Nordic Council of Ministers

FLEXIBLE DEMAND FOR ELECTRICITY AND POWER

Barriers and opportunities

Flexible demand for electricity and power

Barriers and opportunities

NORDIC ECOLABEL
5041 0457
Ecolabelled Printed Matter
Rosendahls

Nordic co-operation
Nordic co-operation is one of the world's most extensive forms of regional collaboration, involving Denmark, Finland, Iceland, Norway, Sweden, and the Faroe Islands, Greenland and Åland.

Nordic co-operation has firm traditions in politics, economics and culture and plays an important role in European and international forums. The Nordic community strives for a strong Nordic Region in a strong Europe.

Nordic co-operation promotes regional interests and values in a global world. The values shared by the Nordic countries help make the region one of the most innovative and competitive in the world.

The Nordic Council of Ministers
Nordens Hus
Ved Stranden 18
DK-1061 Copenhagen K, Denmark
Tel.: +45 3396 0200 www.norden.org

Download Nordic publications at **www.norden.org/nordpub**

Contents

Preface

This is our report on flexible demand for electricity and power, conducted in the spring, summer and fall of 2017. We would like to thank our reference and steering groups, and in particular to thank Karin Alvehag, Ulrika Bäärnhielm, Terje Gjengedal, Juha Kiviluoma, Ville Väre and Kristina Östman for their extensive and useful comments to earlier drafts. Ingeborg Rasmussen has provided quality control at Vista Analysis. Any remaining errors and omissions are the responsibility of the authors.

This version replaces a previous version of 29 September 2017.

Haakon Vennemo
Project Manager
Vista Analyse AS

Executive summary

Demand side flexibility is the ability of power consumers to reduce their demand in periods of peak load, possibly shifting demand to other periods. We perform a literature survey (meta study) of demand side flexibility and assess the potential for, and benefit of demand side flexibility. Based on the survey we highlight implementation barriers and possible contributions from Nordic regulators to reducing these barriers.

Demand side flexibility is becoming more important and valuable

Nordic and European electricity markets are phasing in renewable energy sources that depend on wind and sunlight, and variation in production ensues. To reduce cost and increase efficiency it would be helpful if the demand side accommodates the variation in production. Variable renewable energy therefore makes demand side flexibility more important.

Demand side flexibility also helps to reduce peak pressure on the grid. In Oslo, for example, power demand in the 0.5% coldest hours is 10% higher than in the remaining 99.5%. If demand were flexible during these periods of peak pressure, society could avoid or delay grid investments and save significant investment costs.

Important barriers to demand side barriers are lifted, but many remain

Traditionally, the electricity consumption of most Nordic consumers over the day has not been monitored. This is now changing and modern smart meters are being introduced. The installation of smart meters removes an important barrier to demand side flexibility since it enables real-time pricing of electricity and power consumption. Yet, barriers and obstacles remain. These are related to the concrete design of real-time prices; the interaction between pricing signals and regulation of distribution grid operators; the role of aggregation of small consumers, and more.

Nordic energy regulators are seeking advice on common positions

Confronted with the necessity of demand side flexibility on the one hand, and the remaining barriers to demand side flexibility on the other hand, the Nordic energy regulators are calling for advice on common positions and "what to do next". Our study is a response to this call.

The purpose of the study is to:

- Explore available information on demand side flexibility in a Nordic perspective and highlight key findings that may develop into concrete measures.
- Make an overview of existing barriers and of potential and value for demand side flexibility in the Nordic market.

Our study is a "meta study" where we draw inferences and make assessments based on reports and peer reviewed research.

A hierarchy of barriers to demand side flexibility

Several barriers to demand side flexibility are mentioned in the literature: Lack of ICT and automation services, immature market for aggregation services, too few smart meters, no real-time prices that incentivize consumers to save electricity and power during peaks, and more.
    We find it useful to organize the barriers in a hierarchy, see Figure 1.

Figure 1: Benefits of removing barriers as a function of other barriers
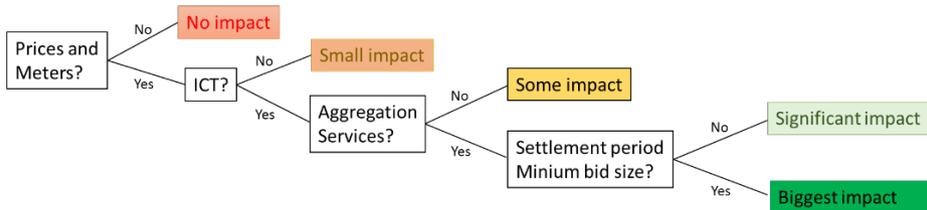
Note: The figure should be read from left to right. If no real-time prices and smart meters there will be practically no impact. If prices and meters, but no ICT and automation service there will be a small impact. If prices and meters, ICT but no aggregation services there will be some impact. If prices and meters, ICT and aggregation services, but no change in the settlement period or minimum bid size there will still be significant impact. If settlement period and minimum bid size change as well the impact will be the biggest.

To the left of the figure are meters and prices. Without real-time monitoring of power consumption, consumers cannot be rewarded for lower consumption during peaks and demand side flexibility will be stymied. Without real-time, flexible prices that inform about peaks and troughs in production and grid, consumers will not be rewarded either. "No" to prices and meters in the figure indicates that without smart meters and real-time pricing there will be no impact on demand side flexibility irrespective of other barriers. Hence smart meters and real-time prices are in our view the key enablers of demand side flexibility.
    Next come measures that reduce transaction costs. Information- and communication technology (ICT) and automation help consumers respond to price signals, by informing about high prices, and by automatically turning equipment on and off in response to price signals. To draw a parallel, nobody would be able to maintain

constant indoor temperatures by manually turning each radiator up and down. A thermostat makes it simple. Similarly, ICT and automation may decisively reduce the transaction cost and burden of demand side flexibility, thereby increasing the price elasticity of demand. Without ICT, metering and real-time prices will have a smaller impact on demand side flexibility.

Aggregation services are services that help (small) consumers respond to price signals by managing all or some of their consumption. Aggregators will also coordinate and aggregate consumers in power system markets (both wholesale and retail) or in terms of selling services to the system operator(s). Aggregation services imply lower transaction costs for consumers that would not have bothered to respond to price signals, and increase demand side flexibility. They can also reduce the risk of demand exceeding supply during peaks.

The Nordic wholesale markets have some features that are not conducive to demand side flexibility. In particular, there is a 60-minute settlement period and a 5–10 MW minimum bid size. The 60-minute settlement period blunts the effectiveness of the 15-minute interval that characterizes current smart meters. The 5–10 MW minimum bid size in the wholesale market implies that aggregators must form larger aggregates. Modification of the 60 minutes and 5–10 MW rules will enhance the flexibility of the system and facilitate demand side flexibility. There are signs that this is happening. A move to a 15-minute imbalance settlement period is discussed at the EU level and written into the draft commission guideline on electricity balancing. Nordic TSO's are currently carrying out pilot projects on electronic ordering, which could pave the way for a lower minimum bid requirement. A requirement of 1 MW has been proposed.

It is important to design real-time prices properly

Smart meters are being rolled out in the Nordic countries. Finland has had 100% penetration of smart meters since 2014. In *Denmark* the government has decided a national roll out of smart meters by 2020. In 2016 roughly half of consumers already had smart meters installed. Hourly metering is mandatory for large consumers (more than 100 000 kWh/year). In *Norway,* smart meters are to be rolled out by 2019. Large consumers have had hourly metering since 2005. In *Sweden* smart meters were installed in 2006, but do not meet current requirements of hourly or 15 minute frequency of metering etc. A second generation of smart meters are expected to be installed between 2017 and 2025.

With smart meters on their way attention should turn to the price structure. We conclude from the literature that the need for real-time prices is recognized, but the concrete design is not fully developed. This is an omission that Nordic regulators could help remove.

Efficient electricity pricing of the consumer (purchaser's price) usually requires a component based on energy (kWh) and another component based on power (kW). The kWh based electricity price should indicate the marginal cost of production and grid

loss, and marginal strength of demand. It should be dynamic in real-time. The pros and cons of different designs have been discussed for some time.

By contrast, the design of an efficient power tariff based in the characteristics of the grid has not been studied as much. Economic theory suggests that the *marginal* tariff should be dynamic in real-time and respond to peaks in demand. This means it should also be regional or based in nodes since the nature of peaks will depend on location. Still, in most situations there will be common elements between locations because of the simultaneous nature of the grid.

The recommendations from theory has be squared with practical considerations. A practical tariff structure is one that is simple to understand and use. Nordic regulators could usefully work on balancing the theoretical and practical concerns into an actual power design.

Besides working on the design it is of course important to estimate the rate, i.e. how many eurocent/SEK/NOK/DKK per kW should constitute the marginal tariff in different regions. From a theoretical point of view the rate depends on marginal bottleneck costs in the grid. Nordic regulators could address this issue.

A regional, fluctuating marginal grid tariff will not guarantee revenue. Given that the DSO and TSO face revenue requirements there should be a second, inframarginal term in the grid tariff. This inframarginal term is similar in nature to a tax in that its purpose is to collect revenue. There are different ways of designing the inframarginal tax-like part of the tariff: Per subscription and year, per electricity consumption, per power consumption during off-peak, etc. Second-best pricing theory in economics gives general advice on the best design, and the design should consider the tax-like inframarginal part of the tariff in conjunction with existing excise and ad valorem (percentage) taxes on power and electricity. Nordic regulators could have a role to play in working out practical, efficient designs.

Current grid tariffs in the Nordic countries do not correspond to the theoretical ideal, and the design of tariffs differs between DSOs. All of the designs cannot be efficient. There is a need to streamline and harmonize. Nordic energy regulators have begun this work. In Norway, for instance, the regulator NVE is set to send a new network tariff design for comments in the fall of 2017. To support demand side flexibility it is important to harmonize to a standard that is supported by theory. Nordic regulators could have a role to play in this.

The consequences of implementing inefficient designs may be significant. Most consumers don't distinguish clearly between production and grid, but perceive that there is one "electricity" price that includes production and grid, as well as taxes and fees. Consider now a situation in which there is high production from solar and wind in a region, but there are capacity constraints between production sites and the consumer. The energy price should then be low, but the marginal power tariff should be high. The price of "electricity" will compromise between the two: it will be medium. The consumer may then wish to consume more than the grid can deliver, but not enough to take up all production. The market delivers a compromise between two problems, that of abundance of production and that of capacity constraints in the grid.

In other words, there will be some capacity problems remaining and some of the production potential may not be realised.

One could argue against this example that optimal electricity price and power tariff will price the two scarcities independently and the market will respond efficiently, but that requires that both price components are theoretically sound (and the scarcities are not perfectly correlated). Hence it is important for Nordic regulators to move beyond the principle of real-time prices to the nitty-gritty of designing them in practice according to economic principles and practical considerations.

Regulation of DSO's and TSO's needs consideration

Nordic countries use revenue regulation to regulate their DSO's and TSO's. In a traditional revenue regulation model, the DSO's and TSO's can pass on the cost of investing in the grid. Since they can pass on the cost of investing in the grid they do not obtain significant cost savings from demand side flexibility. Hence their incentive to facilitate demand side flexibility is weak. This is a potential barrier that Nordic energy regulators should consider. In fact, the Swedish regulator is currently looking into the issue. If DSO's and TSO's were given a share of the cost saving and benefit when grid investment is postponed and shelved, they might engage more fully in promoting demand side flexibility. Nordic regulators should in our view address the possible lack of incentives that is inherent in the regulation of DSOs and TSOs, examine how prevalent the problem is, and what can be done about it.

A level playing field for aggregation services

It is possible that there are costs to be saved and money to be made from adjusting consumption in response to price variation, at a minimal cost to comfort, but many consumers do not bother. Aggregation services are likely to fill this gap in the market. An aggregator can offer a consumer a discount in return for taking control of all or parts of the energy and power consumption of the consumer. Some pilots are underway in the Nordic countries, for instance a pilot in Finland whereby Fortum manages a fleet of 70 household water heaters and bids their capacity into the power market.

In principle, there are at least three sets of actors that could provide aggregation services. The DSO has the advantage that it is manages part of the grid. It also has ownership to the smart meters. Utilizing smart meters and its relationship with customers it could offer customers a choice between a real-time price contract and a contract where, say, the price is stable and low, while the DSO is allowed to cut, say, space heating and water heaters, for an agreed length of time, under specified conditions. Allowing DSOs to offer such contracts in competition with other providers of aggregation services will however challenge the notion that DSOs should confine its activities to those that are characterized by natural monopoly. If one is to engage DSOs in aggregation services it is important that the provision of aggregation service is

separated from the natural monopoly, e.g., by performing the aggregation service in a separate legal entity. This is important in order to avoid cross-subsidies from the monopoly to the competitive service.

The retail supplier of electricity is another entity that could provide aggregation services. The retailer knows the customers well and is in a good position to induce flexibility that accommodates variations in production and in grid capacity utilisation, as Fortum does in the Finnish pilot. The regulator in Norway recently allowed the retail companies to issue one comprehensive invoice that covers electricity consumption and grid usage.

Third party entities are also possible. These could be specialized companies in the form or energy service companies, that act as middlemen between consumers and the grid and retail organisations. Or it could be large consumers that take on an aggregation business on the side.

Nordic regulators may usefully facilitate aggregation services by arguing for a "level playing field" among prospective market participants. Access to smart meters should for instance be non-discriminatory. It should be further considered whether DSOs should participate in the market for aggregation services, and if so, what measures to take to make sure that the monopolistic part of their business does not subsidize their entry into aggregation services. The revenue regulation model of DSOs should be examined for their impacts on DSO incentives towards aggregation services.

The potential seems to be the largest in residential space heating

Our survey indicates that space heating offers the highest potential for demand side flexibility. The literature focuses on residential space heating. Estimates from Sweden, Germany and elsewhere in Europe suggest that residential space heating contributes at least half of the total potential. To utilize this flexibility to control morning peaks in demand, for instance, one must turn up heating night and turn down in the morning, or turn down in the morning and turn up in the day, or both. Residential space heating is particularly well suited for hour-to-hour flexibility. If the supply problem has longer duration, say a day or a week of low wind, flexibility naturally is lower. This goes for most load-shifting possibilities.

Besides space heating, water heaters offer a potential, and in a future of larger penetration of electric vehicles their batteries will offer a significant potential. Electric cars now constitute close to 20% of all new cars in Norway. In other Nordic countries the share is much lower. Another emerging trend that offers possibilities for demand side flexibility is data storage centers.

The cost savings of demand side flexibility is uncertain, but could be large

We are not aware of research that explicitly estimates the cost savings of measures to enhance demand side flexibility. These cost savings will depend on the degree and design of the measures. For instance, there is a difference between implementing theoretically efficient prices, and prices that only go part of the way towards efficiency. There is a difference between assuming efficient prices in a setting of ICT, automation and a mature market for aggregation services, as opposed to another setting without these enhancers.

Available research typically assumes costless shifting of power consumption between hours, and studies the impacts of accommodating variable electricity production. These assumptions are consistent with theoretically efficient prices in a market that benefits from ICT, automation and aggregation services.

Some research contributions consider cost savings and benefits based on historical data, such as data for 2010, 2012. Other contributions build scenarios for the year 2030 or similar. Some focus on cost savings to consumers, others consider producers as well. With some exceptions, the research literature does not focus on benefits to the grid. Despite some differences, the estimates from the research literature tend to fall in the same range of about billion SEK 1–2 (billion EUR 0.1–0.2) annual economic benefit in the Nordic countries.

Annual cost savings are likely to be repeated over several years. Assuming that the market for flexibility grows 1% annually, for instance because of a growing share of renewable energy, and using a 4% discount rate, the discounted benefit of demand side flexibility is around billion SEK 33–66 (billion EUR 3.3–6.6) in the Nordic countries. Benefits to the grid would be additional to this estimate. The grid employs more capital than does the production sector, indicating that demand side flexibility may generate significant cost savings in the grid as well.

Introduction

Further studies on demand side flexibility at a Nordic level would strengthen the competence and common Nordic understanding of what role demand side flexibility could play in the future, and be an enabler of common Nordic positions at European policy arenas. This report is a response to this call for further studies on demand side flexibility. As stated in the ToR the study has two objectives:

- Explore available information on demand side flexibility in a Nordic perspective and highlight key findings that may develop into concrete measures.
- Make an overview of existing barriers and of potential and value for demand side flexibility in the Nordic market.

Tasks flowing from these objectives are listed in the ToR. The ToR is appended to the report.

The two key concepts in the study are *potential* and *demand side flexibility*. We distinguish between *technical* and *economic* potential. The technical potential is the amount of power that is technically feasible to lift out of peak periods and either shed altogether or shift to an adjacent period. The economic potential is the amount of power that is socially profitable to lift out of peak periods. The economic potential is never larger than the technical potential and it is usually smaller.

Both the technical and economic potential depend on what is meant by peak period and adjacent period. Also, the penetration of variable electricity production is expected to increase over time, the grids will change and both the economic and technical potentials depend on the time frame. Hence, there is no single "number" for economic or technical potentials. To fix ideas it is nevertheless useful in a report like this to quantify potentials, with supporting assumptions stated as clearly as possible.

Demand side flexibility is the ability of the demand side to reduce consumption. The interest is primarily in flexibility to reduce consumption during net demand peaks. Demand during peaks can be cut permanently (load shedding) or moved to an adjacent period (load shifting).

The scope of our report is demand side flexibility and demand side storage, as opposed to supply side flexibility or full system flexibility. The Nordic countries in focus are Norway, Sweden, Denmark and Finland. The electricity markets comprise retail and wholesale markets.

The report is structured as follows. Chapter 1 reviews relevant literature and contains the meta-study. Chapter 2 focuses on a family of options that emerge from the literature review as particularly promising, namely options addressing residential space heating. Implementation measures to release the potential in this family of options are discussed. Chapter 3 takes a broader perspective on barriers to demand

side flexibility, in accordance with the ToR. It discusses pros and cons of changing the barriers individually. The concluding Chapter 4 assesses the existing potential and value of demand side flexibility in the Nordic market and suggests points of action for Nordic regulators.

1. The literature

The purpose of this chapter is the following:

"Conduct a meta study by gathering and presenting available information at both research level and from real life experiences (such as already implemented measures and pilot projects) relevant from a Nordic perspective, on the topic on demand side flexibility and storage.

- The presented information should be relevant for the Nordic perspective, but could include experiences and knowledge from outside the Nordic region.
- The focus should be holistic, and should span from forward markets, wholesale markets (including balancing and ancillary services), retail markets, network operations and network investments.
- Experiences from markets or market segments where smart meters and settlement based on frequent meter values, and how the price elasticity could be improved, are of special interest."

(source ToR)

We organize the chapter in the following way: First, we introduce the concepts of reduced base load demand, load shifting and load shedding, and give examples of *options* of each sort. Second, we survey estimates of the *potential* for demand side flexibility, and the *benefit* of increased demand side flexibility. Third, we discuss *barriers* to demand side flexibility in the retail and wholesale markets. And fourth, we discuss the *price elasticity* and the influence of smart metering. We conclude by summarizing useful lessons for our discussion of options in the chapters to come.

1.1 Options: Reduced base load demand, load shifting, load shedding

When discussing options for demand side flexibility it is useful to distinguish between flexibility to *reduce base load* demand, flexibility to *shift load* demand (load shifting), and flexibility to *reduce peak load* demand (load shedding). Figure 2 illustrates these options.

Figure 2: Typology of options for demand side flexibility
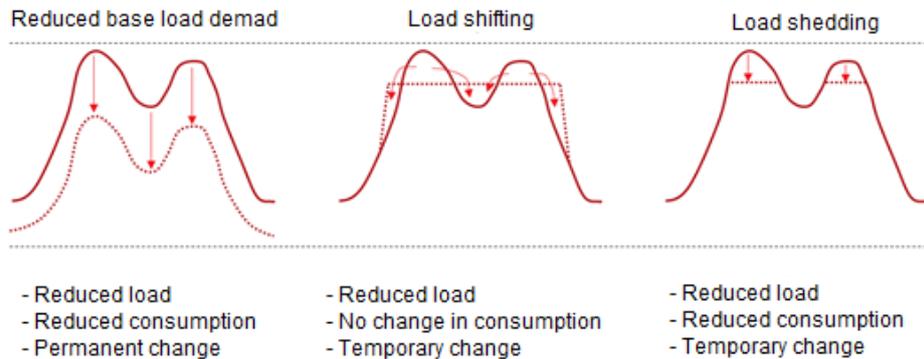
The figure shows a typical load curve over the day in the Nordic countries. There are peaks in the morning and afternoon, a somewhat lower load at mid-day, and much lower load during the night. On cold days, the whole load curve shifts upwards and often the peaks become higher too, with the consequence that peak load demand on extremely cold days is very much higher than average demand on ordinary days. It is expensive to build generation or transmission capacity just for peak demand on a few very cold days, which is one reason to utilize demand side flexibility. Another reason is that demand side flexibility can be used to counteract variations in electricity production from renewable energy sources. Flexibility for this purpose will be increasingly more valuable with larger penetration of renewables in the electricity production and in the energy system as a whole.

What can be done? *Reducing base load demand* has the effect of shifting the full load curve downwards and hence the load curve on the coldest days/days of low renewable energy production will also shift downwards as illustrated by the left part in Figure 2. Examples of options in this area are improved insulation of buildings, replacing electricity with other energy sources (so-called substitution), and improvements in the energy efficiency of electric installations such as lighting and electric equipment. Reducing base load demand is of course not helpful if the task is to accommodate peak renewable electricity production.

Load shifting shown in the mid-part of Figure 2 implies no reduction in energy consumption, but consumption is moved from peak load periods in the morning and afternoon to off peak periods of the night and mid-day. The literature points to space heating and water heaters, along with household appliances, as household technologies that can be shifted relatively easily without significant loss of comfort. Electric vehicles are gaining ground in the Nordic countries, most notably in Norway, and many electric vehicles may charge at other times and/or more slowly in order to implement load shifting. New technologies for two-way communication with the grid facilitate several of the load shifting options, as do price signals and commercial services such as aggregator services. Load shifting will alleviate intra-hour and intra-day fluctuations in supply and grid bottlenecks. Some examples of options are:

- Disconnection of water heaters for short periods, combined with additional heating before these periods and a gradual phase after these periods (to avoid steep ramps and/or a new peak load).
- Time displacement of space heating by utilizing the buildings' thermal inertia as heat storage, or by using dedicated thermal storage applications.
- Charging of electric vehicles and plug in hybrids at night and management to reduce simultaneity.
- Management of ventilation units: reducing air flow rates for short intervals
- Management of household appliances, in particular washing machines, dryers and dishwashers (e.g., Finn et al., 2013).
- Large scale load management in commercial buildings.
- Large scale load management in manufacturing industry.
- Intermediate storage of pulp in the paper industry (Paulus & Borggrefe, 2011).

Reducing load demand (load shedding) (illustrated in the right part of Figure 2) implies lower demand for power without compensating adjacent periods. Some examples of options are:

- Fuel switch to fossil fuel (oil, natural gas), biofuel or similar during peak load periods.
- Disconnection of loads of non-critical value, in manufacturing industry, office buildings outside office hours etc.

Load shedding in the Nordic market is conventionally associated with large industrial customers and the wholesale market. Time-variable pricing and smart metering of retail customers may change this.

Load shedding is useful to alleviate production shortfalls and network bottlenecks, but cannot accommodate peak production.

1.2   Potential and net benefit

This section surveys the potential of demand side flexibility and the net benefit of making use of the potential. We go through literature sources one by one, starting with country specific estimates, then a European survey paper that builds on underlying research literature, and finally two examples of research that provide original estimates.

Our aim in this section is to describe the reasoning and findings of each report and paper in a faithful manner, without comments. Section 1.5 contains our synthesis and assessment of the literature.

1.2.1 Estimates of the potential in Finland

A report by NordREG (non-dated) relays estimates of the amount of demand side flexibility currently participating in the markets of Finland. It is updated here with current information, see Table 1.

Table 1: Current extent of demand side flexibility being utilized in Finland

Marketplace/Source of demand side flexibility	Estimated amount
Elspot day-ahead	200–600 MW
Elbas intraday	0–200 MW
Regulating power market and balancing capacity market, mFRR	100–300 MW
Peak load reserve	22 MW
aFRR (currently not procured)	0 MW
FCR-N	0.5 MW
FCR-D	230 MW

Note: FCR-N refers to frequency containment reserve (primary reserve) in normal operating conditions. FCR-D refers to disturbance of operating conditions.[1]

Source: NordREG and Vista Analyse.

From the table, the current size of the market (a lower bound on potential) in Finland could be around 400–1200 MW, with a mean of around 800 MW. Large part of this comes from a small number of large industrial consumers. The energy authority in Finland is currently purchasing 729 MW as reserve capacity, of which 22 MW is demand response capacity.[2] Almost all retailers in Finland offer hourly based products, and retail customers can already participate in some balancing market places. Independent aggregators are allowed in the FCR-D market (with pilots running in the FCR-N and mFRR markets).

1.2.2 The potential in Denmark

Nordreg (nd) also relays estimates of the amount of demand side flexibility currently participating in the markets of Denmark. Household and industry electricity consumption is lower in Denmark than in other Nordic countries, and the current size of the Danish market is considerably smaller than the potential in Finland, only around 20 MW (Table 2).

---

[1] http://www.statnett.no/Global/Dokumenter/Kraftsystemet/Systemtjenester/ Vilk%C3%A5r%20gjeldende%20fra%2019%20mars%202015.pdf

[2] https://www.energiavirasto.fi/en/web/energy-authority/-/the-energy-authority-is-purchasing-729-mw-as-reserve-capacity

Table 2: Current extent of demand side flexibility being utilized in Denmark according to NordREG

Marketplace/Source of demand side flexibility	Estimated amount
Elspot day-ahead	0.2 MW
Elbas intraday	0.2 MW
Regulating power market and balancing capacity market, mFRR	20 MW
aFRR (currently not procured)	1 MW
FCR	0.6 MW

Source: Nordreg.

Several recent studies in Denmark have considered options for demand side flexibility in the future. A recent such study is Energinet.dk and Quartz+Co (2014). It suggests that flexible demand increase from the current 20 MW to 250–1400 MW in 2030. The higher end of the range corresponds to a best case scenario in which all consumers have smart meters and hourly pricing from 2020, and there are 200 MW large heat pumps and 280 MW more electric boilers, 160% more individual heat pumps, 50% more electric vehicles than previously assessed by Energinet.dk.

The organisation Dansk energi (Danish Energy Association) (nd) has summarized background research on demand side flexibility. The organisation suggests a long term technical potential of 500 MW, of which 200 MW from household dwellings and 300 from manufacturing industry, service and the public sector. Despite being denoted technical potential this number is obviously lower than the best case potential of Energinet.dk and Quartz+co (2014).

Another illustration from Denmark is Ea Energianalyse (2015), which considers the potential for demand side flexibility in Copenhagen. The study finds that flexible consumption corresponds to around a quarter (27%) of all consumption on an energy basis.

We deduce from these studies that the medium-long term potential in Denmark is 500 MW and maybe as high as 1400 MW under favourable regulatory conditions, high stock of heat pumps and electric boilers, and high penetration of electric vehicles.

1.2.3   The potential in Norway

In Norway the TSO Statnett has made agreements with local distribution grids on so-called interruptible loads. The agreements on interruptible loads amount to 709 MW (personal communication, Statnett). This is a lower bound on the economic potential in Norway as the regulatory power market in the country also contains interruptible loads. A report by Meland et al. (2006) suggests that the potential in Norway was 2,700–4,000 MW at the time. The ongoing R&D project "Alternatives to grid investments" (2017) carried out by Vista Analyse and AsplanViak on behalf of the Norwegian TSO Statnett and the energy efficiency promoter Enova, is likely to provide current bottom up estimates of potentials in the household and retail sectors.

1.2.4   The potential in Sweden

The Swedish Energy Markets Inspectorate (2016a) has recently assembled an estimate of the economic potential in the residential sector and industry in Sweden, Table 3. We devote some space to the Swedish estimate since it we will use its results in forthcoming chapters. Moreover, it demonstrates methods that often are used when developing estimates of potential and benefits of demand side flexibility.

Table 3: Current potential for demand side flexibility in Sweden according to The Swedish Energy Markets Inspectorate (2016a)

	Households	Real estate	Service	Energy intensive industry	Other industry
Feasible potential	5500 MW	200 MW	300 MW	1700 MW	300 MW
Remark	Space heating in winter. Lower potential spring, summer, fall. Estimate based on 1.3 million single family dwellings.	Ventilation	Back up aggregates	Load shedding or substitution to own production esp. in paper and pulp industry	Load shedding in light industry such as foodstuff, machinery, sawmills
Economic feasibility	Available at low cost			Highly price sensitive	Highly price sensitive
Source of estimate	Nyholm et al., 2016	Cronholm et al., 2006	Swedish Energy Markets Inspectorate	NEPP (2016)	NEPP (2016)

Source: Swedish Energy Markets Inspectorate.

The estimate in Table 3 refers to current conditions. The Energy Markets Inspectorate remarks that the future potential is likely to be larger than the current potential as electric vehicles penetrate the market and data storage centers become more common in Sweden. The storage centers often have significant reserve capacity.

The large (5,500 MW) potential in households partly or exclusively heated with electricity stands out. The potential is reported in Nyholm et al. (2016), based on simulations of the building stock as heat storage. The simulation model assumes optimization on behalf of households to minimize the cost of electricity consumption in response to spot prices of electricity. Hence the authors focus on flexible response to volatility in production. In the reference scenario a constant temperature of 21.2 degrees is maintained at all times, while simulations of the heat storage capacity is subject to a constraint that indoor temperature is kept between 21 to 24 degrees C. Storing heat within these constraints requires the average indoor temperature to be higher than in the reference scenario, resulting in somewhat higher energy consumption.

In winter the observed maximum load decrease during one hour is as high as 5,500 MW and the maximum load increase is 4,400 MW. The estimate is confined to single family dwellings with direct or indirect electric heating, of which the authors find there are an estimated 1.3 million in Sweden.

The estimated potential is uncertain. Sensitivity analysis indicates that a one percent change in the power rating of the heating system, and the effective heat

capacity, both increase the potential by about one percent. Similarly, a one percent increase in the U-value (reduced insulation) and the surface of building envelope, both decrease the potential by about 0.7%.

Benefits of realizing the potential in Sweden

Moving from potential to benefits of realizing the potential the Swedish Energy Markets Inspectorate (2016a) performs a cost-benefit evaluation of demand side flexibility related to household load shifting, and industry load shedding. The reference year for the benefit estimation is 2030 since it takes time to phase in measures to support flexibility. On the benefit side, the authors assemble estimates for different sub-markets (Table 4). On the cost side, they assemble estimates of different options (Table 5).

Table 4: Annual benefits of demand side flexibility in Sweden according to Swedish Energy Markets Inspectorate. Million 2012-SEK

Market/problem	Consumer segment	High annual benefit (all single-family dwellings are flexible) Million 2012-SEK.	Low annual benefit (half of single-family dwellings are flexible) Million 2012-SEK.	Source
Automatic frequency reserves (primary, secondary)	Households	370	370	ENTSO-E (2012)
Regulating power (tertiary reserves)	Households, industry	128	128	Energy Markets Inspectorate
Optimal adjustment to electricity prices	Households, industry	675	381	Energy Markets Inspectorate
Avoided grid investments, network losses	Households	587	294	Energy Markets Inspectorate based on Koliou et al. (2015)
Total benefit except line 1		1,390	803	

Source: Swedish Energy Markets Inspectorate (2016a). The calculations behind the numbers are explained below.

The benefits (and costs) of demand side flexibility are difficult to estimate. The benefits depend on the dosage and configuration of incentives; how market agents respond to incentives; and on the technology and substitution possibilities available to market agents.

It is not straightforward to add individual benefits. The Swedish Energy Markets Inspectorate (2016a) points out that automatic frequency reserves tie up household potential, and is an alternative to other utilisations of the potential. However, optimal adjustment to electricity prices and avoided investment grid network losses could be realised by the same potential, and regulating power (tertiary reserves) is mainly drawing on power flexibility from industry at high prices. Hence, the Energy Markets Inspectorate adds benefits except automatic frequency reserves to arrive at a total of million SEK 1,390 if all single family dwellings are flexible, and million SEK 803 if half of them are flexible.

Table 5: Costs of demand side flexibility in Sweden according to Swedish Energy Markets Inspectorate. Million 2012-SEK

Option	Fixed costs (million 2012-SEK)	Annual variable cost (million 2012-SEK)	Source
Investment support for heat management		200.5	Enova
Customized information on demand side flexibility	20		Swedish Consumer Agency, Swedish Energy Agency, Statistics Norway
Requiring grid companies to inform customers about opportunities for cost savings		1	Energy Markets Inspectorate
Smart meters for hourly metering and dynamic tariffs		567	Energy Markets Inspectorate and Sweco
Grid tariffs included in the price comparison site "Elpriskollen"	1.5	0.5	Energy Markets Inspectorate
Allow new tariff structures and pilots	0	0	Energy Markets Inspectorate
Total cost	21.7	769	

Source: Energy Markets Inspectorate (2016a). The calculations behind the numbers are explained below.

Assuming cost items are independent we can subtract total costs from the benefits above. Benefits are million SEK 803–1,390 per year. Costs are million SEK 769 per year. On this basis the Swedish Energy Markets Inspectorate (2016a) argues that benefits exceed costs and demand side flexibility should be pursued.

Further explanation of the Swedish individual benefit and cost estimates is useful. On *benefits* (Table 4) the benefit of providing *automatic frequency reserves* are sourced from ENTSO-E (2012). ENTSO-E worked in euros and the original estimate is EUR 43.1 million/year. The sources of flexibility in the ENTSO-E study are household appliances (refrigerators, freezers, air conditioning and heat pumps). Their study assumes that frequency reserves from these sources fully and wholly replace hydro power reserves.

The Swedish Energy Markets Inspectorate (2016a) remarks that the payment in Sweden for stand-by participation in the *regulating power market (tertiary reserves* amounted to million SEK 64 in 2015. The study assumes that in 2030, twice as much incentive is needed, i.e. million SEK 128. The whole amount is counted as a benefit of demand side flexibility, which will make stand-by participation unnecessary.

The quantities behind *the optimal adjustment to electricity prices*, the next benefit item of Table 4, are taken from the Nyholm et al. (2016) study, but the Swedish Energy Markets Inspectorate (2016a) estimate of the benefit associated with these quantities is independently calculated by means of the simulation model Apollo. That is, the estimates of feasible potential in MW for demand side flexibility in Sweden from Nyholm et al. are used as inputs to the simulation model Apollo, but the study uses a different load shift assumption. A price difference of 10% between periods is assumed to trigger load shifts. It is assumed that 50% of the technical potential of Nyholm et al. can be shifted one hour without discomfort; 30% can be shifted two hours; and 20% can be shifted three hours.

The estimate of benefit comprises consumer surplus, producer surplus and bottleneck/congestion change.

Two estimates of the benefit of flexibility in residential space heating

Since residential space heating is the biggest item it is of interest to compare the estimate coming out of Apollo to the original Nyholm et al. (2016) estimate.

In the simulations of Nyholm et al. (2016) there is no significant cost to the household associated with the shifts.[3] There emerges a gain to households as the electricity bill is lowered despite higher energy consumption. The potential is based on 2010 prices. 2010 was a year of high and volatile prices, and the average household should be able to gain from 10 to SEK 3,300 per year, depending on insulation, heating technology and heating demand. According to the authors 2012 was a normal year. If 2012 year prices are used instead the savings are 3 SEK til 1000 SEK per year, 4 mill SEK til 1300 mill SEK in total. The representative, median saving is SEK 800 per year, billion SEK 1.04 in total.[4]

In the Nyholm et al. article load shift is subject to temperature constraints in temperature and a constraint on heating power capacity. Given these constraints, energy and power demand of dwellings are allowed to respond to actual prices of 2010 and 2012. The analysis endogenously determines how much power is shifted in response to price, and for how long, under different assumptions. Multiplying the consumption shifts with prices yields the monetary benefit.

The Apollo-based estimate of The Swedish Energy Market Inspectorate (2016a) has the same potential as Nyholm et al., but employs a different load shift assumption and a reference scenario of 2030. The benefit estimate is comprehensive: producer surplus and bottleneck income change are additional to the estimate of Nyholm et al.

Despite these differences the Energy Markets estimate of benefit is within the range given by Nyholm et al. and similar to the median gain of Nyholm et al.: million SEK 675 versus billion SEK 1.04 (range million 4 mill SEK til 1300 mill SEK). This similarity indicates that modelling choices regarding reference year, components to include etc. may be subsumed in the overall uncertainty of an estimate of this kind.

Grid investments and network losses

The estimate of benefits associated with *avoided grid investments and network losses* in Table 5 relies on a study by Koliou et al. (2015) from a Swedish distribution grid. The authors do not specify which one. Koliou et al. find an annual cost saving per household of SEK 124.[5] The Energy Markets Inspectorate multiplies this number by the total number of households in Sweden, 4.7 million. The resulting estimate is of course

---

[3] The authors remark that 24 degrees C "is clearly high in terms of what is a reasonable comfort level", i.e. a welfare cost. In some cases, depending on ventilation, materials, activities and other factors influencing the indoor climate, this temperature level may not be free of additional welfare or health cost.

[4] Nyholm et al. work in Euros, and their original estimates are EUR 0.9-330/year at 2010 prices, and EUR 0.4-100/year at 2012 prices. The median is EUR 72/year.

[5] Their estimate is EUR 13.7 per customer and is the outcome of a scenario of 10% load shift. Reduced grid investment (actually a two-year postponement of investment) is EUR 8.3, peak demand distribution network cost is EUR 3.3 and power loss is EUR 2.1. The EUR 13.7 per customer is exchanged to SEK using an exchange rate of SEK 1 = EUR 0.11.

vulnerable to the underlying Koliou et al. study, its data and methods; as well as the representativeness of the distribution grid providing the data.

Costs of realizing the potential in Sweden

On costs (Table 5) the two main items are investment support for heat management (million SEK 200 annual cost) and smart meters (million SEK 567 annual cost). It should be noted that smart meters also bring other benefits than facilitation for demand response, such as reducing the cost of billing (through fewer site visits) and providing data. The 200 million estimate for heat management is based on the support level in Norway (NOK 4,000 per installation) multiplied by an assumption that in Sweden such a level of support would lead to 50,000 applications per year.

The estimate associated with smart meters is based on two earlier reports by the Swedish Energy Markets Inspectorate (2015, 2016b). The costs originate in communication and collection systems, not the meters themselves.[6] The reason is that the meters are EU requirements but the implementation of support systems are not.

1.2.5   Lund et al. (2015) survey paper of flexibility in Europe

A paper by Lund et al. (2015) titled "Review of energy system flexibility measures to enable high levels of variable renewable electricity" attempts to take stock of what is known about demand side flexibility and storage in the retail and wholesale markets. The paper has a European perspective, which means that characteristics of the Nordic market are not emphasized. Still it provides many relevant insights for our topic and we consider it a main reference in the academic literature.

Lund et al. (2015) residential sector and industry

In the residential sector Lund et al. focus on the potential and benefits in Germany as developed by Stadler (2006, 2008), see Table 6. Note carefully that the numbers in the table are relative. Positive capacities (decreasable power) refer to the minimum and maximum total net load (16 and 75 GW) in Germany during 2010–2012. Total net load is defined as total load less variable renewable energy such as wind and solar. We understand this item to be relevant for flexible options that reduce demand.

Negative capacity (increasable power) refers to maximum variable renewable power feed in, 29 GW in 2010. We understand this item to be relevant for options that increase supply, in practice load shifting options during off peak. The virtual storage capacity obtained by load shifting is given relative to total pumped hydro storage, 40 GWh in 2010. The investment, variable and fixed costs are relative to those of a typical gas turbine for power balancing (USD 520/kW, USD 88/MWh and USD 23/kW).

Hence, night storage heaters are deemed to contribute 19% of 75 GW/88% of 16 GW (14 GW) to reducing demand during maximum net load and contribute 128%

---

[6] Per meter the Swedish cost included in the analysis is SEK 131 (around EUR 14). By comparison the full cost of the meter is much higher, at least in Norway and Finland. In Norway the average cost is estimated to be NOK 3,504 (around EUR 300) according to NVE (2016). In Finland 3 million "smart" meters were installed during 2008–2013 at a cost of MEUR 800 (EUR 267 per meter). The prices have come down since then and the expected cost for the next round is MEUR 600–700.

(37 GW) to increasing supply compared to maximum variable renewable power feed in. In addition, it contributes 58% (23 GWh) in terms of load shifting. The investment cost is 10% of a gas turbine for power balancing (USD 52) and the variable cost is zero.

Table 6: DSM/DSF potential and benefit in the residential sector, Germany

Load	Positive capacity (%)	Negative capacity	Storage from load shifting	Investment costs	Variable costs	Fixed costs
Night storage heaters	19–88	128%	58%	10%	~0%	11%
Domestic hot water heaters	1–5	17%	90%	113%	~0%	11%
Ventilation systems	8–38	55%	8%	N.A.	N.A.	N.A.
Refrigerators	2–9	15%	90% with freezers	298%	~0%	298%
Freezers	9–19	12%	90% with refrigerators	298%	~0%	298%
Hot water circulation pumps	3–14	None	98%	1625%	~0%	250%
Washing machines, dryers and dishwashers	5–24	72%	105%	185%	~0%	183%
Heat pumps with storage	0.3–1	0.7%	8%	38%	N.A.	N.A.

Source: Lund et al. (2015). Columns – percentages – are explained in the text above.

The main inference from the table is that *night storage heaters* are highly competitive on cost and have a high potential. *Heat pumps with storage* and *ventilation systems* could be competitive on cost, but key cost items are not known. According to Lund et al. the potential is lower than night storage heaters. The other options are less competitive on cost or not competitive at all. These inferences may be of interest in a Nordic context as well.

In the service sector Lund et al. (2015) present the relative potential and benefit in the same fashion as in the residential sector.

Table 7: DSM/DSF potential and benefit in the service sector, Germany

	Positive capacity (%)	Negative capacity (%)	Investment costs (%)	Variable costs (%)	Fixed costs (%)
Food store refrigerators	1–7	10	0.8–222	1	~0
Electric hot water generation	0.1–0.7	3	7–4.5	1	~0
Ventilation systems	0.6–3	5	87–307	1	~0
Air conditioning	0.6–3	8	4–148	1	~0
Night storage heaters	1–5	33	2–12	1	~0
Municipal waste water treatment	0.2–0.8	None	4–187	1	39–231

The sources here are the "dena grid study" of EWI and University of Cologne (2010), and Stadler (2008). Investment costs range from 2% to 300% of the gas turbine, which obviously is too large a span for general empirical conclusions. Lund et al. comment that "the spread of the cost for the DSM measures is large, but at the lower end of the

costs, DSM could be highly motivated". The potential is in any case much lower than in the residential sector.

Finally, Lund et al. (2015) consider the industrial sector. They point out that energy-intensive industrial loads are already being used as reserves in most countries. These loads are price responsive to some extent. A summary industry-by-industry is provided in the table below. The points of reference are again the same. Sources are the dena grid study, Stadler (2006) and Paulus and Borggrefe (2011).

Table 8: DSF/DSM potential and benefit in manufacturing industry, Germany

Load	Positive capacity (%)	Negative capacity	Storage from load shifting	Investment costs	Variable costs	Fixed costs
Chloralkali electrolysis	0.2–4	Small	3%	<0.3%	>147%	~0%
Mechanical wood pulp refining	0.3–2	0.1–0.4%	1%	3–4%	<15%	~0%
Aluminium electrolysis	0.4–2	None	None	<0.3%	740–2,206%	~0%
Cement milling	0.3–2	0.1–0.4%	8%	4–5%	588–1,471%	~0%
Steel melting in electric arc furnaces	1–7	None	None	<0.3%	>2941%	~0%
Compressed air with variable spreed compressors	0.3–1	0.1–0.6%	40%	6%	N.A.	N.A.
Ventilation systems	1–7	0.2–0.9%	N.A.	97%	N.A.	~0%
Cooling and freezing in food industry	2–9	0.9–4%	N.A.	N.A.	N.A.	~0%
Process cooling in chemical industry	0.8–4	None	None	N.A.	N.A.	~0%

From Table 8 it appears that *load shifting in the pulp and paper industry* (mechanical wood pulp refining) is competitive on cost compared to the gas turbine. *Chloralkali electrolysis* may be competitive on cost, depending on the ratio of investment cost to variable cost.[7] The potentials given in the table are quite low compared to the residential sector, but the authors comment that the potential of energy-intensive industries may be higher in Finland than in Germany. For instance, in Finland grinderies in the pulp and paper industry consume 6% of total peak load, according to Lund et al. (2015). Some of this potential may already be in use.

Lund et al. (2015) on the wholesale market

Lund et al. (2015) argue that load shifting is an excellent candidate for providing balancing support at the level of primary, secondary and tertiary reserves.

Load shifting can be used for frequency stabilization in a decentralized fashion with frequency-responsive loads. Short et al. (2007) have studied decentralized frequency stabilization with a population of frequency-responsive domestic refrigerators. According to Lund et al. (2015) their simulations showed that such an aggregation of loads can significantly improve frequency stability. Callaway (2009) showed that thermostatically controlled loads can be managed centrally to follow wind power variability at one minute intervals. In a study of the U.S. Kondoh et al. (2011) analyzed direct control of electric water heaters to follow regulation signals and found that 33,000 electric water heaters corresponded to 2 MW regulation over a 24 hour period.

---

[7] Industrial process for the electrolysis of NaCl, used to produce chlorine and sodium hydroxide (lye/caustic soda). Clorine is produced by companies such as INOVYN in Norway and Sweden, Kemira and AkzoNobel in Finland, and Borregaard in Norway.

To put these ideas into practice pilots and experiments are useful. Pilot projects are being conducted in Finland and Sweden. In Finland, Fortum has recently bid in 0.1 MW in the balancing market assembled from water heaters of roughly 70 households, see Box 1. The Swedish TSO Svenska kraftnät is currently conducting a similar pilot project in which 100 household water heaters are aggregated and bid into the automatic frequency management reserves (Swedish Energy Markets Inspectorate (2016a) citing Thell (2016)).

Box 1: Using water heaters to provide frequency reserves in Finland

Fortum has launched a pilot project in which a pioneering virtual power plant based on demand flexibility will be built together with customers. Fortum will build an over 100-kilowatt virtual power plant from an aggregated network of roughly 70 water heaters located in single family homes. The capacity of this power plant will be offered to the Finnish national grid company Fingrid to maintain a continuous power balance in the electricity system (primary/secondary reserves).

It is Finland's first – and probably Europe's first – project in which households are together participating to maintain the power balance, and in which the capacity is offered to the national grid company. Similar projects have previously been done with industry's electricity loads.

"Our virtual power plant pilot based on water heaters doesn't produce electricity, but it momentarily stops using a certain amount of electricity.

This capacity can be used to balance the electricity system in the same way as the output produced by a power plant. For the purpose of balancing, it doesn't matter if more electricity is produced or if less is consumed," Janne Happonen, Development Manager at Fortum, explains the basic idea of the pilot project.

In Fortum's pilot, the virtual power plant is based on remote control of the water heater. When more power is required in the system, Fortum momentarily takes over control of the water heater without any impact on the heating of the home or on the hot tap water. The customers participating in the pilot project will be provided with a mobile energy monitoring application that enables real-time monitoring of their household's electricity consumption. Increased information on electricity consumption helps customers to pay more attention to their own consumption habits and often also reduces consumption.

_____

Source: Fortum press release 9 March 2016. http://www.fortum.com/en/mediaroom/Pages/fortum-and-a-group-of-households-participate-together-in-the-balancing-power-market-in-an-virtual-power-plant.aspx

---

Demand side flexibility, e.g., in the form of load shedding by energy intensive industry, is currently in use in the Nordic market (Lund et al., 2015). In the Nordic market, almost half of the contingency reserves come from flexible loads (Tuohy et al., 2014).

1.2.6 Gils (2014) Model based on theoretical potential in Europe

The purpose of Gils (2014) is to estimate the theoretical potential for demand response in European countries, including the Nordic countries. By theoretical the author means something that is even greater than the technical proposal.[8] Gils considers load shedding, load shifting to a later point in time, and load shifting to an earlier point in time. Load shedding is only considered for energy intensive industries. He proceeds in four steps. Since he arrives at quite high potentials it is useful to review these steps.

In the first step, 30 processes and appliances are considered for load shifting and shedding, see Table 9. The analysis is limited to loads that can be shifted or shedded for at least 1 h. Detailed descriptions of their technical properties and demand response behaviour are gathered from previous references, in particular Stadler (2008) and Klobasa (2009).

Table 9: Processes and appliances suitable for load shedding and load shifting

Sector	Process	Flexibility
Industry	Electrolytic primary aluminium	Load shedding
	Electrolytic refinement of copper	Load shedding
	Electrolytic production of zinc	Load shedding
	Steelmaking in electric arc furnaces	Load shedding
	Chloralkali process (membrane/amalgam)	Load shedding
	Cement mills	Advance/delay
	Mechanical wood pulp production	Advance/delay
	Recycling paper processing	Advance/delay
	Paper machines	Advance/delay
	Calcium carbide production	Advance/delay
	Air liquefaction in cryogenic rectification	Advance/delay
	Cooling in food manufacturing	Advance/delay
	Ventilation w/o process relevance	Delay
Tertiary	Cooling in food retailing	Delay
	Cold storages	Advance/delay
	Cooling in hotels and restaurants	Advance/delay
	Commercial ventilation	Delay
	Commercial air conditioning	Delay
	Commercial storage water heater	Advance
	Commercial storage heater	Advance
	Pumps in water supply	Advance/delay
	Waste water treatment	Advance/delay
Residential	Freezer/Refrigerator	Delay
	Washing machines, Tumble dryer, Dishwasher	Advance/delay
	Residential air conditioner	Delay
	Residential electric storage water	Advance
	Residential heat circulation pump	Delay
	Residential electric storage heater	Advance

Source: Gils (2014),

---

[8] "Whereas the theoretical potential comprises all facilities and devices of the consumers suitable for DR, the technical potential includes only those that can be controlled by the existing information and communication infrastructure." Gils (2015) p. 2.

In the second step the shiftable and sheddable loads are combined with load profiles. Seasonal, weekly and daily load profiles are considered in great detail. The flavour of the modelling is indicated by the following quote:

> "Energy-intensive production processes are typically running at very high capacity utilization levels. For this reason, a constant load is applied during all hours of the year. Only exception is the cement industry where utilization ranges between 40% and 100%. In addition to winter times when construction activities are typically reduced, production is also lowered in the daytime on workdays. It is assumed that utilization in winter is by 20% lower than in summer, and in the daytime on workdays at all seasons reduced to two thirds of its night load. For industrial ventilation energy demand, a weekend decline of 40% (Saturday) and 50% (Sunday) is assumed; commercial ventilation is furthermore reduced by 50% at night-time. The electricity demand of cooling appliances in private homes, retailing, hotels and restaurants is estimated to be by 10% lower in winter times than in summer; it additionally declines by 20% at night, given that the frequency of user interventions tends to go down."(Gils 2014, 3).

In the third step, annual electricity demands and installed capacities in the year 2010 are quantified, and a flexible load share for each consumer category is evaluated.

In the fourth and final step the geographical distribution of demand response potentials is investigated. For instance, in the residential sector:

> "potentials are allocated according to the population distribution. The population grid used is derived from Eurostat statistics, a GIS data set prepared by the JRC (Joint Research Centre) and the Grump data of the Center for International Earth Science Information Network at Columbia University. Eurostat provides the population in each Nuts-3 region of EU countries, Norway, Switzerland, Croatia, Turkey and Liechtenstein. Within the regions, the population is allocated according to the JRC data. For the rest of Europe, the Grump data is used." Gils (2014, 6).

The outcome of this modelling is a set of forward and backward load shifting and shedding potentials for each European country and for most of the 30 processes and appliances. Aggregated results for the Nordic countries are shown in Table 10 and Table 11. Note that these include load shedding options within energy intensive industries (part of "manufacturing"). We note that Nordic potentials obtained by the procedure of Gils are quite high compared to other authors. Presumably the allocation rule of the potential (the fourth step of the procedure) is a source of uncertainty since population density is probably not the only or even the best scale indicator of demand side flexibility. The author does not compare potentials for individual countries to other, bottom-up information. Given the processes and appliances considered it is reasonable to assume that the figures refer to winter time.

Table 10: Theoretical potential for shedding or shifting to a later point in time according to Gils (2014)

Country	Manufacturing	Tertiary	Residential	Total
Denmark	111	310	499	920
Finland	1,203	516	368	2,087
Norway	835	832	382	2,049
Sweden	1,049	949	801	2,799

Source: Vista Analyse based on Gils (2014). Estimated potential in MW for 2010.

Table 11: Theoretical potential for shedding or shifting to an earlier point in time according to Gils (2014)

Country	Manufacturing	Tertiary	Residential	Total
Denmark	54	280	2,398	2,732
Finland	313	464	5,784	6,561
Norway	124	749	7,042	7,915
Sweden	290	853	9,637	10,780

Source: Vista Analyse based on Gils (2014). Estimated potential in MW for 2010.

According to Gils the potential for shifting electricity consumption back to an earlier point in time is much higher in the Nordic countries than the opposite shift. This is due to the use of electricity for space heating purposes, primarily in the residential sector. The most important technology for achieving this is referred to as *residential storage heater*, which we interpret as the same as using the effective thermal capacity of the building itself to store heat during the night, thereby reducing loads the following day. The potential is comparatively smaller in Denmark, but even there it is large.

1.2.7   Tveten et al. (2016) gross benefits of demand side flexibility in Northern Europe

A different perspective on the potential and benefits of demand side flexibility is provided by Tveten et al. (2016). Theirs is a model based analysis of the Northern European power market in the year 2030.[9] It is assumed that in 2030 the share of variable renewable energy is higher than the current share, increasing the need for flexibility in the system.

Their study assumes a fixed technical potential for demand side flexibility. This potential is taken from two IEA reports (2011a, b) and indicate that 18% of peak load in the Nordic region, on average, may be moved from peak to off-peak periods. This 18% estimate is in fact constructed by Nordel (2005) and cited by the IEA.[10] Among the Nordic countries it is Norway that is allocated the highest potential (3.8 GW), followed by Sweden (2.8), Finland (2.0) and Denmark (0.8).

The next step in their analysis is a what-if exercise: What if a share of demand can be costlessly shifted from one hour to another, keeping 24 hour demand constant? What share of the potential is then economical to shift in response to prices? What is the cost saving to consumers? What is the response in supply and how does variable renewable energy fare? The authors investigate two scenarios, a moderate scenario where half of the technical potential is available, and a full scenario where all the potential is available. We report from the full scenario here. The reader recognises the approach from the Nyholm et al. (2016) and Swedish Energy Markets Inspectorate (2016a) studies of Sweden.

---

[9] Germany, the Netherlands and the UK in addition to the four Nordic countries.

[10] IEA (2011a, p 44). Working on the 18% number the IEA finds that the potential for demand response in Denmark is 8% of current peak demand, 19% in Finland, 24% in Norway and 15% in Sweden. These figures are similar in size to the Tveten et al. figures.

Simulating their model the authors find that variable renewable energy increases its share of production, and residual demand, defined as demand minus variable renewable energy production, decreases about 23 GW in peak (annual maximum) across the North European countries. This figure is 11% of capacity assumed for 2030 (212 GW annual maximum). Results for demand side flexibility in isolation are not reported. Nor are results for each Nordic country reported, but Norway appears to utilize its demand side flexibility quite modestly in optimum, about 0.9 GW in peak (annual maximum) out of the 3.8 GW potential. The average daily maximum is 0.2 GW. No explanation is provided except the general fact that utilization depends on the price structure and it is not economical to shift more.

The authors calculate the benefit of the what-if exercise. They find a cost-saving to consumers of EUR 1.4 billion, corresponding to 1.8% of consumers' total cost of electricity. Aggregate impacts on producers (producer surplus) are not reported, but it is reported that variable renewable energy and nuclear gain, while coal, natural gas and reservoir hydro lose. Savings or costs of transmission investments do not seem to be included in the estimates.

The figures provided by Tveten et al. also ignore any costs of inducing the consumers to increase their flexibility. This tends to overstate the benefits. On the other hand, as just noted, cost savings in transmission investments seem to be excluded, and this understates the benefits. The impacts on producers are mixed, which both under- and overstates the benefit. The potential for demand side flexibility is exogenous.

1.3   Barriers to demand side flexibility

This section surveys policy barriers to demand side flexibility. Policy here includes institutional and regulatory practice. These are the obstacles that need to be removed for demand side flexibility to release its potential. We start in the retail market and continue in the wholesale market. Our main sources are a report by NordREG (nd) and by Thema (2014).

1.3.1   Barriers in the retail market

A report by NordREG (nd) summarizes the main barriers to demand side flexibility in the retail market. A report by Thema (2014) contains a similar summary. In short they are:

- Many consumers face prices that do not depend on the time of day (real-time prices), hence prices cannot reflect underlying scarcity of capacity in the grid nor in electricity production.
- Although the situation is changing rapidly, smart meters are still not installed and continuous metering of most end-users is not yet performed. Hence, even if prices were real-time neither the consumer nor the producer would know the actual load at any point in time.

- The market for flexibility services is immature. Perspective participants face problems of market access. Revenue regulation, the system used to regulate DSOs and TSOs, is not conducive to developing demand side flexibility for network bottlenecks.

- Availability of "big data" on consumption patterns is important if one is to offer new products tailored to demand side flexibility. The Nordic countries are establishing national data hubs, but these are not yet up and running in all countries.

- Technological barriers still exist for using consumer installations for demand side flexibility (water heaters, space heating, electric vehicles etc.). These are related to automation and ICT.

The barriers are to some extent interconnected. For instance, the market for flexibility services (barrier no 3) would benefit from improved consumer technologies (barrier no 5). It is worth recalling a point made by Thema (2014), namely that "large customers including large buildings have had smart meters for years without increasing the price sensitivity of the demand side. Hence, new and improved data will also be needed to enable different types of demand response."

From an economic point of view there are basically two incentives to support demand side flexibility. One is real-time pricing of scarcity in production and grids on a continuous or close to continuous (hourly or less) basis in combination with smart meters that record instantaneous consumption (load). To such an incentive can be attached apps and other devices to inform and alert customers about their consumption in peak-load periods when prices are high. Real-time pricing will motivate customers to delay heating of water, charging of electric vehicles etc. in peak load periods.

The other incentive is for customers to sign a load shifting contract with the utility directly, or with a broker performing an aggregator service, to allow the broker to turn off designated devices during peak-load periods and phase in the devices in an orderly fashion later. In principle, it could also be a load shedding contract. The customer will receive a compensation in return. The flexibility of the consumer price contract does not matter and may be fixed or time-dependent. In this case it is the load shedding/shifting contract that takes up the flexibility. The aggregator will of course face a real-time price. This model transfers risk to the aggregator and utilizes economics of scale in ICT etc while lowering transaction costs in the individual household. It may thus have some advantages compared to individual responsibility for responding to real-time prices.

To the extent that real-time pricing and load shedding contracts are not available there are barriers in the market to realizing demand side flexibility.

There are in principle at least two scarcities that dynamic pricing and/or aggregator services should address. One is a scarcity of grid capacity. The cost of this scarcity is given by the risk of brown outs. The scarcity of grid capacity can be further divided into scarcity of distribution grid, regional grid and national grid. Another scarcity is supply scarcity. The cost of this scarcity is given by the marginal cost of production and

transport losses in high versus low peak periods, and by bottlenecks. The grid and production scarcities will often overlap, but not always and not exactly.

The report from NordREG (nd) gives clues to the current status of dynamic pricing in the Nordic countries. The report notes that in *Finland* around 10% of electricity contracts are based on hourly market prices, and there are projects run by Fortum and OptiWatti to install advanced control technologies. Finland has had 100% penetration of smart meters since 2014. The meters have one hour resolution and are expected to be replaced by meters with 5–15 minute resolution. In *Denmark* the government has decided on a national roll out of smart meters by 2020. In 2016 roughly half of consumers already had smart meters installed. Hourly metering is mandatory for large consumers (more than 100,000 kWh/year). In *Norway* smart meters are to be rolled out by 2019. Smart meters have features geared towards demand side flexibility, such as ability to support at least 15 minute intervals, and ability to disconnect or limit power output. Large consumers have had hourly metering since 2005. In *Sweden* smart meters were installed in 2006, but do not meet current requirements of hourly or 15 minute frequency of metering etc. A second generation of smart meters are expected to be installed between 2017 and 2025.

On barriers to aggregator services the report notes that there might be an uneven playing field between energy service companies (ESCOs) and incumbent district system operations (DSOs) that hamper competition in this market (Vaasa ETT, 2014). The Vaasa report states that "there is a lot of concern that DSOs are allowed to provide additional services, such as feedback, smart home and other services, either on their own or with their bundled supplier, that compete directly or indirectly with the services of new entrants, unbundled suppliers or ESCOs." A report by the Smart Energy Demand Coalition (SEDC, 2015) discusses the market for aggregator services and barriers to their use in more detail.

All Nordic countries have taken steps to establish national data hubs.

1.3.2 Barriers in the wholesale market and in the reserve markets

NordREG (nd) provides a survey of barriers to flexibility in the wholesale market. A report by Thema (2014) contains a similar summary. The headings are:

- Inefficient settlement solutions
- Minimum bid size requirements
- Balancing product design
- Locational information requirements
- Pricing methodology for balancing capacity
- Transparency of prices

Inefficient settlement solutions: The imbalance settlement period in the Nordic market is currently 60 minutes. The 60 minute period implies that market results are adapted to 60 minute blocks, which do not necessarily reflect the physical production and

consumption pattern and the scheduled exchanges between bidding zones. With shorter imbalance settlement periods, price signals in each period would, to a higher degree, reflect the status of the overall system and potentially enable automatization of demand response in response to the price signals. A move to a 15 minute imbalance settlement period is discussed at the EU level and written into the draft commission guideline on electricity balancing.[11]

Minimum bid size requirements: While the minimum bid in the day-ahead and intraday markets is 0.1 MW, it is 10 MW in most of the Nordic Regulating Power Market. Such a large minimum bid introduces lumpiness to the market.

According to NordREG the large minimum bid may be related to the manual ordering of frequency restoration reserves (mFRR). It is still mostly performed by phone from the TSO's control centers and there is a limit to the number of phone orders one can handle. Nordic TSO's are currently carrying out pilot projects on electronic ordering, which could pave the way for a lower minimum bid requirement. A requirement of 1 MW has been proposed.

Balancing power design: One impact of reducing the imbalance settlement period from 60 to, say, 15 minutes is that more agents may participate on the demand side. The reason to hope for increased participation is that marginal costs of shifting/shedding load will often increase with time: It is more expensive on the margin to live without (some) electricity as time goes by. Hence prospective participants may not find it worthwhile to participate if their electricity consumption is cut for a full hour. For example, disconnecting a hot water heater or reducing ventilation for a short period of time may not be noticeable for consumers, but the inconvenience of such measures will increase if disconnection continues. A related issue that also concerns design is whether to define certain resting times between activation of balancing energy bids, since marginal costs may increase in frequency.

NordREG (nd) lists product design as a barrier with characteristics independent of the imbalance settlement period, and observes that it is a complex issue that also concerns operational security. In general, uncertainty about the availability and actual response from demand side flexibility is an issue of concern for TSOs. Another issue relates to the complexity of dealing with different markets in demand response, such as navigating between different products with different gate closures. However, if large and diversified portfolios of demand side flexibility options are managed as a priority enterprise, complexity and risks should be acceptable.

Locational information requirements: While in the day-ahead and intraday markets bids are submitted at the bidding zone level, there are additional requirements in the balancing markets. For instance, in Norway the TSO requires that bids are specified at station group/node. These locational requirements may serve as barriers for aggregation of demand response. NordREG (nd) notes that to relax locational requirements raises concerns of operational security that must be solved or weighted against the need for additional flexibility.

---

[11]https://www.entsoe.eu/major-projects/network-code-development/electricity-balancing/Pages/default.aspx

Pricing methodology for balancing capacity: In the procurement of balancing capacity one may distinguish between pay-as-cleared or pay-as-bid pricing. Pay as cleared means that all market participants receive the price that clears the market. In a competitive market the price that clears the market equals marginal cost. Pay as bid means that participants receive the price they bid and the law of one price does not hold.

According to a survey of European TSOs by ENTSO-E (2015), Automatic Frequency *Containment* Reserve is settled as pay-as-bid in Sweden and with "marginal (cost) pricing" in Denmark, Norway and Finland. Automatic Frequency *Restoration* Reserve is pay-as-bid in Sweden, Finland and Denmark, and marginal pricing in Norway.

In general the pay-as-cleared scheme (marginal cost) provides the most efficient investment signals to participants. The existence of pay-as-bid may therefore act as a barrier for the development of demand response.

Transparency of prices: transparency of prices is important for market actors. Transparency may be especially important for actors who consider investing in order to enter the market. Non-transparent or opaque prices constitute a market barrier. At the same time, as NordREG points out, publishing individual bids could lead to market abuse and gaming of the auctions. That would also constitute barrier to an efficient market.

1.4 The price elasticity and influence of smart metering

In this section we discuss consumers' response to price. The response to price has traditionally been low, but a likely reason for that is the lack of transparency in prices and lack of monitoring of consumption. Consumers do not know at which times of the day prices are high, and even if they knew they would not be rewarded for reducing consumption since the reduction is not monitored.

Smart meters offer the possibility to change this. Monitoring will obviously be possible, but it is a simple step to relate consumption to prices and provide this information jointly to consumers or to aggregators. Aggregators can be seen as brokers between consumers and the production/grid side, entities that consumers outsource certain services to. Aggregators will induce an aggregate price elasticity of consumers, i.e. a correlation between high prices and low household consumption over a certain time interval. Unless otherwise noted we will in this section comment specifically on whether or not consumers respond to price with the help of an aggregator, or independently.

We report on the price elasticity as it has been estimated from the earliest days till the current question of whether smart metering induces higher price elasticities.

Because residential demand varies more over the hours than industrial use of electricity, the key issue is how responsive residential demand is to price changes. We will therefore focus on residential demand for electricity and how prices affect demand. Residential demand for electricity depends on a variety of factors, such as:

- Temperature; heating degree-days and cooling degree-days
- Household income

- Household size and composition by age and gender
- Consumption patterns due to work hours, weekends and holidays
- Location of dwelling
- Dwelling structure characteristics
- Fuel substitution
- Electricity price structure and the variation of prices over time
- How informed the consumers are about prices
- Technical solutions and ICT that reduce transaction costs and facilitate demand side flexibility in response to price

Over the years there have been numerous studies on how these factors affect electricity demand. In the beginning, the studies focused on estimating how prices and other factors affected demand, using data ranging from daily to annual data.

Studies using hourly data, with emphasis on the effect of time-differentiated prices on demand, were rare in the beginning, mainly because such prices were not much in use. In recent years, there have been more studies of time-differentiated prices and their effect on demand, including on the effect of hourly price differentials on load shifting.

In economics one often assumes perfectly-informed customers, but such customers may be rare in practice. The question then arises: to what electricity prices do consumers respond? If prices per kWh are not uniform, e.g. a two-part tariff, consumers are facing marginal and average prices. Moreover, if prices change over hours the consumers may respond to ex-ante prices, current prices, ex-post prices and the prices they expect will occur in the following hours. To what prices the consumers respond will have an impact on electricity demand.

The installation of smart meters, informational tools and automated equipment for demand response, which provide the consumers with real-time information about own consumption and marginal prices, may have an impact on electricity demand and the shifting of electricity loads.

In the literature, there is a distinction between short-run and long-run responses to electricity prices. Demand for electricity is derived from the flow of services provided by household's durable energy-using appliances. The short-run responses to an increase in electricity prices could be to turn off lights when leaving a room or tolerate warmer air in the summer or colder air in the winter. Long-run responses are meant to incorporate both changes in utilization behaviour and any adjustment to the stock of appliances owned by the household. We will thus expect that the long-run responses are stronger than the short-run. The distinction between long-run and short-run here has parallels to the distinction between reduced base load demand, load shedding and load shifting in Figure 2, with reduced base load demand making up much of the long term addition to the price elasticity.

1.4.1 Early studies of residential electricity demand

In Table 12 we report some estimates of price elasticities in residential electricity demand in the US from the 1950s–1960s to the beginning of the 1970s. The reason for many energy demand studies in the 1970s in the US was the sharp increase in energy prices that followed from the formation of OPEC in 1972–1973.

Price elasticities show the change in demand from a 1% increase in price. For example, if a price elasticity is -0.10 this means a 1% increase in price would reduce demand by 0.1%. From Table 12 we observe that the price elasticities range from -0.07 to -0.34, with most of the estimates being between -0.10 and -0.20. The range of the long-run estimates is wider, and the estimates are clearly numerically higher than the short-run estimates. The two short-run estimates for Norway are not much different from the US estimates, while the long-run estimates are rather on the lower side compared to the US estimate. Of course, the estimates may vary due to different type of samples, statistical methods and periods. But the estimates indicate that electricity demand was rather price inelastic, particularly in the short-run, in the first decades after 1950. Table 13 gives estimates for price elasticities for more recent years in the US. We observe that the short-run elasticities tend to be numerically a bit higher than the elasticities related to the studies from the 1970s (Table 12). Again, the differences could be due to different samples and methods. However, since the 1970s income has risen and more and advanced appliances are now owned by the households. That means that more appliances can be turned off in periods with higher electricity prices and thus make electricity demand more price elastic. The price sensitivity may however be influenced by other factors besides abundance. For instance technological change may render some electricity consumption more valuable on the margin and harder to disconnect. The character of demand should be crucial.

New designs of price structures could also have given the consumers stronger incentives to respond to changes in prices. Reiss and White (2005) have evaluated the effects of alternative tariff designs on residential electricity use. In their analysis they account for nonlinear electricity pricing and heterogeneity in consumer price sensitivity. In the 1990s California introduced new five-part tariff structure for households. The design was intended to reduce energy consumption. Data are survey data from 1993 and 1997 and cover a representative sample of Californian households. Only short-run price elasticities are estimated. The main result is that a small fraction of households accounts for most of the aggregate response, which is estimated at -0.39. This response is numerically on the high side compared to the other estimates set out in Table 13. The responses vary according to household characteristics. The strongest response is found in households with electric space heating and central air conditioning.

Competition in the electricity market can create a wider range of prices and hence give the consumers more choices. Consumers, or agents acting on their behalf, can buy electricity where it is cheapest. Deryguiana et al. (2016) exploit a "natural experiment" that the state of Illinois in the US introduced in 2009. Illinois passed a law allowing municipalities to choose electricity suppliers on behalf of their residents. Individual residents were allowed to opt out of their municipality's "aggregation" if so desired. As of

February 2016, 741 of Illinois' 2800 communities had an approved aggregation program, and the vast majority of consumers in these communities switched electricity suppliers as a result. In the evaluation of this experiment the authors compared the behaviour and prices in the communities that had approved the aggregation program ("the treatment group") with the behaviour of residents and prices paid in communities with similar characteristics that had not approved this program ("the control group"). The authors estimate that prices fell by 22% and that usage increased by 5.1% in the months after the program was implemented, relative to in the control group. This experiment allowed for estimation of price elasticities in the treatment group; the short run price elasticity was estimated to be -0.14 and the long run price elasticity -0.29. Of special interest is the finding that consumers reacted in anticipation of the price changes. Usage began changing after policy was announced, but prior to the price change.

In the last half of the previous century there were few examples of time-differentiated electricity pricing where the consumers are continuously informed about real-time prices. Thus the consumers did not observe the marginal or average prices they faced during a billing period. Borenstein (2009) used US data from 2000 to investigate to what electricity prices the consumers responded. He found that consumers responded to expected marginal prices or even less precise information about prices. The common approach in previous studies, also in those referred to above, is based on prices that consumers pay after consumption has taken place (ex-post prices). Borenstein argues that this practice underestimates how responsive consumers would be if they were fully informed about possible variation over time.

The results referred to above indicate that consumers respond to electricity price variation, and more so in the long-run than in the short-run. For several reasons it seems that consumers have been more responsive over the last decades. The question then is: Will time-differentiated pricing and fully informed consumers make the consumers more price-responsive? That is the topic of the two next sections.

Table 12: Estimates of price elasticities in residential electricity demand for the US and Norway done in the 1970s

Author	Period	Short-Run	Long-Run
USA			
Baughman (1975)	1968–1972	-0.19	-1.00
Cohn (1977)*	1951–1974	-0.14	-1.16
Cohn (1977)*	1969–1974	-0.14	-0.47
Gill (1976)*	1962–1967	-0.49	-0.57
Gill (1976)*	1968–1972	-0.34	-0.62
Griffin (1974)	1951–1971	-0.06	-0.52
Hewlett (1977)*	1973–1975	-0.16	-0.45
Houthakker(1970)	1947–1964	-0.13	-1.89
Houthakker(1974)	1960–1971	-0.09	-1.19
McFadden (1975)*	1975	-0.25	-0.66
Mount(1973)*	1946–1970	-0.14	-1.21
Taylor (1977)	1956–1972	-0.07	-0.81
Taylor (1977)	1961–1972	-0.16	-0.72
Norway			
Blaalid (1977)	1966–1975	-0.14	-0.29
Rødseth(1976)	1957–1975	-0.23	-0.78

Note: *See Bohi (2013).

Table 13: Estimates of price elasticities in residential electricity demand in recent periods

Author	Short-Run	Long-Run	Country
Bernstein (2005)	-0.24	-0.32	USA
Bohi (1984)	-0.20	-0.70	USA
Dahl (2004)	-0.23	-0.43	USA
Dergiades (2008)	-0.39	-1.07	USA
Epsey (2004)	-0.35	-0.85	USA
Nakajima (2010)	-0.14	-0.33	USA
Supawat (2000)	-0.21	-0.98	USA
Athukorala (2010)	-0.16	-0.62	Sri Lanka
Halicioglu (2007)	-0.33	-0.52	Turkey
Holtedal (2004)	-0.15	-0.15	Taiwan
Narayan (2005)	--0.26	-0.47	Australia
Narayan (2007)	-0.11	-1.45	G7

1.4.2   Time-differentiated price studies

The concepts of time-of-use pricing, real-time pricing or critical peak pricing are not new. However, their application in the past has been very limited in the residential sector.

An early study is Atkinson (1981) who analysed an experiment in the US in 1975. In data from 140 households in Arizona and 700 in Wisconsin, grouped in three categories according to the incentive structure offered, he found peak own-price elasticities of -0.78 (Arizona) and -0.83 (Wisconsin).

In 1988–1993 the largest Finnish electricity producer and two local electric utilities carried out a pricing experiment. Around 80 residential customers took part in the experiment. The experiment implied that during exceptionally cold days the price of electricity was set high at critical peak hours. To help customers to respond to peak hour prices, the utility used indicator lamps to warn customers that peak price periods were forthcoming or in effect. In the evaluation of the experiment Räsänen et al. (1995) found that a significant part of the consumers responded to the peak hours pricing, by shifting substantial parts of their electric loads, up to 71%, from peak hours to off-peak hours.

Electricité de France has also used critical peak hour pricing. Aubin et al. (1995) found strong responses in one of the French experiments. The implied price (short-run) elasticity, related to shifting electric loads, was -0.79.

Filippini (1995) studies the elasticities of peak and off-peak residential electricity consumption using data on 220 Swiss households. He found that both off-peak and peak electricity is price elastic, with off-peak and peak electricity being substitutes. A one percent increase in electricity peak hour price was estimated to give an increase in off-peak consumption of 2.56%, in other words a quite high response. The reason is that the price increase in peak hours shifts a large portion of electricity use to off-peak hours.

Data from a critical-peak price project in the US, Braithwait (2000), also found strong demand responses; significant and substantial parts of the peak-hours consumption were shifted to off-peak hours.

Ericson (2006) has analyzed a Norwegian experiment. The electric consumption of 134 households was metered between November 2003 and April 2004. The consumers

were offered different types of time-differentiated tariffs with automatic meter reading and with and without possible direct load control of water heaters. The group of consumers who could observe real-time prices was the most responsive one.

These examples show that information matters: The better-informed consumers are about real-time electricity prices, the more they respond. As discussed above, however, responsivity may not be independent of time span. Also, the response to demand management may wear off the longer the experiment runs. A study of customer load reductions during the electricity crisis in California in 2000 and 2001 showed that about 20–50% of the customers that participated in a load management program in 2000, had opted out by 2001 (Goldman et al., 2002).

1.4.3   Price elasticities and the influence of smart metering

As mentioned above metering of electricity consumption, combined with real-time pricing, has been tried out in several experiments in the US and Europe. The smart electricity meter is different from the traditional meter that has been used before and referred to above. It is a device with two-way communication and a range of additional functions connected to communication networks, see Haney et al. (2009) for an overview of smart meters that are planned and in use in some countries. The world's largest smart meter roll-out was deployed in Italy between 2000 and 2005, covering more than 30 million customers. All Nordic countries have either installed smart meters or have plans for installation, see our discussion above.

The demand response benefit of smart meters is related to the fact that they can:

- facilitate direct load controls of appliances
- act as a platform for automated forms of demand response by connecting with smart appliances such as smart thermostats
- based on the automated forms of demand response they may facilitate optimized electricity consumption with or without an aggregator service provider as a middle-man
- facilitate the introduction of time-varying prices
- provide additional consumption information
- overcome information asymmetry.

The demand response impacts of smart metering depend on the tariffs offered by the suppliers and DSOs, the number of customers attached to the system and load control options. As we saw in the preceding chapters, residential consumers respond to electricity price, more now than before, and more the better designed prices or tariffs are to reflect scarcity in the electricity market in real-time and peaks in demand. Smart metering of electricity can contribute to further responsiveness.

Caroll et al. (2014) used a randomized controlled smart metering trial in Ireland in 2009/2010. One part of the sample had access to smart meters, another part did not. They estimated demand responses using a model based on modern treatment practice.

They found that participation in the smart metering program with time-of-use tariffs significantly reduced peak demand. No price elasticity was provided since the independent variable is a technological change (the meter).

Borenstein et al. (2002) also found that electricity demand responds more after the introduction of smart meters. Peak loads are shifted to off-peak periods. No price elasticity was reported since the independent variable is a technological change (the meter).

Based on smart meter data in Norway Kipping and Trømborg (2016) estimated how electricity demand varied with some co-variates like out-door temperature, dwelling group, floor space and number of residents. There were no prices included in the dataset, but their findings indicate that smart meters had an effect on demand.

Although there are just a few studies of smart meters and its influence on residential electricity demand, there are good reasons to expect that smart meters, combined with real-time pricing of electricity, may make demand more elastic, moving the short-run price elasticity from levels around (-0.20, -0.50) in the last decades in the previous century to levels closer to -1.00 or even lower. A main reason for this change is that smart meters and real-time prices encourage load shifting. The higher elasticities, in other words, pick up load shifting. As far as we know there are no studies how smart meters may influence long-run adjustments of energy using appliances in households.

1.5   Key findings from the literature

Based on the preceding survey we draw the following key inferences.

The potential for demand side flexibility in the Nordic countries is large. According to the work of Nyholm et al. (2016), Gils (2014) and others the maximum economic potential at present is probably more than 15 GW, and it may be 20 GW or more. The Gils figure for load shedding to an earlier point in time across the Nordic nations is 28 GW, but he calls his figure a theoretical potential. The Swedish Energy Market Inspectorate presents an economic potential in Sweden of 8 GW. The number refers to the maximum potential in winter. Even if the Swedish potential is as high as 50% of the Nordic potential the total would be 16 GW.

Of course, the actual economic potential will depend on prices and other circumstances in the market, as well as the legal and institutional framework and it may be that some of the studies have gotten the assumptions wrong, but an interval of 15–20 GW represents our best reading of the current literature.

The potential is higher in Sweden, and lower in Denmark. Finland and Norway seem to have roughly the same potential in-between Sweden and Denmark.

The potential is higher in the residential sector than in industry. This emerges from Nyholm et al., Gils, as well as the European survey of Lund et al. (2015), and other sources. Options in the residential sector may play a role in the balancing markets as well as the retail market.

The residential sector options that from the literature appears to have significant potential are alternatively called *residential storage heater* (Gils), *night storage heaters*

(Lund et al.) and *space heating*. All refer to the use of the building stock as heat storage and/or to dedicated storage applications, facilitating load shifting where electricity is used, directly or indirectly, for space heating purposes. Different potentials mainly reflect country-specific structural conditions regarding energy use, especially the use of electricity for space heating purposes.

Other flexibility options in the residential sector include domestic hot water heaters and appliances such as washing machines, dryers and dishwashers. These seem to have lower potential and higher cost (Lund et al.). Heat pumps with storage and ventilation systems have costs that can be highly case dependent and consequently it is difficult to source reliable estimates.

Overall, studies seem to suggest that the benefit to consumers and to society of implementing demand side flexibility is moderate (Nyholm et al., 2016), Energy Markets Inspectorate (2016a), Tveten al. (2016). It is reasonable to recall a warning voiced by Thema (2014), who writes that "the cost of time and focus required by the consumers is often underestimated when considering the potential for energy efficiency and demand response."

On the other hand, it seems reasonable that the phase in of more variable renewable energy, along with automation, ICT and new business models, will increase the benefit of demand side flexibility over time. Further, most reviewed studies do not account for the cost savings that may be obtained from avoided generation and transmission investments.

Lund et al. (2015) point to load shifting in the pulp and paper industry as a cheap industry level option, while chloralkali electrolysis may be competitive on cost. Several Nordic countries already engage manufacturing industry in load shedding and -shifting.

Lack of smart meters and real-time pricing are two major barriers for realizing demand side flexibility in the Nordic countries. Our reading of the literature suggests that when and if smart meters and dynamic real-time pricing are implemented the residential hourly price elasticity that includes load shifting may shift from below 0.5 in absolute value, towards 1.0 in absolute value. The price elasticity is larger the more transaction costs are taken down by ICT, automation and aggregation services. The literature on this topic is so far not mature, however and the inference carries uncertainty.

Aggregator services, in which it is the aggregator who faces the dynamic real-time price and responds on behalf of participating consumers, is a supplement to individual real-time pricing that may reduce informational barriers and transaction costs. The market for aggregator services in the Nordic countries is emerging. The literature suggests that it is important not to maintain unnecessary barriers towards this market. The "market test" should decide whether consumers prefer to respond to real-time pricing in an individual manner, or through aggregators. Current barriers exist in regulation of market entry/market participation.

In the next chapter we will assess the family of options related to residential space heating. Our review of residential space heating is followed, in the chapter thereafter, by a discussion of benefits as well as costs of removing barriers to demand side flexibility. In the final chapter we present an overview of the existing potential and value of demand side flexibility within the Nordic market, based on our assessment and previous information.

2. Options in residential space heating

The purpose of this chapter is the following:

> "Highlight the key findings from the meta-study that may have a potential to develop into concrete measures undertaken both regionally and nationally at the Nordic level."

<div align="right">(source ToR)</div>

The previous chapter has indicated that load shifting in space heating has significant potential at a low cost when utilising the building as heat storage. When we pursue this option in the following, most of the discussion is generic in the sense that it covers all buildings where electricity is used directly or indirectly for space heating purposes, regardless of their size and function.

The actual potential across the Nordic countries will be determined by size, heating systems and a large number of other factors. Many of these factors can be altered or modified in the future, for example by investing in dedicated, active or passive heat storage systems, by increasing the capacity of electric heating systems in buildings and in the production of district heating etc.

2.1 Factors determining the efficient use of heat capacity in buildings for load shifting purposes

2.1.1 The building as a medium for heat storage

By storing heat produced from electricity during periods with low power prices, it is possible to shift electric heating from high prices to lower prices. Provided the price structure gives the right signals and other barriers are overcome to a sufficient degree, this shift will become economically feasible for the customer and create value to the energy system as a whole.

Heat can be stored in dedicated storage appliances as latent heat or as sensible heat.[12] Hot water tanks can be used to store sensible heat for space heating or domestic hot water use. A growing number of heat storage products based on phase change materials (PCM) are becoming available on the market, and can be used to store latent

---

[12] Latent heat is heat required to change phase – convert a solid into a liquid or vapour, or a liquid into a vapour, without change of temperature. Sensible heat is related to changes in temperature of a gas or object with no change in phase.

heat (at approx. constant temperatures).[13] However, our discussion is limited to the use of buildings to store sensible heat for flexibility purposes – load shifting.

In its simplest form, storing sensible heat for load shifting is done by allowing the indoor temperature to be higher than normal in periods of low electricity prices, thereby heating materials in the interior (inside the insulation) of the building. When electricity prices are high, the indoor temperature is lowered, which causes heat to be released. This absorb-and-release cycle requires the indoor temperature to be higher while absorbing heat than when releasing it. The amount of energy absorbed and released in each cycle depend on the difference between the highest and lowest temperature. Considerations regarding health and indoor climate can restrain the temperature variations, thus limiting the amount of energy and loads shifted.

The simple storing technique that uses the existing building stock is readily available, has a seemingly large potential and relatively small costs in the most suitable parts of the existing building stock. To enhance the potential, it is possible to build dedicated, active heat storage appliances, but these will demand larger investments in most cases. Furthermore, future buildings can be designed to make even better use of their inherent thermal mass and thus make them even more suitable for heat storage/flexibility purposes. A key concept in this regard is effective heat capacity.

Effective heat capacity

Like all materials, each building material has its own specific properties. Two of these are essential in understanding the use of buildings for heat storage purposes and how buildings can be improved; thermal conductivity and specific heat capacity:

- *Thermal Conductivity*: The property of a material to conduct heat. Heat transfer occurs at a lower rate across materials of low thermal conductivity than across materials of high thermal conductivity.
- *Volumetric Heat Capacity*: The amount of heat per unit of volume required to raise the temperature by one degree Celsius.

Heavy buildings tend to have a high heat capacity as they use lot of materials with a high volumetric heat capacity, like brick, concrete and stone. Light buildings rely more on materials with a low volumetric heat capacity like wood and gypsum. Stone based materials, like concrete, also have a relatively low thermal conductivity and as a result they dampen temperature swings by absorbing or releasing heat depending on the temperature differences between the ambient air, the building envelope and the indoor air.

In addition to adequate material and structural properties, the interaction between different parts of the building, its technical installations, the inhabitants and the outdoor climate affects its use as heat storage and flexibility resource. The ventilation

---

[13] Examples are BASF and DuPont. See for instance
https://www.lowex.info/projekte/Importe/projekto8/FL_SmartBoard_e.pdf

system, for example, can be an asset in load shifting provided it has adequate functionality, while it can constrain it in the opposite case.

The total heat capacity of a building is not necessarily utilised in the charge/discharge cycle. The term effective heat capacity is used to quantify the heat capacity that is actually in use for a specific purpose, within given limitations.

2.1.2   *The heating systems*

We have explained how the building envelope may store energy as heat. In order to make use of this storage and thus provide for load shifting and demand side flexibility in the electricity system, each building must be able to utilise electricity for space heating, directly or indirectly. Thus, the potential for load shifting will not only be affected by the building as such, but also by the heating systems and the interaction between energy carriers in the building and in the production of heat (and power) in district heating systems.

Provided there are no limitations in heat supply/production or effective heat capacity, it is on the coldest days the shifted loads can be at their maximum, simply because that's when the counterfactual loads are peaking.

Table 14 illustrates the relation between heat demand that is met by electricity on the margin, effective heat capacity, load reduction, duration and energy amounts that are shifted.

Table 14: Load reduction, duration and energy shifted as a function of effective heat capacity, and heat demand met by electricity

		Effective heat capacity, (Wh/m2)	
		High	Low
Heat demand met by electricity (W/m2)	High	Large amounts of energy shifted: High load reductions, medium duration	Small amounts of energy shifted: High load reductions, short duration
	Low	Large amounts of energy shifted: Small load reductions, long duration	Small amounts of energy shifted: Small load reductions, medium duration

2.2   Potential in the short and long run

As discussed above, the potential for load shifting based on buildings as heat storage is determined by many factors. Some of them are site specific and essential when evaluating the potential at a local level:

- The building as a heat storage
- Interactions between the building, its installations and the indoor air
- The heating system

- Sensitivity and acceptance of the inhabitants towards indoor temperature/climate variations

While the site-specific factors determine the technical potential for load shifting, the price structure and other facilitators/barriers constitute the main incentives for its economic potential and actual use.

Potential in the short run

Estimates of the potential for each country involve significant uncertainties, especially related to the thermal properties of buildings and the interaction between interior building elements, ventilation and heating installations.

Without a large amount of data one must turn to structural characteristics and metadata to find suitable inputs for estimating load shifting potentials in the Nordic countries. Among many factors influencing this potential, the installed capacity to use electricity, directly and indirectly, to supply heat demand in buildings is an important one, see Table 14. The Nordic countries are different in this respect: In Norway electricity dominates for space heating purposes. In Denmark, the electricity share is very small, while in Finland and Sweden it covers approximately 25% of the heating demand in the residential and service sectors. We use Patronen et al. (2017) as our source of information and find that electricity used for space heating[14] in the four countries in 2013 was:

- Denmark 1.5 TWh
- Norway 62 TWh
- Sweden 22 TWh
- Finland 13 TWh

Tentatively, if we assume proportionality between electricity consumption and maximum load shift, the calculations in Nyholm et al. (2016) can be used as a guide to estimate maximum load shifting potential in the other countries. Nyholm et al. estimate a maximum economic potential of 5.5 GW in Swedish single-family dwellings. Applied to all energy consumption in buildings, 22 TWh, the potential increases to 7 GW. Assuming the same proportionality between current electricity consumption for space heating and maximum load shift potential in the other countries would indicate a 0,5 GW load shift potential in Denmark, 20 GW in Norway and 4,5 GW in Finland. The small potential in Denmark and the large one in Norway stand out. We have compared the 20 GW for Norway to ongoing work by Vista Analyse in the Greater Oslo area, which comprises approximately 92 million square meter heated building area, with specific heating demand comparable to the numbers in Nyholm et al. Aggregated loads in the transmission grid indicate that the maximum load that can be shifted will not be as large as 20 GW.

---

[14] Including domestic hot water heating, which we for reasons of simplification disregard here.

It is also important to emphasise once again that the economic potential depends crucially on the price structure and implementation measures. In Chapter 3 we turn to these measures.

Potential in the long run

The estimates above contribute to a simplified snapshot of the load shift potential in a short-term perspective. In the longer term, the share of electricity in providing heat will change and possibly increase as new renewable energy is phased in. The size of the building stock will probably increase, and its character may be more conducive to demand side flexibility. These trends indicate that the long-term load shift potential in Denmark, Sweden and Finland will be larger than it currently seems to be based on proportionality with current electricity consumption for space heating.

Furthermore, as buildings are remodelled and new buildings are built it is possible to increase their effective heat capacity. Much can be achieved with small investments (e.g. communication and control systems), even more with upgrading of existing installations with e.g. resistance heaters and hybridisation (increased flexibility and redundancy by being able to use more than one energy carrier for heating purposes) and improvements of ventilation and heat distribution systems. In addition, active and passive heat storage units can increase the heat capacity in existing and new buildings. During spring, summer and autumn seasons, the technical potential for load shifting will be smaller than in the winter simply because heating demand is significantly lower.

3. Impacts of removing barriers to demand side flexibility

The purpose of this chapter is the following:

"Based on the key findings of the meta-study, make an overview of existing barriers for demand side flexibility and storage, and discuss the pros and cons of changing each of these barriers individually. These barriers should not only be interpreted as technical details, but also include any possible larger fundamental questions about the markets.

While doing so, the consultant should make qualitative or quantitative assessments, where relevant, on the net benefit of each identified measure, and seek to rank any proposed measure according the expected net benefit of each individual measure."

(source ToR)

3.1 Existing barriers

Based on the survey of Chapter 2 the following barriers to demand side flexibility seem key:

- *Real-time pricing and metering* are essential features if consumers independently or aided by aggregator service shall respond to scarcity in production and/or the grid(s). Prices and the pricing schedule should, as accurately as possible, inform end-users about scarcity in production and grids.

- *A market for aggregator services* may relieve consumers of the mental cost of keeping afoot with the hourly volatility of the power price while at the same time providing assurance to the grid company that power consumption will really be reduced when capacity is strained.

- *ICT and automation services* will help to inform consumers and aggregators about the best responses to high and low prices. ICT and automation services are additional to the basic information service from the meter to the consumer that is assumed in the barrier *Real-time pricing and metering*.

- *A shorter settlement period,* from 60 minutes to e.g., 15 minutes, will allow the market to track scarcity on a more continuous basis, which obviously reduces a barrier.

- *A lower minimum bid size* similarly makes the market less lumpy and allows a better tracking of peaks. In addition, smaller players are invited in, which may be important given that demand side flexibility allows individual households to offer flexibility in small amounts.

Of these, *Real-time pricing and metering* is the one feature that everything hinges on. To see this, note that a market for aggregator services will not thrive unless there is an underlying real-time price structure with metering. ICT and automation services are of less use unless one has retail real-time pricing or aggregator services that respond to real-time pricing. The nudging provided by well-designed services such as comparison tools across time or between consumers in a neighbourhood will have independent value, but they will arguably be much more efficient if supported by the price structure. A shorter settlement period or a lower minimum bid size is of little use unless prices are allowed to respond to scarcity in real-time.

3.2   Pros and cons of removing existing barriers

We have collected pros and cons of removing existing barriers in Table 15.

Table 15: Pros and cons of removing existing barriers to demand side flexibility

Market	Barrier	Pro	Con
Retail and grid/DSO	Real-time pricing and metering	Real-time prices with real-time metering reflect scarcity. Should lead to better resource allocation, lower investment in grid.	Real-time prices are more volatile than consumers are used to. This may create uncertainty and animosity. A fixed price contract between the local grid and/or aggregator and the consumer, can overcome the problem. To be effective electricity prices must reflect both production scarcity and grid scarcity. For prices to work properly the price structure needs to be precisely designed. It is difficult for one price or even two prices (energy and power) to inform about the nuances of scarcity and peaks. Taxes and fees are another potential problem. Producing and installing meters is costly. However, this cost is mostly "sunk" since meters are under installation.
	Aggregator services	Aggregator services that coordinatedisaggregated consumers will improve the response to price signals. This should lead to better resource allocation, lower investment in grid and improved utilization of intermittent production (wind, solar).	There are basically three sets of agents that can perform aggregator services: An independent entity, a grid company (DSO, TSO), or a production/retail company. (Independent entity in this context includes e.g., large consumers controlling a fleet of buildings etc.) The role of these in providing aggregation services should be clarified. For instance, some worry that if a grid company enters aggregation services the basic distinction between production and grid will be challenged. Another issue concerns the current revenue regulation of DSOs/TSOs. In this regulatory model the DSO/TSO can pass on the cost of investing in grids. Since the cost of grid investment can be passed on the incentive to invest in alternatives to networks is limited.
	ICT and automation services	ICT and automation services, e.g., using big data, will improve response to price signals and to scarcity. Helpful for better resource allocation and lower investment in grid.	Issues of personal privacy may arise.
Wholesale	Settlement period	Shorter settlement period facilitates better coordination between prices and underlying scarcity.	Requires upgrading of control equipment and ICT infrastructure of system operators and market participants.
	Minimum bid size	Lower minimum bid size lowers barriers to entry and facilitates a market that functions better, providing better resource allocation and lower investment in grid.	Burdensome when certain operations are manual. There is a very large numbers of potential actors at the kW level – this would require ICT systems that can handle much more traffic than current ICT systems can manage. ICT security will also become more difficult to maintain.

3.2.1 Real-time pricing and metering

The price of electricity to consumers (purchaser's price) consists of payment for electricity production (and capacity in the case of variable renewable production) (energy price), payment to the transmission and distribution grids for electricity transport (network tariff/power price), and taxes and fees to the government. To maximize efficiency the energy price should be paid at real-time rates and include components for fuel etc. (kWh), capacity (ideally kW, in practice included in the Nord Pool kWh based energy price in the Nordic countries) and grid loss (kWh). The marginal network tariff should be paid on a per kW basis at real-time rates. An infra-marginal network tariff should cover fixed costs on a per kWh or some other basis, such as a fixed fee independent of consumption. How to set the infra-marginal network tariff is a problem of "second best taxation".

Nordic wholesale energy prices have been real-time for many years, but except for some large end-users consumers have not been able to respond to real-time prices since real-time smart meters have been absent. Smart meters are now being rolled out, see section 1.3.1, incentivizing all end-users to respond to production scarcity. How to design network tariffs is however still under discussion in the Nordic countries. It is important for economic efficiency that network tariffs are properly designed, e.g., the marginal network tariff should be real-time and for instance not a function of peak demand, or an average of peak demands, or similar.

Enabling efficient real-time pricing and metering is the key to demand side flexibility. Efficient real-time pricing and metering will motivate households to conserve power when production and/or network capacity is strained, and consume and store power when capacity is ample. Typically there is ample capacity both in production and grid systems at night. In a real-time system prices will then tend to be low. There will also quite often be ample capacity in summers, since consumption is lower in moderately hot Nordic summers that don't rely on air condition, and production from wind and solar tends to be higher. Prices will often be low. During cold days of winter there is strained capacity since consumption is high and production of solar and wind is low (usually little wind on the coldest days). Prices will be high. Peak prices may be expected in the morning and afternoon rush of cold days, when consumption is the highest of the year.

To function according to intentions real-time prices will fluctuate over day and night, over the week and over the seasons. At peak times prices will probably be higher than today. Consumers who don't adjust their consumption pattern run the risk of paying more. Some consumers may not like this, and/or they may find it burdensome to regularly check their electricity consumption and associated prices. These are negatives of a real-time pricing system.

Both technology and the introduction of aggregator services to the market may alleviate the problem. The "market test" will determine whether or not consumers will change their habits in response to incentives, e.g., charge their electric cars at night, turn off heating between 7 and 9 am, or whether consumers will leave the operation of their charging and heating, or their full electricity consumption pattern, to an

aggregator. In the latter case, cost savings will be shared between the aggregator and the consumer.

In theory, the efficient electricity price structure will often be sufficiently flexible to distinguish cost of production (price of energy) from network scarcity (marginal network tariff). In practice however, we submit that many consumers will treat the price of electricity as one since there is significant positive correlation between the two scarcities and they may be presented in one bill, for instance in Norway.

If the price is viewed as one, and even in theory in some cases, a flexible real-time price will have difficulty solving all problems related to capacity. For instance, consider a situation in which there is high production from solar and wind in a region, but capacity constraints between production sites and the consumer. The price of energy, which is regional, should then be low, but the marginal network tariff should be high. The price of electricity will compromise between the two: it will be medium. The consumer may then wish to consume more than the grid can deliver, but not enough to take up all production. The market delivers a compromise between two problems, that of abundance of production and that of capacity constraints in the grid. In other words, there will be some capacity problems remaining and some production may go unused. The remaining capacity problems in the grid must be solved by other means since exceeding grid capacity often means power brownouts over larger areas.

The third element of the price, taxes and fees, further complicates the picture. In most countries electricity is subject to excise fees that are constant in nominal terms, and ad valorem taxes such as VAT that are a constant percentage of the underlying price. Taxes and fees insert a wedge between consumer and producer and grid operator prices. Tax wedges are a general problem in economies, they stop some mutually beneficial trades from being carried out. In the electricity sector the mutually beneficial trades involve electricity that consumers would be willing to pay for (production and transport) but they are not willing to pay the price including taxes and fees, and so the trade is not carried out, electricity is not consumed. Some may worry that this problem of taxes and fees stopping trades is worse under real-time flexible pricing. In particular, the worry is that nominal, flat fees take up a higher percentage of the net price when the net price is low. We do not agree with this worry. Whether a high percentage tax at a low price in combination with a low percentage tax at high price is worse than a constant percentage tax depends on the shapes of demand curves at high and low prices. Nothing can be said about this issue in general, it is an empirical question. For that matter, an ad valorem tax may have empirically different effects on trades at high and low prices. A further complication is the infra-marginal part of the network tariff, which is designed to collect revenue and therefore is a tax for all practical purposes. This tax interacts with the formal taxes and fees.

3.2.2 Aggregator services

Faced with volatile and informationally demanding electricity prices a market for aggregator services may emerge to provide consumers stability while obtaining savings that are larger than the household could have managed on its own.

The aggregator is a middleman or broker between the consumer on the one hand, and the retail production company, or the grid company, or both on the other hand. The household is given a deduction in its electricity bill in return for allowing the aggregator to tweak electricity demand at critical junctures. This tweaking includes the right to turn off or turn down electricity consumption of certain units in the home for certain lengths of time, usually in combination with a promise to turn up electricity consumption of these same units either before or after consumption is turned down.

An agreement with an aggregator could be limited to certain units (space heating, water heating) while the consumer has a contract with the electricity retail and electricity grid companies for the rest of his consumption. The disadvantage of such an arrangement is that the consumer may not have full control of total electricity consumption during periods of high prices since part of the total is controlled by the aggregator. It then becomes difficult to plan the rest optimally. A different scenario, which perhaps is more realistic, is that the aggregator takes full responsibility and risk of demand side flexibility on behalf of the consumer. The consumer can have a fixed price contract with the aggregator, removing the stress of monitoring electricity consumption. The aggregator, by aggregating the response of many consumers, will probably obtain a better price of flexibility than a consumer acting alone. The extent of flexibility could be greater too since the service reduces transaction costs for consumers. On the other hand, there is an additional player in the marketplace who takes a cut. And importantly, by controlling loads physically, uncertainty in response is greatly diminished. Diminishing uncertainty is important to producers and grid companies because of the serious consequences of exceeding grid capacity.

There is a question of who could be approved as aggregators. Given that consumers have a relation with their DSO and/or retail company already, could it not be the DSO or retail company that performs this service? From the perspective of the grid company, for instance, taking responsibility for the aggregation service will eliminate the uncertainty of having to deal with a middleman. Moreover, it would fit well with other ongoing trends, such as the trend of building "plus houses" that from time to time deliver electricity to the grid. The basis for the control in question will be the smart meters, which are owned by DSOs. A DSO would not need to rent access to the meter, as would an independent aggregator (with the rate depending on regulatory issues, a third party access obligation is possible).

Others worry about the consequences if DSOs move into the role of aggregator service providers. There is a long-standing division in the Nordic electricity markets between the natural monopoly of the grid, and the competitive market of production. In this division the price of electricity is set in the market and the price of grid service – transport – is regulated to curtail monopoly profits. This division has served the market well. Aggregator service provision would seem to be a competitive business where consumers would benefit from comparing offers made by different companies. If DSOs are allowed to enter this business they would arguably take on activities outside of the domain of natural monopoly.

Why is it problematic to take on activities outside the natural monopoly? Arguably the main worry from an efficiency point of view is that the monopolistic activities of a

DSO may finance part of the competitive aggregator activities, to the damage of fair competition in the market for aggregator services. The act of using profit from one activity to finance a different activity is called cross-subsidization.

Current revenue regulation in the Nordic countries allows DSOs to pass on to the regulator the cost of investments in the grid. Hence the DSOs have little incentive to balance the benefits of investing in alternatives to network investments against the costs. Whether or not DSOs are allowed to engage in supplying aggregation services it should be conducive for demand side flexibility to incentivize DSOs to balance benefits against costs.

There are arguments in favour of allowing grid companies to take on the delivery of aggregator services, and there are arguments against. Future deliberations will have to weigh these arguments carefully.

3.2.3   ICT and automation services

The point of real-time prices and metering is to inform consumers about scarcities in the system and encourage them to act accordingly by turning electricity consumption up or down. Instead of consumers the system may inform aggregators that represent consumers.

A key concept here is *inform*. While the meter itself will provide some information, it may be hidden in a cupboard etc. Any vision of the benefit that real-time pricing and metering can provide, assumes that informational services quickly will emerge to ease the monitoring of consumption and prices, as well as the response in electricity consumption.

Tools that monitor consumption and prices could for instance be apps that allow the consumer to track consumption in real-time, perhaps giving off a sound or sign when certain triggers are released. Inhabitant preferences for comfort could be linked in. One can envision comparisons and competitions in local communities devised by apps, etc.

However, we believe that the biggest potential lies in using ICT and automation services to make demand response automatic. There is both a potential vis-à-vis the individual consumer and vis-à-vis the aggregator.

The individual consumer may install equipment that keeps track of the electricity price and cuts consumption whenever prices are high (go above a certain level, say). As a simplified example, the future electric car may be programmed to stop charging whenever prices go above a certain strike price. The water heater may be programmed to do likewise. And the washing machine may be told to start its cycle when prices are at their lowest based on the last month of price statistics.

Aggregation services require similar equipment, and more. The aggregator needs equipment that turns off or turns down consumption in response to high prices and in response to the consumption patterns of their portfolio of units. The aggregator manages a fleet as a portfolio and must take that fact into account. For instance, it will often be beneficial to phase in consumption in a sequential fashion in order to avoid a

recoil effect in the aggregator portfolio after a decrease in indoor temperature is regained.

One possible negative side of ICT and automation services is reduced privacy. To function well, many services require large amounts of data about individual buildings and inhabitant behaviour. There is a risk that information that should be kept private is leaked to the public. For instance, apps that compare consumption patterns to community consumption patterns may run the risk of revealing information that should have remained private.

3.2.4   Settlement period

The settlement period in the wholesale market is currently 60 minutes. This fairly long settlement period is a barrier to demand side flexibility, especially for non-aggregated demand response that cannot reach such durations. This means that this kind of demand response cannot take advantage of e.g., daily peaks. When prices are designed to be constant for 60 minutes there is no way to adapt to scarcities in between.

The 60 minutes settlement period may be convenient in a setting where energy prices are fairly stable. Other costs include the need to reprogram and upgrade ICT systems of DSOs. But as the Nordic countries move to pricing power we see many advantages of reducing the settlement period to, e.g., 15 minutes, which has been proposed.

### 3.2.5   Minimum bid size requirements

Currently the minimum bid is 10 MW in most of the Nordic Regulating Power Market. Such a large minimum bid introduces lumpiness to the market, which is a disadvantage for demand side flexibility as consumers providing a block of 10 MW must then accept the same price. In Figure 3 it was calculated that water heaters from 70 households represent 0.1 MW of load. The minimum quantity of 10 MW would then require about 7,000 households, the size of a town. Furthermore, not all water heaters would offer the same potential duration for demand response and in practice one would need to aggregate much more than 7,000 households to have a useful portfolio. Consequently, the 10 MW minimum bid functions as a barrier to entry for new market players without existing portfolio, e.g., aggregators who do not at first have as much as 10 MW. A new player should be able to test and improve their systems with a small initial investment and consequently a small portfolio. Otherwise the risks are too high for all but the biggest players, or for those who already have a large portfolio on the generation side.

According to NordREG the large minimum bid may be related to the manual ordering of frequency restoration reserves (mFRR). It is still performed by phone from the TSO's control centres and there is a limit to the number of phone orders one can handle. Once electronic ordering is in place there is no reason to maintain such a high minimum bid requirement as 10 MW. In the day-ahead and intraday markets the minimum is 0.1 MW, which seems more reasonable.

3.3   Benefits of removing barriers

We will argue that there is a hierarchy to the barriers listed above. The hierarchy is described in Figure 3. All the other barriers hinge on real-time pricing and smart meters. It is the key element to address first. In Figure 3 this is indicated by a red box saying no impact in response to the answer no. Real-time pricing and smart metering is essential to releasing the benefits of flexibility.

Figure 3: Benefits of removing barriers as a function of other barriers
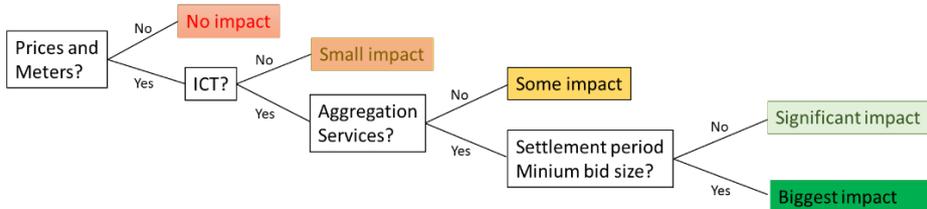
Note: The figure should be read from left to right. If no real-time pricing and smart metering there will be practically no effect. If prices and meters, but no ICT and automation service there will be a small effect. If prices and meters, ICT but no aggregation services there will be some impact. If prices and meters, ICT and aggregation services, but no change in the settlement period or minimum bid size there will still be significant impact. If settlement period and minimum bid size are changes as well the impact will be biggest.

The other barriers then fall in line. The benefits of real-time pricing and smart metering will be enhanced by automation and ICT services. As argued above, even without the additional benefit of aggregator services, automation and ICT services will stimulate the consumer to respond more flexibly to market prices. Hence, some impact if there is ICT, but no aggregation services.

Aggregation services depend on real-time pricing, smart meters and ICT and automation services. Hence it is barrier no. three in line. With prices, meters, ICT and aggregation services there will be significant impacts on demand side flexibility even without changes to the settlement period and minimum bid size. But if these barriers are lifted as well, the impact will be biggest.

4. The existing potential and value of demand side flexibility

The purpose of this chapter is the following:

> "Present an overview of the existing potential and value of demand side flexibility and storage within the Nordic market, based on previous assessments and already existing information."

<div align="right">(source ToR)</div>

We proceed in the following manner: Section 4.1 gives our best judgement of the potential for demand side flexibility in the Nordic countries. Section 4.2 discusses the benefits that may be obtained from demand side flexibility and the sources we have found that estimate some of the benefits. Finally, section 4.3 discusses possible next steps for Nordic energy regulators to advance demand side flexibility.

4.1 The economic potential for demand side flexibility

Total production capacity in the Nordic market has been estimated to around 110 GW (Thema Consulting, 2015).[15] According to estimates collected by NordREG (nd), NVE (2006), Energinet.dk and Quartz+co (2014) and the Swedish Energy Market Inspectorate (2016) the economic potential for demand side flexibility is a reasonably large share of this total: 0.4–1.2 GW in Finland, 0.5–1.4 GW in Denmark, 0.7–4 GW in Norway and 8 GW in Sweden. The basis of these assumptions differs between countries and they are not directly comparable. The estimate for Finland is based on current flexible loads. The low end of the estimate for Norway is based on the current flexible loads, while the high end of the potential in Norway, and the Swedish estimate is based on assumptions of how much potential could be released given favourable conditions in winter. The estimate for Denmark is long term under favourable conditions.

The cited numbers refer to economic potential. The technical potential is larger. For instance, in the household sector in Sweden 7.3 GW is the estimated technical potential while 5.5 GW is the estimated maximum economic potential on winter days.

The economic potential depends on whether or not barriers to demand side flexibility are lifted. For instance, to arrive at the 5.5 GW estimate Nyholm et al. (2016) assume optimal response to year 2010 and 2012 spot prices of electricity, given a constraint on indoor temperatures. One must assume that in the background ICT and

---

[15] Around 32 GW in Norway, 38 GW in Sweden, 18 GW in Finland and 12 GW in Denmark, see figure 4 of Thema Consulting (2015). Figures as of 2013.

automation equipment is used to full effect, and aggregators exist to reduce transaction costs of making use of demand side flexibility. Hence important barriers are lifted as a background assumption.

On the other hand, the Nyholm analysis does not emphasise network tariffs. Hence one must assume that the barrier on real-time pricing is only partially lifted since prices do not integrate real-time power tariffs.

Also, modelling assumptions matter for the estimate of economic potential. Again using Nyholm et al. (2016) as our example, their potential of maximum 5.5 GW assumes that homes are heated prior to the period of high prices/scarcity. This in effect assumes that the household or the aggregator has perfect foresight of the prices to come the next morning. In practice, the households and aggregators must guess the forthcoming morning prices based on historical evidence and it will not be possible to fine tune flexibility to the assumed power.

Another important modelling assumption is that the 5.5 GW of demand response would not affect power prices. In a real situation, there will be repercussions, reducing price volatility, which would in turn make some of the original demand response unprofitable in equilibrium.

In the future electricity system with more variable electricity generation it is likely that the electricity prices will be more volatile than 2010 or 2012. The choice of year and pattern of price volatility is important for the economic potential.

Other modelling exercises including Tveten et al. (2016) and Lund et al. (2015) also contribute estimates of the economic potential of demand side flexibility. Gils (2015) contributes an estimate of the theoretical potential. An early estimate by Nordel (2005) suggests an 18% technical potential. When applied to 110 GW one reaches 20 GW. We concluded in Chapter 2 that a fair summary of the estimates of the literature is a *15 – 20 GW economic potential in the Nordic market if barriers are taken down to a significant degree.*

The true economic estimate of potential and benefit will also depend on whether barriers to flexibility are removed. We turn next to this issue.

4.2   Benefits of demand side flexibility

There is not very much to build on for preparing estimates of the benefits of lifting barriers for demand side flexibility. The two most comprehensive sources, in our view, are Nyholm et al. (2016) and Tveten et al. (2016). Above we discussed how to interpret the estimate of Nyholm et al. in relation to barriers that the study assumes lifted. Conclusions from the discussion are given in Table 16.

Table 16: Barriers assumed removed in studies of demand side flexibility

Source of benefit	Recipient of benefit	Included in Nyholm et al. (2016)	Included in Tveten et al. (2016)
Real-time pricing and metering, production only	Consumers, producers and retailers of variable electricity (solar, wind)	X	X
Additional benefit of real-time pricing and metering, grid	Consumers, DSOs, TSOs		
Additional benefit from ICT and automation	Consumers, suppliers of ICT and automation equipment	X	X
Additional benefit from aggregation services	Consumers, aggregators, producers, (consumers)	X	X
Additional benefit from reducing settlement period and minimum bid size	Grid companies, aggregators, (consumers)		

Like Nyholm et al. (2016), Tveten et al. (2016) consider constraints associated with variable production and do not consider grid services. In the scenario of full flexibility, which we reported above, the study assumes costless shifting of demand up to the technical potential. It is reasonable to assume that this presupposes full utilization of ICT and automation facilities, and aggregator services.

Also like Nyholm et al., Tveten et al. (2016) assume that electricity consumption can be shifted to an earlier point in time in response to perfect foresight of future prices. An important difference from Nyholm is that the Tveten et al. study considers a price scenario of year 2030 in which there is significantly more variable electricity production than currently; and they assume endogenous price formation. In their study, in other words, quantities feed back to prices, and the potential for demand side flexibility is based on prices that are consistent with the potential.

Table 16 makes clear that it is difficult to quantify each of the barriers of real-time pricing, metering, ICT and automation equipment, and aggregator services. However, Nyholm et al., (2016) and Tveten et al., (2016) give an idea of the benefit of lifting all of them. Nyholm et al. work in two price sets. Here we assume that the 2010 price set, which has the higher volatility, is closer to a future situation of real-time and somewhat volatile prices. Given 2010 prices Nyholm et al. estimate a benefit of EUR 0.9–330 (SEK 10–3,300) per household per year. The exceptionally wide range is due to characteristics of the dwellings. The representative, median savings is EUR 72 per year, SEK 800.

The estimate pertains to consumers. In addition, in a real situation there will be benefits to producers and DSOs/TSOs, and to third parties, see Table 16.

Applying the number SEK 800 on 1.3 million single family dwellings of the study one obtains billion SEK 1.04. Using the same potential as Nyholm and a price scenario of 2030 obtained by an electricity market model, the Swedish Energy Market Inspectorate arrives at million SEK 675, which is lower, but within the range given by Nyholm et al. The million 675 number includes benefits on the production side, while

Nyholm et al. only include the consumer side. The difference is therefore greater than it seems at first sight.

The Tveten et al. study states that gross benefits to consumers in the Nordic countries are million EUR 176, almost billion SEK 2. The benefit to consumers in Sweden in their study is million EUR 64, or million SEK 711. This number is similar to the Nyholm et al. and Swedish Energy Market Inspectorate studies.

Based on the literature findings we suggest that billion SEK 1–2 is a reasonable estimate of the annual benefit in the Nordic countries from removing barriers to retail pricing and metering within production, ICT and automation services, and aggregation services. The range of the estimate covers current prices as in Nyholm et al., and future prices as in Tveten et al. The range also covers benefits to consumers of improved wholesale market operations. Improvements in wholesale market operations will in the first instance benefit grid operators and aggregators. Indirectly, through market forces and income regulation the benefits will seep through to consumers.

What remains to cover is the benefit of making use of marginal network tariffs in the grid, i.e. the volatility grounded in variable scarcity in the grids (including the central grid, regional grids and local grids). We acknowledge the estimate of Koliou et al. (2015) that is the basis for the estimate by The Swedish Energy Markets Inspectorate (2016a), but the Koliou et al. estimate depends crucially on an assumption that demand side flexibility amounts to a two year postponement of grid investment. The paper claims that "delaying investments for 2 years is a way of optimizing for short-term operational objectives," but no further explanation is given why demand side flexibility delays grid investments precisely two years. A two year delay amounts to assuming that the potential for demand side flexibility is twice the size of annual demand growth over the next two years. That is in our view a fragile assumption. Typically the potential for demand side flexibility is not static and new opportunities arise over time. Demand growth typically varies in time and place. As a practical matter, the cost of grid expansion is often difficult to distinguish from the cost of refurbishment of the grid.

Here we focus on the correlation between price volatility and efficiency gains. The underlying economic idea is that in a system that balances demand side flexibility and network investments in an optimal way the marginal network tariff will contribute to volatility in the electricity price. At the same time efficiency gains will be realised. The size of optimum volatility may indicate the size of the efficiency gain. In practice, we interpolate from the association between volatility and efficiency gain in the electric energy market, to a similar association in the electric power market.

Since variable marginal network tariffs are uncommon its optimum volatility is not known, but it is not unreasonable to assume that it is similar to that of optimal electric energy.

The capital stock/asset value of networks is commonly higher than in production, which indicates that it is at least as important to increase efficiency in networks. Given a similarly sized price volatility to production it is possible that the efficiency gain in the grid networks is similar to production. However, this is far from certain and we consider it an argument to illustrate the size of the efficiency gain in networks.

Combining our findings we suggest *annual benefit to consumers in the Nordic market from real-time pricing and metering of billion SEK 1–2 in the market for production, plus a similarly sized gain in the market for network/grid services*. The estimate assumes automation and ICT equipment, as well as a mature market for aggregator services.

An annual gain has the feature that it is repeated in a more or less similar fashion over time. From the perspective of welfare economics the full gain is the discounted sum of annual gains. We illustrate the discounted sum.

When calculating the discounted sum it is necessary to consider whether the annual gain relative to the reference situation will decrease, increase or stay constant over time. We find it reasonable that the annual gain increases since the market grows and more variable electricity production is phased in. A reasonable illustration may be a 1% annual growth in the gain. This assumption fixes the numerator in the discounted sum.

The denominator depends on society's discount rate (also called the social discount rate). There is no common Nordic standard for society's discount rate. The standard in Norway is 4% for 40 years, then 3%, then 2%.[16] The Danish standard is quite similar.[17] The "life-time" of the project "removing barriers to demand side flexibility" is somewhat uncertain, which is an argument in favour of a reasonably high discount rate in the long run. To illustrate our calculation here we consider 4% per year and infinite life time a reasonable approximation.

Combining these assumptions, one obtains a discounted gain from real-time pricing and metering of billion SEK 33–66, plus a similarly sized gain in the grid. With an exchange rate of EUR/SEK 0.1 the corresponding EUR-amounts are billion EUR 3.3–6.6, plus a similarly sized gain in the grid. A low estimate corresponding to zero change in the annual gain produces billion SEK 25–50. A high estimate corresponding to 2% growth in the annual gain produces billion SEK 50–100.

4.3 What's next? Possible next steps for Nordic regulators

4.3.1 *It is important to design real-time prices properly*

Smart meters are being rolled out in the Nordic countries, see section 1.3. Finland has had 100% penetration of smart meters since 2014. The meters have one hour resolution and are expected to be replaced by meters with 5–15 minute resolution. In *Denmark* the government has decided on a national roll out of smart meters by 2020. In 2016 roughly half of consumers already had smart meters installed. Hourly metering is mandatory for large consumers (more than 100,000 kWh/year). In *Norway* smart meters are to be rolled out by 2019. Smart meters have features geared towards demand side flexibility, such as ability to support at least 15 minute intervals, and ability to disconnect or limit power output. Large consumers have had hourly metering since 2005. In *Sweden* smart meters were installed in 2006, but do not meet current requirements of hourly or

---

[16] https://www.regjeringen.no/globalassets/upload/fin/vedlegg/okstyring/rundskriv/faste/r_109_2014.pdf

[17] https://www.fm.dk/nyheder/pressemeddelelser/2013/05/ny-og-lavere-samfundsoekonomisk-diskonteringsrente

15 minute frequency of metering etc. A second generation of smart meters are expected to be installed between 2017 and 2025.

With smart meters on their way attention should turn to the price structure. Our survey in the preceding chapters indicates that the need for real-time prices is recognized, but the concrete design is not fully developed. This is an deficiency that Nordic regulators could help remove.

Efficient electricity pricing of the consumer (purchaser's price) usually requires a component based on energy (kWh) and another component based on power (kW). The kWh based electricity price should indicate the marginal cost of production and grid loss, and marginal strength of demand. It should be dynamic in real-time. The pros and cons of different designs have been discussed for some time.

By contrast, the design of an efficient power tariff has not been studied as much. Economic theory suggests that the *marginal* tariff should be dynamic in real-time and respond to peaks in the grid. This means it should also be regional since the nature of peaks will depend on location. Still, in most situations there will be common elements between locations because of the simultaneity in the grid. The recommendations from theory must be squared with practical considerations. A practical tariff structure is simple to understand and use. Nordic regulators could usefully work on balancing the theoretical and practical concerns into an actual power design.

Besides working on the design it is of course important to estimate the rates, i.e. how many eurocent/SEK/NOK/DKK per kW should constitute the marginal tariff in different regions. From a theoretical point of view the rates depend on marginal bottleneck costs in the grid. Nordic regulators could address this issue.

A regional, fluctuating marginal grid tariff will not guarantee revenue. Given that the DSO and TSO face revenue requirements there should be a second, inframarginal term in the grid tariff. This inframarginal term is similar in nature to a tax in that its purpose is to collect revenue. There are different ways of designing the inframarginal tax-like part of the tariff: Per subscription and year, per electricity consumption, per power consumption during off-peak, etc. Second-best pricing theory in economics can give advice on the best design, and the design should consider the tax-like inframarginal part of the tariff in conjunction with existing excise and ad valorem (percentage) taxes on power and electricity. Nordic regulators have a role to play in working out practical, efficient designs.

Current grid tariffs in the Nordic countries do not correspond to the theoretical ideal, and the design of tariffs differs between DSOs. All of the designs cannot be efficient at the same time. There is a need to streamline and harmonize. Nordic energy regulators have begun this work. In Norway, for instance, the regulator NVE is set to send a new power tariff design for comments in the fall of 2017. To support demand side flexibility it is important to harmonize to a standard that is supported by theory. This is a task where Nordic regulators could usefully contribute.

The consequences of implementing inefficient designs for power tariffs and the retail electricity price may be significant. Most consumers don't distinguish clearly between production and grid, but perceive that there is one "electricity" price that includes production and grid, as well as taxes and fees. Consider now a situation in

which there is high production from solar and wind in a region, but there are capacity constraints between production sites and the consumer. The price of electricity production should then be low, but the marginal power tariff should be high. The price of "electricity" will compromise between the two: it will be medium. The consumer may then wish to consume more than the grid can deliver, but not enough to take up all production. The market delivers a compromise between two problems, that of abundance of production and that of capacity constraints in the grid. In other words, there will be some capacity problems remaining and some production may go unused.

One could argue against this example that an optimal electricity price and power tariff will price the two scarcities independently and the market will respond efficiently, but that requires that each of the power tariffs and electricity prices are theoretically sound (and the scarcities are not perfectly correlated). Hence it is important for Nordic regulators to move beyond the principle of real-time prices to the nitty-gritty of designing them in practice according to economic principles.

4.3.2   Regulation of DSO's and TSO's needs consideration

Nordic countries use revenue regulation to regulate their DSO's and TSO's. In a traditional revenue regulation model, the DSO's and TSO's can pass on the cost of investing in the grid. Since they can pass on the cost of investing in the grid they do not obtain significant cost savings from demand side flexibility. Hence their incentive to facilitate demand side flexibility is weak. This is a potential barrier that Nordic energy regulators should consider. In fact, the Swedish regulator is currently looking into the issue. If DSO's and TSO's were given a share of the cost saving and benefit when grid investment is postponed and shelved, they might engage more fully in promoting demand side flexibility. Nordic regulators should in our view address the possible lack of incentives that is inherent in the regulation of DSOs and TSOs, examine how prevalent the problem is, and what can be done about it.

4.3.3   A level playing field for aggregation services

Aggregation services are likely to fill a gap in the market to the extent that there are costs to be saved and money to be made from adjusting consumption in response to price variation, at a minimal cost to comfort, but many consumers do not bother. An aggregator can offer a consumer a discount in return for yielding control of all or parts of the electricity and power consumption of the consumer. Some pilots are underway in the Nordic countries, for instance a pilot in Finland whereby Fortum manages a fleet of 70 household water heaters and bids their capacity into the power market.

In principle, there are at least three sets of actors that could provide aggregation services. The DSO has the advantage that it is manages part of the grid. It also has ownership to the smart meters. Utilizing smart meters and its relationship with customers it could offer customers a choice between a real-time price contract and a contract where, say, the price is stable and low, while the DSO is allowed to cut, say,

space heating and water heaters, for an agreed length of time, under specified conditions. Allowing DSOs to offer such contracts in competition with other providers of aggregation services will however challenge the notion that DSOs should confine their activities to those that are characterized by natural monopoly. If one is to engage DSOs in aggregation services it is important that the provision of aggregation service is separated from the natural monopoly, e.g., by performing the aggregation service in a separate legal entity. This is important in order to avoid cross-subsidies from the monopoly to the competitive service.

Currently there are legal obstacles in the Nordic countries to a DSO wishing to take part in competitive activities. The obstacles are based in the fundamental distinction between the increasing returns to scale (natural monopoly) of the grid and the constant returns (facilitating competition) of production and retail. However, the market is changing in many ways, challenging the clean division between the natural monopoly and competition. Time (2016) recently ran the article *Your Utility Company Wants to Sell You More than Just Electricity*. The message of the article is that the utilities in the U.S. "have decided that they don't want to be a commodity provider any longer. What they want to be is an energy service provider". Utilities consider selling solar panels and energy efficiency solutions, and they interact more closely with consumers, providing in-depth analysis of electricity use, etc. As dwellings become "plus-houses" that supply electricity to the grid, the level of integration will increase. This trend suggests the distinction between natural monopoly and competitive activities might need a regulatory re-think. Nordic energy regulators should to contribute the discussion of the issues.

The retail supplier of electricity is an alternative to the DSO in the market for aggregation services. The retailer knows the customers well. It is in a good position to induce flexibility that accommodates variation in production. The regulator in Norway recently allowed the retail company to issue one comprehensive invoice that covers electricity consumption and grid usage.

Third party entities are interested in participating in the market for aggregation services. These could be specialized energy service companies, that act as middlemen between consumers and the grid and retail organisations. Or they could be large consumers that take on an aggregation business on the side.

Nordic regulators may usefully facilitate aggregation services by arguing for a "level playing field" among prospective market participants. Access to smart meters should for instance be non-discriminatory. It should be further considered whether DSOs can participate in the market for aggregation services, and if so, what measures to take to make sure that the monopolistic part of their business does not subsidize their entry into aggregation services. The revenue regulation model of DSOs should be examined for their impacts on DSO incentives towards aggregation services.

References

Athukorala, P. and C. Wilson (2010): Estimating short and long-term residential demand for electricity, *Energy Economics* 32 (S1).

Atkinson, S. (1981): Reshaping residential electricity load curves through time-of-use pricing, *Resources and Energy* no 3.

Aubin, C.D., E. Fougere, E. Husson and M. Invaldi (1995): Real-time procing for residential customers: Econometric analysis of an experiment, *Journal of Applied Econometrics*, 10(4).

Baughman, M and P. Joskow (1974): The effects of fuel prices on residential appliances choice in the US, *Land Economics*, 50, no 1.

Bernstein, M.A., and J. Griffin (2005): Regional Differences in Price-Elasticity of Demand for Energy. *The Rand Corporation Technical Repo*rt.

Blaalid, J. and S.Log (1977): Husholdningens etterspørsel etter energy, *Artikkel nr 105*, Statistisk sentralbyrå, Oslo.

Bohi, D.R. and M.B. Zimmerman (1984): An Update on Econometric Studies of Energy Demand and Behavior. *Annual Review of Energy* 9: 105–54. https://doi.org/10.1146/annurev.eg.09.110184.000541

Bohi, D. R. (2013): *Analyzing demand behavior: A study of energy elasticities*, Resources for the Future.

Borenstein, S. (2009): *To What Electricity Price Do Consumers Respond?*

Residential Demand Elasticity Under Increasing-Block Pricing.

Borenstein, S., M. Jaske and Rosenfeld A. (2002): *Dynamic pricing, advanced metering and demand response in electricity markets*, Center for the Study of Energy Markets; University of California Energy Institute.

Braithwait, S. (2000): Residential TOU price response in the precense of interactive communication equipment, in A. Faruqui and E. Eakin (eds): *Pricing in electricity markets*. Kluwer Academic Publsiher, Boston. https://doi.org/10.1007/978-1-4615-4529-3_22

Callaway, D.S. (2009): Tapping the energy storage potential to deliver electric load following and regulation, with application to wind energy, *Energy Conversion Management*, 50, 1389-1400. https://doi.org/10.1016/j.enconman.2008.12.012

Caroll, J., S.Lyons and E. Denny (2014): Reducing household electricity demand through smart metering: The role of improved information about energy saving, *Energy Economics* 45. https://doi.org/10.1016/j.eneco.2014.07.007

Cronholm, L.-Å., M. Forsberg and M. Stenkvist (2006): *Studie av effektreduktioner hos mellanstora kunder,* Stockholm: Elforsk 06:11.

Dahl, C., and C. Roman (2004): *Energy Demand Elasticities – Fact or Fiction: A Survey Update*. Unpublished manuscript.

Dansk energi (nd): *Sådan bliver bygninger aktive medspillere i det intelligente energisystem.*

Dergiades, T. and L. Tsoulfidis (2008): Estimating residential demand for electricity in the United States 1965-2006, *Energy Economics*, 30 (5). https://doi.org/10.1016/j.eneco.2008.05.005

Deryugina, T., A. MacKay and J. Reif (2016): *The long-run price elasticity of electricity demand, Paper presented at Annual Meeting*, American Economic Association, January 7, 2017.

Ea Energianalyse (2015): *Energibesparelser og fleksibelt elforbruk – Potentialevurderinger til "Energi på tvers".* April.

Energinet.dk and Quartz+co (2014): *Markedsmodel 2.0 – Rapport for fase 1.*

ENTSO-E (2012): *Network code on demand response connection – frequently asked questions,* Brussels: entsoe.

ENTSO-E, (2015): *Survey on Ancillary services procurement, Balancing market design 2014.*

Ericson, T. (2006): *Time-differentiated pricing and direct load control of residential electricity consumption*, Discussion Paper no 461. Statistics Norway.

Espey, E. (2004): Turning on the Lights: A Meta-Analysis of Residential Electricity Demand Elasticities. *Journal of Agricultural and Applied Economics* April.

EWI and University of Cologne (consortium leader) (2010): dena Grid Study II. Integration of renewable energy sources in the German power supply system from 2015-2020 with an outlook to 2025. Berlin: German Energy Agency.

Filippini , M. (1994): Estimating electricity demand by time-of-use: A share equation approach, *Economia delle fonti di energia e dell'ambiente* 37 (1).

Finn, P., M. O'Connell, and C. Fitzpatrick (2013): Demand side management of a domestic dishwasher: Wind energy gains, financial savings and peak-time load reduction, *Applied Energy*, 101, 678–685. https://doi.org/10.1016/j.apenergy.2012.07.004

Gils, H.C. (2014): Assessment of the theoretical demand response potential in Europe, *Energy*, 67, 1–18. https://doi.org/10.1016/j.energy.2014.02.019

Goldman, C. A., Barbose, G. L. & Eto, J. (2002). California customer load reductions during the electricity crisis: Did they help to keep the lights on? *Journal of industry, competition and trade*, 2:1/2, 113–142. https://doi.org/10.1023/A:1020883005951

Griffin, J.M. (1974): The effects of higher prices on electricity consumption, *The Bell Journal of Economics and Management Science*, Autumn.

Halicioglu, F. (2007): Residential electricity demand dynamics in Turkey, *Energy Economics* 29 (2). https://doi.org/10.1016/j.eneco.2006.11.007

Haney, A. B., T. Jamasb and M. Politt (2009): *Smart metering and electricity demand: Technology, economics and international experience*, CWEP 0905, ERPG 0903.

Henley, A. and J. Peirson (1998): Residential energy demand and the interaction of price and temperature: British experimental evidence, *Energy Economics* 20 (2). https://doi.org/10.1016/S0140-9883(97)00025-X

Holtedahl, P. and F.L. Joutz (2004): Residential electricity demand in Taiwan, Energy Economics, 26 (2). https://doi.org/10.1016/j.eneco.2003.11.001

Houthakker, H.S. and L.D. Taylor (1970): Consumer demand in the US: Analysis and projection, Harvard University Press, Cambridge, Massachusetts.

IEA (2011a): *Empowering customer choice in electricity markets*. Paris: International Energy Agency.

IEA (2011b): *Impact of smart grid technologies on peak load to 2050*. Paris: International Energy Agency.

Kipping A. and E. Trømborg (2016): Modeling and disaggregating hourly electricity consumption in Norwegian dwellings based on smart meter data, *Energy and Buildings*, 118.

Kim, J-H. and A. Shcherbakova (2011): Common failures of demand response, *Energy*, 36, 373–380. https://doi.org/10.1016/j.energy.2010.12.027

Klobasa, M. (2009): Dynamische Simulation eienes Lastmanagements und Integration von Windenergie in ein Elektrizitätsnetz auf Landesebene unter regelungstechnischen und Kostengesichtspunkten. Stuttgart: Fraunhofer RB-Verlag.

Koliou, E., C. Bartusch, A. Picciariello, T. Eklund, L. Söder, and R.A. Hakvoort (2015): Quantifying distribution-system operators' economic incentives to promote residential demand response. *Utilities Policy*, 35, 28–40. https://doi.org/10.1016/j.jup.2015.07.001

Kondoh, J., N. Lu and DJ Hamerstrom (2011): An evaluation of the water heater load potential for providing regulation service. In *Proceedings of the 2011 IEEE Power and energy society general meeting*. https://doi.org/10.1109/PES.2011.6039149

Lund, P.D., J. Lindgren, J. Mikkola and J. Salpakari (2015): Review of energy system flexibility measures to enable high levels of variable renewable energy, *Renewable and Sustainable Energy Reviews*, 45, 785–807. https://doi.org/10.1016/j.rser.2015.01.057

Meland, P., A. Tjeldflåt and T. Stamer Wahl (2006): *Forbrukerfleksibilitet i det nordiske kraftmarkedet*. NVEs delrapport til den nordiske Elmarkedsgruppen 2006. Rapport 7/2006. NVE, Norway.

Meld S (2015–16): Kraft til endring (Power for change). Meld S (2015–16) 25.

Nakajiima, T. (2010): The residential demand for electricity in Japan: An examination using empirical panel analysis techniques, *Journal of Asian Economics*, 21 (4). https://doi.org/10.1016/j.asieco.2010.03.005

Narayan, P.K. and R. Smyth (2005): The residential demand for electricity in Australia: An application of the bounds testing approach to cointegration, *Energy Policy* 33 (4). https://doi.org/10.1016/j.enpol.2003.08.011

Narayan, P.K., R. Smyth and A. Prasad (2007): Electric consumption in G7 countries: A panel conintegration analysis of residential demand elasticities, *Energy Policy* 35 (9). https://doi.org/10.1016/j.enpol.2007.03.018

NEPP (2016): *Reglering av kraftsystemet med ett stort inslag av variabel produktion,* Stockholm: NEPP.

Nordel (2004): *Demand response in the Nordic countries: A background survey.*

Nordel (2005): *Power and Energy Balance, Forecast 2008*, prepared by Nordel's Balance Group.

NordREG (nd): *Status report on regulatory aspects of demand side flexibility*. Nordic Energy Regulators.

NVE (2016): *Smarte målere (AMS). Status og planer for installasjon første halvår 2016*. Rapport 79/2016.

Nyholm, E., S. Puranik, E. Mata, M. Odenberger and F. Johnsson (2016): Demand response potential of electric space heating in Swedish single-family dwellings, *Building and Environment* 96, 270–282. https://doi.org/10.1016/j.buildenv.2015.11.019

Patronen, J., E. Kaura and C. Torvestad (2017): *Nordic heating and cooling. Nordic approach to EU's Heating and Cooling Strategy*. TemaNord 2017:532, Nordic Council of Ministers.

Paulus, M. and F. Borggrefe (2011): The potential of demand-side management in energy-intensive industries for electricity markets in Germany, *Applied Energy*, 88, 432–441. https://doi.org/10.1016/j.apenergy.2010.03.017

Reiss, P.C. and M. White (2005): Household electricity demand, revisited, *The Review of Economic Studies*, 72 (1). https://doi.org/10.1111/0034-6527.00354

Räsänen, M., J. Ruusunen and R.P. Hämäläinen (1994), Customer level analysis of dynamic pricing, experiments using consumption-patter models, *Energy* 20(9).

Rødseth, A. and S. Strøm (1976): *Demand for electricity*, Memo, University of Oslo.

SEDC (2015): *Mapping demand response in Europe today 2015*. Brussels: Smart Energy Demand Coalition.

Short, J, D. Infield and I. Freris (2007): Stabilization of grid frequency through dynamic demand control. IEEE Transmission Power Systems, 22, 1284–1293. https://doi.org/10.1109/TPWRS.2007.901489

Stadler, I. (2006): Nichtelektrische Speicher für Electrizitätsversorgungssysteme mit hohem Anteil erneuerbarer Energien. Habilitation, Universität Kassel.

Stadler, I. (2008): Power grid balancing of energy systems with high renewable energy penetration by demand response, Utilities Policy, 16, 90–98. https://doi.org/10.1016/j.jup.2007.11.006

Swedish Energy Markets Inspectorate (2015): *Funktionskrav på framtidens elmätare*. Ei R2015:09.

Swedish Energy Markets Inspectorate (2016a): *Åtgärder för ökad efterfrågeflexibilitet i det svenska elsystemet*, Ei R2016:15.

Swedish Energy Markets Inspectorate (2016b): *Slopad schablonavräkning för timmätta kunder?* Ei R2016:03.

Taylor, L.D., G. Blattenberger and P. Verleger (1977): The residential demand for energy, EPRI EA-235, *Final Report* Vol 1.

Time (2016): Your utility wants to sell you more than just electricity. Time Magazine June 03, 2016.

Thell, L. (2016): *Förbrukningsflexibilitet – Presentation at Elmarknadsrådet 20 september 2016.* Stockholm: Svenska Kraftnät.

Thema Consulting Group (2014): *Demand response in the Nordic electricity market. Input to strategy on demand flexibility.* TemaNord 2014:553. Nordic Council of Ministers. https://doi.org/10.6027/TN2014-553

Tuohy, A., B. Kaun and R. Entriken (2014): Storage and demand side options for integrating wind power, *Wiley Interdisciplinary Review of Energy and the Environment*, 3, 93–109. https://doi.org/10.1002/wene.92

Tveten, Å.S., T. F. Bolkesjø and I. Ilieva (2016): Increased demand-side flexibility: Market effects and impacts on variable renewable energy integration, *International Journal of Sustainable Energy Planning and Management*, 11, 33–50.

Vaasa ETT (2014): *Market Entrant Processes, Hurdles and Ideas for Change in the Nordic Energy Market – the View of the Market*. Final report to NordREG.

Sammendrag på norsk

Fleksibel etterspørsel etter elektrisitet og kraft: Barrierer og muligheter

Etterspørselsfleksibilitet er energiforbrukerens evne til å redusere etterspørsel i perioder med høy etterspørsel etter effekt, og muligens flytte etterspørselen til andre perioder. Vi foretar en litteraturstudie (meta-studie) om etterspørselsfleksibilitet og evaluerer potensialet for og nytten av slik fleksibilitet. Basert på studien peker vi på barrierer mot implementering og muligheter for nordiske regulatorer til å redusere barrierene.

Ny fornybar, uregulerbar energi fra sol og vind mates i større grad inn i de nordiske og europeiske elektrisitetsmarkedene. For å øke effektiviteten og redusere kostnadene kan det være nyttig om etterspørselen kan tilpasse seg variasjonen i produksjon bedre. Etterspørselsfleksibilitet kan også bidra til å redusere topplasten i nettet. Dette kan gi signifikante besparelser i form av utsatte eller unngåtte investeringer.

Smarte målere rulles ut til alle sluttbrukere, og fjerner dermed en viktig barriere mot etterspørselsfleksibilitet, men det er fortsatt barrierer som består. De nordiske regulatorene har bestilt denne studien som skal

- utforske eksisterende informasjon om etterspørselsfleksibilitet i et nordisk perspektiv og peke på funn som kan lede til konkrete tiltak
- lage en oversikt over eksisterende barrierer mot og potensiell verdi av etterspørselsfleksibilitet i det nordiske markedet.

Hierarki av barrierer mot etterspørselsfleksibilitet

Vi har organisert de viktigste barrierene i et hierarki, hvor den mulige effekten av etterspørselfleksibilitet øker for hver barriere man fjerner. Det viktigste er å få på plass *målere og priser* som faktisk kan belønne adferd hos sluttbruker. Dernest kommer *IKT løsninger* som kan senke transaksjonskostnader, og dermed gjør det mer sannsynlig at målere og priser faktisk kan påvirke adferd hos forbruker. Etter IKT, kommer *aggregerings-tjenester*, disse kan senke administrasjonskostnadene ytterligere ved å samle etterspørselsfleksibilitet fra flere sluttbrukere. I tillegg kan aggregerings-tjenester automatisere eller administrere atferdsendringer på vegne av sluttbruker. Den siste barrieren som må brytes for å få størst effekt av etterspørselsfleksibilitet, er å *redusere minste budstørrelse og «settlement period»* i engrosmarkedet.

Viktige funn for de nordiske regulatorene

Smarte målere rulles ut eller har litt installert i alle nordiske land. Dette må kombineres med en effektiv tariffdesign for å gi sluttbruker riktige prissignaler. Gjeldende tariffdesign varierer mellom de nordiske landene og er ikke i tråd med idealet i økonomisk teori om effektiv prising. Det er et behov for å harmonisere dette og de nordiske regulatorene har startet dette arbeidet.

Alle nordiske nettselskap er underlagt inntektsregulering. I tradisjonelle modeller for inntektsregulering kan nettselskaper videresende investeringskostnadene rett til kundene sine. En slik modell kan være en barriere for å utnytte etterspørselsfleksibilitet. Reguleringsmodellen bør sørge for at nettselskapene får en del av gevinsten som oppstår dersom bruk av etterspørselsfleksibilitet fører til utsatt eller unngåtte investeringer. Regulator bør utforske hvor stort dette problemet er, og hva som kan gjøres.

Selv om det skulle være litt penger å spare og lite komfort å miste, vil mange sluttbrukere ikke ta seg bryet med å endre adferd. Derfor vil aggregerings-tjenester være viktige for å utnytte potensialet for etterspørselsfleksibilitet. Flere aktører i markedet kan tilby disse tjenestene, slik som DSOene, strømselskapene eller andre aktører. Det er viktig at regulator sørger for like vilkår for alle.

Nordisk potensiale for etterspørselsfleksibilitet

Vår undersøkelse indikerer at oppvarming har høyest potensial for etterspørsels-fleksibilitet. Estimater fra blant annet Sverige og andre europeiske land viser at over halvparten av potensiale for fleksibilitet finnes i oppvarming av bygninger. Deretter følger oppvarming av vann, et potensiale man tror vil øke når man får flere batterier og elektriske biler.

Verdien av dette potensiale er usikkert, men muligens høy. Verdien vil avhenge av hvilke tiltak som innføres, hvordan de innføres, og hvordan brukerne reagerer på tiltakene. Basert på tidligere forskning kan verdien være ca 1–2 milliarder SEK (0,1–0,2 milliarder EUR) per år. Med økt integrasjon av uregulerbar fornybar energi, kan denne årlige verdien øke. Verdien av å fjerne barrierer i et livstidsperspektiv vil inneholder mye usikkerhet, men gitt en rekke forutsetninger, er estimert verdi mellom 33–66 milliarder SEK (3,3–6,6 milliarder EUR). Nytte i nettet kommer i tillegg til dette estimatet.

Appendix 1 – The Terms of Reference

Introduction

About the contracting authority

On behalf of the organisation for the Nordic energy regulators, NordReg, Nordic Energy Research (NER) invites you to compete on the task described in this document.

Nordic Energy Research is an intergovernmental institute under auspices of Nordic Council of Ministers. In this task Nordic Energy Research will be the contractual part and contact point. A steering group will consist of experts from NordREG. The Electricity Market Group (EMG) is co-receiver of results.

The focus area for this task is to gather available information about demand side flexibility and storage at both research level and from real life experiences, relevant from a Nordic perspective. And to get an overview of the existing potential and value of demand side flexibility in the Nordic market.

The assignments objectives and content

Background for assignment

The European Commission's Energy Union Package[18] from 25th February 2016 emphasizes that "Smart technologies will help consumers and energy service companies working for them to reap the opportunities available on the energy market by taking control of their energy consumption (and possible self-production). This will deliver more flexibility in the market and potentially reduce consumer bills."

Furthermore, the recent European Parliament report *Towards a New Energy Market Design*[19] from 21st June 2016 states that "...in order to achieve the climate and energy targets, the energy system of the future will need more flexibility, which requires investment in all four flexibility solutions – flexible production, network development, demand side flexibility and storage.". It was approved in September 2016 by the European Parliament in its plenary session in Strasbourg.

Clearly market design for demand side flexibility is a European focus.

---

[18]https://ec.europa.eu/energy/sites/ener/files/publication/FOR%20WEB%20energyunion_with%20_annex_en.pdf
[19] http://www.europarl.europa.eu/sides/getDoc.do?pubRef=-%2f%2fEP%2f%2fTEXT%2bREPORT%2bA8-2016-0214%2b0%2bDOC%2bXML%2bV0%2f%2fEN&language=EN

The report *Challenges and Opportunities for the Nordic Power System*[20] from the Nordic TSOs dated 15 August 2016 addresses an adequate market design as important in relation to demand side flexibility.

The Nordic Energy Research report *Demand response in the Nordic electricity market*[21] by Thema provided an overall framework for the principles of demand response and how a strategy could be built to ensure that demand side flexibility is efficiently discovered within the markets and network regulation.

NordREG has assessed the need and concluded that further studies will be beneficial, especially considering the increasing attention demand side flexibility has been given. Further studies on demand side flexibility at a Nordic level would strengthen the competence and common Nordic understanding of what role demand side flexibility could play in the future, and be an enabler of common Nordic positions at the European arenas.

Objectives

The purpose of the study is to:

- explore available information on demand side flexibility in a Nordic perspective and highlight key findings that may develop into concrete measures
- make an overview of existing barriers and of potential and value for demand side flexibility in the Nordic market.

Content

The study should be delivered as a report. It should be written in English for the purpose of dissemination.

1. Conduct a meta study by gathering and presenting available information at both research level and from real life experiences (such as already implemented measures and pilot projects) relevant from a Nordic perspective, on the topic on demand side flexibility and storage:
   - The presented information should be relevant for the Nordic perspective, but could include experiences and knowledge from outside the Nordic region.
   - The focus should be holistic, and should span from forward markets, wholesale markets (including balancing and ancillary services), retail markets, network operations and network investments.

---

[20] http://www.statnett.no/Global/Dokumenter/Challenges%20and%20opportunities_Report.pdf
[21] http://www.nordicenergy.org/publications/demand-response-in-the-nordic-electricity-market/

- Experiences from markets or market segments where smart meters and settlement based on frequent meter values, and how the price elasticity could be improved, are of special interest.

2. Highlight the key findings from the meta-study that may have a potential to develop into concrete measures undertaken both regionally and nationally at the Nordic level, and describe the needed implementation measures.

3. Based on the key findings of the meta-study, make an overview of existing barriers for demand side flexibility and storage, and discuss the pros and cons of changing each of these barriers individually. These barriers should not only be interpreted as technical details, but also include any possible larger fundamental questions about the markets:
   - While doing so, the consultant should make qualitative or quantitative assessments, where relevant, on the net benefit of each identified measure, and seek to rank any proposed measure according the expected net benefit of each individual measure.

4. Present an overview of the existing potential and value of demand side flexibility and storage within the Nordic market, based on previous assessments and already existing information

Method

It will be up to the consultant to define an approach for this assessment.

Appendix 2 – Concepts and markets

Concepts

Demand-side flexibility (DSF) can be defined as the capacity to change electricity usage by end-use consumers from their normal or current consumption patterns, in response to:

- market signals such as time-variable electricity prices or incentive payments
- acceptance of the consumer's bid, alone or through aggregation, to sell demand reduction/increase at a price in electricity markets or for internal portfolio optimisation.[22]

Energy storage is the capture of energy produced at one time for use at a later time (thereby facilitating flexibility). We include *demand side* energy storage such as storage in domestic hot water tanks, buildings,[23] batteries or electric vehicles etc. When we in this report refer to demand side flexibility it is understood that it includes demand side energy storage, among other means by which demand side flexibility can be achieved.

Ancillary services are services bought by transmission system operators (TSOs) to ensure that they have access to the resources necessary to ensure stable and reliable power system operation. Ancillary services may be bought in the wholesale market.

Potential for demand side flexibility. We distinguish between technical and economic potential. The technical potential is the amount of power that is technically feasible to lift out of peak periods and either shed altogether or shift to an adjacent period. The economic potential is the amount of power that is socially profitable to lift out of peak periods. A socially profitable reduction in peak is one that passes the cost-benefit test. The economic potential is never larger than the technical potential and it is usually smaller. The economic potential is not a fixed entity, but depends on the price incentives and regulatory incentives since they determine what is profitable. The technical potential is not fixed either, but dependent on cost and the time perspective. However, to fix ideas it is useful in a report like this to state the potentials as set numbers, with supporting assumptions stated as clearly as possible.

---

[22] http://www.emissions-euets.com/internal-electricity-market-glossary/1141-demand-side-flexibility-dsf
[23] Thermal mass inside the insulation; mainly the building envelope and floor slabs.

The markets within the Nordic electricity market

The retail market

The retail market is the market for end-use of electricity. The end-users comprise households, small-scale consumers in service, industry etc., and large-scale consumers in manufacturing industry etc.

The wholesale market

The wholesale electricity market is the "sale-for-resale" market of electricity where competitive producers, professional traders and other participants engage in trade.

Before considering flexibility in the wholesale market it is useful to revisit facts about market structure. In the Nordic context there are several markets:[24]

- The day-ahead market Elspot
- The continuous intra-day market Elbas
- Balancing markets

Elspot
Elspot is the main market for trading electricity in the Nordic and Baltic countries. It is often referred to simply as the spot market. Elspot is a day-ahead market.

Elbas
Elbas trading take place on a continuous basis between day-ahead and one hour prior to the hour of operation. It allows participants in Elspot the opportunity to trade up or down if actual production or consumption is likely to differ from the expectation the day before. Elbas covers the Nordic and Baltic countries, Germany and the UK.

Balancing markets
Short term energy balance in the Nordic power system is maintained with primary reserves, secondary reserves and tertiary reserves that include the balancing power market. Primary reserves are used for constant control of system frequency. If imbalance is sufficiently large, secondary reserves are utilized to release primary reserves. Manually activated tertiary reserves, typically procured from the balancing power market, are used to balance mounting deviations in the balance and also to release secondary reserves if the need arises.

Balancing market – primary reserves
Primary reserves (Frequency Containment Reserves, FCR) are traded in one daily and one weekly Nordic market. The weekly market is run before the Elspot market, while

---

[24] Our main source for this paragraph is the report from the Norwegian Government to Stortinget Meld S (2015-16) 25 Kraft til endring (Power for change).

the daily market is run after the Elspot market. The daily market is intended to cover residual needs following trade at Elspot, including transmission demands from the transmission system operators (TSOs).[25]

Balancing market – secondary reserves

Markets for secondary reserves (automatic frequency regulating reserve, aFRR; Load Frequency Control, LFC) are so far not fully integrated across the Nordic countries. The Nordic TSOs jointly decide what volumes to purchase, when to use them, and how do distribute them between the Nordic countries. The reserves are purchased in national Nordic markets of somewhat different designs. Work is ongoing to establish a common Nordic market for secondary reserves.[26]

Balancing market – tertiary reserves, regulating power

Tertiary reserves (regulating power, "regulerkraft", manual frequency regulating reserve, mFRR) are reserves with a lead time of up to 15 minutes. They are still invoked by phone or similar. Tertiary reserves are traded in the Nordic balancing power market (RK or RKM).[27] Importantly for our subject, flexible loads from the demand side are supplied in this market. In addition to RK each Nordic country has additional arrangements to ensure participation in the RK market. Norway for instance has a market for participation called the regulating power options market (RKOM).

---

[25] http://www.statnett.no/Kraftsystemet/Markedsinformasjon/Primarreserver/

[26] http://www.statnett.no/Kraftsystemet/Markedsinformasjon/sekundarreserver/

[27] Tertiary reserves can also be procured through other channels. See for example http://www.fingrid.fi/en/electricity-market/reserves/acquiring/Pages/default.aspx. However, alternative tertiary reserves are only used as a last resort.

FLEXIBLE DEMAND FOR ELECTRICITY AND POWER

Demand side flexibility is the ability of power consumers to reduce their demand in periods of peak load, possibly shifting demand to other periods. The organisation for the Nordic energy regulators, NordREG, has ordered this study to explore demand side flexibility in a Nordic perspective. The study contains a literature survey of demand side flexibility and assess the potential for, and benefit of demand side flexibility. Based on the survey, the report highlights implementation barriers and possible contributions from to reducing these barriers. Existing barriers are e.g lack of ICT, automation services, smart meters and real-time prices. The greatest potential for demand side flexibility in the Nordics is within residential space heating. The value of demand side flexibility is uncertain, but may be 1-2 billion SEK per year.