0.13	0.16 *	0.13	1									
SC	-0.03	0.06	0.03	0.08	0.06	1								
BP1	0.11	0.07	0.18 **	0.16 *	0.08	0.25 ***	1							
BP2	0.11	-0.05 ***	0.23 ***	0.21 **	-0.03	0.24 ***	0.45 ***	1						
BP3	0.08	0.08	0.27 ***	0.21 **	0.13	0.17 *	0.17 *	0.26 ***	1					
SP1	0.10	0.09	0.11	-0.04	0.12	-0.05	-0.03	0.04	0.06	1				
GAG	0.20 **	0.07	0.08	0.32 ***	-0.06	-0.03	0.07	0.09	0.00	0.06	1			
GAH	0.21 **	0.13	0.16 *	0.27 ***	0.04	-0.07	0.09	0.08	0.05	0.09	0.68 ***	1		
GAN	0.29 ***	0.22 **	0.29 ***	0.41 ***	0.06	0.04	0.06	0.04	0.07	0.10	0.72 ***	0.64 ***	1	
WTP	0.24 ***	0.15 *	0.30 ***	0.35 ***	0.21 *	0.01	0.14 *	0.09	-0.05	0.25 ***	0.48 ***	0.44 ***	0.51 ***	1
mean	4.91	3.13	5.94	5.44	4.91	5.64	5.24	4.91	4.03	2.71	5.16	5.01	5.50	5.49
St. dev.	1.67	1.36	1.31	1.51	1.17	1.17	1.51	1.65	1.43	1.52	1.72	1.63	1.49	1.44

* p<0.05, ** p<0.01, *** p<0.001

The table 5.2 also shows that environmental concern (EC), ascription of responsibility (AR) and awareness of consequences (AC1 and AC2) constitute a inter-correlating set, where all theses factors correlate to each other, pointing at an “environmentally beneficial package” of concern, awareness and duty. The strongest correlation in the set can be found between EC and AC1, which is expected, since AC1 addresses climate changes in general, while AC2 and AR address the connection between electricity usage and climate change specifically. The more specific AR & AC questions, relating to electricity use, do not correlate as strongly with environmental concern. This finding could imply that a significant fraction of the people who generally care about environmental problems are not concerned about electricity use and its environmental consequences. This is further confirmed in the opened ended question where several respondents have written that they do not view consumption of electricity in Sweden as a central environmental issue.

Environmental concern, ascription of responsibility and awareness of consequences can also be seen to correlate with both willingness to participate and normative goal accessibility (GAN). Awareness of the connection between electricity and climate change (AC2) is the variable strongest correlating with WTP, as well as with all three specific motivations. As stated above, all people that care about environmental problems do not see changes in residential electricity use as part of the solution. Thus, it is reasonable that, as seen in table 5.2, the respondent who experiences that electricity savings help reduce climate change (AC2) will primarily feel motivated to take part in the scheme for environmental reasons (GAN).

Non-Existent Correlations

One of the least expected results is the lack of correlation between investigated barriers, on one hand, and goal accessibilities and willingness to participate, on the other. The most unexpected result, seen in table 5.2, is the slight positive correlation between the respondents experiencing the scheme's data gathering as problematic, and their willingness to participate in the scheme. For this correlation, it should be emphasized that the respondents generally stated that they do not regard the data collection related to the scheme as a problem. This could result in a skewed result, from which no central conclusions should be drawn.

The more interesting result, however, relate to the lack of correlation between barriers and willingness in general, indicating that a reduction of barriers related to knowledge and trust is not central in increasing household willingness to participate in heating DSM. Still it should be mentioned that only a few specific barriers are investigated in the survey, leaving it open what other barriers that might hinder the respondents participation.

Goal Accessibility and Problem Focus: Partial Correlation

The initial hypothesis was that a high correlation would be found between the different goal accessibilities and problem foci, e.g. that a respondent with a low and insufficient income would be more interested in the DSM-scheme economic gains. However, as seen in table 5.3, all three goal accessabilities correlate significant with environmental concern, but none of them with either subjective comfort of subjective economy.

Table 5.3. Correlation between different goal accessibilities and problem foci. Light red marks expected but non-existent correlations, green marks found correlations.

	SE	**SC**	**EC**
GAG	-0.06	-0.03	0.20
GAH	0.04	-0.07	0.21
GAN	0.06	0.04	0.29

As mentioned, strong correlations can be seen between the three goal accessibility variables. There is a chance that these internal correlations shines through when regarding these goal accessibility variables correlation with the types of problem focus above. A partial correlation analysis is thus carried out in order to unravel this interconnectedness and to test two hypotheses.

Hypothesis One - Pseudo Correlation

When investigating the first hypothesis (see section 4.3.3), the partial correlation tells that when controlling for normative goal accessibility, the correlations between the other goal accessibilities and environmental concern disappears. Correlation between GAG and EC is found to be -0.01, and correlation between GAH and EC ends up at 0.03. This means that there is no direct connection between respondent attitude toward DSM monetary or comfort aspects, and their environmental concern. Hypothesis one is thereby confirmed.

Hypothesis Two - Hidden Correlation

When investigating the second hypothesis (see section 4.3.3), the partial correlation tells that even after isolating the specific goal accessibility and problem focus, no vital economic or comfort benefits are experienced by the respondents to be related to the DSM-scheme, even for those who are expected to be open to economic and comfort incentives in general. The correlation between GAG and SE is found to be -0.16, while the correlation between GAH and SC ends up at -0.11. Hypothesis two is thereby not confirmed. This could be due to that the economic benefits stated are too small to attract the respondents, and the indoor climate improvement is too hard to relate to without experiencing it. Most likely, economical benefits would attract people to participate if reaching some certain level, and an improved indoor climate would possibly attract people if they had the chance to feel the difference.

5.2 Modelling Results

The results show a system with investments according to the green policy scenario constraints (see section 4.4.1), in the year of 2032. Demand and wind data for the modelled results are from the year of 2012. The modelling results for the system without DSM is first described. Thereafter, the system with the DSM-scheme is compared to the system without DSM. Lastly, the different DSM-scheme scenarios are compared to each other.

5.2.1 System without DSM

The system studied, placed in northern europe, covers about half of its demand with wind power, and has a significant amount of hydropower (14% of production) available to balance the system. Still, the available hydro is not enough to completely balance the wind intermittency, and as a result, a significant extent of flexible fossil (gas, coal) production is needed to help manage the wind variation, as a result amounting to about 12% of the yearly system production.

Load and Net Load

On a system level, about 8% of the available wind is curtailed over one year. Figure 5.1 shows the system load as well as the net load when intermittent production and variation management through hydro is extracted. As can be seen in the figure, the slight and recurring variations in the load turn to larger, irregular variations in net load, which need to be handled by the rest of the system. These variations force most of the production technologies to regular cycling (see section 3.3.1), and there is hardly any room for base load in the system.

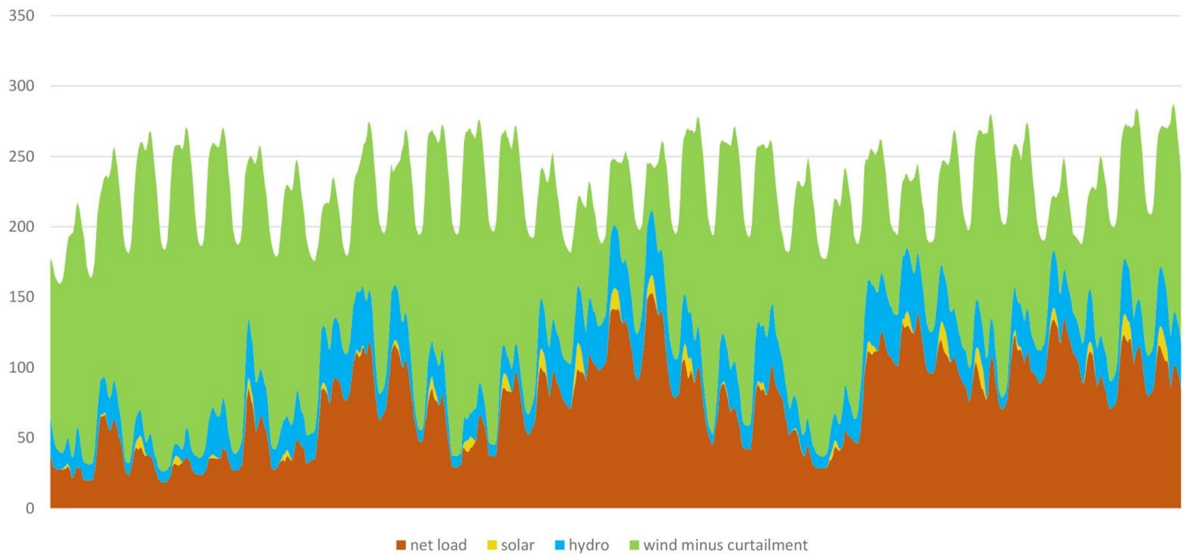


Figure 5.1. System load and net load variations for one month (January) [GWh].

Swedish Variation Management

Swedish wind production amounts to roughly 32% of the Swedish load, which is a fairly low fraction compared to the other countries. As has been discussed previously in section 2.2, and as can be seen in figure 5.2, hydropower, plays a significant role in the Swedish management of the complex net load variations. Together with trade, this results in a fairly unproblematic net load for which production is to be covered by thermal production, as well as a close to negligible level of curtailment (<0.1% of wind production).

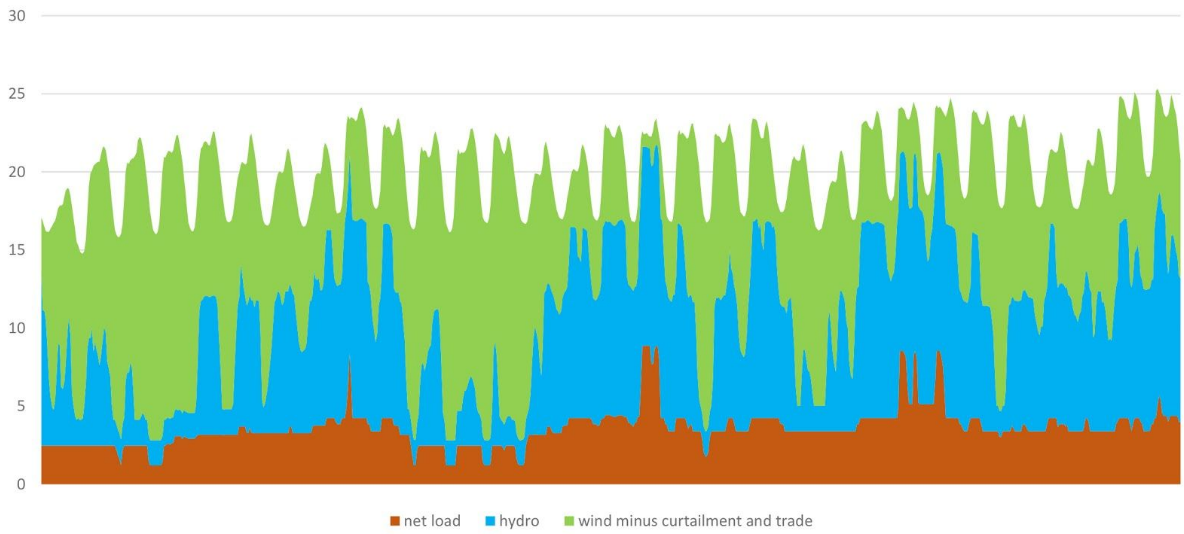


Figure 5.2. Swedish load and net load variations for one month (January) [GWh].

Trade

As mentioned previously, the Nordic countries frequently use trade in order to manage Danish wind variations by import of Norwegian and Swedish hydropower. By investigating the import and export from Denmark (DK1) to the south of Sweden, it is found that the maximum transmission capacity is utilized for large parts of the year. This means that the transmission capacity between the countries is a limiting factor in managing system wind variations through Swedish hydropower.

This dynamic is further visible when investigating Danish wind curtailment in relation to times when the export capacity to Sweden is fully utilized (figure 5.3). As can be seen, there is an apparent correlation between the Danish curtailment and the times when maximum transmission capacity to Sweden is reached, meaning Danish curtailment might be reduced if the transmission capacity to Sweden was to be increased, or utilized differently, avoiding congestion.

Figure 5.3. Relation between Danish (DK1) wind curtailment and electricity export to southern Sweden (SE1) over one month (January) [GWh]. The positive values mark available export capacity while the negative values mark wind curtailment for every hour.

Hydropower

As almost 80% of the Swedish hydro production occurs in the northern part of the country (SE3, SE4), while around 90% of electricity demand and wind production is located in the southern part (SE1, SE2), transmission within the country is crucial in order to manage variations. As can be seen in figure 5.4, there is an apparent bottleneck for export from SE3 to SE2, with the transmission capacity frequently limiting the possibility to export hydropower to the southern parts of Sweden. This also has an effect on the potential for Swedish hydro to manage system wind variations in general, since most of the trade with the rest of the system occur from the southern parts of Sweden.

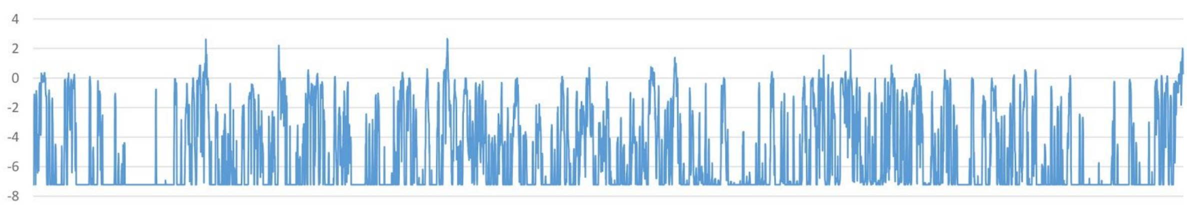
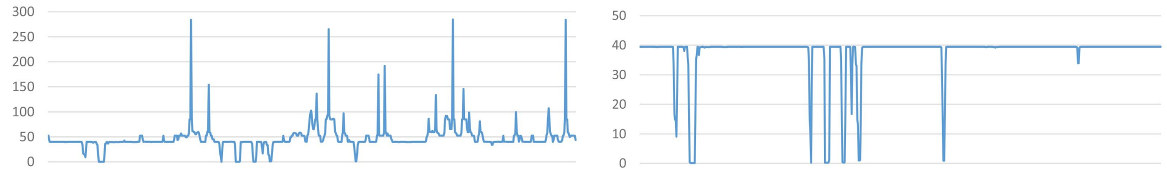


Figure 5.4. Transmission [GWh] over one year between Swedish regions SE2 and SE3, negative values mark import to SE2 and positive values mark export from SE2.

This bottleneck between the north and south of Sweden is also evident when looking at the marginal cost variations over one month (figures 5.5a-b). Since the northern part of the country has a high availability of hydro capacity but a low electricity demand, the electricity prices in the northern regions are constantly low. In the southern part of the country, however, hydro capacity is limited while electricity demand is high. At the same time, the relatively low marginal costs of southern Sweden are increased by a high transmission availability connecting the regions to other parts of Europe and leveling out the cost variations between countries.



Figures 5.5a-b. Marginal cost variations [€/kWh] for one month (January) in Swedish regions SE2 (a) and SE4 (b), chosen to represent the northern and southern part of the country.

Congestion

Table 5.6 gives an idea of where congestion occurs, before DSM is applied, between Sweden, Denmark, Norway and Germany. Problematic congestion is coloured red in the table and slightly problematic congestion is coloured yellow. Uninvestigated congestions are coloured grey in the table. As seen there is a severe difference in marginal costs between southern Germany (DE1-3), where production of coal and gas takes place, and Denmark (DK2) where the availability of wind power is high. The difference is also big between Denmark (DK2) and Norway (NO1), where both hydro and gas production occurs. Northern Germany (DE4), connecting southern Germany with Scandinavia, is further found to highly differ, in marginal costs, from Denmark and Norway. Also between southern Sweden and Denmark congestion is found.

Tabel 5.6. Congestion in system without DSM, measured as difference in average marginal costs between regions [€/kWh].

	SE1	**SE2**	**DK1**	**DK2**	**NO1**	**DE1**	**DE2**	**DE3**
DK1	15.12	14.24						
DK2	14.27	13.68						
NO1		8.61		18.93				
DE1				23.18	20.66			
DE2				17.55	17.89			
DE3				17.48	17.84			
DE4	12.04	11.31	19.50	16.77	17.24	6.43	0.78	0.71

System Costs and Emissions

The yearly production for meeting system demand without DSM emits about 308.5 ktonnes CO_2. It is related to system costs of the magnitude of 30 000 M€. Around 97% of these costs are in the form of running costs, while only 3% are system cycling costs.

5.2.2 Effects of DSM

The system effects of DSM are investigated in terms of changes in demand, supply, costs and emissions.

System Demand

The modelled DSM-scheme only has an impact on Swedish demand, while the load in all other system countries stay unchanged. The Swedish demand fraction constituted of SFD heating demand, however, is allowed to increase, decrease and shift in time, with the temperature profiles constraining the allowed load changes. Since the model is a cost optimization model, demand changes will occur whenever they have potential to reduce system costs.

Energy Conservation

Since energy conservation is allowed, and directly linked to reduced system costs, the DSM-scheme involves energy conservation. Over one year, electricity use is reduced by about 1.6 TWh, through reduced indoor temperatures in the Swedish SFDs. This is a significant quantity, amounting to around 9% of the SFDs electric heating demand, and around 1% of the total Swedish electricity demand. This reduction is in line with, but slightly higher than, Nyholms (2016) previous findings of 1.46 TWh.

DR and Net Load

Except for the obvious system value of load reduction, there is also an apparent system value of load shifting, as can be seen by the DR variation pattern in figure 5.6, indicating the system sees a value in decreasing demand at times, while increasing it at other. The exact DR benefit is harder to measure, though, since all seen system benefits of the DSM-scheme could be attributed to either energy conservation, DR, or a combination of the two.

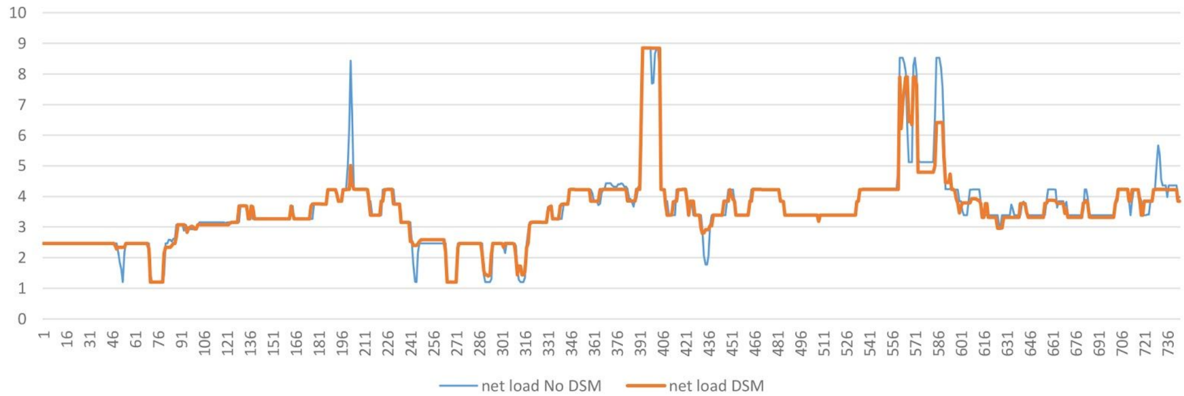


Figure 5.6. Swedish net load to be supplied by chp, bio, waste and gas for one month (January) [GWh].

When investigating the Swedish net load to be supplied by thermal and chp plants (figure 5.6) it is apparent that DSM acts by decreasing net load variations. Further investigations show a pattern where avoided net load dips (hours 53, 244, 435) result from a reduced need for the chp technologies to cycle production, while the avoided peaks (hours 202, 585, 731) result from a decreased need for gas peak production. It is apparent from figure 5.6

that DSM succeeds in reducing the net load variations related to fast variations, but not the variations which span over longer time frames of several hours (e.g. hours 71-79, 466-482).

Temperature Variations

As seen in figure 5.7, the system utilizes the opportunity to decrease the indoor temperature to a much higher extent than the opportunity to increase it. This is expected, since energy conservation, through lower temperatures, usually implies lower costs. Still, the actual temperature in figure 5.7 does differ from the minimum temperature curve, which indicates that the system sees a value in DR, and uses the ability to increase the temperature now and then.

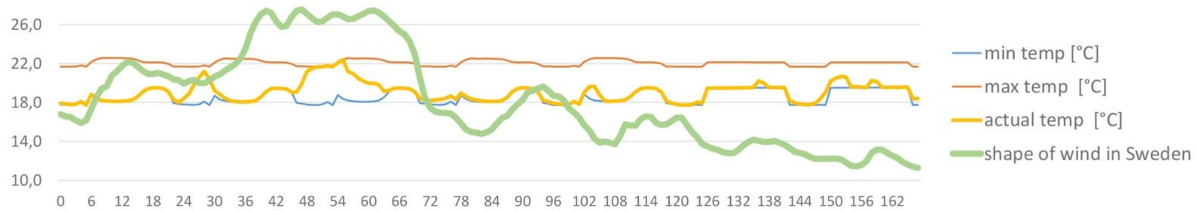


Figure 5.7. Temperature variations within accepted temperature span during one week (1st of January) compared to wind production pattern [°C].

It is seen in figure 5.7 that when the allowed minimum temperature is highest, during evenings (e.g. hours 16-21), the system wants to stay on this lowest allowed temperature. The opportunity to increase in temperature is taken mostly at night time (e.g. hours 22-30), when the net load is usually low. The strong temperature increase, even reaching the maximum allowed temperature, during the wednesday of the plotted week (hours 48-56) can be seen to mirror the high level of wind in the system at the same time, while the tuesday peak (hours 25-30) seem to be caused by an attempt to smoothen the net load and avoid the need for cycling, which can be seen in the removed net load dip in figure 5.6 (hour 53).

System Production and Trade

The most apparent effect on the yearly level, of applying DSM, is a decreased net electricity import to Sweden, roughly equal to the level of energy conservation achieved by the scheme. Also important effects are seen in areas of wind curtailment and peak load technologies.

Curtailment

For the system as a whole, the wind curtailment is reduced by 218 GWh for the entire year, which can be compared to the 1614 GWh load reduction achieved by the DSM-scheme. The reductions in curtailment happen mainly in Denmark, but also to a high extent in UK and Poland (figure 5.8), all three being countries with high penetrations of wind power production. In relative terms, the biggest curtailment effect can be noticed in Sweden, where 100% of the previous curtailment is avoided through DSM. However, it should be noticed that curtailment levels in Sweden were extremely low even before applying DSM, due to a high availability of other variation management strategies.

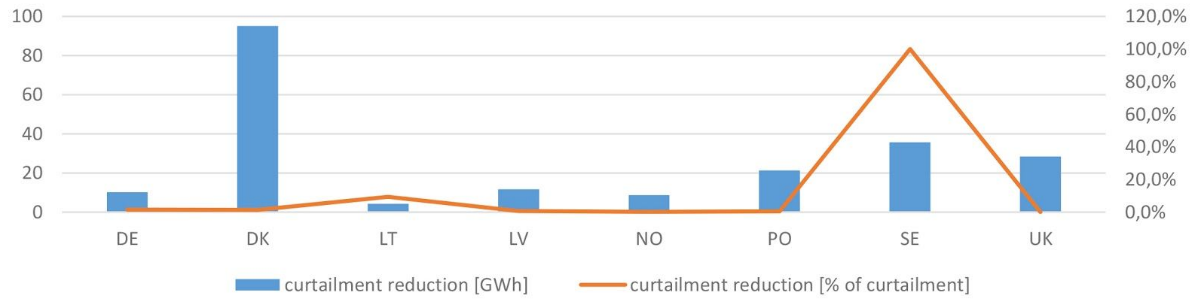


Figure 5.8. System wind curtailment reductions for one year divided into the system countries and presented in terms of absolute reduction [GWh] as well as reduction in relation to curtailment without DSM [%].

It could be imagined that applying DSM in the southern parts of Sweden would help decrease Danish curtailment even further but the congestion problem related to Danish wind production and curtailment, discussed further below, seems to limit the effect the Swedish scheme has on Danish curtailment.

Peak Load Production

For the system as a whole, production from (non-chp) coal and gas can be seen to decrease 1560 GWh over the year, which is roughly equivalent in size to the total energy conserved by the scheme. The gas production decrease occurs mainly in Norway and Germany, while the coal production decrease occurs mainly in Germany (figure 5.9). Both in absolute terms and relative to initial peak production, the largest difference overall occurs in Norway, where about 95% of the country's gas and coal production is avoided due to DSM.

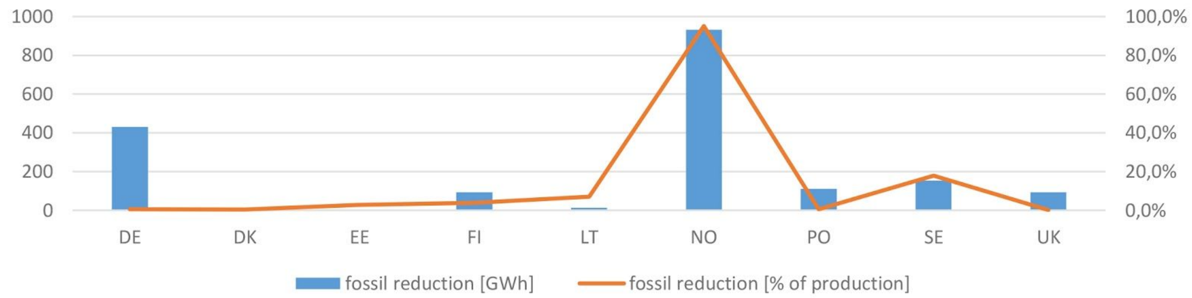
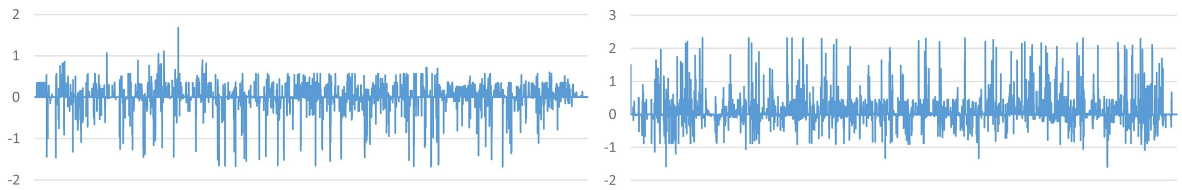


Figure 5.9. System fossil (coal and gas) production reductions for one year divided into the system countries and presented in terms of absolute reduction [GWh] as well as reduction in relation to production without DSM [%].

When studying the gas and coal production decrease over time, it is evident that the production decreases in Norway and Germany have vastly different characteristics. While the German production decrease show clear signs of a reduced need to manage system variations by peak fossil resources (figures 5.10a-b), the Norwegian gas production decrease does not have the same peak load characteristics, but rather acts as a base load with no significant variation management qualities (figure 5.11). This could imply that the German production decrease is a consequence of increased levels of available variation management in the system, while the Norwegian production decrease is rather the result of a reduced system load, cutting production where it is most expensive. It seems like gas can be run as base load in Norway, which is likely due to their high level of flexible hydropower.



Figures 5.10a-b. Avoided coal (a) and gas (b) production in Germany for one year [GWh].

Figure 5.11. Avoided gas production in Norway for one year [GWh].

This hypothesis is strengthened by looking at the country's load profiles before DSM is applied. When observing the net load, excluding intermittent production as well as variation management through hydro and trade, it is apparent that the need for increased variations management is high in Germany (figure 5.12a), while almost non-existent in Norway (figure 5.12b).

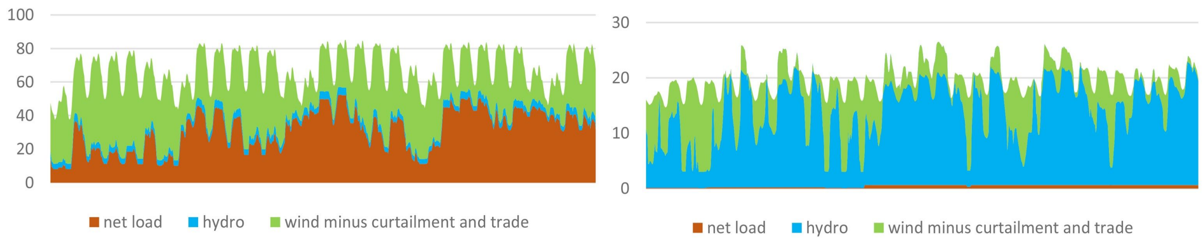


Figure 5.12a-b. Load and net load over one month (January) for Germany (a) and Norway (b) before DSM is applied [GWh].

Congestion

When the congestion situations before and after the DSM are compared, the change, indicates how well the Swedish DSM manages to reduce congestion problematics in the system. Presented in table 5.7 on the next page, significant congestion decreases are colored green, while uninvestigated congestion changes are colored grey.

Table 5.7. Reduction of congestion through DSM, measured as decreased difference in average marginal costs between regions [€/kWh].

	SE1	SE2	DK1	DK2	NO1	DE1	DE2	DE3
DK1	-1.04	-0.06						
DK2	-0.62	0.07						
NO1		-0.46		-0.10				
DE1				0.15	0.06			
DE2				-0.04	-0.04			
DE3				0.02	0.01			
DE4	-0.49	0.35	0.29	0.14	0.10	-0.01	-0.18	-0.12

When DSM is introduced in the system, congestion seem to decrease between Sweden and the closest located regions (SE1 with DK1-2 and DE4, SE2 with NO1, see figure 5.13), while the schemes effects on congestion tend to fade away with increased distance from Sweden. Regarding southern Germany on one hand and Norway and Denmark on the other, the congestion even seems to increase from before the DSM, indicating that these transition problems are too wide to be handled, which is reasonable due to the limited scale of the DSM in Sweden. The strong reduction in congestion between SE1 and DK1 clearly shows that the Swedish demand uses DSM to adjust to Danish wind production, confirming that congestion effects mainly take place on more local scale.

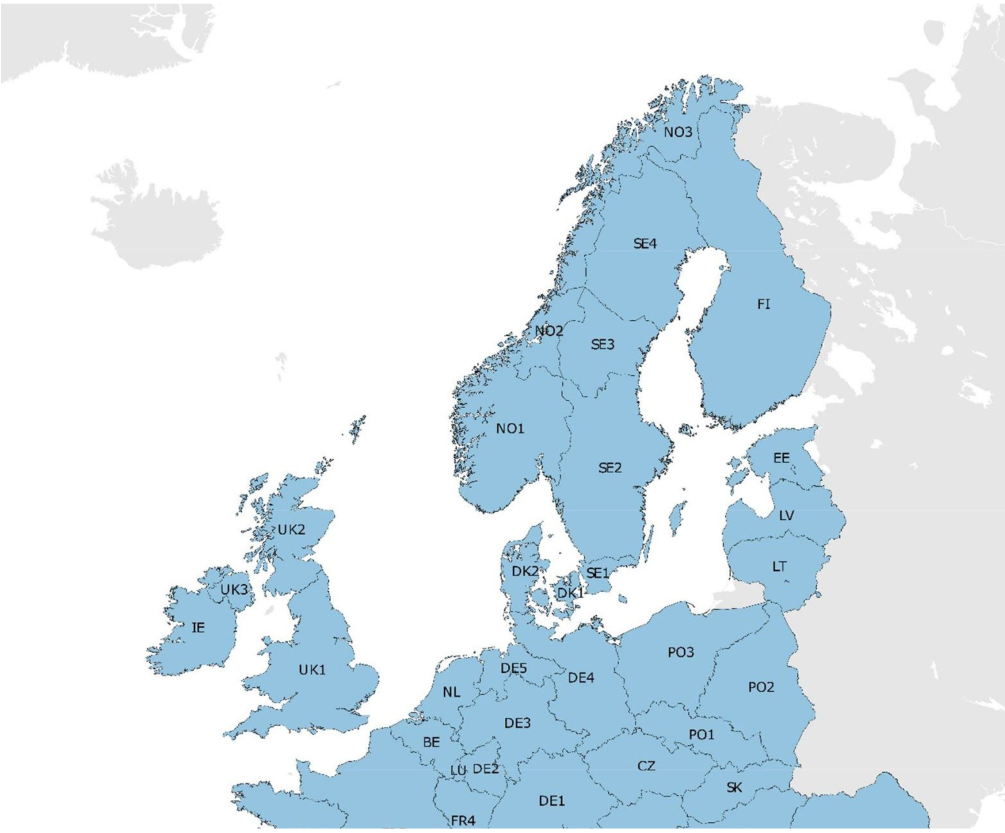


Figure 5.13. Modelled regions adjacent to Sweden (Nyholm 2016, p. 35 figure 7).

System Costs and Emissions

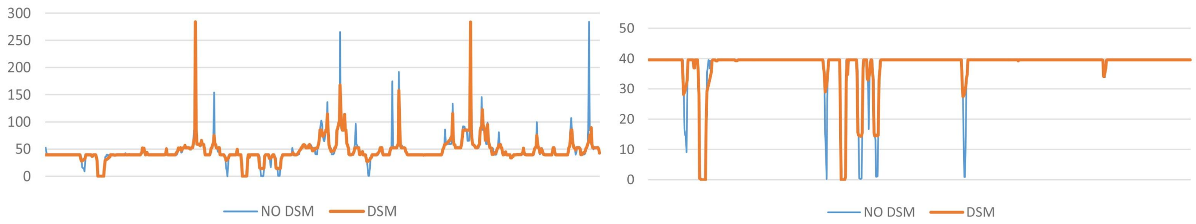
While the green policy scenario implies a cap on CO_2 emissions, this cap is not certainly a binding constraint, wherefore it is interesting to investigate the emissions impacts of applying the DSM-scheme.

System Emissions Reductions

The total yearly system emissions can be seen to decrease with 869 tonnes CO_2 when the DSM-scheme is applied. A reduction is expected, since the system demand and thus production decreases due to energy conservation. However, it is hard to draw conclusions around how much of the emissions reductions that are due to DR and improved variation management.

Marginal Costs

When investigating the marginal costs over one month in Sweden, it can be noticed that applying DSM helps decrease the marginal cost variations in the regions, as well as between the regions (figures 5.14a-b). This implies that the scheme has helped to reduce the bottleneck problematic within the country, as well as in relation to other countries, allowing the system to allocate the electricity more cost efficiently.



Figures 5.14a-b. Marginal cost variations for one month (January) before and after DSM, for Swedish regions SE2 (a) and SE4 (b) [€/kWh].

Cycling and Running Costs

The total savings from the DSM-scheme is almost 120M€ for the entire system, with about 16% of these savings occurring in Sweden. As can be seen in figure 5.15, about 90% of these savings comes from a reduction in running costs, while the remaining 10% is a result of reduced cycling costs due to the plants running more efficiently.

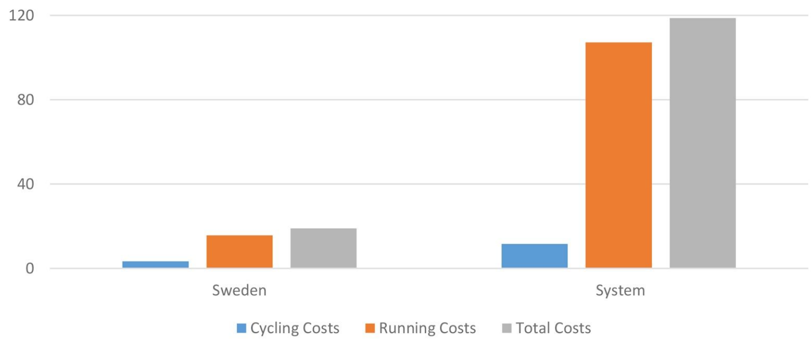


Figure 5.15. Savings in Sweden and system savings due to DSM [M€].

The apparent reduction of running costs might be related to decreased production in more expensive plants, as a combination of energy conservation and efficient DR. As expected, the largest savings in running costs occur in Norway and Germany, which relates well to the reduced fossil production in these countries. Further, the cycling costs are reduced most in Germany and Sweden, with almost no reduction in Norway. This gives further weight to the theory that German fossil production decrease as a result of DR, while the Norwegian fossil decrease simply as a result of its expensive running costs. The Swedish cycling costs are reduced by almost 15% as a result of the scheme. On the system level the reduction exceeds 1%, which is significant since the source of the reduction is solely the management of electric heating in Swedish SFDs. That the cycling cost reduction is relatively high in Sweden could imply that the DSM-scheme is effective in managing variations in local production.

5.2.3 DSM Scenarios

The three scenarios are found to have significantly different impacts on the electricity system. In terms of energy conservation, system costs and reduction of CO_2 emissions, the lifestyle change scenario is the most effective one.

Energy Conservation

The variation in energy conservation between the different scenarios is a straightforward way to roughly measure their relative efficiencies (figure 5.16). As expected, the scenario where the households have to invest in the scheme (no subsidy scenario) is related to the least energy conservation, with a quite significant reduction of 27% relative to the DSM base case. This reduction in energy conservation can be compared to the reduction of participating households by 35%.

For the two other (technical fix and lifestyle change) scenarios, the yearly energy conservation is, as expected, increased relative to the base case. The most interesting result is the relationship between the two scenarios, where it can be noted that the largest energy conservation levels are achieved by allowing for slightly larger temperature variations all the time (lifestyle change scenario), for which the energy conservation is increased by 50% relative to the base case, resulting in a reduction of SFD heating electricity demand with 14% (figure 5.16).

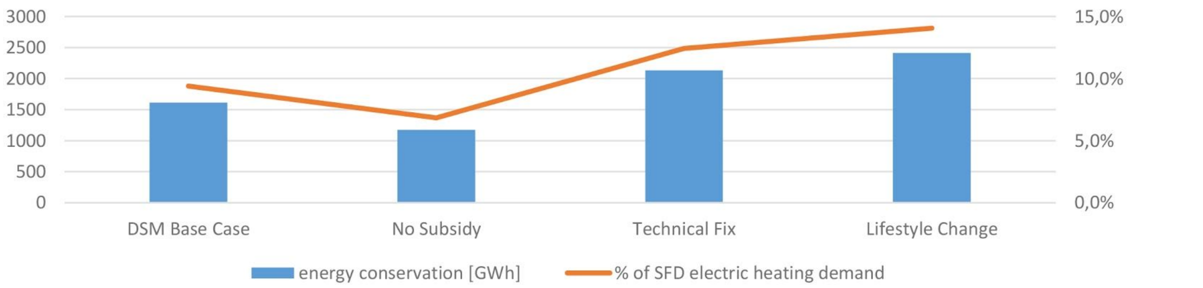


Figure 5.16. Energy conservation, in absolute terms [GWh] and in percentages [%], for the DSM Base Case and the three scenarios.

Temperature Variations

When the temperature curves chosen by the system are compared between the three scenarios, they are found to be a quite similar in shape to each other as well as to the base case. The no subsidy curve, and the span it is restricted to (figure 5.17), can be described as a slightly squeezed version of the base case's (see section 5.2.2).

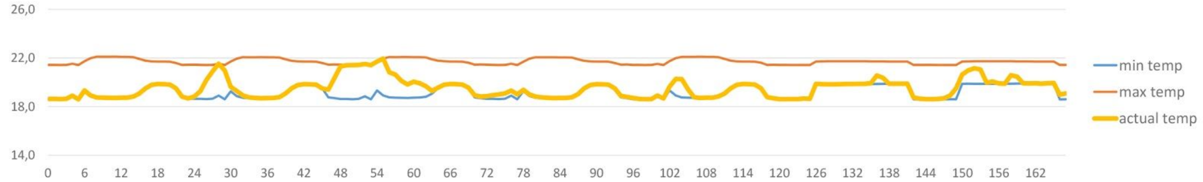


Figure 5.17. Actual temperature variations within accepted span for no subsidy scenario, during one week (1st of January) [°C].

In the technical fix scenario, the system is allowed to both increase and decrease the temperature substantially during working hours, but as seen in figure 5.18, the allowed extension upwards is not utilized except slightly during the wednesday. Still the valleys are seldom fully utilized, possibly resulting from the requirement for the temperature to increase sufficiently before the residents come home in the evening.

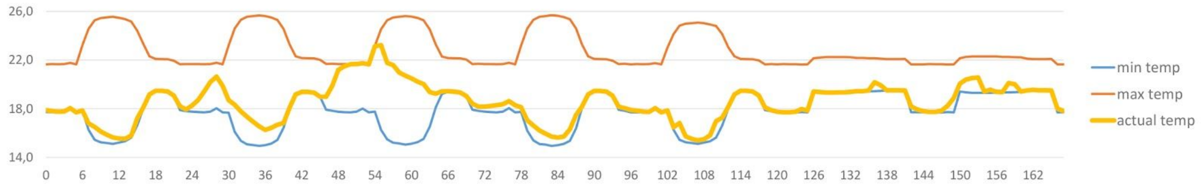


Figure 5.18. Actual temperature variations within accepted span for technical fix scenario, during one week (1st of January) [°C].

The lifestyle change curve utilizes the for all hours decreased minimum temperature to a high extent, which is the reason why this scenario is related to the highest level of energy conservation (figure 5.19). While the allowed temperature span is occasionally bigger in the technical fix scenario, the well utilized opportunity to keep a slightly lower temperature at all hours is found to result in higher levels of energy conservation, possibly due to the technical constraints for reducing and increasing the temperatures greatly at a short time frame.

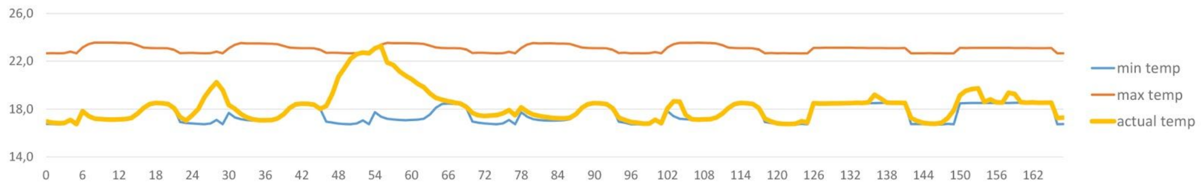


Figure 5.19. Actual temperature variations within accepted span for lifestyle change scenario, during one week (1st week of January) [°C].

System Emissions

The emission reduction is 24% less in the no subsidy scenario compared to the base case, which can be compared to the reduction in energy conservation by 27%, entailing the loss in participation affects the emissions reduction benefits of DSM less than it affects the load reduction.

For the lifestyle change scenario emissions are reduced an additional 45% (393 tonnes CO_2), compared to the DSM base case, while emissions reductions increase only by 26% for the technical fix scenario. This entails a significant difference in emissions reduction from DSM dependent on what approach is chosen for developing and implementing the scheme.

System Costs

The total system savings from DSM differs significantly between the scenarios, from 95 to 162M€, with the overall largest difference being in terms of the level of running cost reductions achieved by the scenario. The total cost reductions are mainly due to decreased running costs in all the scenarios. Data on cycling costs, running costs and total costs can be found in Appendix X.

A comparison between the base case and no subsidy scenario (figure 5.20) implies that about 20% of the system cost reduction from DSM may be lost by forcing the households to invest economically in the scheme. Since the related decrease in households participating in the scheme is around 35%, this means the systems costs reductions do not follow the decreased participation level linearly.

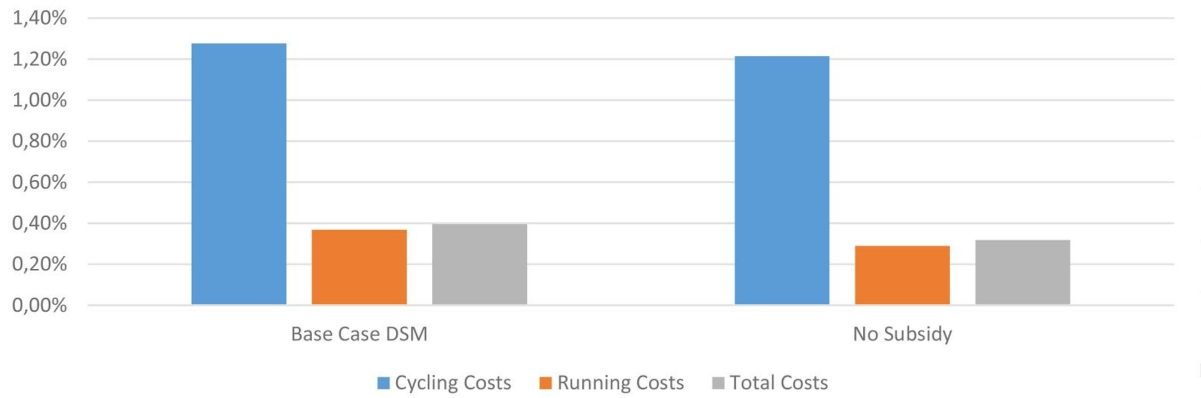


Figure 5.20. System savings in percentages for the different DSM scenarios, showed as reduction of costs relative to costs in the system without DSM [%].

The outcome of the technical fix versus lifestyle change scenarios (figure 5.21) implies that increasing the household residents tolerance for slight temperature variations any time is more effective than focusing on technical possibilities to save energy when no one is at home, when it comes to reducing system costs. The difference in savings between the scenarios is significant, with the technical fix scenario increasing savings with 20% compared to the DSM base case, while the lifestyle change scenario increases systems savings by over 35%. It should however be noted that this outcome is highly depending on the assumptions used for the scenarios.

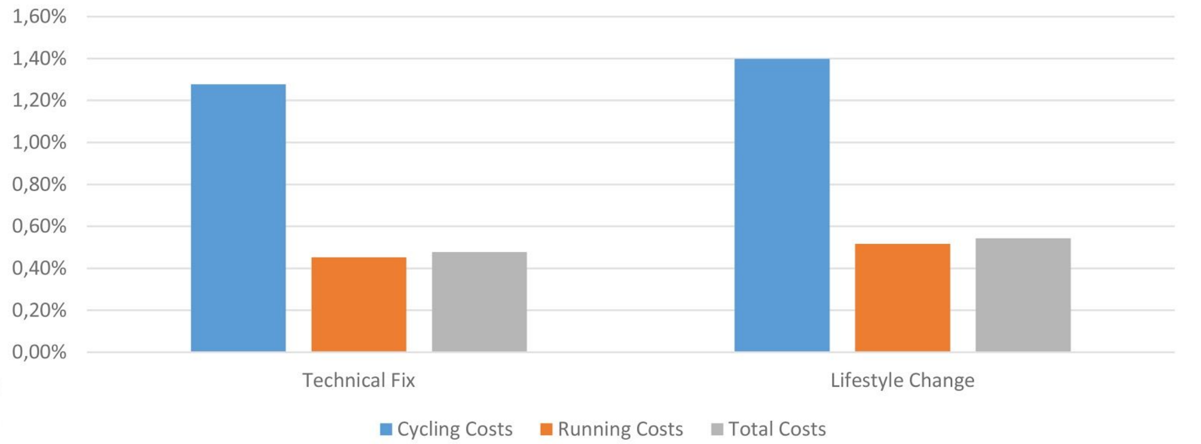


Figure 5.21. System savings in percentages for the different DSM scenarios, showed as reduction of costs relative to costs in the system without DSM [%].

6 Discussion

In the first section (6.1) of this chapter, the methods chosen in the work and what impacts these choices may have had are discussed. In the second and third section (6.2-6.3) the outcome of the behavioural and the modelling analysis, its uncertainties and implications are discussed. In the last section (6.4) the need for further research on the subject is discussed.

6.1 Methods

The methodological choice of using a survey to capture SFD household's attitudes toward DSM is reasonable for the scope of the thesis. However, it limits the results, since all behavioural conclusions are drawn from theoretical, rather than practical information. Asking respondents to imagine how they would feel and act in a specific scenario is obviously not as ideal as watching them act in real life. This is potentially even more striking when asking about abstract concepts such as temperatures and how different temperatures would be experienced by the household.

Another issue related to the survey outcome is that, even though the survey is designed to be neutral in terms of motivations for participation, the survey is sent out from the department of Energy and Environment. There is a risk that this, together with the significant amount of questions in the beginning of the survey relating to environmental issues, might have biased the respondent's answers, activating their environmental values and increasing their will to answer positively toward environmental benefits.

When it comes to normative motivations and actions, the core of previous research on environmental psychology is that people generally state climate mitigating actions as important and good but that when studying people's actual behaviour, they are less likely to act on these climate mitigating motivations. Thus, it is not certain that the stated willingness to participate based in normative, climate mitigating, motives would perfectly translate into real household participation. Rather, the thesis outcome can help reveal the existing household interest and support for climate mitigating DSM-schemes, if implemented in a good way.

The method of using different participation scenarios was judged to be a good way to highlight different potentials of heating DSM, selecting three scenarios as representatives of three theoretical aspects of DSM. However, the relative outcome of the different scenarios are to a high degree dependent on specific assumptions made when differentiating the scenarios, rather than to the different conceptual approaches they represent. The lifestyle change scenario assumption of increased temperature variation acceptance of +/- 1°C all the time is specifically crucial, since this assumption is what the resulting findings that this scenario is the most efficient, is based on. The assumption is not grounded in any findings, but is rather chosen as an example of increased acceptance for temperature variations. This means that the exact benefits of the scenario are highly uncertain, and is not to be seen as a realistic potential today. However, the scenario is chosen in order to investigate what it would imply if people would become more flexible in the future.

Important to note is the fact that the very foundation of the modelling outcome of the thesis is based on a minimisation of running and cycling costs of the system plants. Another valid alternative when investigating electricity demand and supply options in relation to climate mitigation could be to combine the cost optimization with an optimization related to minimising system emissions. To a significant extent, however, the two optimization choices would probably result in similar outcomes in a context such as the green policy scenario, with large penetrations of wind power and caps on CO_2 emissions. This is due to that, as can be seen in the outcome, the most fossil heavy fuels are the ones first cut by the cost minimising models. This is also evident for the different scenarios, as the scenarios with the largest DSM effects under cost minimisation are also the ones achieving the most reductions in emissions. However, it should be noted that while the cost minimizing model removed gas production before coal production, an emissions minimizing model would probably remove the fossil heavy coal production first.

6.2 Behavioural Results

The main behavioural finding of the study is that normative, climate change mitigating, motives seem to primarily guide household willingness to participate in heating DSM. Climate change mitigation benefits of DSM seem to be far more explanatory for household participation level than all examined barriers, which implies that it is not of central importance to lower the barriers, but rather to emphasize the benefits.

While survey respondents with a high willingness to participate stated both climate benefits, economic benefits and comfort benefits as important, a further analysis showed that respondent beliefs about the climate benefits of the DSM-scheme guided them to also see benefits in the other aspects of the scheme. This might imply that the households experience DSM to be related to the social dilemma of climate change, connecting the scheme to collective rather than private interests and motives. This is an interesting result since previous studies have noted that households do not view simply energy conservation as a social dilemma, but engage in it rather due to private economic benefit.

More specifically, the factor which is found to have the highest importance for household participation is to what extent the residents see electricity savings as helping to reduce climate change. This means that believing that climate change is a societal problem is not enough for the households to want to participate in heating DSM. This is expected, since attitudes toward more specific issues are generally seen to stronger predict people's actions in specific situations. In line with that, a way to increase household willingness to participate could be to make the connection between electricity consumption and climate change more apparent for electricity consumers; thereby emphasizing the social dilemma aspects of DSM. This is of central importance, since many people today see consumption of Swedish electricity as being related to relatively little climate impacts, which could be an explaining factor for the current gap between the general and situation specific attitudes on the issue.

The findings of the study imply that the household benefits related to economy and comfort do not guide household willingness to participate in heating DSM. However, there can be several valid explanations for this result. One potential explanation is that while climate mitigation is a general, societal issue for which people are relatively used to taking a stand, the DSM-scheme benefits related to comfort and economy are small scale and situation specific, and may thus be harder for the survey respondents to relate to in terms of how they would feel about their indoor temperatures being more stable, or electricity costs reducing slightly. Another possible explanation is that households might not be that sensitive to economic incentives related to their electricity bill, due to the complexity of its different cost constituents as well as electricity being a relatively small household expense in Sweden today. In contrast to the comfort benefits of heating DSM, however, the economic benefits for the households could be increased significantly, which might alter their attitude toward the benefit and increase the economic motivation for participation. It is, however, beyond the scope of this thesis to investigate whether economic incentives in general are not effective in heating DSM-schemes, or whether the economic incentives for this case are simply too low to motivate participation.

When presenting the survey result in terms of household willingness to participate as well as correlation between variables, the survey responses are not weighted to increase representability of responses in relation to target group. Since this is done for the modelling, this means the modelling results relate to a somewhat different group than the behavioural results. It also means that the behavioural results is biased in terms of an overrepresentation of male respondents, and a subsequent underrepresentation of female responses. This might represent a significant bias of the result, since important variables for guiding willingness to participate are found in the survey to differ between genders. The female respondents of the survey display a more positive attitude toward heating DSM in general, as well as toward all three different motives for participating. This is likely guided by their awareness of consequences, ascription of responsibility and environmental concern; factors that are seen to be higher for the average female respondent than the average male respondent. Based on these differences between genders, the average willingness to participate extracted from the survey is likely underestimated.

The other big demography factor seen to correlate with environmental concern and willingness to participate is geographic location of the household. Somewhat unexpectedly, survey respondents living in the northern part of Sweden (Norrland) is seen to display higher environmental concern, as well as a more positive attitude toward all three motivations related to the specific DSM scenario. Although not biasing the result, since the representation of the group in the survey to a high degree match that of the target group, this result is interesting since it implies that the willingness to participate is higher where the conditions are less favorable. As mentioned before, the SFD electric heating demand in the north of Sweden is low, while at the same time there is a high availability of variation management through hydropower. This means that although the behavioural potential for households in the north of Sweden might be high, the actual physical potential of DSM taking place and having system effects is limited.

6.3 Modelling Results

The geographical boundaries of the study clearly limit the findings, since the Swedish net load variations differ extensively from those commonly seen in a country with high penetration of wind power in the system. If the investigated DSM-scheme would have been placed in another country with a larger need for variation management, the effects would probably have been far different, likely resulting in larger cost and emissions reductions, both on the system level and within the country applying DSM. With this in mind, it could be argued that in order to increase the efficiency of DSM, the schemes should be located in the countries and regions with the most need for variation management, avoiding congestion to limit the DSM benefits.

The expectations on DSM to handle curtailment of wind power are not fully met in the outcome, a finding which must be discussed in the light of geographical boundaries. Most of the Danish curtailment is still in place even when DSM is introduced in Sweden, which could be attributed to the transmission capacity being fully utilized between the countries during times of curtailment. This points at the transmission capacity between the countries as being one limiting factor in decreasing the curtailment, which means that new investments in transmission capacity, or placing the scheme in a country with more curtailment, could be a way to increase the scheme's impact on curtailment. Still it is found that the congestion between Sweden and Denmark is reduced when DSM is introduced in the system. This could be understood as that while improved transmission capacity is needed to fully utilize the DSM potential effects, the DSM simultaneously reduces the size of needed transmission capacity.

In the result it is hard to separate the DSM-scheme DR related effects from scheme's energy conservation effects, but it can be seen that both DSM qualities are utilized by the system. For the individual participant the cost reductions are mainly due to energy conservation, meaning that participating in a centralized scheme is a kind of "sacrifice for the greater good" from the individual's perspective. This increases the importance of the findings that respondents seem to regard DSM participation as handling a social dilemma.

The annual savings that could be achieved on system level from the implementation of DSM is found to be extensive, but spread out among the participating households, the amount is not a very impressive economic incentive for participation. What is not considered when doing this rough calculation is that households that consume the most electricity for heating, thus creating the most significant burden on the system, have the highest economic incentives for DSM participation. This means that households that are most important to attract, from the system perspective, automatically get the strongest economical incentives for participation, while those who already have a low electricity consumption could expect a more or less negligible economic incentive, unless the participation is subsidized.

Furthermore, while the available DSM flexibility decreases in the no subsidy scenario, the decrease is not linearly related to the number of households not participating in DSM. This implies that the decrease in benefit from losing the least interested households is not of vital importance, since these households display a relatively low willingness and potential to participate, meaning their contribution if participating would be relatively low.

The technical fix scenario explores the effects of allowing the system to do almost whatever it wants with the participants temperatures when they are not at home, while the lifestyle change scenario explores the effects achieved by allowing an increased level of temperature variations at every hour of the day. The outcome of the modelling shows that the lifestyle change scenario outranks the technical scenario, both in terms of energy conservation, cost savings and reduction of CO_2 emissions. This result could imply that there is more to gain for a policymaker to direct effort toward achieving an DSM-scheme in line with the lifestyle change scenario over one similar to the technical fix scenario. Still, as discussed above, the household acceptance of the lifestyle change and sacrifice implied by the scenario must be further investigated before a well informed policy decision could be made.

The fact that the DSM is modelled to take place in Sweden limits the conclusions which can be drawn regarding the value of DSM in a wind dominated system. The low need for wind variation management in Sweden is not representative for the system countries in general, and the limitations in trade reduces the impacts the scheme can have outside of Sweden. Thus, it is hard to draw conclusions around if the noted system effects, and lack thereof, are a result of heating DSM interacting with a wind dominated system, or simply, to a large degree, the result of energy conservation in a system where there is no need for extensive variation management.

6.4 Further Research

This study has found the potential to reduce the heating demand for Swedish electric heated SFDs by about 9%. This indicates a large inefficiency in the system, which could be mitigated by adapting SFD heating to household habits and behaviour. These possibilities of improvements, although significant, rely on the household resident's acceptance and participation. Therefore, there is a clear need to go on with more concrete behavioural studies and pilot schemes in order to increase understanding and optimize the electricity use in the residential heating sector.

Even though this study has hopefully helped decrease the gap between behavioural studies and electricity systems modelling, it is limited in the sense that it is based on people's theoretically stated routines and temperature preferences. Further studies allowing people to experience different temperatures at different times are needed in order to get reliable values of what people actually find acceptable and not in terms of comfort. Pilot studies are also needed in order to investigate to what extent people's willingness to participate translate into actual participation if exposed to a similar scheme in reality, and if the normative motives of reducing climate change will motivate them to act also in real life.

Although environmental benefits are found to be the most motivating incentive, a pilot study could also help investigate what role economical and comfort benefits of different magnitudes can play in increasing actual participation.

7 Conclusions

The willingness to participate in DSM of electric heating, among Swedish SFD residents, is investigated through a survey and found to be overall high. Among the investigated household types, residents with children are found to show the highest willingness to participate. This household type is also found to have the highest potential to participate, measured as acceptance of temperature variations throughout different hours of the week. Retired residents are found to show the lowest level of both willingness and potential to participate, which is likely a result of their limited hours away from home.

Environmental benefits (normative goal accessibility in figure 7.1) are found to be the main motivation for participation in the DSM-scheme, often needed to be in place to enable the respondents to embrace economical and comfort incentives, while the investigated barriers do not seem to be of central concern. This indicates that people relate DSM to the social dilemma of climate change and connect the scheme to collective rather than private interests and motives. In line with this, the psychological factor strongest guiding their willingness to participate is found to be their awareness of how electricity savings help to reduce climate change (specific AC in figure 7.1), indicating that the households willingness to participate may be increased by emphasizing the connection between electricity use and climate change.

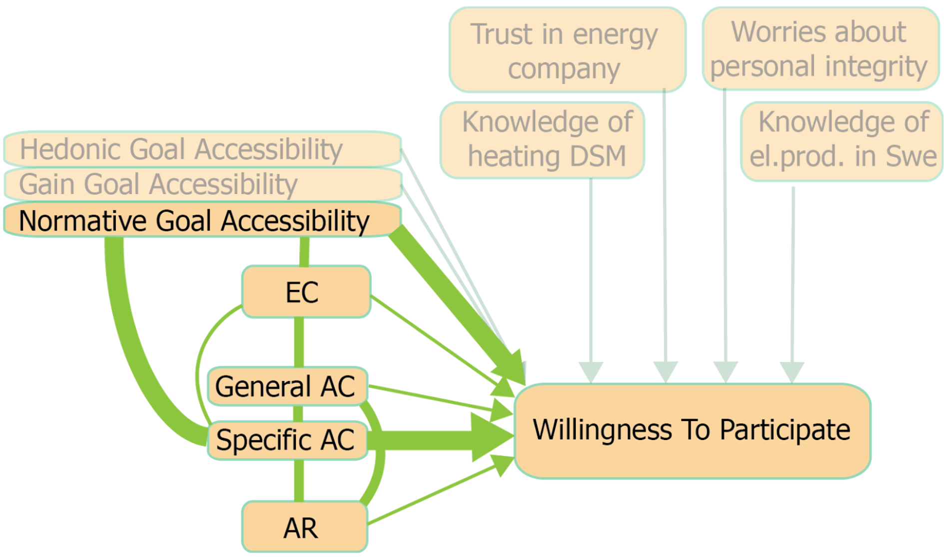


Figure 7.1. Relationships between psychological factors.

The results of the survey are incorporated in a techno-economic model of the north-european electricity electricity system and gives that applying electric heating DSM for Swedish SFD is seen to reduce system running and cycling costs by around 120M€/year, and to reduce system emissions by around 870 tonnes CO_2/year. The most apparent system effect of the DSM-scheme is the electricity demand decrease of around 1.6TWh/year due to energy conservation, which amounts to a reduction of around 9% of today's electric heating demand for Swedish SFDs. This decrease in demand is reflected by a decreased production from gas power plants in Norway and coal and gas power plants in Germany. While the production decrease in Germany shows characteristics of reduced fossil peak production, the production decrease in Norway shows signs of resulting from a reduced electricity demand, cutting production where it is most expensive.

The scheme entails a slight reduction in system wind curtailment, mainly in Denmark. The small amount of curtailment previously existing in Sweden is removed due to the scheme, but the reduction in curtailment on a system perspective seems to be limited by congestion. Congestion problematics are further found to decrease between Sweden and its closest neighbouring regions, especially between south of Sweden and Denmark, while the DSM scheme's effect on congestion in more distant regions is limited.

Through exploring a series of scenarios the study indicate that there are large system benefits related to increasing household acceptance of a slight increase in temperature variations at all hours of the day (figure 7.2, lifestyle change). Focusing on technical possibilities to decrease indoor temperatures rapidly and extensively at times when the residents are away from home (figure 7.2, technical fix) also increases the benefits from the base case scenario, but to a less extent than the lifestyle change scenario. The study further indicates that limiting the DSM participation to households who are open to invest in DSM equipment decreases the system benefits of DSM (figure 7.2, no subsidy). However, although this would decrease household participation by 35%, it would only reduce system monetary savings from DSM by around 20%.

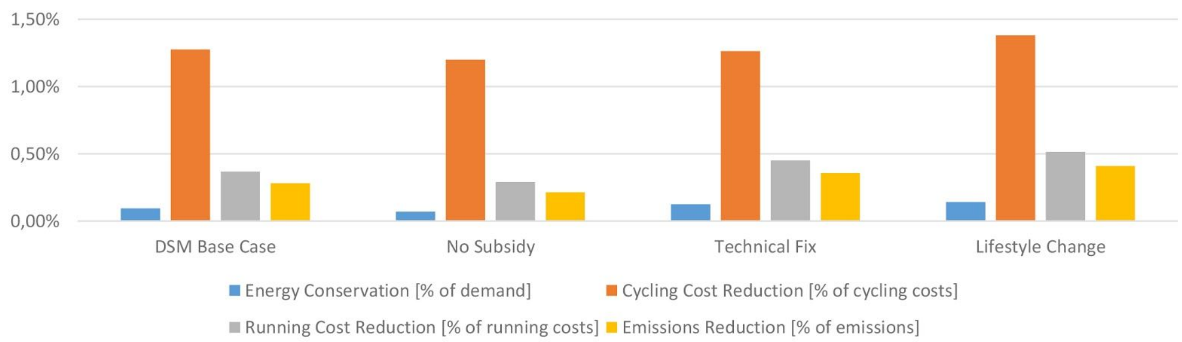


Figure 7.2. System effects of different DSM scenarios [%].

The work suggests further research on DSM in other countries than Sweden in order to be able to fully grasp the interplay between residential heating DSM and wind variations. Further behavioural research is also needed, exceeding the limited theoretical approach used in this thesis and looking at resident's actual routines, preferences and motivations through pilot studies, increasing understanding of not only intention to participate, but actual participation.

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Appendix I - Survey

GÖTEBORGS UNIVERSITET

CHALMERS
UNIVERSITY OF TECHNOLOGY

ATTITYDER TILL INOMHUSKLIMAT

Denna enkät riktar sig till dig som bor i småhus i Sverige. Den skickas ut i samband med ett tvärvetenskapligt examensarbete kring hur människors inställning till värmereglering påverkar svensk elanvändning. Examensarbetet utförs i samarbete med Chalmers Institution för Energi och Miljö och Psykologiska Institutionen på Göteborgs Universitet.

Enkäten innehåller frågor om kunskap, vanor och attityder kring elförbrukning och temperaturreglering och den tar ca 5-10 minuter att besvara. Alla frågor är frivilliga och svaren kommer inte att kunna kopplas till dig eller ditt hushåll då enkätens resultat endast redovisas i sammanställd form.

I slutet av enkäten finns möjlighet att lämna kommentarer och det är välkommet att kontakta oss om något är oklart!

Yrsa Dahlman (yrsad@student.chalmers.se)
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Studenter på Industrial Ecology vid Chalmers Tekniska Högskola i Göteborg

ELFÖRBRUKNING

Vänligen ange till vilken grad du instämmer med följande påståenden kring eluppvärmning och klimatförändringar.

	1 Instämmer inte alls	2	3	4	5	6	7 Instämmer helt
Jag har goda kunskaper om hur jag kan minska mina uppvärmningskostnader genom värmereglering.	○	○	○	○	○	○	○
Jag har goda kunskaper om hur den el jag förbrukar produceras.	○	○	○	○	○	○	○
Jag har förtroende för att mitt elbolag tar rimliga elpriser.	○	○	○	○	○	○	○
Klimatförändringen är ett samhällsproblem.	○	○	○	○	○	○	○
En minskad elförbrukning bidrar till minskade klimatförändringar.	○	○	○	○	○	○	○
Enskilda individer är inte ansvariga för att bemöta klimatförändringen genom att förändra sin elförbrukning.	○	○	○	○	○	○	○
Jag upplever att bidraget från min elförbrukning är försumbar för klimatförändringen.	○	○	○	○	○	○	○
Jag är bekymrad över miljöproblem i allmänhet.	○	○	○	○	○	○	○

I vilken del av Sverige bor du?

- Götaland
- Svealand
- Norrland

Bor du i småhus (villa, radhus, kedjehus, parhus eller motsvarande)?

- JA
- NEJ

tiden på ett optimalt vis i termer av komfort, ekonomi och klimatbelastning. Detta innebär att **parallellt med minskade koldioxidutsläpp medför denna typ av värmereglering minskade el-kostnader och ett förbättrat inomhusklimat för dig som bor i eluppvärmt småhus.**

Vänligen besvara följande frågor kring din inställning till värmereglering.

	1 Verkligen inte	2	3	4	5	6	7 Verkligen
Är du spontant positiv till denna typ av värmereglering?	○	○	○	○	○	○	○
Skulle du kunna tänka dig att investera i denna typ av värmereglering om det betalar sig på sikt?	○	○	○	○	○	○	○
Upplever du att denna typ av värmereglering skulle medföra datainsamling som kan hota den personliga integriteten?	○	○	○	○	○	○	○

ETT VÄRMEREGLERINGSSCENARIO

Tänk dig att ditt hushåll väljer att **prova automatisk värmereglering i ett år** och väljer en profil där en **inomhustemperatur på 21,2 °C** önskas, men som accepterar att temperaturen **kan stiga till 24 °C** och kan **sjunka till 18 °C på natten** och till **15 °C under arbetsdagen** (då ingen är hemma) om det gynnar elsystemet (hela variations-spannen behöver sällan utnyttjas, men flexibiliteten finns).

Ditt hushåll kommer då vid årets slut (genomsnittligt) ha **sparat ca 500 SEK** genom den förändrade elanvändningen. Samtidigt kommer hushållet ha **undvikit utsläpp av ca 760 kg koldioxid**, vilket motsvarar en flygresa från Göteborg till södra Frankrike. I termer av förbättrad komfort kommer du märka hur inomhustemperaturen ligger på 21,2 °C, d.v.s. på exakt **önskad temperatur 98% av tiden** som hushållet har registrerat som vaken icke-arbetstid.

Vänligen ange till vilken grad du instämmer med följande påståenden kring scenariot ovan.

	1 Instämmer inte alls	2	3	4	5	6	7 Instämmer helt
Jag är positiv till detta fall av automatisk värmereglering då det skulle spara pengar och vara ekonomiskt fördelaktigt.	○	○	○	○	○	○	○
Jag är postitiv till detta fall av automatisk värmereglering då det skulle bidra till minskade koldioxidutsläpp och minskade klimatförändringar.	○	○	○	○	○	○	○
Jag är postitiv till detta fall av automatisk värmereglering då det skulle undvika otrevliga svängningar i inomhustemperaturen.	○	○	○	○	○	○	○

DU OCH DITT HUSHÅLL

Kön (du)

Kvinna

Ålder (du)

18 år - 29 år

Hur många personer (inklusive du själv) ingår i ditt hushåll i respektive ålderspann?

0 1 2 3 4 5

under 10 år

10 år - 17 år

18 år - 29 år

30 år - 45 år

46 år - 65 år

över 65 år

När byggdes huset du bor i?

1960 eller tidigare

Hur stort är huset du bor i?

105 kvm eller mindre

Vilken typ av uppvärmning har huset du bor i?

100 % el: primärt luft-vattenvärmepump

RUTINER

Hur upplever du idag ditt hushålls sammanlagda inkomst?

Låg	O	O	O	O	O	O	O	Hög
Otillräcklig	O	O	O	O	O	O	O	Tillräcklig

Vänligen besvara till vilken grad du instämmer med följande påståenden kring hushållets rutiner.

	1 Instämmer inte alls	2	3	4	5	6	7 Instämmer helt
Det finns en hög grad av regelbundenhet i hushållets gemensamma sovtider (tid då alla sover).	O	O	O	O	O	O	O
Det finns en hög grad av regelbundenhet i hushållets gemensamma arbetstider (tid då ingen är hemma).	O	O	O	O	O	O	O
Hushållets sovtider skiljer sig tydligt mellan vardag och helg.	O	O	O	O	O	O	O

Dra markören över hushållets (ungefärliga) **gemensamma sovtider** (alla i hushållet sover), bekräfta valet genom att klicka på etiketten ("gemensamma sovtider") som kommer upp.

OBS: om du fyller i enkäten på mobilen markerar du en tid genom att klicka på den och bekräftar valet genom att klicka på "gemensamma sovtider". Gör sedan likadant med övriga tider du vill markera.

18 19 20 21 22 23 00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17

Dra markören över hushållets (ungefärliga) **gemensamma arbetstider** (ingen i hushållet är hemma), bekräfta valet genom att klicka på etiketten ("gemensamma arbetstider") som kommer upp.

OBS: om du fyller i enkäten på mobilen markerar du en tid genom att klicka på den och bekräftar valet genom att klicka på "gemensamma arbetstider". Gör sedan likadant med övriga tider du vill markera.

05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 00 01 02 03 04

Vänligen ange för vilka dagar dessa **gemensamma arbetstider** gäller (flera alternativ kan anges).

Måndag Tisdag Onsdag Torsdag Fredag Lördag Söndag

TEMPERATURER

Hur upplever du idag din inomhustemperatur?

Otillfredsställande	○ ○ ○ ○ ○ ○ ○	Tillfredsställande
Kall	○ ○ ○ ○ ○ ○ ○	Varm
Instabil	○ ○ ○ ○ ○ ○ ○	Stabil

Vilka inomhustemperaturer upplever du som behagliga (flera alternativ kan anges)?

17 °C	18 °C	19 °C	20 °C	21 °C	22 °C	23 °C	24 °C	25 °C

Vilken temperaturvariation (°C) **nedåt** (från ovan valda temperaturintervall) tycker du är rimlig under delar av dygnet då...

0 -1 -2 -3 -4 -5 -6 -7 -8

...alla i hushållet sover?

...ingen i hushållet är hemma?

... delar av hushållet är hemma och vakna?

Vilken temperaturvariation (°C) **uppåt** (från ovan valda temperaturintervall) tycker du är rimlig under delar av dygnet då...

0 1 2 3 4 5 6 7 8

...alla i hushållet sover?

...ingen är hemma?

... delar av hushållet är hemma och vakna?

MÖJLIGHET TILL KOMMENTARER

Har du någonting du vill delge som inte fångats in i frågorna?

MÖJLIGHET TILL KVALITATIV INTERVJU

Skulle du kunna tänka dig att ställa upp i en intervju om inomhustemperaturer och värmereglering?
Vänligen ange isåfall din epostadress:

MÖJLIGHET ATT TA DEL AV RESULTATET

Skulle du vilja ta del av enkätens resultat?
Vänligen ange isåfall din epostadress:

Appendix II - DSM Scenario Calculations

Household Average Monetary Gain

An average monetary household gain is calculated by dividing the model system monetary gain for the case D15N18DR (Nyholm 2016) by the modelled number of households. The average is calculated to 54€, and rounded of to 500 Swedish kronor (SEK) (from 511). Calculation:

System value of DR: 30800 €/year

Average dwelling reduction: 30800 €/year/571 dwelling = 54 €/year

Corresponds to approximately 500 SEK

Household Average Contribution to Reduced CO_2 Emissions

For the calculation of an average contribution to reduced CO_2 emissions, it is assumed that, since coal is on the margin in the swedish electricity system, the electricity savings due to the scheme would have been fueled by coal power. The whole system's electricity savings from space heating in SFDs for the case D15N18DR are therefore multiplied with the content of CO_2 per kWh coal power and then divided by the modelled number of households, giving an average contribution of about 760 kg CO_2/dwelling (rounded from 763 kg). This number is then compared to a flight distance, Gothenburg to south of France, emitting the same amount of CO_2, to make the number more graspable for the respondents. Calculation:

saved electricity per dwelling:

1,0296 TWh/year/1.3 million dwellings= 792 kWh/dwelling,yr

CO_2 emissions from coal power production:

0.963 kg CO_2/kWh for coal power

Average CO_2 emission reduction per dwelling:

0.963 kg CO_2/kWh for coal power * 792 kWh/dwelling,yr=

= 763 kg CO_2/dwelling,yr 2012

Corresponds to 1600 km flight ~ Gothenburg to south France

Household Average Indoor Temperature Profile

By printing graphs of minimum temperature, mean temperature and maximum temperature for all of the modelled households for the case D15N18DR it is confirmed that the temperature never falls below the lower level of acceptance (15°C night time, 18°C working times, 21.1°C rest of the time). It is also found that the system possibility of rising above 21.2°C up to 24°C is never utilized. This gives the average household a temperature of exact the chosen 21.2°C in principle the whole time that the household has claimed that they are usually at home and not asleep.

Appendix III - Imputations of Missing Answers

- Respondents who have not answered which part of sweden they live in can be assumed to live in Götaland, due to that EON mainly has customers in this area.
- Missing answers on 7-scale-questions can be imputed by a value of 4, since this does not affect the mean value of any grouping.
- Questions offering an answer alternative of the kind “don’t know/other” can be imputed by this alternative.
- Missing values on questions about age of the respondent, or number and age of other persons in the household (Questions HR1, HR3), will not be imputed.
- The design (sliders that the respondent should pull) of the questions about common routines (Questions MR1-MR2) might be a bit hard to manage, which could result in some of the respondents skipping these questions. If both questions (work and time routines) are unanswered, the respondents open ended question will be consulted in hope for explaining information. If no explaining comments are given, the question will be regarded as missed/not understood, and the respondent will not be considered when temperature profiles are created. If the respondent has answered one of these questions (work or sleeping routines), but not both, it will be assumed that the household has no common routine of unanswered kind (since the respondent has shown to understand how to answer the question). This can be the case even in a single household.
- If the respondent has not answered for which days the stated working hours apply (Question MR3), and not given any clarifying comments, a monday to friday working routine will be assumed.
- In case the question about temperatures regarded as pleasant (Question PT1) is left unanswered, but acceptable variations are stated, the mean (pleasant) temperature of all the respondents will be ascribed to the respondent (provided that no comments of significance for this assumption is given).
- A respondent who has not specified acceptable temperature variations (Questions AT1-3), beyond the temperature(s) stated as pleasant, will be interpreted as not accepting variations outside of this span.

Appendix IV - Ascribing Temperature Spans

$$
\begin{aligned}
&\text{if } U \neq 0, \quad V \neq 0 \\
&\qquad Tmin = X - U \\
&\qquad Tmax = Y + V
\end{aligned}
$$

$$
\begin{aligned}
&\text{if } U = 0, \quad V \neq 0 \\
&\qquad Tmin = (X + Y)/2 \\
&\qquad Tmax = Y + V
\end{aligned}
$$

$$
\begin{aligned}
&\text{if } U \neq 0, \quad V = 0 \\
&\qquad Tmin = X - U \\
&\qquad Tmax = Y
\end{aligned}
$$

$$
\begin{aligned}
&\text{if } U = 0, \quad V = 0 \\
&\qquad Tmin = (X + Y)/2 \\
&\qquad Tmax = Y
\end{aligned}
$$

X = *minimum stated pleasant temperature* °C
Y = *maximum stated pleasant temperature* °C

U = *acceptable temperature decrease* °C
V = *acceptable temperature increase* °C

$Tmin$ = *minimum temperature accepted* °C
$Tmax$ = *maximum temperature accepted* °C

Appendix V - Temperature Profile Weighting

Weighting Data

Table V.I. Data used for weighting the two gender based temperature profiles of each household type.

Demographic Sub-grouping	Statistical percentage of SFD residents of female gender	Statistical percentage of SFD residents of male gender
Seniors	48.2%	51.8%
Families with children	48.1%	51.9%
Single	33.7%	66.3%
Other	48.8%	51.2%

Table V.II. Data used for weighting the four temperature profiles of the household types.

Demographic Grouping	Definition of household type	Statistical percentage [% of households]
Seniors	Household containing at least one person 65 over years.	28.7%
Families with children	Household containing at least one person under 18 years (and no person over 65).	37.5%
Single	Household containing only one person (who is under 65 years).	5.6%
Other	Household not meeting any of the three definitions above.	28.2%

Assumptions

The statistical division between different types of residents is seen to be close to the division between different types of residents in the survey. Thus, the assumption is made that these similarity shines through as a similarity in division between different types of households.

Acceptable Temperature Formulas

Weighting of the sub-groups (for every tmin, tmax, every timestep 1-168):

$t_{group} = t_{women,group}\ \%_{women,group} + t_{men,group}\ \%_{men,group}$

Weighting of the groups (for every tmin, tmax, every timestep 1-168):

$t_{tot} = t_{senior}\ \%_{senior} + t_{children}\ \%_{children} + t_{single}\ \%_{single} + t_{other}\ \%_{other}$

Appendix VI - House Size Based Weighting

When comparing the survey respondent distribution to the statistical distribution, they were found to have a quite high similarity for most aspects, except for building year and building size (Questions BC2-BC3). Thus, temperature profiles for different building sizes and building years were calculated in order to assess if a relationship could be found between these factors and respondent temperature profiles. The largest difference in distribution, as well as in temperature profiles, were found for respondents with different building sizes.

To investigate if this difference could influence the results, a weighting is done based on groupings for different building sizes. The households are divided into 6 groups based on house size, according to the table be table VI.I.

Table VI.I. Grouping and weighting data for house size based weighting.

Building Size	Statistical Distribution	Survey Respondent Distribution
<105 m^2	53.3%	6%
106-125 m^2	11.2%	20%
126-145 m^2	11.4%	24%
146-165 m^2	11.4%	21%
166-205 m^2	7.1%	19%
>205 m^2	3.2%	10%

For each of the six groups, one average temperature profile is created from the respondent answers within the group. In this version, no gender weighting is carried out, since the respondent data for some of the groups is already small (group <105 m^2), and doing a weighting also based on gender would entail very few respondent to have a very large impact on the resulting temperature profile. Due to that it is the effects of the house type and not the inhabitants that are investigated.

A slighter modification of the model allows a non-even distribution of profiles to the 571 model households. Each average temperature profile can then be ascribed to every model household corresponding to the size span of the profile, which allows the model to take into account different aspects, such as efficiency of heating system and thermal storage capacity of building mass when distributing the profiles, which was not possible in the version 1 described above. No statistics are needed in this scaling, since the statistics are implicit to the model, where households are already representative of the swedish SFDs.

Appendix VII - Index Correlations

Table VII.I. Correlation between survey questions (HR4-HR5) on subjective economy.

Subjective Economy	**low - high (HR4)**
insufficient - sufficient (HR5)	0.62

Table VII.II. Correlation between survey questions (ET1-ET3) on subjective comfort.

Subjective Comfort	**unsatisfying - satisfying (ET1)**	**cold - warm (ET2)**
cold - warm (ET2)	0.35	1.00
unstable - stable (ET3)	0.59	0.38

Appendix VIII - Interview with Björn Berg

2017-02-13
Björn Berg
CEO Ngenic

Björn säger att smart meters kommer att genomföras i framtiden vare sig vi vill det eller inte, men att han är tveksam till dess potential, som han tror är överskattat. Han tror att den stora potentialen för smart meters är att göra konsumenter mer medvetna om sitt konsumtionsbeteende och hjälpa konsumenter att fatta smarta energieffektiviserings-beslut, exempelvis gällande om de bör köpa en ny tvättmaskin. Till skillnad från smart meters är tanken med Ngenic att kunden inte ska inte behöva ha koll, vara aktiv och ta beslut. Apparaten ska samla informationen och ta besluten själv. Det bygger alltså inte på kommunikation till användaren, utan bygger på att koppla bort användaren från beslutsprocessen. Ngenics Tune främsta mål som produkt är att förbättra inomhusklimatet, och alltså inte att minska elkostnader eller sänka koldioxidutsläpp.

Björn tror att folk inte förstår det komplicerade upplägget på elsystemet och att det viktiga inte är hur mycket energi man förbrukar utan vilken typ av energi som förbrukas. Det är svårt och tar tid och energi att sätta sig in i, och människor ska inte behöva göra det. Björn ser Ngenics potential i att undvika beteendestyrd reglering av elnätet genom att använda sig av husens inneboende möjlighet till temperaturstyrning, vilket på så vis möjliggör ett bortkopplande av beteenden och preferenser ur ekvationen.

I snitt finns en potential att spara omkring 10% på sin elräkning genom att skaffa Ngenic Tune, men kunderna sparar i snitt mindre än så på grund av att många idag har problem med inomhusklimatet och när möjligheten finns väljer att förbättra det snarare än att spara pengar och energi. En del kunder förbrukar till och med mer energi på uppvärmning efter att de skaffat Ngenic Tune.

Björn säger att de kan se två tydliga early adopters för sina produkter: nybildad, ung familj (30+) som precis flyttat in i sin första villa och är vana vid smart teknologi, samt män 50+ som bor i villa och älskar att arbeta med sitt hus. Kundundersökningar visar att 50% köper för ett förbättrat inomhusklimat och 50% köper för att spara energi. Det framgår dock att bland de som köpt produkten skattar alla det förbättrade inomhusklimatet mycket. Björn säger att elbranschen har ett i allmänhet mycket dåligt rykte bland konsumenter, som har en bild av att elbranschen bara vill tjäna massor av pengar. I verkligheten tjänar dock elbolagen väldigt lite pengar, medan det är elnätsbolagen (distributionen) som tjänar de stora pengarna. Idag finns det stora kostnadsvinster i denna typen av system, fast den stora kostnadsvinsten ligger i elnätet och inte hos konsumenten, vilket såklart minskar incitamentet att delta.

Just nu används Ngenic Tune främst av early adopters, vilka kan tänkas ha en överrepresentation i deras kunskap om elsystem och uppvärmning. Ngenic arbetar just nu med hypoteser till hur de ska nå ut till “den stora massan”. Bland annat tror Björn att det idag finns en stor vilja bland konsumenter att vara miljövänliga och flexibla. Däremot vet de kanske inte hur de ska uppnå detta, eller är motvilliga att anstränga sig för mycket. Därför tycker Björn att man måste göra det “lika lätt eller lättare” att vara klimatsmarta. På villaägarnas hemsida kan man läsa mer om vad de är oroliga för, och de är mycket oroliga för elkostnader/energikostnader.

Björn tror att konsumenter behöver mindre information än de får i dagsläget. Han hänvisar detta till hur många som faktiskt förstår sin elräkning. Konsumenterna behöver inte information i form av data och variabler som de själva måste sätta ihop, de behöver konkreta råd och förslag på hur de kan agera.

Björn tror att frågan om datainsamling är extremt viktig för konsumenterna. I grunden, säger Björn, handlar det om förtroende, och att arbeta med att bygga förtroende. Björn vill även påpeka att han tror att folk som oroar sig för denna typ av datalagring är naiva inför all data som genom lagras om dem via andra kanaler såsom facebook redan idag.

Appendix IX - Open Ended Answers

1. vissa frågor är svåra att besvära om man inte arbetar längre pga att man är pensionär

2. använder braskamin dagligen för uppvärmning

3. Halva huset byggt på 50-talet resten byggt på 70-talet

4. Alla frågor rör inte oss, som är pensionärer, exempelvis de om arbetstider.

5. Ursäkta men plötsligt tappade jag respekten för enkäten. Minns inte frågan men jag frågar er; Vet ni vad 5G kan komma att innebära. Jag sover mindre än min hustru varje natt, går i kalla årstiden och tänder kaminen. Var fanns de frågorna? Elförbrukning: Det dröjer inte länge förrän allt fler med möjlighet har egen fristående elförsörjning. Vad är er enkät värd?

6. Eldar även i kakelugn

7. Vi är pensionärer så jag skulle nog svarat annorlunda på en del påstående! Anser att jag gjort en hel del för att spara el - bl.a. "satt mössa på huset" d.v.s. tilläggs isolerat vinden på huset med ett 20cm lager av cellulosa isolering, bytt ut ytterdörrar & fönster till lågenergi och bytt ut alla lampor till LED (både inomhus & utomhus). Har på detta sätt sänkt min el-förbrukning med ca 4000kw/år!! Men vad hjälper det, för priset på fakturan är i stort sett den samma (t.o.m. högre ibland)!!! Vad jag menar är varför ska jag spara när elbolagen höjer priserna på de fasta delarna (går med enorma vinster) och politikerna höjer skatterna på elen???!!! Kan väl också informera om att våra elradiatorer nästan aldrig går igång utan vår Luft/Luft värmepump värmer upp hela huset (enplanshus).

8. Det är inte elproduktionen som avger koldioksid men väl radioaktivt avfall som är ett gigantiskt problem. Sätt solpaneler på varje nyproducerat hustak som har bra med solstrålar, gör det till en byggnorm. Skrota kärnkraften, ta vara på förnybara energikällor.

9. Se upp med reliability av svaret på negativa frågan i första sektionen. Respondenter kan svara fel av misstag då man generellt förväntar sig och får även här positivt ställda påstående att ta ställning till. Lycka till med uppsatsen.

10. Vi arbetar ju inte som pensionärer,,,

11. arbetar hemma

12. Inomhusstyrning av temperaturen!!'

13. Ena vuxna i hushållet har oregelbundna arbetstuder varpå jag lämnade frågorna gällande tid som ingen är hemma tom.

14. Kommentar 1 - Vi jobbar en hel del hemifrån. Detta sker oregelbundet både rörande veckodagar och tider. Detta fall täcks inte in av frågorna. Kommentar 2 - Vårt hus är ifrån 1908. Större förändringar i utomhustemperatur slår igenom på inomhustemperaturen. (för varmt eller för kallt till det stabiliserat sig) Vi vill alltså undvika hastiga förändringar.

15. svaren ang sov/arbetstider är svåra att ange då mannen jobbar skift och jag dagtid.

16. För miljöpåverkan tycker jag det är bättre att försöka påverka folk att flyga vid mindre antal tillfällen, då det sparar på miljön snabbare och mer effektivt.

17. Jag eldar med ved.

18. Jag är pensionär med ensamhusdhåll.

19. har en luftvärmepump och en insatskamin...i öppen spis.. om bra saker fanns så skulle jag gärna byta upp mig till det.. har även kvar min Gamla Varmvattensberedare. skulle behöva hjälp för uppdateringar tack.....

20. Frågor om arbetstid. Vi båda är arbetslösa. Vi har 100% hemmatid

21. Vårt hus är för varmt på sommaren och tidvis för kallt på vintern.

22. Alla som har hus är inte praktiska och vill inte bli lurade av hantverkare hur isolerar/sköter man sitt hus på bästa sett gärna mbegriplig info om detta från de som vill att energi skall sparas

23. varför som uppvärmning av huset finns inte fjärrvärme som alt.

24. många hus är för tröga för att ändra inne temperatur dag / natt

25. Övriga familjen föredrar 2-3 grader varmare vid "vaken/hemma" och 2-3 grader kallare vid "sover" än vad jag svarat. Jag får svettas när de är vakna och frysa nackhåren av mig när jag skall sova.

26. pga. ledsjukdom behövs mer värme än normal = högre elförbrukning

27. Vi pensionärer som ej arbetar längre och ofta därmed är i hemmet dagtid, hur kan vi deltaga?

28. FTX-system, visste inte var det gick in som. Med stöd av kamin.

29. Golvvärme ger en tröghet i värmen som gör att svängningar mindre intressant

30. dom sista frågorna fungerade inte

31. Litet hushåll 80 m2 relativt liten besparing

32. Vi har luftvärmepump och vedkamin för att inte använda så mycket el

33. En del frågor var irrelevanta då vi har ett avtal med endast förnyelsebar el.

34. Husets konstruktion gör att temperatur svängningar medför ökad kondensering i väggar och tak som kan ge mögelproblem

35. Vi är pensionärer och har alltså inga arbetstider

36. Har i dag fjärrvärme vilket levereras till halva kostnaden mot vad el kostar

37. Fjärrvärme är vanligt

38. Ni anger ingenting om att förhindra att solens värmestrålar skapar kylbehov inomhus, vilket skapar mer elförbrukning. Stora glasfasader på kommersiella fastigheter, människor förstör många gånger också klimatet i kontorsfastigheter genom att öppna fönster mm. Markiser & persienner är en kostnadseffektiv lösning på både privata & kommersiella fastigheter, för att minska temperatur ökning samt ökat energibehov

39. Reglerar redan nu mellan dag o natttemperatur.

40. Frågorna borde ta hänsyn till fler uppvärmningsalternativ, det finns pensionärer i samhället. El behöver inte belasta CO2 utsläppet. Att oavsett vad vi gör i Sverige står vi för mindre än 1% av globala utsläpp. Vad gör mest nytta en miljöcertifierad vedpanna eller solceller?

41. vi är pensionärer...arbetar ej.

42. Funkade inte på en iPad

43. jobbar oregelbundet

44. Värmereglering i all ära, men är inte den långsiktiga lösningen att enbart använda sig av förnybara energi källor? Borde inte alla hustak vara klädda med solceller? Borde det inte vara lättare att få bygga vindkraftverk? Vad ni flreslår låter mäst som ett sätt att skjuta problemet på framtiden.

45. Frågorna på slutet blir lite felaktiga då man är pensionär o ej jobbar.

46. Vi är pensionärer, frågor kring arbetstid o dyl irrelevanta. Alternativ för detta saknas

47. Jag har vedeldning som huvudsaklig värmekälla

49. Som pensionär kan man inte ange några fasta tider "när ingen är hemma".

49. Prisskillnaden mellan olika el . Ex. Vind ,vatten, kärnkraft för kunden.

50. Vi arbetar inte.

51. Svarssidan om gemensammma tider verkar inte fnka

52. Jag och min man vill inte ha samma temperatur. Han vill ha mellan 22-25 grader

53. Har även miljömärkt täljstenskamin för uppvärmning

54. Kärnkraft bidrar inte i hög grad till klimatförändringarna.

55. Har även stor braskamin. Vissa rum används inte och är kalla vintertid.

56. Effekten av olika uppvärmningsformer.

57. Värmer huset med ved

Appendix X - System Costs and Savings

Table X.I. Costs and Savings for No DSM and Base Case DSM.

	No DSM [M€]	DSM [M€]	Reduction [M€]	Reduction [%]
Cycling Costs Sweden	22.6	19.3	3.3	14.7%
System Cycling Costs	908.0	896.4	11.6	1.3%
Running Costs Sweden	720.6	704.9	15.7	2.2%
System Running Costs	29058.4	28951.2	107.2	0.4%
Total Costs Sweden	743.2	724.2	19.0	2.6%
Total System Costs	29966.4	29847.6	118.8	0.4%

Table X.II. Costs for Scenarios.

	Cycling Costs [M€]	Running Costs [M€]	Total costs [M€]
No Subsidy	897.1	28974.4	29871.5
Technical Fix	896.5	28927.3	29823.8
Lifestyle Change	895.4	28909.0	29804.5

Table X.III. Savings for Scenarios.

	Cycling Savings [M€]	Running Savings [M€]	Total Savings [M€]
No Subsidy	10.9	84.0	94.9
Technical Fix	11.5	131.1	142.6
Lifestyle Change	12.5	149.4	161.9