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Consumer Preferences and Soft Load Control on the Swedish Electricity Market

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* This report presents the result from the EFORIS-project ”Elkunden, en ny kraft på elmarknaden?” (The electricity customer, a new power on the electricity market?), financed by Energiforsk. We are greatful for the financial support and would also like to thank the reference group for this project for their valuable comments and input to the survey.

Sammanfattning på svenska

Huvudsyftet med föreliggande rapport är att redovisa resultaten från projektet ”Elkunden, en ny kraft på elmarknaden?” Huvudsyftet med projektet är att uppskatta förlorade mervärden till följd av olika restriktioner i hushållens elanvändning, vilket ger oss ”priser” på schematiska effektreduceringar via beteendeanpassningar bland svenska hushåll. Ett annat syfte är att uppskatta hushållens kostnader för korta strömavbrott, vilket ger ett ”pris” på en riktad frånkoppling av elektricitet. Viljan bland hushåll att anpassa sin elanvändning styrs av flera faktorer – både ekonomiska och icke-ekonomiska. Ett delsyfte med projektet är därför att analysera i vilken utsträckning hushållen är villiga att anpassa sig av icke-ekonomiska skäl, exempelvis för att underlätta integrationen av förnybar elproduktion som sol- och vindkraft. För att uppnå syftena med projektet analyserar vi hushållens vanor och elanvändning i samband med dagliga efterfrågetoppar under vintertid i Sverige. Vi har valt en metodansats där hushåll utsätts för val mellan hypotetiska elavtal där olika typer av begränsningar i användning av storförbrukande hushållsapparater är inkluderade. De olika egenskaperna i avtalen relaterar till (1) maximal elanvändning i watt, (2) längden på begränsningen, (3) antal tillfällen för begränsning och (4) möjligheten att ändra val av apparater under begränsningen.

I tillägg till den ovan nämnda ansatsen studeras även hur detta förhåller sig till övrig elanvändning (tex. uppvärmning, belysning, TV, etc.). Detta görs genom att fråga hushållen om kompensationskrav för att acceptera fullständiga strömavbrott. Genom att studera skillnaden i kompensationskrav mellan den ”mjuka” begränsningen och det fullständiga strömavbrottet kan värdet av olika laster uppskattas.

Resultaten visar att hushåll i allmänhet kräver en kompensation motsvarande 2000 - 3700 kronor beroende på hur hård begränsningen i elanvändning är. Beroende på hur vi definierar den potentiella förlusten i möjlig elanvändning för olika scenarier kan resultaten översättas till ett värde mellan 20 och 40 kronor per kWh. När det gäller totalt strömavbrott är värderingen betydligt högre och motsvarar mellan 3000 och 4600 kronor. Detta kan i sin tur översättas till motsvarande 400 – 600 kronor per kWh. Det är alltså stora skillnader mellan ”mjuka” begränsningar i elanvändning och totala strömavbrott, vilket tyder på skillnader mellan olika typer av elanvändning. Vid en jämförelse med andra studier ger våra resultat relativt höga värderingar av förlorad last (effekt). Detta är dock inte oväntat då den föreliggande studien studerar användning vid efterfrågetoppar och återkommande begränsningar, eller avbrott.

Ett delsyfte med rapporten var att studera eventuella effekter av att informera hushåll om varför deras elanvändning bör begränsas. Hälften av hushållen fick information om att begränsningarna införs för att underlätta omställningen till förnyelsebara energikällor. De övriga fick ingen sådan information. Resultaten tyder på att denna information gör hushållen mer benägna att acceptera avtal med fler tillfällen av begränsningar. Däremot hittas inga tydliga tecken på att hushållen skulle bli mer positivt inställda till begränsningar i allmänhet.

En implikation av våra resultat är att politiska åtgärder riktade mot beteendeförändringar på elmarknaden troligtvis skulle vara ineffektiva och/eller dyra. På hushållsnivå bör således åtgärder snarare fokusera på automatisering och passiv respons. Slutligen, resultaten tyder även på att det inte nödvändigtvis är mer kostnadseffektivt med efterfrågeflexibilitet än anpassningar på utbudssidan, dvs. produktionen av el.

Summary

The main purpose of the present report is to present the results of the project "The electricity customer, a new power on the electricity market?" The main purpose of the project is to estimate lost values due to various restrictions on household electricity consumption, which gives us "prices" of schematic reductions in power through behavioral adaptations among Swedish households. Another purpose is to estimate households' costs for short power outages, which gives a "price" of a targeted disconnection of electricity. The willingness of households to adjust their electricity consumption is governed by several factors - both economic and non-economic. An additional objective is therefore to analyze the extent to which households are willing to adapt for non-economic reasons, for example, to facilitate the integration of renewable electricity production such as solar and wind power.

To achieve the objectives of the project, we analyze household habits and preferences for electricity usage in connection with daily demand peaks during winter time in Sweden. We have chosen an empirical approach where households are subjected to choose between hypothetical electricity contracts where different types of restrictions in the use of large-scale household appliances are included. The different characteristics of the agreements or contracts relate to (1) maximum power usage in watts, (2) the duration of the restriction, (3) number of occasions of restriction and (4) the ability to change the selection of which electrical appliances to be used during the restriction.

In addition to the above-mentioned approach, we also study how this relates to other electricity usage (e.g. heating, lighting, TV, etc.). This is done by asking households for compensation requirements to accept full power outages, i.e. black-outs. By studying the difference in compensation requirements between the "soft" limitation and the black-outs, the value of different loads can be estimated.

The results reveal that households on average require a compensation of SEK 2000 - 3700 depending on the severity of electricity consumption constraint. Depending on how we define the potential loss in potential electricity usage for different scenarios, the results can be translated to be between SEK 20 and 40 per kWh. In the case of total power outages, the valuation is significantly higher and corresponds to SEK 3000 to 4600. This can in turn be translated to the equivalent of SEK 400 - 600 per kWh. The results thus indicate a significant difference between the value of the load in a soft control DSM program, and the remaining load (e.g. heating, lighting and TV). Compared to previous literature on the value of lost load, VOLL, our estimates fall in the higher range, especially compared to Swedish studies. We believe this is in line with the context outlined in the present study with rather many occasions of disruptions at the peak demand hour.

The results also show that a pro-environmental cheap talk make people more likely to opt into a DSM program with load controlled at many occasions. It did not, however, make people see more lenient on hard load controls in general.

An immediate policy implication from the results is that specific policies aiming at stimulating behavioral changes probably are very ineffective and/or costly. As a result, policies to affect demand response should focus on automatization and passive response. A related policy implication is that it is far from obvious that demand response is always more cost effective than supply response, i.e., increasing production of electricity.

List of content

1. Introduction

Is more demand response the ultimate solution to support a safe and secure power system based on renewable energy sources? The increased interest in demand response in Sweden and many other countries can be traced to the ongoing transition of the electricity system towards more renewable and intermittent power, in combination with fast development of information and communication technology. Power consumption is now commonly measured in real time and prices and requests can be timely communicated to the customers at low costs. The ongoing digitalization of machines, devices and installations will bring new business models to the power market. The customers will no longer only serve as the lender of last resort, but will provide services to the power market in competition with the traditional supply side actors.

Historically, demand-side management (DSM) in Sweden has focused on exploiting large industrial electricity consumers at moments of imminent power shortages. These moments have typically occurred on days with high power consumption due to exogenous factors, sometimes combined with problems in the power grid or in large-scale nuclear power production.

The demand-side resources utilized so far can thus be characterized as a discrete and inflexible reserve. The balancing of intermittent power production, however, requires more adaptable resources that can be activated at short notice during all times of the year. In general, large industrial plants are ill-suited to provide such continuous (dynamic) demand response. For that reason, interest has shifted towards the household sector. The household sector in general, and detached and terrace houses in particular, may have a large potential.

At the household level, demand response can work through either an automatic response on the appliances level, or through more ”manual” behavioral changes. Sometimes these strategies are referred to as efficiency and curtailment activities (see, e.g., Gardner and Stern, 2008). Because many single- and two-dwelling buildings in Sweden are heated by electricity, an automatic response of heating systems has a significant potential to help balance fluctuations in the power system. When it comes to demand response working through curtailment activities, however, the story may be different, as such activities are dependent on behavioral changes.

Our previous research (see Broberg et al., 2014, and Broberg and Persson, 2016) suggests that people demand substantial economic compensation, on average, to engage in demand-side management (DSM) programs. For example, people were found to very much dislike restrictions on the use of household appliances during the evening peak hours (Broberg and Persson, 2016). This was concluded from a so-called choice experiment where people were asked to repeatedly choose between hypothetical electricity contracts. The suggested contracts stipulated restrictions on the use of electricity in different dimensions in exchange for economic compensation.

In this report, we use a similar approach to complement the previous study (Broberg et al., 2014, Broberg and Persson, 2016). To control the experimental setting and the interpretation of the results, we work with a hypothetical DSM-program focusing on soft load control. We use the term soft load control to denote a temporary restriction in the maximum possible load (in watt) that a household can use to run high-power appliances and installations. The new experimental setting contributes to our previous research in at least three important dimensions. First, in our previous study, the hypothetical DSM-program involved a strict control of specific appliances and installations lasting for 3 or 6 hours every workday of the year. In this report, the focus is on shorter restrictions (0.5-3 hours) for high-power appliances at specific times during the typical peak hours of the day and year. Second, in our previous study, we did not allow for any flexibility in the restrictions faced by respondents who opted into the DSM program. In this report, we allow for some flexibility in the restrictions. Third, in the previous study, we did not address the individual's perception of contribution to society through DSM programs. In this study, we explicitly study a green framing of the DSM program. Our question is whether the context of a transition to renewable energy sources matters. More specifically, we want to test whether a transition motivated by environmental reasons encourages people to opt in or accept lower compensation for restrictions on their electricity use.

The focus on shorter periods of restriction is motivated by our expectations on how future DSM programs may function. Based on our previous research, we expect people to require high compensation for engaging in extended curtailment activities (Broberg and Persson, 2016). These levels of compensation are far higher than the cost (benefit) associated with supply-side flexibility. It is therefore unlikely that there will be a notable market for extended curtailment activities. Besides, we want our results to relate as much as possible to the value of lost load (VOLL). In the literature on VOLL, it is often assumed that a power outage, or black-out, lasts for several hours, although they often are shorter than one hour (see Energy Market Inspectorate, 2016). In this report, we address the duration issue by comparing load control of shorter durations. The hypothetical DSM programs are characterized by controlling the maximum level of load at the household level. That is, instead of a strict focus on VOLL, we report on values of potential lost load (VOPLL). In essence, VOPLL captures the value of a secure and sufficient power supply to the household customer. From the household customer perspective, VOPLL is the disutility of not being able to use all of their loads as they are used to. The disutility stems both from actual load shifting, but also a loss of option value. The option value could be interpreted as the possibility to use an appliance or installation when needed. Note that a given limit in load is not necessarily binding at all times. By definition, or at least by logic, VOPLL must be lower than VOLL and perhaps more relevant for analyzing demand response. Using the method of contingent valuation, we also separately estimate, the average monetary compensation required to accept a DSM program that includes five 30 minutes black-outs during the winter season. Given the specific design, we estimate VOLL while also assessing the relative importance of different categories of household appliances and installations.

In addition to the contributions mentioned above, we also explore what households' power consumption for home appliances looks like in the peak hours. A better knowledge of household habits and consumption patterns is important not only for determining the potential for demand response, but also for determining the costs in terms of utility losses associated with curtailment actions. Importantly, this analysis is based on respondents' reported consumption patterns and habits.

Our interest in the contributions outlined above has its background in research in behavioral science suggesting that people are concerned with issues related to integrity, autonomy and identity. People dislike not being in charge of their own daily activities (Sintov and Schultz, 2015) and, for this reason, it is important to have flexibility built into any DSM program. For example, flexibility may be ensured through possibilities to opt out, or through being part of deciding curtailment actions (e.g., choice of affected appliances). It can also be quite important to motivate actions by alluding to social norms, e.g., by stressing the environmental benefits of curtailment activities. Behavioral science suggests that people look at their past behavior to project their own identities as good citizens (Van der Werff et al., 2014). By framing curtailment activities in terms of environmental benefits, policy makers can encourage people to project their own environmental identities, which may encourage them to opt in and accept more curtailment activities given the same economic incentives.

The rest of the paper is structured as follows. In Section 2, we provide background about our interest in demand response and explain why our approach is based on a DSM program and not on dynamic pricing. Section 2 also includes an overview of the survey on which the empirical analysis is based. In Section 3, we report on household use of home appliances during the peak load hours and how households perceive the reliability of their internal grid. In Section 4, we present the choice experiment analysis concerning VOCL. In Section 5, we present the results of the contingent valuation question concerning VOLL. Finally, Section 6 is devoted to discussions and conclusions based on our empirical findings.

2. Survey study - Background and design

2.1. BACKGROUND

The attention paid to demand response almost seems like a paradox in a Swedish context. Sweden has for a long time been able to produce electricity at low cost and distribute it safely and securely to firms and households, not the least as a result of a large share of hydro power. The reliability of the power system seems to be as good as ever. The electricity produced in Sweden is to a large degree based on renewable energy sources (63 percent, mostly hydro power), plus nuclear, and only a small share is based on fossil fuels (Swedish Energy Agency, 2017). Swedish electricity production therefore has relatively small environmental impacts compared to power production in many other countries. Sweden also has relatively flexible electricity generation. About half of the electricity production is hydroelectric power that can be controlled in real time. During a year with normal weather conditions, the domestic production of electricity is higher than the domestic demand, resulting in export of electricity. The power grid is well developed and extended power outage seldom occurs. Furthermore, electricity prices are competitive in relation to the prices of alternative energy sources, such as district heating, oil and gas. As a result, a significant part of the Swedish building stock is heated by electricity, typically in combination with different types of heat pumps. In 2015, about 45 percent of the final use of energy for heating of one- or two-dwelling buildings[1] was electricity (Swedish Energy Agency, 2017).

Importantly, however, the interest in demand response is not driven by historical successes but rather by future challenges. Several trends on the supply side are expected to increase stress on the future power system. Three factors of particular interest are:

- Increased production of wind and solar power that cannot be controlled or stored at any large scale.
- The phasing-out of nuclear power.
- The integration of the European market through increased transmission capacity.

As the grid connections to continental Europe and the Baltics are expanded, more attention must be paid to the workings of the integrated power system. The challenges for Sweden are to a large extent shared globally, and in many places the transitions that power systems are undergoing are even more challenging than in Sweden. One reason is that many countries are implementing policies that guide the power sector away from use of fossil fuels and nuclear energy.[2] Huge efforts are now being put into development and diffusion of renewable energy. These international changes increase the need for cross-border exchanges in electricity, in particular of flexible resources. The demand for Nordic hydroelectric power and other flexible resources therefore will likely increase in the future on a European level. It is from this transition that the inherent potential in demand response will grow and develop.

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[1] Throughout the report, one- or two-dwelling buildings refer to detached houses and terrace houses (linked houses). Apartment buildings are not included.

[2] The most striking and nearby case is the German "Energiewende", where the aim is to move away from fossil fuels and at the same time abandon nuclear power (see Beveridge and Kern, 2013).

As implied above, to balance the intermittency of power systems that will be more reliant on wind and solar power, more flexible and controllable energy sources are needed. Such resources exist both on the supply and demand side of the power market. On the supply side, hydroelectric power and fossil fuels are the key adjustable resources used today. However, the possibility of expanding hydropower in Sweden is limited due to environmental constraints, as well as the fact that most major rivers are already utilized for hydro power. Neither are new plants using fossil fuels a realistic option, both for environmental and economic reasons. Given these constraint on the supply side, opportunities are created for demand-side actors to profit from market-based demand response.

2.2 OVERALL OBJECTIVE OF THE SURVEY

The main objective of this report is to study household customers' preferences concerning demand response to learn more about the potential for demand-side resources. To do so, we use an empirical method called ”choice experiments”, which is based on customers' stated preferences. To control the experimental setting so that we can interpret the results as accurately as possible, we work with a hypothetical DSM program focusing on load control and load shifting.

DSM is only one approach to accomplish demand response; pricing is another. Some argue that the fundamental problem with most of the power systems globally is that the pricing structure does not reflect the underlying scarcity of the resources involved. Most household customers, as well as small and medium-sized enterprise customers, have agreed upon contracts with their supplier to pay a price that is fixed for at least one month. These electricity customers have therefore no incentive to take into account the momentary scarcity of electricity by shifting load away from such moments. As a result, electricity consumption is too high when the power situation is strained and too low when there is a high supply of power. The cost of these misaligned incentives is shared among the customers through unnecessarily high electricity prices and network charges.

In theory, if households are risk-neutral (that is, if they can tolerate variation in their electricity price from one hour to another), consumers' incentives can be aligned with the system operator's objectives if electricity is metered and billed per hour according to real-time prices. For this reason, it is logical to argue that a broad transition to hourly pricing would realize an accurate level of demand response. However, demand response that works through dynamic pricing requires that households make informed choices. As argued in Sintov and Schults (2015), this requires an active response in which individuals (1) attend to the signal (change in price), (2) mentally catalogue power consumption in their home, (3) decide what actions to take, (4) execute these actions, and (5) maintain the actions until a new signal is received. This multi-step process is associated with hidden costs to the customers, such as mental effort and the time spent searching for information. These hidden costs, as well as a dislike of uncertainty about power costs, constitute obstacles to the wide diffusion of real-time price contracts.

Sweden is a good example of slow diffusion of real-time pricing. Since October 2012, the electricity grid companies have been obliged by law to measure customers' power consumption per hour, which has enabled suppliers to launch hourly price agreements. Consumer interest in these agreements, however, has so far been low. In 2014, only 8 600 households had signed such price agreements (Energy Market Inspectorate, 2014). The relatively low interest is also revealed in the survey presented in this report. Another reason for the slow uptake of real-time pricing contracts is that many households may be risk averse and dislike price volatility.

Unlike real-time pricing and active response, DSM programs can be used to create timely load shifting among households by centrally controlling parts of their loads. Contracts can be designed so that households are economically compensated if they reduce their power demand at moments when the stability of the power system is threatened. Such contracts may be designed in different ways, but ultimately some of the load is controlled or constrained remotely by an external actor (Babar et al., 2014). When demand response is managed externally, it can be classified as a ”passive response”, but note that the consumer did make an active choice to enter such a contract. In the contractual context, a central role is given to aggregators that mediate energy services between suppliers, grid owners and end users. The role of the aggregator is to consolidate the fragmented supply of household power services and package it in products that can be sold on the spot market or the regulating markets.

As we see it, both dynamic pricing schedules and DSM programs can be designed to cost-effectively stimulate demand response. However, it should be pointed out that DSM programs face some administrative challenges that dynamic pricing does not. One obstacle for trade in DSM products is that it may be difficult to verify that load curtailment really has taken place. Such verification is necessary if such trade is to result in power reductions that are equalized with power production (Borenstein, 2014). On the other hand, DSM programs may be easier for customers to handle, especially if the targeted loads are automatically controlled and not noticeable to customers.

2.3 THE SURVEY

The data analyzed in this report was collected through a web survey conducted in 2017. The survey was undertaken to learn more about the potential for demand response through behavioral changes among Swedish households. The ultimate objective was to gather information to estimate average values for the compensation needed to make people voluntarily opt into a DSM program characterized by soft load control. This also involves investigating how compensation may vary with the specific features of the program. To some extent, we also explore potential differences in compensation requirements between different types of households.

The survey consists of three parts addressing three different research questions:

(1) The first part focuses on household use of electricity in general and the use of specific appliances during Swedish peak demand hours.

(2) The second part concerns households’ choices of hypothetical electricity contracts. The contract choices reveal household preferences for the different attributes defining our DSM program. Basically, we ask about the circumstances under which households would accept a restriction on their use of home appliances

(3) The third part introduces a contingent valuation question to reveal the minimum compensation required to accept a full power outage, mimicking the design of the DSM program.

The study population comprises Swedish homeowners, here defined as households living in one- or two-dwelling houses. For this population, we expect more or less all households in the survey to pay their own energy bills and to control their major power-consuming appliances, which are placed within their residence.

In total, the questionnaire was answered by 2014 respondents sampled from a web-panel managed by Norstat. General characteristics of the respondents are provided in Table 1. In general, nothing in the descriptive statistics raises fundamental questions about the representativeness of our sample. Males are somewhat overrepresented (52 percent), which also has been the case in other energy related surveys in Sweden (see Broberg and Persson, 2016 and Ek and Söderholm, 2010). The average age in the sample may appear high, but, for all characteristics of the sample, one must consider that the context is homeowners and not the entire Swedish population.

Table 1: General descriptive statistics of survey sample of Swedish homeowners.

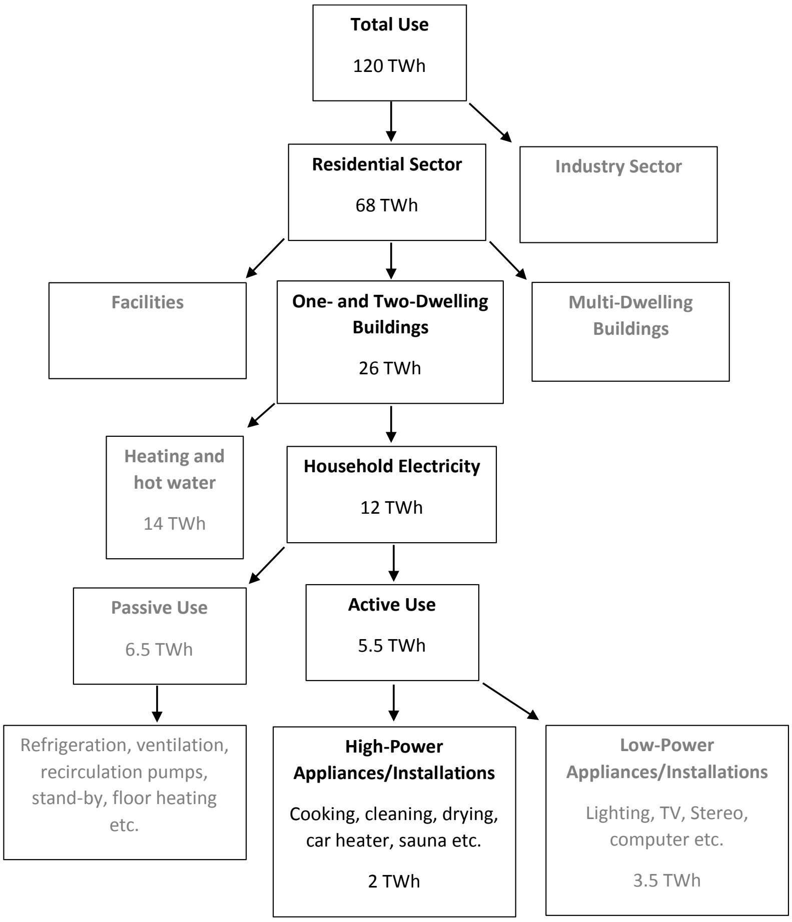
	Mean/share	Std.Dev
Age	53.15	16.78
Male	0.52	0.50
Retired	0.33	0.47
Single household	0.11	0.32
Households with children	0.33	0.47
District heating/Combustion (main or additional source)	0.32	0.47
Upper north counties	0.05	0.22
The three big city counties	0.50	0.50
Stockholm county	0.19	0.39
Highly educated	0.52	0.50
Median household income (SEK) (category variable)	40 000 – 50 000	

3. Household use of appliances

3.1 DEMAND FOR ELECTRICITY IN THE RESIDENTIAL SECTOR

To get a better understanding for the households' preferences for using load in the peak hours, we here discuss empirical results from previous research and from our survey. The latter reveals information about the average reported load profile of homeowners. In an attempt to focus on homeowners and high-power appliances/installations in a broader context, in Figure 1 we have disaggregated the total use of electricity in Sweden into different sectors and purposes. As can be seen, in 2014 the total use of electricity in Sweden was 120 TWh, of which 68 TWh (57 percent) were used in the residential sector. Homeowners used 26 TWh, of which 14 TWh were used for space heating and heating of water. The remaining 12 TWh were used to run different appliances and installations. The households' demand for electricity is a "derived" demand, as electricity is used to produce energy services that provides utility to the household, such as light, heat and motion. This means that the amount of electricity that is used depends not only on the price of electricity, but also on the household's daily routines, their stock of appliances and installations, and the efficiency of these items.

Figure 1: Electricity demand in Sweden 2014 focusing on electricity use in the residential sector.



Source: Swedish energy agency (2015; 2016) and own calculations based on estimates from Zimmerman (2009).

A typical Swedish household uses many appliances/installations in everyday life. A significant proportion of the aggregated homeowner electricity use (approximately 6.5 TWh) is passive in the sense that some appliances/installations operate every day of the year and are regulated automatically. Examples are refrigeration, fans, recirculation pumps and the stand-by mode on many appliances. In a more active way, homeowners use appliances and installations sporadically or as part of their daily routine. This category includes more and less power-intensive appliances. Typical examples of high-power appliances are stoves, ovens, water boilers, dishwashers, washing- and drying machines, etc. Low-power appliances include lightbulbs, TV, stereo, computers, toys, hobby equipment, etc. As can be seen in Figure 1, low power appliances contribute more to the total demand of household electricity than high-power appliances do.

From a power system perspective, electric appliances and installations are loads drawing power. In order to balance the power system, it is therefore important to understand how the peak load builds up from, among other things, household behavior. Figures 2 and 3 show average daily load curves for two different types of homeowner households. These load curves are copied from Zimmerman (2009), who report the results from an advanced metering campaign including 400 Swedish households in total, primary residing in the Mälardalen region. The purpose of the campaign was to gather detailed information of households' use of energy by metering power consumption on the appliance level (see also Vesterberg and Krishnamurty, 2016).

Figure 2 shows the structure of household electricity use on workdays (Mon-Fri) among 35 Swedish families consisting of middle-aged adults with children, residing in one or two dwelling buildings.[3] The pattern is as expected, with lowest use in the night time and highest use in the afternoon/evening. On average, the households' peak hour is between 7 pm and 8 pm, which is a bit later than the system peak hour, which typically happens around 6 pm. At this time, the households' active use of electric appliances primarily concerns lighting, cooking, dishwasher, TV and computer-related appliances.

Figure 3 shows an average daily load curve for 19 middle-aged couples without children residing in one or two dwelling buildings. As can be seen, households without children seem to reach their peak demand later than households with children. They also seem to use more electricity for the TV, stereo and appliances related to these, and less for cooking and the dishwasher, particularly in the peak hours.

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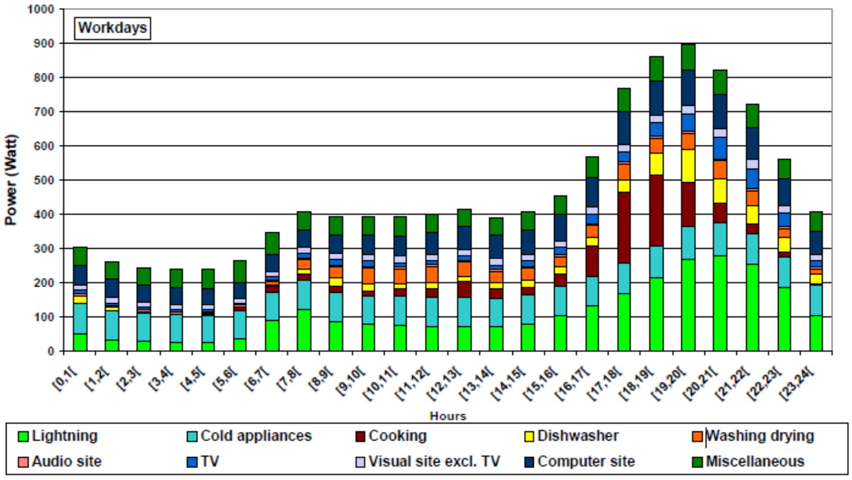
[3] Most households were observed for one month, spread over the seasons, and a few households were observed for a whole year.

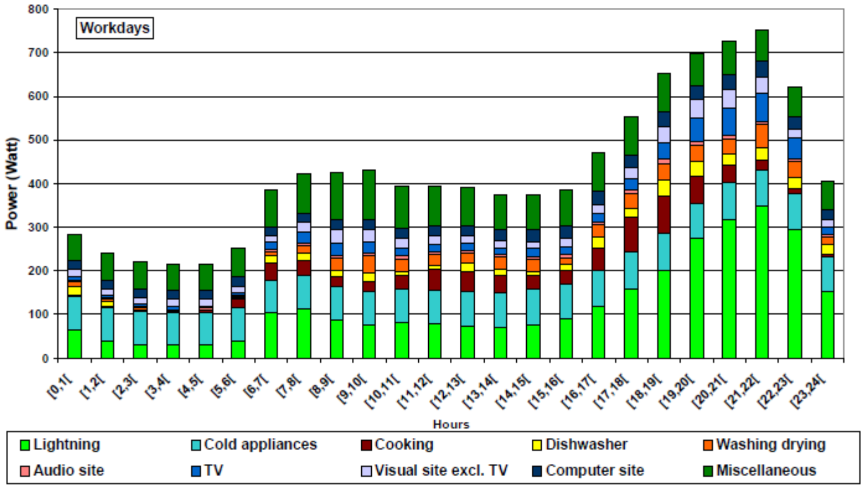
Figure 2: Average daily load curve for middle-aged families in 1-2 dwelling buildings in Sweden.



Source: Zimmerman (2009) Figure 2.65.

It is important to remember that the load curves presented above are averages based on a small sample of Swedish households. To complement this picture, we present results from our survey of Swedish households residing in detached houses or terrace houses. In the survey, the respondents were asked to state how often they use specific high-power appliances on workdays in the winter season between 4.30 pm to 7.30 pm and then were asked to focus on 5.30 to 6.00 pm.

Figure 3: Average daily load curve for middle-aged couples without children residing in 1-2 dwelling buildings in Sweden.



Source: Zimmerman (2009) Figure 2.85.

Figure 4 shows the share of the households reporting that they use specific appliances/installations during these time intervals on four or five workdays during a typical week. As can be seen, about 90 percent of the households use the stove, and about 25 percent run their laundry machine between 4.30 and 7.30 pm. Between 5.30 to 6.00 pm, about 50 percent of the households use their stove, while less than 10 percent use their laundry machine. A general pattern is that households tend to use kitchen appliances during the power system peak hours.

Figure 4: Share of households using specific high-power appliances/installations at peak hours in the winter season.

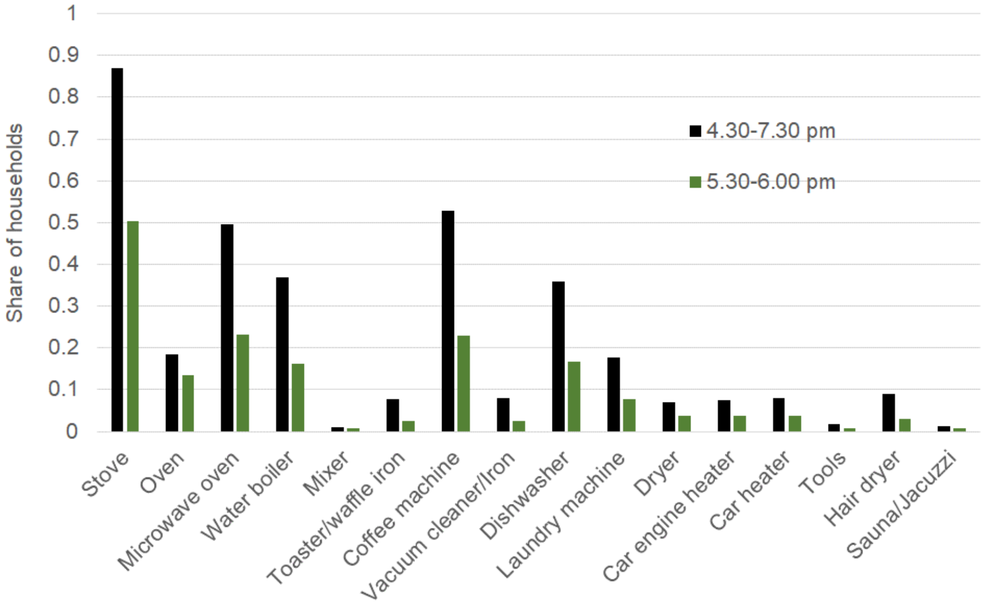
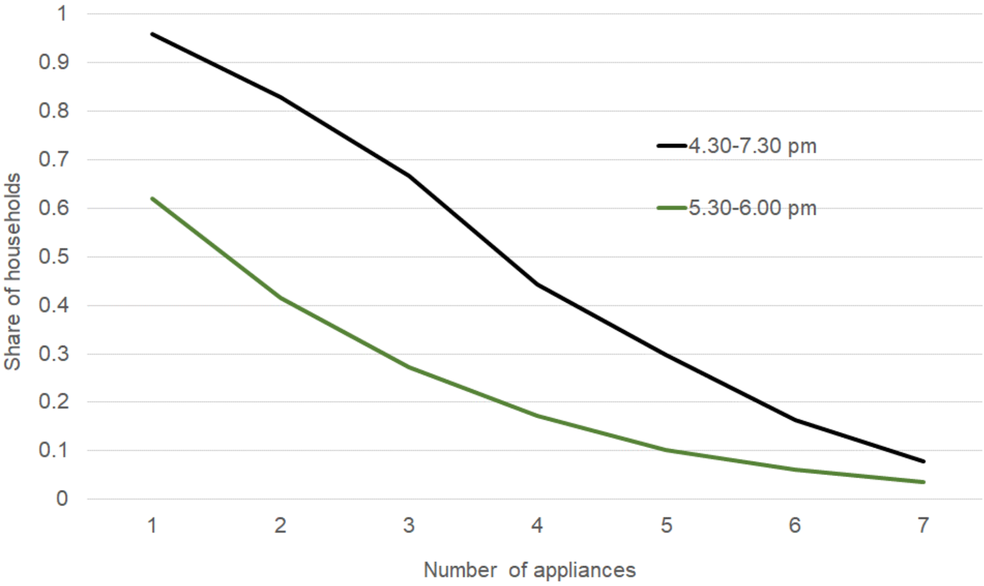


Figure 5 shows the number of appliances that households use (their own statement) during the peak hours 4-5 workdays per week. According to the results, almost all households responded that they use one or more electrical appliances during 4.30-7.30 pm, while about 60 percent responded that they use one or more appliances 5.30-6 pm. The median household uses four appliances during the three-hour peak and 1-2 appliances during the half-hour peak.

Figure 5: Number of high power appliances/installations that households use during the peak hours on 4-5 workdays in a typical week. Share of households that use at least a specific number of appliances/installations.



To illustrate some of the heterogeneity in the sample, the same figures are presented for households with and without children. Figures 6 and 7 reveal that, in comparison with households without children, households with children more frequently use the dishwasher, laundry machine and dryer from 4.30-7.30 pm and 5.30-6 pm respectively. On the other hand, the latter group seem to use the coffee machine more frequently. The figures also show that households with children seem to more frequently engage in kitchen activates in the half-hour peak.

Figure 6: Share of households with and without children using specific high-power appliances/installations at peak hours (4.30-7.30 pm) in the winter season.

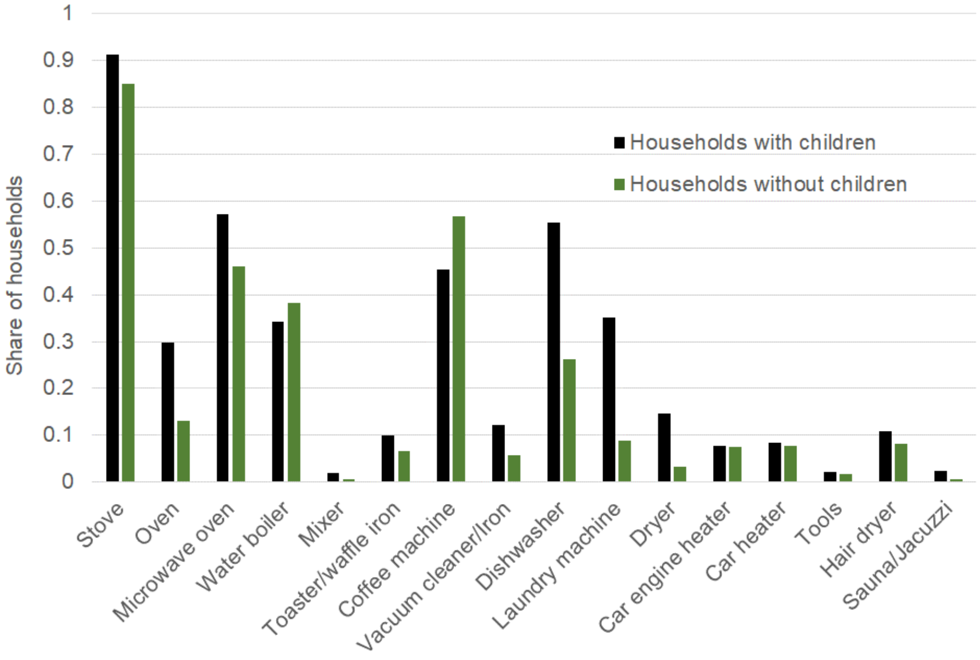
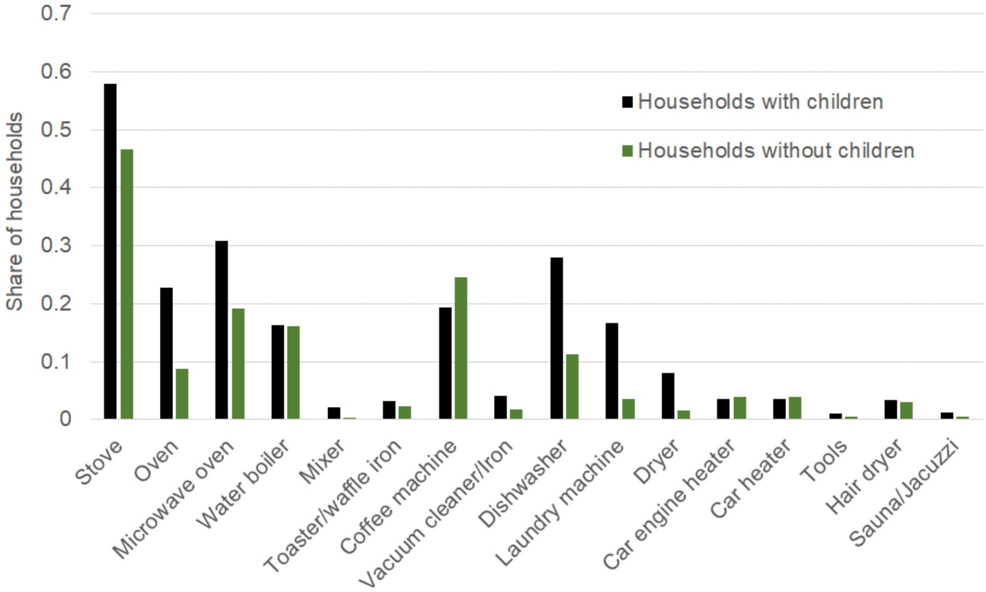


Figure 7: Share of households with and without children using specific high-power appliances/installations at peak hours (5.30.6 pm) in the winter season.



As can be seen in Figures 8 and 9, the median household with children tends to use approximately one more high-powered appliance during the peak hours on four to five workdays, in comparison to the median household without children. There are two tentative explanations for this.

First, households with children on average include more people. Second, households with children have more time restrictions to consider, e.g., the children's scheduled time at school and after-school activities.

Figure 8: Number of high-power appliances/installations that households with and without children use during the peak hours (4.30-7.30 pm), 4-5 workdays in a typical week. Share of households that use at least a specific number of appliances/installations.

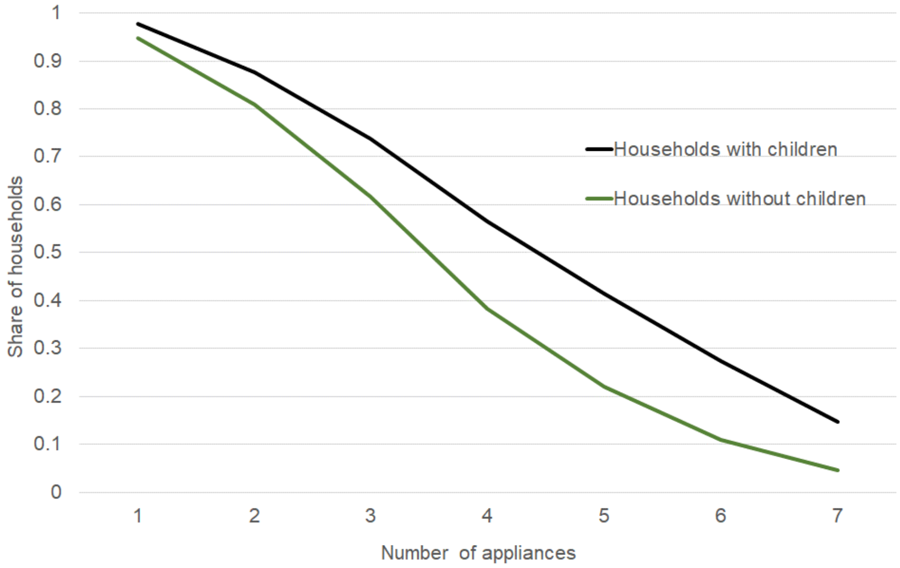
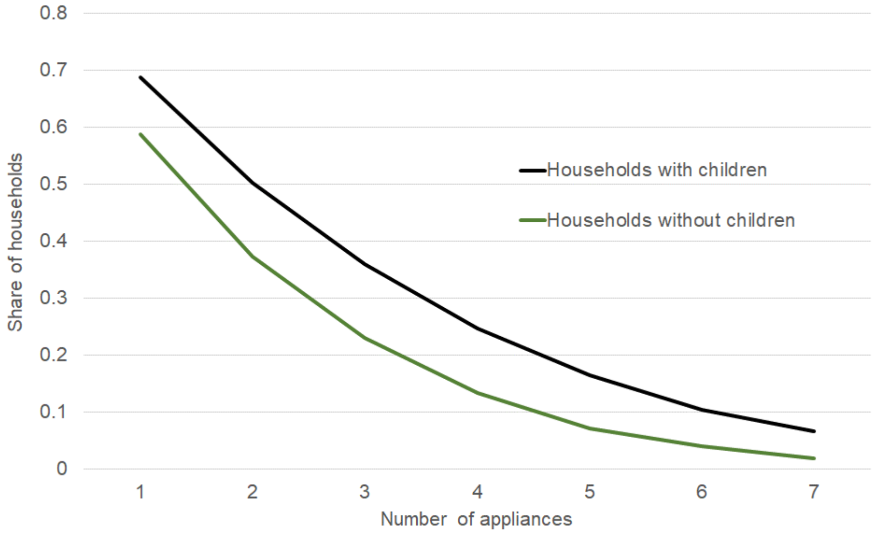


Figure 9: Number of high-power appliances/installations that households use during the peak hours (5.30-6 pm), 4-5 workdays in a typical week. Share of households that use at least a specific number of appliances/installations.



In a separate question, we asked the respondents to choose what high-power appliances they would prefer to have control over if their maximum load were to be restricted to 2000 watts during workdays 5.30-6 pm. As expected, a large fraction of the respondents chose kitchen appliances: 35 percent chose the stove, 16 percent the oven, 10 percent the micro oven, 10 percent the coffee machine, and 6 percent the water boiler. Only 5 percent chose the dishwasher, 5 percent the laundry machine and 1 percent the dryer. Even if these numbers are small, they suggest that these appliances are important to the households actually using them at the time of the restriction. As can be seen in Figure 4, a low share of households actually uses the laundry machine and/or the dryer at the time of the restriction.

To further deepen our understanding of household use of power, we asked a set of knowledge-based questions related to household specific characteristics. Below, we briefly review the answers to these questions.

- What main fuse rate does your home have? 16A, 20A, 25A, >25A or ”I don’t know”.

  Almost 60 percent answered 16A or 20A, while 29 percent answered ”I don’t know”.

- Do you know the maximum possible load (in watts) for your household, given your fuse rate subscription? Yes or no.

  As much as 77 percent answered that they do not have this understanding.

- Do you deliberately adjust your power consumption to avoid domestic power failures? Yes or no.

  As much as 32 percent answered that they do adjust their power consumption.

- How many times on a yearly basis do you have to change any of the main fuses in your home? Five categories were available (0-1, 1-5, 5-10, >10 and ”I don’t know”.

  Around 25 percent answered that they must change a main fuse at least one time per year. Around 5 percent answered ”I don’t know”.

- What kind of electricity contract does your household currently have? Six categories were available (variable price, fixed price, default, no contract, other and ”I don’t know”).[4]

  About 38 percent of the respondents answered they pay a variable price, 43 percent a fixed price, and 13 percent ”I don’t know”. Among the households paying a fixed price, as much as 70 percent said they use electricity (incl. geothermal energy) as their only heating source.

- Approximately, how many kWh of electricity did your household consume during 2016? Please look at an old bill from your utility. Six categories were available.

  About 6 percent said 1-4999, 17 percent 5 000-9 999, 32 percent 10 000-14 999, 26 percent 15 000-19 999, 14 percent 20 000-24 999 and 4 percent >25 000 kWh.

- In a follow-up question, we asked how certain the respondents felt about their answer on the size of their use of electricity. The respondents could answer on a scale from 1 to 10, where 1 was labeled ”Absolutely sure” and 10 was labeled ”Very uncertain”.

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[4] In the Swedish context, a variable price contract means that the customers pay a monthly average of the corresponding spot prices. A fixed unit price contract means that the customers pay the same price for an agreed time period, e.g. one or five years. The default contract means that the households never actively have chosen a contract and in such cases the default contract typically is a variable price contract with a high markup.

Around 66 percent of the respondents answered the categories 1-3, whereas approximately 19 percent answered categories 7-10.

- Do you know that it is possible for you to have an electricity contract based on hourly prices? Six categories were available.

  Only 36 percent knew about this possibility, of whom less than 2 percent had such a contract; 30 percent did not prefer such a contract; and 68 percent had not reflected upon the pros and cons of paying hourly prices. Among the respondents who did not know about hourly-based contracts, 38 percent said it sounded interesting, 40 percent did not prefer such a contract and 22 percent answered "I don't know" (of whom 32 percent also answered they did not know what electricity contract their household had or never actively agreed upon a contract).

Based on the descriptive statistics summarized above, it seems like a fairly large fraction of homeowners in Sweden have a limited understanding of their power consumption regarding quantities, prices and contract possibilities. At the same time, a notable share of the households has a tight internal restriction on their power consumption.

3.2 ELECTRICITY USE AND DEMAND RESPONSE

As described in the previous section, household electricity use is built of different loads, which differ in the way they function technically and how and when they are used. Not all loads are easily shifted. As mentioned earlier, a significant proportion of the typical household's electricity use is passive in the sense that some appliances and installations operate every day of the year and are regulated automatically. This part of the household load has the greatest potential to be controlled by technical means without causing significant comfort losses or demanding any major behavioral adjustments. However, even if discomfort may not be an issue if the load control is not too long, there are economic costs that must be considered. Some appliances and installations are optimized to provide energy services cost effectively. For example, houses may be heated with advanced heat pumps that optimize energy use to produce the desired level of indoor temperature. Similarly, fridges and freezers operate according to an optimized scheme for maintaining the desired temperature. Thus, to change the way these appliances operate efficiently, there has to be at least one additional and binding constraint on energy use besides energy minimization, e.g., cost-minimization based on real-time pricing of electricity.

Besides passive use of electricity, households use appliances and installations sporadically and actively as part of their daily routines. To achieve demand response in this part of the household's electricity use, the household has to change its behavior by planning its time and possibly by breaking old habits. In this part of the household's electricity usage, the devices "themselves" cannot optimize the electricity consumption to maximize the utility of the household members. This is because the utility of the service/benefits from consuming electricity depend to a large degree on the timing of the production of energy services. In other words, the production cost of these energy services largely consists of the opportunity cost of the households' use of time and attention. As the energy cost constitutes a small share of the total production cost, the price of electricity has to increase by a relatively large amount to create a significant demand response. Technical measures may to some degree reduce this barrier but do not have as much potential as the automatization mentioned above.

The remaining part of the household electricity use consists of lighting and activities related to, for example, TV, stereo, computer, toys, hobby equipment, etc. This part of electricity use is stimulated by the instantaneous needs of the household members and is more or less planned. If the tasks cannot be performed as the individual wants to, there will be a utility loss. Technical measures cannot stimulate demand response in this segment. This makes this part of the energy use relatively inflexible.

In the rest of the report, we empirically analyze household preferences related to load control via behavioral changes. The main focus will be on high-power appliances.

4. The choice experiment analysis

4.1 DESIGN OF THE HYPOTHETICAL DSM PROGRAM

As discussed above, we analyze consumers' preferences related to hypothetical electricity contracts involving DSM. It is important to emphasize that the electricity contracts as such are not our primary interest. Instead, hypothetical contracts are used as a means of eliciting behavioral aspects of electricity use at the household level. A fundamental part of the approach is that people reveal their preferences for electricity consumption when they choose between hypothetical electricity contracts that differ from each other in at least one attribute.

A contract involving DSM can be defined by many attributes. However, from a methodological point of view it is necessary to restrict the number of attributes. Among other things, it is important to consider that the cognitive capacity of the average respondent is limited. It is also important that the suggested contracts are reasonable and realistic from the respondent's point of view. Considering this, our hypothetical contracts center on four attributes related to load control, and one attribute in the form of monetary compensation. The compensation is included to create an incentive to accept a contract, because the other attributes are related to restrictions on electricity use, which logically translates into discomfort.

The attributes and the respective levels are presented in Table 2. The attributes describe the total amount of electricity the household can consume, the number of electricity interruptions during the winter season, the duration of each interruption, whether there is flexibility in which appliances will be curtailed, and the amount of monetary compensation.

Table 2: Contract characteristics.

Attribute	Description	Levels
Load control	Equipment will be installed to monitor and restrict the use of electricity. During the restriction, your household must adapt and consume accordingly. If not, the main fuse will blow. Only the appliances mentioned in the previous questions are considered for the restriction.	Max 2000 watt Max 3500 watt Max 5000 watt
Choice of appliances	During any restriction, the contract is designed such that you are free to choose which appliances to use within the limit or not. If not, you are bound to use the chosen appliances in the previous question. Irrespectively of whether or not there is flexibility, you still need to adapt to the total load control.	Pre-specified Flexible
Duration and timing	The contracts are designed such that the duration of restriction may vary between contracts. The specific hours are defined in the contract.	5.30pm – 6pm 5pm – 6.30pm 4.30pm - 7.30pm
Days	The restriction on electricity use will occur on a given number of days during December through February. Restrictions will only be on weekdays, but may be spread across separate days.	5 days 10 days 20 days
Monetary compensation	The household will be given monetary compensation for the given period of load control.	SEK 300 SEK 750 SEK 1500 SEK 2500

Importantly, any restriction on electricity use will be communicated the day before at 3pm. In addition to restrictions specified in the contracts, random disruptions (just like today's situation) may still occur.

This type of table was also presented to the respondents in the questionnaire. Prior to seeing the table, the respondents were told that they were soon to be faced with hypothetical contracts. They were also told that the purpose was to, for a monetary compensation, restrict the use of electricity during times when the grid is under pressure. It was mentioned that this would contribute to a more reliable supply of electricity in general. Moreover, the actual choice of appliances considered in the specific attributes was explicitly linked to the previous questions in the questionnaire.

The hypothetical contracts were tested in focus groups and in pilot studies. Two pilot studies were conducted with 100 respondents in each. The pilot studies also served as inputs in the explicit design of the final versions of the hypothetical contracts.

As discussed earlier, one objective of the study was to test whether a green framing of the DSM contracts would change the respondents' choice patterns. For this reason, the respondents were divided into two separate groups: ”neutral” and ”green”. The only difference between the two groups was how the contract choice was introduced. In the ”green” group, a short text was placed just before the choice task and also above each choice set. The text was the following.

”By reducing the use of electricity during times of high pressure on the grid, the transition to renewables such as solar and wind is facilitated. In this way, Swedish electricity production can be fully CO2 free in the future.”

In addition to this, the text in each choice card was extended to include ”*The new contracts facilitate the transition to renewable energy sources*.” The motivation for this design was to study the potential effect of a change in mind-set among the respondents. We hypothesized that this simple ”green cheap talk treatment” would induce respondents to be more open to contracts with restrictions on their electricity use. Of course, it is also possible that this framing does not have a significant effect on respondent choices at all. Below in Figure 10 is an example of a choice card describing one of the choice sets presented to the neutral group.

Figure 10: Example of choice card

Which of the following A, B or C contracts would you choose if offered to you? Unless otherwise stated in the agreement, everything else works as today, for example, the electricity price you pay and how often it changes.

	Contract A	Contract B	Contract C – as today
Load control	5000 watt	3500 watt	As today
Choice of appliances	Pre-determined given the load	Flexible given the load	As today
Duration	4.30pm-7.30pm	5pm-6.30pm	-
Number of days	5 days	20 days	-
Compensation	2500	750	-
My choice	[ ]	[ ]	[ ]

By design, each respondent was faced with eight choice sets, where the attribute levels were varied in a statistically efficient way.[5] This implies a total of 8056 choice observations in each group. By analyzing these choices in the multinomial logit

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[5] In detail, the total number of different choice sets was 16 and the respondents were divided into two blocks to reduce the cognitive burden. The explicit design was created in the software Ngene to consider statistical efficiency.

framework, we can estimate the probability of choosing a contract and how it is related to the different attributes.[6] This implicitly gives information about the trade-offs respondents make between the different attributes characterizing the contracts. Given the monetary compensation, we are able to translate the preferences to marginal willingness to accept (WTA) in terms of SEK for each of the attributes. The marginal WTA is the compensation required to move from the opt in base, or reference, contract to a contract with the specified attribute level. In principle, and by the econometric specification, we allow for negative compensation levels.[7] In the analysis, the models are specified such that all the attribute levels except the monetary compensation are dummy coded. The reference levels are ”5000 watt”, ”pre-specified appliances”, ”5.30pm-6pm” and ”5 days”, respectively. In the results, this means that the marginal WTA reported for, say, 2000 watts translates to how much compensation, on average, the respondents require to accept the corresponding one-dimensional move from a contract made up by the attributes, compared to the reference levels.

4.1.1 Interactions

The attributes defined in Table 2 and their respective effect on choices may to some extent be correlated. First, the load control is a prerequisite for the other attributes, which motivates the dummy coding structure defining a reference case as a combination of attribute levels. The other attributes are simply not relevant without the load restriction. Second, it is possible that there is a link, or interaction mechanism, between the attributes. The level of restriction may matter for the disutility of, say, duration. For example, a stricter load control is probably worse if it is combined with a longer duration. To be more complete in our analysis, we present results from estimation of both a main effects only specification and a specification allowing for interactions between the 2000 watt restriction and the levels of the other attributes in the contract.

4.2 DESCRIPTIVE STATISTICS IN THE CHOICE EXPERIMENT

The choice experiment described above was conducted on the national level to be representative of Swedish households living in detached houses or terrace houses. Data was gathered in June 2017 and respondents were sampled from a probability based internet panel using stratified random sampling. In total, 1007 respondents answered the neutral and green questionnaire, respectively (2014 respondents in total). A comparison of descriptive statistics for the two groups reveal that they do not differ in a statistically significant way in terms of age, gender, education, income and peak hour appliance use.

In the neutral group, there were 3645 status quo choices made, while in the treated (green) group there were 3539 status quo choices made (of the total of 8056 choices made in the respective groups). This is not a very large difference, but the tendency is what may be expected, namely that the green framing induces respondents to consider a change to a new type of contract. On the other hand, there may be an adverse effect if the green framing provokes some respondents, which could give rise to more

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[6] Although based on the multinomial (MNL) framework, the actual results presented are from the well-established random parameter logit framework. This is an extension of the MNL to allow for preference heterogeneity across respondents. Specifically, the assumption of common preference parameters for all respondents is relaxed and heterogeneity is modelled such that the parameters are characterized by normal distributions with a mean and variance.

[7] Although unlikely, it is possible that households may be willing to pay for a restriction in their use of electricity.

protest votes (e.g., people stick to the current contract no matter what or give random answers). The latter is, however, less likely in our view.

In choice experiment studies, it is not surprising to find respondents systematically choosing the same alternative (e.g., A or B) in all choice questions. In this study, most of them chose the status quo, or the ”as today” contract, which has several explanations. First, it may imply that some respondents used a simplifying strategy to answer the questionnaire as quickly as possible. Second, it may be the result of the respondent’s true preferences. As such, it might be the case that no monetary compensation offered is high enough to make some respondents accept the new contracts involving DSM and therefore the status quo contract is preferred. In the previous literature, there is strong evidence for what is called a status quo bias, meaning that people in general tend to dislike changes. This implies that people may require compensation just to seriously consider a change from the status quo. The problem is that we cannot with certainty distinguish between these two decision strategies. The recommendation in the statistical literature is to not exclude observations that is not obviously false. Hence, in the analysis that follows we keep all respondents in the sample, whether or not they consistently chose the status quo. Concerning systematically status quo answers, we see no obvious difference between the two respondent groups. In the neutral group, 290 respondents chose the status quo, while the corresponding number for the green treatment was 279. It is relevant to note that only twelve respondents in the respective treatment groups consistently chose either alternative A or alternative B. Given that the systematic protest answers are randomly distributed on the three alternatives, this is an indication that the vast majority of the respondents considered the compensation levels to be too low and therefore chose the status quo contract.

4.3 RESULTS FROM THE CHOICE EXPERIMENT

The model used is specified with dummy variables. This means that the parameter estimates for the different attributes of the contracts must be interpreted as deviations from the reference level. For example, the parameter estimate for 2000 watts should be interpreted as the change from 5000 watts, which is the base level.

Table 3 reports the results from the main effects-only specification. The estimates within parentheses are not statistically different from zero at any relevant probability level.[8] The point estimates translate to the ”average” compensation and the confidence intervals indicate the statistical precision. First, we see that all the statistically significant estimates have the expected sign. Given that a restriction on the use of electricity is related to discomfort or disutility, the respondents logically require positive compensation for any of the attributes in the contracts. We also find that stricter restrictions are associated with higher compensation. Starting from the reference opt in contract characterized by 5000 watts, 30 minutes and 5 days, we find that among the possible changes of the contract an increase of the duration to 180 minutes is associated with the largest increase in the average compensation level, more than SEK 1000.

Turning to the potential treatment effect in the two groups, we find no significant difference. Of course, the point estimates differ quite a lot in some cases, but, as the confidence intervals are overlapping, the estimates are not statistically different from

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[8] The standard errors and confidence intervals are calculated with the Wald procedure in the software Limdep using the Krinsky-Robb method with 1000 draws.

each other. It is, however, interesting to find that 3500 watts is statistically significant in the treatment group (green framing), but not for the neutral group.

The results show that the average compensation required to accept the reference scenario (including the status quo preference) is in the range of SEK 1036-1293. This compensation level is low in comparison to the status quo valuation (keeping the no-restriction contract) found in Broberg and Persson (2016). In that study, the average compensation required to make people consider opting into a new contract was estimated at almost SEK 3000. The likely reason for this difference is that the contracts presented in the current study are characterized by more flexibility and, in general, softer load control.

Table 3: Valuation of contract characteristics in SEK.

	No treatment		**Green treatment**	
	Point estimate	**95% confidence interval**	**Point estimate**	**95% confidence interval**
Compared to a 5000 watt limit on electricity use, the compensation required for a…				
3500 watt limit is…	(61)	(-62 – 184)	195	61 – 330
2000 watt limit is…	576	424 – 729	566	414 – 719
Compared to a pre-determined choice of appliances, the compensation required for flexible choice of appliances is…	(-69)	(-179 – 41)	(88)	(-31 – 206)
Compared to a duration of 30 minutes, the compensation required for a duration of…				
90 minutes is…	235	109 – 362	239	107 – 372
180 minutes is…	1020	856 – 1185	1174	993 – 1355
Compared to 5 days during the period, the compensation required for…				
10 days is…	454	351 – 558	339	225 – 453
20 days is…	686	552 – 821	470	325 – 616
Compared to the status quo, the compensation for…				
contract A is…	1293	1059 – 1528	1217	990 – 1444
contract B is…	1036	812 – 1260	1048	827 – 1269

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4.3.1 Attribute interactions

Interaction terms between the most stringent load control of 2000 watts and the other attribute levels were introduced in a second model specification. This was done to capture the potential relationship, or link, between the different attributes of the contracts. Specifically, it is reasonable to believe that the perception about stringent load control is related to the duration, number of days, etc. The results, presented in Table 4, are fairly clear.

Table 4: Valuation of contract characteristics in SEK – with attribute interactions.

	No treatment		Green treatment	
	Point estimate	**95% confidence interval**	**Point estimate**	**95% confidence interval**
Compared to a 5000 watt limit on electricity use, the compensation required for a…				
3500 watt limit is…	(42)	(-78 – 163)	193	61 – 325
2000 watt limit is…	(176)	(-138 – 491)	(229)	(-103 – 560)
Comparted to a pre-determined choice of appliances, the compensation required for flexible choice of appliances is…	(-80)	(-224 – 64)	(11)	(-145 – 166)
Compared to a duration of 30 minutes, the compensation required for a duration of…				
90 minutes is…	(104)	(-30 – 237)	(123)	(-29 – 275)
180 minutes is…	679	458 – 900	898	666 – 1129
Compared to 5 days during the period, the compensation required for…				
10 days is…	469	346 – 593	383	249 – 518
20 days is…	759	574 – 944	582	379 – 786
Compared to the status quo, the compensation for…				
contract A is…	1483	1214 – 1752	1345	1079 – 1612
contract B is…	1146	913 – 1380	1154	927 – 1380
2000 watt in combination with…				
duration	4.9	2.7 – 7.0	4.0	1.8 – 6.1
days	(-6.7)	(-25.2 – 11.8)	(-11)	(-30.3 – 8.2)
flexible choice	(-7.0)	(-279 – 265)	(160)	(-112 – 432)

The interaction between the 2000 watt load control and duration is statistically significant and corresponds to positive compensation. On the other hand, it is also clear that the number of days and flexibility in choice of appliances is not correlated to the load control of 2000 watts. The results hold for both the treatments. Notice that in the case of the interaction term, the duration and number of days are defined as continuous variables and not as dummy variables. This means that, for example, in case of a 180-minute duration, the parameter must be multiplied by 180. Finally, the standard likelihood ratio test reveals that the specification that allows the attributes to interact with 2000 watt load control is preferred for both treatments. To aid in interpretation, however, some of the coming discussion is based on the main effects specification.

4.3.2 Implications of DSM programs

Based on the results above, it is not possible to calculate a single value of the potential loss of load (VOPLL) in terms SEK per kWh, but only an interval. The reason is that the preferences for the respective contract attributes involved are found to be non-linear. For example, consider two contracts with 2000 watt and 20 days restrictions, but with a duration of 30 and 180 minutes respectively. The average compensations for these two contracts would be SEK 2356 and SEK 3671 respectively (see Table 5).[9] That is, the compensation associated with the latter contract is only about 60 percent higher although the duration is 600 percent longer. As a result, we present an interval for VOPLL based on the difference in compensation between the reference contract and contracts with a load control set to 2000 watt. As mentioned above, the WTA for the reference contract is approximately[10] SEK 1300. A contract with a change from 5000 to 2000 watt, 5 to 20 days and 30 to 180 minutes duration implies a difference in time involved equal to 15*(180-30) = 2250 minutes, or 37.5 hours. The 3000 watt increase in restriction would consequently translate to 113 kWh and, since the compensation required for this contract is SEK 2356, a VOPLL equal to SEK 21 per kWh.

A similar calculation based on a change from 5000 to 2000 watt only, would result in a VOPLL equal to SEK 39 per kW/h. In other words, the value households attach to their unrestricted use of high-power appliances and installations is estimated to be between SEK 20 and 40. As was mentioned in the introduction, this value captures both the value of appliances and installations used, but also an option value capturing the possibility to use appliances and installations up to the contract-limit without temporary restrictions.

An alternative way to illustrate our results is to simply look at the aggregate valuation of different hypothetical contracts in different settings. The contracts are designed to highlight both "hard" and "soft" restrictions on homeowners' electricity use and also to test the hypothesis that shorter, but perhaps more frequent, disruptions may be easier to handle and compensate for. In Table 5, we report on four different contracts. In the contracts, we elaborate on all the different attributes except the flexible versus predetermined, choice of appliances. The reason is that this attribute turned out to not be significantly different from zero in any specification. *Hard control* refers to a case with the seemingly toughest restrictions for all the attributes – 2000 watt load control, 180-minute disruptions and 20 days. *Hard but short* refers to 2000 watt and 20 days, but only 30-minute disruptions. *Hard load only* refers to 2000 watt, 30 minutes and 5 days. Finally, *soft but often* refers to 20 days, but 5000 watt and 30 minutes. Recall that this is calculated for the specification including attribute interactions between 2000 watt, duration and number of days.[11] All point estimates are statistically significant at the 1 percent level, except for the *Hard load only* scenario. Notice also that the scenarios are calculated both with and without the compensation needed to accept the reference DSM contract (the average of the range SEK 1146-1483). As can be seen, the compensation to accept the defined DSM-contracts ranges from SEK 1600 for the hard load only to SEK 3671 for the hardest control. The relatively low average compensation required for the *Hard load only* is explained by the negative interaction for 2000 watts and number of days, which is not part of the softer control.

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[9] These values can also be calculated directly from Table 4 by using the formula:
WTA = 1309 + 176 + 679 + 759 + 4.9* *duration* – 6.7**days*. Note that the numbers in table 5 is calculated with the exact estimates, not rounded values.

[10] Average compensation for contract A and B relative to the status quo.

[11] The significance levels and confidence intervals are calculated with the Wald procedure in Limdep, using the Krinsky and Robb method with 1000 draws.

Table 5: Scenario analysis for model with attribute interactions (confidence intervals within parentheses).

	Without SQ cost		**With average SQ cost**	
	Neutral	**Green**	**Neutral**	**Green**
Hard control	2356	2206	3671	3456
	(2050 – 2662)	(1875 – 2537)	(3323 – 4019)	(3101 – 3810)
Hard but short	947	710	2262	1959
	(717 – 1177)	(452 – 967)	(2018 – 2506)	(1717 – 2202)
Hard load only	289*	293*	1603	1543
	(62 – 516)	(50 – 536)	(1364 – 1843)	(1307 – 1778)
Soft but often	759	582	2074	1832
	(562 – 957)	(385 – 780)	(1837 – 2311)	(1597 – 2066)

* Significance at 5-percent level

There are no significant differences between the neutral and green treatment. It is, however, worth noting that the green treatment group demands slightly less compensation in all scenarios but one. If anything, this result is in line with our expectations that a green framing may influence the respondents' mindset.

4.3.3 Household heterogeneity

All the econometric specifications presented so far are based on the random parameter logit (RPL) model. The RPL allows for preference heterogeneity across households. The point estimates presented in Tables 3 and 4 are the mean estimates for the sample population. In the RPL specification, the heterogeneity is modelled such that respondents are assumed to be "drawn" from a random distribution (in this case a normal distribution). The estimation is done in a simulated maximum likelihood framework based on a number of random draws from the assumed distribution (e.g., normal distribution). Given this modelling approach, it is possible to extract the conditional individual parameter values. Specifically, given the actual sequence of choices made by the respondents and the assumptions regarding the distributions, it is possible to obtain the within-sample conditional individual parameters. This may be contrasted to the population results that just indicate that households are located "somewhere" within the random distribution.

The implication of the somewhat complicated methodological reasoning above is that we can further analyze the heterogeneity in the average compensation levels (marginal WTA) for the different attributes of the DSM program studied. Given the respondents' actual choices, it is possible to analyze how the compensation needed to accept the different marginal characteristics of the DSM program differs across subgroups in our sample. This exercise is done such that the conditional individual marginal WTA measures (attribute level compensations) are used as a dependent variable in linear regression specifications. It is important to emphasize that this is a within-sample analysis and the heterogeneity could be modelled in statistically more advanced ways. Still, we believe it is worthwhile undertaking this exercise to further elicit our respondents' preferences related to load control. To explain the differences in compensation levels, the models include a set of explanatory variables. In total, we estimate seven models, one for each attribute level. For interpretational convenience, we analyze these models for the non-interactions specification presented in Table 3. Moreover, note that the attribute level *Inflex* in Table 6 corresponds to the compensation required for a change in a contract from flexible choice of appliances to the predetermined appliances. It is also important to note that Table 6 only presents the statistically significant results.[12]

The models estimated for the different attribute levels in the contracts include explanatory variables related to personal characteristics, energy related indicators, pro-environmental proxies and survey specific controls. In Table 6, a plus sign should be interpreted as increased demand for monetary compensation and vice versa. Importantly, all variables except age are constructed as dummy variables (either/or questions), such that they refer to retired or not, single household or not, etc.[13] Note also that all the empty cells in Table 6 refer to statistically non-significant effects. Still, point estimates may be interesting to analyze and the reader is free to do so from the extended table in the appendix.

Personal characteristics are captured by the variables age, gender, education, place of residence, whether the respondent is retired and whether the household consists of only one individual. To begin with, except for the result that neither university education nor upper north county residence seems to play a role for any of the characteristics of the DSM contracts, there are no obvious or general patterns. Older respondents tend to demand higher compensation, but it is only statistically significant for the 3500 watt restriction. Male respondents need higher monetary compensation for the 2000 watt and 10-day options, while they are less sensitive to the inflexibility of appliances. Moreover, retired respondents and single households put a higher value on the flexibility of appliance choice.

Turning to the energy-related indicators, all statistically significant results, except having a fixed price contract and 10 days of restrictions, have a negative impact on the compensation levels. Notably, this is just for some of the contract characteristics. For example, having district heating (including combustion heating) reduces the necessary monetary compensation for the 2000 watt and 90-minute restrictions. It is perhaps surprising to find that households using more than three appliances are less sensitive to the flexible choice of appliances. However, considering the design of the restriction, this may be reasonable. A person could be a large user of electricity because of strong habits, and therefore could be relatively more certain about which appliances to use and hence not affected by flexibility in choice.

As expected, the pro-environmental proxies, represented by having green electricity contracts and sorting waste to a larger extent, are associated with a reduced demand for compensation concerning all attributes of the load control. It is, however, important to note that that these effects only are statistically significant for three of the attributes, namely 2000 watt, 10 days and 20 days.

Turning to the survey-specific controls represented by the green treatment and the binary variable created to capture respondents who stated that they put little effort into answering the choice questions. The green treatment seems to have a mixed effect on the compensation levels. The treated respondents seem to care less about compensation for 10 days, 20 days and the inflexibility of appliance choice. Respondents stating that they put less effort into answering the choice tasks tend to ask for more compensations for all contract characteristics except inflexibility. The

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[12] It should be noted that models including household income, which is typically perceived as an important socioeconomic factor for behavior, has been estimated. In our data, about 300 respondents chose to not reveal their household income. Given that the income variable was not found statistically significant for any of the compensation levels, we decided to not include income in the final specifications.

[13] A table with the more detailed results is found in the appendix.

mechanisms underlying this result are unknown, but may reflect a more negative attitude to, and interest in, the issue of electricity use in general.

Table 6. Heterogeneity in compensation[a].

	2000W	3500W	90 min	180 min	10 days	20 days	Inflex
Age		+					
Male	+++				+++		---
Education							
Retired		--			--		++
Single household	--					---	+
Upper north counties							
Stockholm county			++				
Tight power supply		-					
>3 appliances, 5.30-6pm							---
District heating	-		--				
Fixed price contract					+	-	
Green contract	---				-	--	
Waste sorter						-	+
Green treatment		+++		+++	---	---	---
Low answering effort	+++	+++	+++	+++	+++	+++	---

[a] +/- indicates positive/negative statistical significance at the 10-percent level, ++/-- at the 5-percent level, +++/--- at the 1% level. An empty cell indicates a statistically non-significant estimate.

5. The contingent valuation analysis

5.1 DESIGN OF THE CONTINGENT VALUATION SCENARIO

The choice experiment approach is attractive in its potential to simultaneously cover several dimensions of a hypothetical scenario. As described, it is possible to separate the preferences for the different attributes and their respective levels. If this is not of particular interest, but instead the focus is on the attitudes toward a specific ”package” of characteristics, the contingent valuation approach is more appealing, due to its simplicity in relation to the choice experiment. In eliciting preferences related to full black-outs, the contingent valuation method was therefore adopted.

So, after the choice experiment questions in the survey, the respondent was faced with a question related to a full black-out. It was explained to the respondent that the household would receive monetary compensation if they accept that the electricity is cut for 30 minutes, 5 times during the period of December through February. It was made clear that all electricity would be cut, i.e., a black-out, and that it would be at 5.30pm-6pm on weekdays. It was also made clear that they would not be notified in advance. The respondents were then faced with seven bids ranging from SEK 100 to SEK 4000 to accept black-outs as described. Each bid was presented separately, and the respondent did not know how many bids would be offered. The question was designed such that it allowed respondents to express uncertainty when they stated whether to accept the respective bid. In the end, each respondent's answer could be summarized in a matrix as illustrated in Figure 11.

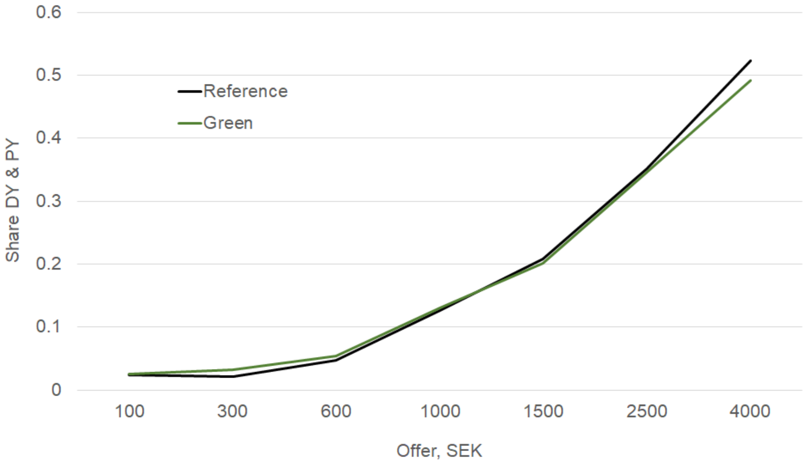
Figure 11: Bid vector for the compensation in the contingent valuation question.

Bid (SEK)	**Definitely Yes**	**Probably Yes**	**Unsure**	**Probably No**	**Definitely No**
100	☐	☐	☐	☐	☐
300	☐	☐	☐	☐	☐
600	☐	☐	☐	☐	☐
1 000	☐	☐	☐	☐	☐
1 500	☐	☐	☐	☐	☐
2 500	☐	☐	☐	☐	☐
4 000	☐	☐	☐	☐	☐

5.1.1 Results from the contingent valuation analysis

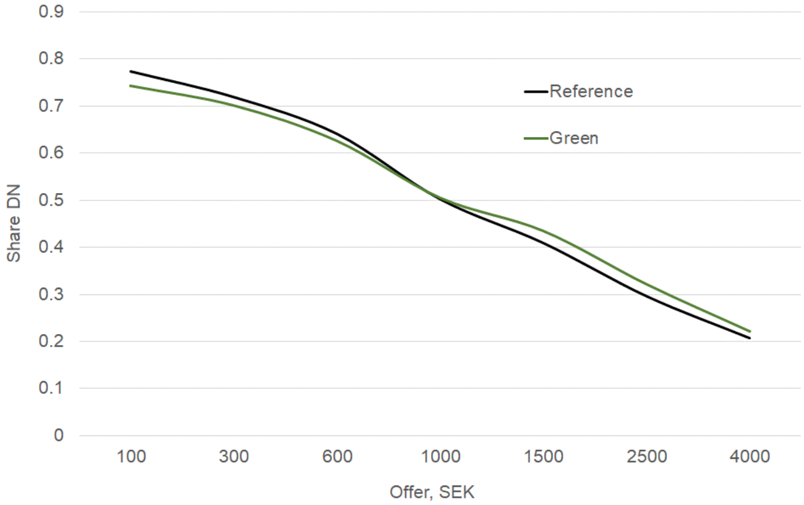
The responses to the CV question are summarized in Figures 12 and 13. Figure 12 illustrates the share of respondents who answered that they *definitely or probably* would accept a specific amount. As can be seen, the acceptance rate increased with the size of the compensation, but even at the highest compensation we offered (SEK 4000), around 50 percent of the respondents turned down the offer. Figure 12 reveals no obvious effect of the green framing, which is in line with the results from the choice experiment regarding the acceptance of a tight power restriction. Stressing the environmental benefits does not seem to encourage people to accept restrictions that involve a great deal of curtailment activities.

Figure 12: Survival curve for accepting compensation for a black-out.



A similar story is told by Figure 13 showing the share of respondents *definitely turning down* specific amounts offered to them. As can be seen, the share of respondents rejecting offers decreases with the level of compensation. At our highest bid, approximately 20 percent answered that they would *definitely not* accept the DSM contract.

Figure 13: Survival curve for rejecting compensation for a black-out.



The average compensation required to accept the DSM program that includes black-outs can be estimated statistically. Because a large fraction of the sample did not accept the highest bid offered, it is difficult to estimate the distribution of the compensation levels with a reasonable degree of accuracy. We simply have too little information about the right-side tail of the distribution, implying that an estimate of the average compensation has to be done by making some sort of assumption about the distribution. An alternative, of course, is to use the median compensation, which equals SEK 4000. To give an estimate of the average compensation, we non-parametrically calculate an interval for the average compensation level by measuring the area under the curves in Figure 12 using two alternative assumptions: (1) People who reject SEK 4000 are assumed to accept SEK 4001, and (2) the accepted compensation among people who reject SEK 4000 is distributed according to an extrapolation of the curves in Figure 12. That is, the curves are extrapolated until the share of households equals unity, which occurs at SEK 8650. The latter simply means that the person with the highest compensation demand would accept the black-out for a compensation of SEK 8650. We view the second assumption as being the most reasonable of the two.

Given this, the resulting interval for the average compensation is SEK 3000-4600. The interval can be compared with the average compensation required for accepting the scenario *hard but short* in the choice analysis. That scenario is similar to the black-out scenario here with respect to duration and number of days. As expected, the comparison reveals that households on average demand higher compensation to accept the black-out scenario. The difference in compensation levels also implies that people place a high value in being fully flexible in their use of both high- and low-power appliances.

Making similar assumptions as in the discussion of the scenarios in the choice analysis, we can calculate the value of lost load for that particular time of day. Assuming a 5 KW loss of load for 30 minutes for 5 days, this implies a total loss of 2.5 kWh. Given a required compensation of 3000-4600, the value of lost load would be SEK 240-368 per kWh. However, if the ultimate goal is to estimate VOLL in terms of SEK per kWh, the starting point must be the actual load in use at the highest peak hour. If we assume that the load lost is approximately 1.5 kWh at each black-out, VOLL is calculated to SEK 400-600 (see Vesterberg and Krishnamurthy, 2016). Again, a comparison with the *hard and short* scenario in the choice analysis reveals that a black-out is perceived as a stricter restriction with more disutility attached to it, which is expected.

To find out more about which households accept the DSM program at the lowest compensation level, we estimate a regression model where the dependent variable is the lowest bid that the respondents said they would *definitely or probably accept*. Because the highest bid we offered is lower than what a large share of the respondents would accept, we adopted a Tobit model. In principle, the Tobit specification is a combination of a linear regression and a binary model. The Tobit model censors the estimated distribution to a specific number – in our case, SEK 4000 – and utilizes the fact that the censored observations are higher than SEK 4000. In the Tobit model, the variables are used to explain the size of the compensation (WTA), given that it is lower than SEK 4000, and given the likelihood that a respondent has a WTA above SEK 4000.

Table 7 reports the results from two different model specifications. In both specifications, the dependent variable is the lowest amount the respondents answered that they *definitely, or probably*, would require to accept the DSM program. The difference between these models is that Model 1 is estimated on the full sample including all relevant variables except household income. Model 2 includes household income and as a consequence is estimated on a sample excluding the 374 respondents with missing income data.

The plus and minus signs in Table 7 relate to the average compensation level, but should not be interpreted as marginal values in a linear regression. The interpretation of coefficients from Tobit models is not straightforward, as the model consist of two components. Here we discuss the coefficients based on their sign and statistical significance. A positive (negative) coefficient significantly different from zero means that the variable is positively (negatively) correlated with the compensation level. As was the case in the choice experiment analysis, many of the variables are binary and should be interpreted as an average comparison between two groups of respondents, e.g., males and females.

By comparing the results for Model 1 and Model 2, income seems to act as a confounding variable in Model 1. Among other things, a relatively low average income among retired households seems to explain why they require lower compensation than others. The same pattern seems to be true for households in the upper north part of Sweden and households buying green labeled electricity. Also, there seems to be a correlation between the low-effort respondents and income[14]. Overall, household income is positively correlated with the compensation levels, i.e., households with high income levels require higher compensations levels, which is fairly intuitive. As noted in Figure 12 and 13, there is no difference between the ”green” and ”neutral” framing.

Table 7: Regression result of minimum compensation (WTA) for a black-out.[a]

	Model 1	**Model 2**
Age	+++	+++
Male		
Retired	--	
Tight power supply	---	--
Single household		
District heating/Combustion		
Upper north counties	++	
Stockholm county	+++	+++
Waste sorter	--	--
Labeled electricity	--	
Fixed price contract		+
Use >3 appliances during 5.30-6 pm		
Highly educated	++	
Green framing		
Household income	N.A	++
Low effort	++	
Constant	+++	+++
NOBS	1 981	1 607
Right-censored	959	766
Log-likelihood	-10 102.29	-8 290.30

[a] +/- indicates positive/negative statistical significance at the 10-percent level, ++/-- at the 5-percent level, +++/--- at the 1-percent level. An empty cell indicates a statistically non-significant estimate.

Interestingly, respondents who already adjust their loads to avoid internal power failures require lower compensation on average. This is also true for respondents who stated that they think it is important for them to sort dairy packaging. Tentatively, these results suggest that preferences may adapt to new circumstances and that people develop new habits because of experience. The point is that people may perceive the cost of a power failure to be higher than it really is. When exposed to a power failure, people learn about the true costs and correct their misperceptions.

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[14] Such correlation may result if some respondents systematically have chosen answers such as “I don’t know”, “Status quo” and “I do not want to answer”.

6. Discussion and conclusions

The main objective of this project and report is to study household customers' preferences concerning demand response, to learn more about the potential for demand-side resources. To do this, we analyze households' preferences for using electrical load in peak demand hours in the winter season (December to February). The ultimate objective is to get a better understanding of the potential for demand response when consumers' behavior is considered explicitly. We analyze only curtailment actions (actions that require behavioral changes) because these actions or responses are expected to be more difficult to accomplish than demand response as a result of automatic control.

To study household preferences and behavior, we apply a survey approach eliciting people's preferences concerning a hypothetical demand-side management program (DSM) involving load control. The DSM program includes load control on a number of occasions during the peak hours in the winter season. By varying the attributes of the DSM program, we elicit people's preferences for these attributes and attempt to place a monetary value on them. The load controls, or attributes, are: (1) maximum high-power loads, (2) duration of load control, (3) number of occasions of load control and (4) degree of self-control over available load.

To estimate the relative value of having full access to high-power loads compared to other loads (e.g., heating, lighting and TV) we also designed a continent valuation scenario involving a complete black-out. The difference between the compensation required to accept the black-out and the compensation to accept a DSM program with a softer load control but with similar duration and number of occasions may then reveal something about the relative value of different loads.

An additional objective of the project is to investigate whether preferences are contingent on the context in which a proposed change takes place. Specifically, we investigate whether the compensation levels consumers demand for accepting load control, or a black-out, are affected by environmental motivation for the load control or black-out. Empirically, this was done by having two versions of the survey, one for each half of the sample. One version was neutral in the sense that it did not include environmental framing, whereas the other version included pro-environmental ”cheap talk” in which load control was said to be motivated by environmental reasons. The hypothesis was that those who were treated with the cheap talk would demand lower compensation. However, the results show no statistically significant framing effect on the compensation levels, except that the pro-environmental cheap talk made people more eager to opt into a DSM scenario in which load is controlled on many occasions.

The overall conclusion from our empirical analyses is that demand response relying on behavioral change is expensive. In other words, it is very costly from the consumers' perspective to change their behavior during the hours under consideration. The “cost” for the consumer can in this case be interpreted as the opportunity cost of time. That is, the risk of not being able to make dinner at the usual time may be very disruptive for the household, and according to our results this disruption is very costly.

The results reveal that households would require minimum compensation ranging between SEK 2000 and SEK 3700, depending on how stringent the control is with respect to maximum load, duration, and number of days. This is a large amount of money, considering that the annual electricity bill for a homeowner household is approximately SEK 15 000 on average. This number can also be compared to the actual potential saving on the electricity bill for that particular load saving, which is about SEK 3 – 5. An additional way to show the significance of the compensation that households demands for load controls is to relate it to the value of lost load. Given some specific assumptions concerning the potential loss of load resulting from the various scenarios, households on average value the potential lost load, VOPLL, to at least SEK 20 – 40 per kWh, which should be compared with the actual electricity consumer price of about SEK 1. This simply means that the value the consumers, or households, attribute to secure access to electricity at the afternoon peak hour is way above the marginal cost of providing electricity.

Looking more specifically at the minimum compensation for accepting a 30-minute black-out in the afternoon peak hour reveals an even higher value than the less restricted load control, which is expected. According to the results, compensation in the range of SEK 3000 – 4600 is needed, where the upper limit is more probable, which corresponds to a value of lost load, VOLL, of approximately SEK 400 – 600 per kWh. This indicates a huge difference between the value of the load that was controlled in the choice experiment and the remaining load (e.g. heat, lighting and TV). Compared to previous literature on VOLL our estimates fall in the higher range, especially compared to Swedish studies. For example, Carlsson and Martinsson (2011) estimate VOLL for the population of Swedish households, conditioned on a scenario with one additional power failure in a five-year period lasting for 24 hours. Translated to one power failure per year, their results points at a VOLL of about SEK 30-40 per kWh (assuming an average annual power consumption of 6000 kWh). The international literature on household VOLL typically report higher estimates than the one just cited and, in several cases, estimates comparable to ours (see the literature review by Schröder and Kuckshinrichs, 2015, and the review in London Economics, 2013). A possible explanation for the high values of VOLL in our case is the scenario they are conditioned on. Compared to today's rather safe power supply, a scenario of five random black-outs in the peak hour winter period mirrors a highly unstable power system. Another explanation is the WTA approach, which typically results in higher values than approaches asking people to state their willingness to pay for avoiding a power failure (see case study in London Economics, 2013).

Concerning heterogeneity, the results here do not reveal any clear patterns. In other words, the results concerning compensation needed do not provide any specific hints of which type of households are more or less inclined to change their behavior. As a result, the results give limited guidance as to which particular group to pinpoint for policy measures. However, as also was shown, families with children appear to use high-power appliances at the peak hour more frequently than households without children, which may indicate they are more reluctant to change behavior.

A policy implication that follows immediately from the results presented here is that specific policies aiming at stimulating behavioral changes probably are very ineffective and/or costly. As a result, policies to affect demand response should focus on automatization and passive response. First, such measures seem to be the low-hanging fruit, not least in the sense that relatively large effects can be achieved without so many negative effects on households. Second, a significant share of homeowners' use of electricity is related to more or less passive use, such as heating, refrigerators, ventilation, etc. This means that the load that could be subject to passive response is relatively large, and hence a relatively large potential for load-shifting follows. A related policy implication is that it is far from obvious that demand response is more cost effective than supply response, i.e., increasing production of electricity. We saw that the value of the load lost is far above the marginal production cost, which means that there is a potential for using fairly high-cost production for some hours of the year.

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Appendix

The tables in this appendix includes the results on a more detailed level than presented in the text.

THE RANDOM PARAMETER LOGIT MODEL

Table A1: The random parameter logit - No treatment.

Attributes	No interactions				Attribute interactions			
	Coeff	Stand. err.	Std. dev.	Std err	Coeff	Stand. err.	Std. dev.	Std err
3500 w	-0.070	0.072	0.842	0.125	-0.049	0.074	0.856	0.125
2000 w	-0.666	0.094	1.411	0.138	-0.204	0.189	1.441	0.139
Flex	0.080	0.065	0.713	0.127	0.093	0.085	0.751	0.125
90 min	-0.272	0.074	1.050	0.108	-0.120	0.082	1.103	0.109
180 min	-1.179	0.102	1.698	0.119	-0.786	0.133	1.685	0.120
10 days	-0.525	0.064	0.139	0.160	-0.543	0.075	0.137	0.163
20 days	-0.793	0.086	1.141	0.107	-0.880	0.115	1.138	0.108
Alfa A	-1.495	0.136	3.014	0.147	-1.718	0.156	2.993	0.148
Alfa B	-1.198	0.132	2.939	0.147	-1.328	0.138	2.930	0.148
Comp/1000	1.156	0.043			1.158	0.043		
I_dur					-0.564	0.125		
I_days					0.778	1.102		
I_flex					0.008	0.158		
Log-likelihood		-6590.419				-6575.179		
Restricted log-likelihood		-8850.421				-8850.421		
McFadden pseudo R2		0.255				0.257		
AIC/N		1.641				1.638		
No of resp		1007				1007		
No of obs		8056				8056		
No of shuffled Halton draws		1000				1000		

Table A2: The random parameter logit - Green treatment.

Attributes	No interactions				Attribute interactions			
	Coeff	Stand. err.	Std. dev.	Std err	Coeff	Stand. err.	Std. dev.	Std err
3500 w	-0.222	0.078	1.105	0.118	-0.219	0.080	1.121	0.119
2000 w	-0.644	0.092	1.333	0.139	-0.260	0.193	1.365	0.141
Flex	-0.100	0.070	0.868	0.131	-0.012	0.090	0.918	0.128
90 min	-0.272	0.076	1.123	0.116	-0.140	0.084	1.169	0.117
180 min	-1.334	0.110	2.000	0.125	-1.020	0.140	2.005	0.127
10 days	-0.385	0.069	0.493	0.161	-0.436	0.080	0.493	0.163
20 days	-0.535	0.089	1.321	0.110	-0.662	0.118	1.320	0.112
Alfa A	-1.383	0.130	2.841	0.136	-1.529	0.150	2.835	0.139
Alfa B	-1.191	0.127	2.706	0.140	-1.311	0.131	2.711	0.141
Comp/1000	1.136	0.044			1.137	0.044		
I_dur					-0.454	0.129		
I_days					1.257	1.125		
I_flex					-0.182	0.161		
Log-likelihood		-6630.322				-6616.964		
Restricted log-likelihood		-8850.421				-8850.421		
McFadden pseudo R2		0.251				0.252		
AIC/N		1.651				1.648		
No of resp		1007				1007		
No of obs		8056				8056		
No of shuffled Halton draws		1000				1000		

HETEROGENEITY IN MARGINAL WTA

Table A3. Regression analysis of heterogeneity in marginal WTA.

	2000W	3500W	90 min	180 min	10 days	20 days	Flex
Age	0.91	1.64*	0.80	2.18	0.25	0.88	-0.20
	(1.37)	(0.90)	(1.04)	(2.20)	(0.21)	(1.26)	(0.63)
Male	138.49***	30.12	19.461	-5.87	11.32***	5.94	40.35***
	(29.21)	(19.34)	(22.67)	(48.01)	(4.64)	(27.36)	(13.71)
Retired	-29.21	-65.01**	-29.60	-91.92	-14.93**	-14.27	-13.64**
	(47.56)	(30.68)	(35.97)	(76.17)	(7.37)	(43.42)	(21.76)
Tight power supply	-27.29	-38.16*	8.92	19.93	-5.81	18.46	-25.28
	(31.89)	(20.57)	(24.12)	(51.08)	(4.94)	(29.11)	(14.59)
Single household	-112.03**	-6.48	4.63	-38.39	7.19	-135.31***	-39.55*
	(48.30)	(31.16)	(36.53)	(77.36)	(7.48)	(44.10)	(22.10)
District heating/Combustion (main or additional source)	-61.78*	10.60	-55.51**	-12.31	-5.94	-9.95	21.45
	(32.24)	(20.80)	(24.39)	(51.64)	(4.99)	(29.44)	(14.75)
Upper north counties	111.58	22.68	4.16	-34.96	-8.11	-43.91	7.50
	(68.75)	(44.35)	(52.00)	(110.11)	(10.65)	(62.76)	(31.46)
Stockholm county	57.80	33.55	58.00**	-96.51	-7.55	36.82	-19.55
	(38.57)	(24.88)	(29.17)	(61.77)	(5.97)	(35.21)	(17.64)
Waste sorter	-9.39	-26.76	-17.88	-28.06	-3.63	-48.78*	-26.17*
	(31.49)	(20.31)	(23.82)	(50.44)	(4.88)	(28.75)	(14.41)
Labeled electricity	-158.82***	-26.29	-22.84	-21.06	-12.89*	-91.71**	-21.79
	(170.36)	(28.49)	(33.40)	(70.72)	(6.842)	(40.31)	(20.20)
Fixed price contract	-23.09	-10.86	4.48	55.57	7.91*	-13.03*	16.10
	(30.73)	(19.83)	(23.25)	(49.23)	(4.76)	(28.06)	(14.06)
Use >3 appliances during 5.30-6 pm	50.94	40.70	26.66	30.80	8.23	22.68	47.91***
	(39.78)	(25.66)	(30.09)	(63.71)	(6.16)	(36.32)	(18.20)
Highly educated	-0.23	-13.46	-5.11	-78.16	-0.93	30.41	-12.19
	(29.97)	(19.34)	(22.67)	(48.01)	(4.64)	(27.36)	(13.71)
Green framing	-6.70	142.97***	-11.72	145.40***	-111.32***	-233.45***	161.48***
	(29.57)	(19.08)	(22.37)	(47.37)	(4.58)	(27.00)	(13.53)
Low effort	194.90***	126.67***	173.56***	235.31***	25.18***	227.55***	146.39***
	(38.15)	(24.61)	(28.85)	(61.10)	(5.91)	(34.83)	(17.45)
Constant	450.13***	-37.13	180.85***	967.63***	441.80***	627.16***	-92.84***
	(69.91)	(45.10)	(52.88)	(111.97)	(10.83)	(63.82)	(31.99)

HETEROGENEITY IN WTA FOR BLACK-OUT

Table A4. Regression analysis of minimum WTA for black-out.

	Model 1	Model 2
Age	23.36***	21.65***
	(5.37)	(6.16)
Male	162.69	134.63
	(117.29)	(129.04)
Retired	-411.72**	-233.48
	(186.91)	(207.47)
Tight power supply	-361.91***	-286.30**
	(124.24)	(137.11)
Single household	-212.38	-137.22
	(189.26)	(206.98)
District heating/Combustion	-155.67	-121.34
(main or additional source)	(125.69)	(137.66)
Upper north counties	616.89**	300.76
	(281.09)	(299.16)
Stockholm county	435.60***	443.90***
	(153.68)	(168.33)
Waste sorter	-274.47**	-336.17**
	(123.57)	(135.24)
Labeled electricity	-355.64**	-296.90
	(170.22)	(183.62)
Fixed price contract	171.95	214.67*
	(120.80)	(130.06)
Use >3 appliances during 5.30-6 pm	108.46	177.76
	(157.03)	(175.68)
Highly educated	234.30**	155.21
	(117.30)	(130.29)
Green framing	83.01	53.90
	(115.79)	(126.43)
Household income	-	318.53**
		(143.33)
Low effort	358.05**	242.71
	(152.62)	(167.44)
Constant	2 381.30***	2 188.84***
	(270.89)	(329.82)
NOBS	1 981	1 607
Right-censored	959	766
Log-likelihood	-10 102.29	-8 290.30