Nordic Council of Ministers

Demand side flexibility in the Nordic electricity market

From a Distribution System Operator Perspective

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Executive summary

Demand side response (DSR) is a question of mobilising potential flexibility in how and when end users choose to use energy, and how such flexibility can provide value to the network. Network value can be in the form of reduced or deferred investments, better system reliability or other system cost reductions.

The report is divided in two. First, a concept study addresses concepts for utilising demand response, discusses models for how demand response can be realised, and regulatory issues related to these models. Second, an interview study among selected DSO respondents in the four Nordic countries addresses the current status, how DSOs assess the potential value of flexibility to their business, what they see as major barriers to realisation, and what plans they have for new activity in relation to demand response.

The focus in the report is on demand side response at small end user level, in particular households. The ongoing roll-out and installation of smart meters for all grid customers, enabling smart solutions at household level, is the main motivation for this focus. Also, the grid benefits discussed are mostly related to DSO and not TSO level. Nevertheless, as we find that many of the smart solutions that are becoming available potentially can provide value to both at DSO level and to TSO operated system services markets, we also include a high-level discussion of system services. However, given the complexity of issues concerning future TSO/DSO coordination and role division, the question of developing new marketplaces for flexibility services is left outside of the scope of this report.

The concept study

There is a vast amount of information on different DSR concepts, and it is a major challenge to categorise different opportunities and ideas into meaningful concepts. At household level, we have chosen to categorise possible measures into five main categories:

- Heating (and cooling) system
- Household appliances
- Local generation of electricity, like PV systems
- Local storage, hot water or electricity (batteries)
- Transportation, i.e. electrical vehicle (EV) charging)

With reference to a number of Nordic and international studies, we assess and discuss the potential flexibility within each category. Flexibility is broadly categorised into two groups:

- Explicit flexibility that can be mobilized in real time or on short notice, and where the volume is controllable. This kind of flexibility is useable for short-term system operation and congestion management purposes;
- Implicit flexibility, which is related to a long-term expected reduction in load demand in the form of e.g. systematic changes in end user behaviour. This flexibility can be part of the long-term planning process, but not for real-time operations.

We find that the most promising areas for demand response are related to the heating and cooling system, and to the potential storage of electricity in batteries and hot water.

Table 1: Main findings: Attractivity of household flexibility sources for explicit and implicit flexibility value to DSOs

Source	Explicit flexibility	Implicit flexibility
Heating (and cooling) system	Suitable for down-regulation for shorter periods, up to hours	Price signal to trigger substitution with other energy carriers, or to flatten demand curve over the day.
Household appliances	Limited flexibility, except refrigeration that can provide down-regulation	Flatten demand curve with systematic shift in time-of-use of wet appliances
Local generation of electricity, like PV systems	Limited capability, may down-regulate	May increase need for flexibility, but also reduce long-term need for capacity depending on technology
Local storage, hot water or electricity (batteries)	May shift load from hours up to days. May provide both up- and downregulation	Flatten demand curve for all usages (el or heating hot water)
Transportation, i.e. electrical vehicle (EV) charging	Suitable for down-regulation, may provide up-regulation (cost issue)	Flatten demand curve with controlled charging behaviour

However, there are significant national differences across the Nordic countries regarding the potential especially for heating systems. While electricity is the main heating source in Norway with 70%, the corresponding share is as low as 25% in Finland and Denmark.

Battery storage is growing along with installations of distributed PV systems, but is still in its infancy and has little impact or importance today. Batteries appear as the technically superior solution to provide flexibility, both for long-term load curve flattening, and for providing real-time services to the grid. However, there are both technological, and not least cost, issues to be resolved to make batteries a significant source for flexibility.

Based on findings in several studies, the most important DSO value from DSR appears to be reduced grid investments. The value lies primarily in deferring capacity expansions, and less in downscaling of capacity once a new investment is decided. Both implicit and explicit flexibility contribute to lower investments. Implicit flexibility provides an extra option value in deferring investment decisions, while explicit flexibility provides an additional source for redundancy in the grid in real-time operations.

Also, the smart solutions at the end user level and in the grid associated with flexibility contribute to lower network costs in other areas. Better information on physical flows can improve grid optimisation and reduce network losses. Better information also reduces the time spent locating network faults, thus improving quality of supply and SAIDI,[1] and contributes to lower maintenance costs.

The potential for reduced network costs relies on measures taken at end user level; in the form of equipment and system investments and changed behaviour and use of electricity. From the end user perspective, the incentives to invest in smart solutions can be driven by several factors. The main types of incentives are:

- Financial incentives, in the form of reduced grid tariffs, energy cost savings, or direct payments to provide flexibility
- Increased comfort from smart solutions
- Increased security, e.g. burglar or fire alarms, or health surveillance services

Being a natural, regulated monopoly, the DSO cannot engage in services other than grid. Hence, to mobilise the full set of incentives to end users, the DSOs rely on other players taking a role towards end users – like energy service providers or aggregators. For DSOs, financial incentives are the most likely instruments. This may be in the form of grid tariffs, investment contributions or purchase of flexibility. Of these, only direct purchase of flexibility under firm contracts (including interruptible grid tariffs) would provide explicit flexibility to the DSO. In this report, the focus is on implicit flexibility and on long-term price signals.

Price signals from grid tariffs affect end user behaviour. This is desirable only if the socio-economic loss of utility to end users from changed behaviour is smaller than the gains that can be realized in other sectors. Hence, grid tariff price signals should only be used in cases where DSOs are able to make network costs savings that exceed the end user loss of utility from changed behaviour. In economic terms, the price signal should not be larger than the marginal, alternative network cost.

It is likely that many of the measures available to end users have a low marginal loss of utility. For example, EV home charging can in most cases be done during off-peak hours at night instead of during evening peak hours. Slow loads like hot water tanks or electric cables may be switched off during peak hours with no real loss of utility.

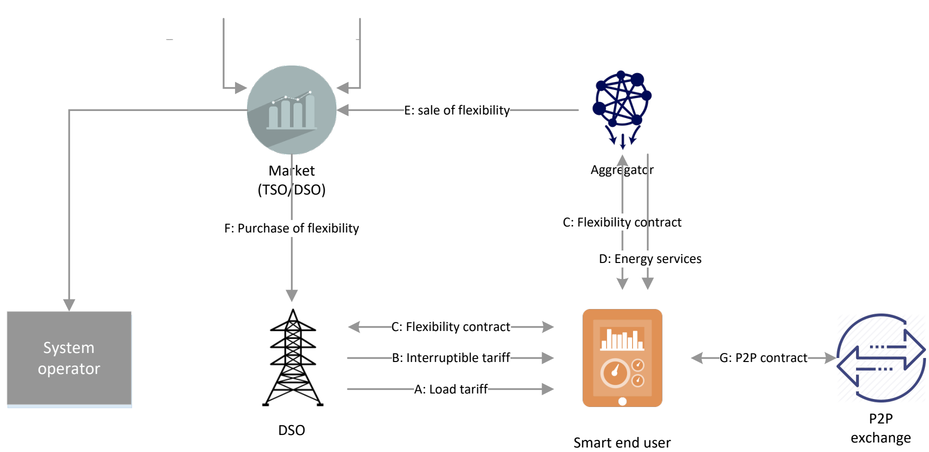
[1] SAIDI: System Average Interruption Duration Index, i.e. a measure of the supply quality.

To incentivize load shifting, tariffs must include a load based element. We discuss several relevant models, and point out that dynamic models where the strength of the price signal depends on the system load, rather than the individual end user load, are more effective at producing network savings at low socio-economic costs than static models. Also, both findings from previous studies, as well as comments from DSOs, show that peak load problems in the grid can normally be addressed with targeted measures from a very limited number of end users – possibly only 10% or less than the total number of households. This means that targeted tariff and dynamic models will have significant cost efficiency advantages over static, general models.

End users may also be incentivized by direct purchase of flexibility. Today, DSOs commonly offer interruptible tariffs which have some of the same characteristics – similar to a tertiary reserve for down-regulation. Purchase of flexibility could be organized directly between the DSO and the end user, or via a third party. From a market perspective, the two models are very different. Direct purchase from the DSO may be the most efficient model in isolation, but will also affect market prices for flexibility and the possibility to develop market-driven models with third-party players. Hence, DSO direct purchase could be negative for developing DSR for use in established and future system services markets at TSO level, or new market solutions at TSO/DSO level.

Smart solutions and new technology provide the basis for a number of new business models. In this report, we look into different models around "smart" end users, including DSOs, third parties and peer-to-peer models.

Figure 1: Illustration of different demand response measures and business models



In the report, we discuss

- DSO-based models, including use of load tariffs, direct purchase of flexibility and purchase of flexibility on organised markets or via aggregators. Load tariffs may include both subscribed and actual load models as well as time-of-use (TOU) models;
- Third-party based models, like Product-Service-Systems or Energy Contracting Models, e.g. Energy Performance Contracting. These could also be combined with new financing schemes.

In addition, we briefly discuss development of more advanced digitalisation and innovative transaction systems like Blockchain, which may enable peer-to-peer (P2P) models.

One important finding is that investments in smart end user solutions and DSR mobilisation requires realisation of several business models. For the end user, the full set of incentives includes financial benefits from lower grid tariffs, energy savings and possibly sale of flexibility, in addition to co-benefits from comfort and security. The DSOs play an important market facilitator role in this picture: By introducing financial incentives for smart end user solutions, they also strengthen the financial business case for new, third-party business models. Hence, DSOs should focus on their role as market facilitators.

A number of neutrality and regulatory issues limit the DSOs' possible roles. Some of these barriers may be subject to regulatory reform, while others are fundamentally linked to the natural monopoly position of DSOs.

Regarding neutrality, we discuss the following four issues:

- Equal access to end user data to all relevant parties
- Equal access to DSO procurement of services from all qualified parties
- Level playing field between grid investments and flexibility mechanisms
- Non-discrimination between grid customers with regards to connection and tariff terms.

First, we discuss the problems associated with direct flexibility purchases from DSOs in relation to efficient market solutions for new, DSR-oriented flexibility markets with aggregators as a third party. Second, we point to how limitations in battery ownership for DSOs affect the level playing field between investments and flexibility mechanisms. Third, we raise the issue of how limited possibilities in tariff differentiation between customers are likely to reduce the potential value of DSR. We continue this discussion in terms of regulatory barriers to DSR in five main categories:

- Tariff regime, with regards both to design and use of price signals, and possibility to discriminate between customers on network benefit grounds. This is judged to be a crucial issue, where forthcoming tariff regulatory reform will significantly affect the possibilities to realise DSR benefits;

- Access to and DSO involvement in flexibility markets for end users. The main issue to consider is whether DSOs should be allowed to use bilateral flexibility contracts, to the possible detriment of aggregator and market-based models;
- Allowed DSO activities and roles, like ownership of certain assets and DSO involvement in flexibility markets. We point out that there are very strong arguments in favour of allowing DSOs to own and operate batteries for grid support;
- Income or profit effects of buying flexibility, e.g. that certain uses of DSR is to detriment of DSO profitability due to income regulation models. We find this to be a problem of moderate importance in the current regulatory models in the Nordics;
- Access to and use of data from end users. This is not found to be a major challenge, as current regulations adequately balance data privacy and customer protection with commercial needs.

There are certain differences between the four Nordic countries in terms of regulatory regimes. Denmark currently has the weakest regime to allow for price signals to stimulate end users to provide DSR. However, all four countries comply with EU regulations and thus have similar regulations.

The interview study

In the interview study chapter, we summarize and discuss data gathered from our in-depth, qualitative interviews. We interviewed 3 DSOs per country that are either currently engaged, or interested engaging in DSR activity. In addition, we interviewed one Norwegian technology vendor.

The focus of the interview study was on following areas:

- Status of DSR activity within their company
- Value and need for DSR flexibility within the Nordic grid system
- Opportunities and barriers of implementation of DSR activity within the Nordic DSO perspective
- Planned DSR activity within their company.

Due to a limited number of respondents, the results from the interview study are of a qualitative nature only, and we do not claim representativeness. To the extent possible, we point to apparent national differences, but also cautiously underline that the responses are too few to allow for strong conclusions on that dimension.

Most DSOs interviewed have already been active in the field, but generally on a research and testing level. With the exception of one DSO in Norway, there are no commercially driven initiatives on-going. The reason for this is, according to the respondents, twofold: the market is not yet developed, and the current grid generally has sufficient capacity. As direct involvement in activating flexibility under current regulations is mostly out of the bounds for the DSOs themselves, there is a need for interest by third party players. As third party players currently are missing, the market is undeveloped. Secondly, the normal measure to ensure adequate grid capacity is to build more grids. Consequently, DSOs point to that the current grid is often over-dimensioned. The DSOs further state that there is enough flexibility in the grid, but at the same time they have little information available on the actual capacity utilisation at low voltage levels. With enough capacity within the grid, the DSOs state that end user flexibility is currently not needed. Both these factors contribute to that the interest for DSR from DSOs appear to be limited. However, the DSOs acknowledge that the need for DSR may increase in the future due to new consumption and production patterns.

When asked to determine where in the system DSR flexibility will be needed, the respondents stated that within a Nordic DSO context; DSR flexibility will mainly be needed to solve local level congestion issues. The exception here is Denmark, where the DSOs state that the main need for DSR flexibility is to balance the wholesale power market. The reason for the division is that controllable hydropower production in Norway, Sweden and Finland can offer flexibility to solve wholesale balancing issues. We believe this to be an important finding, as much of the common view is that DSR can become part of the system services market. In contrast, DSOs point out that the potential value appears to be highest at distribution grid level.

Respondents generally express the view that the main value of flexibility from the Nordic perspective is long term; as a possible means to avoid or mainly postpone otherwise necessary grid investments. None of the respondents have any experience including DSR in the planning process so far. They see potential benefits of using DSR in the planning process, but at the same time are sceptical because of the following reasons:

- Lack of experience give high uncertainty as to whether DSR can actually be taken into account when planning future capacity requirements
- Over-dimensioning is cheap: Cable dimension is a small part of grid investment costs, and the marginal cost of installing extra capacity once an investment decision is taken is low
- Reliability: Will the necessary flexibility be available at the time it is needed?

The DSOs were further asked to describe barriers to DSR implementation, within four areas:

- Technology – is the technology mature enough?
- Regulation – do the rules give space for DSR?
- End user behaviour – are users willing to provide flexibility?
- Market – are there suppliers and buyers of flexibility?

First, according to the DSOs, technology exists and should not be considered as a barrier. Technology vendors are available, albeit current technology is in a "pilot stage"; lacking robustness and experience. Second, the classic regulation, where tariffs are energy oriented and income regulation is focused on CAPEX, is a clear barrier to DSR development. New smart meter technology is expected to lead to new tariff regimes where load and capacity utilization will become the main elements. There has been a pilot project testing capacity tariffs in Norway. In Denmark, a new regulation is being developed where capacity tariffs and a mixed CAPEX/OPEX income regulation are expected to be included. Third, the DSOs state that end user behaviour is a big challenge. In general, end users are not interested in this subject, or are unaware of their flexibility, and the economic incentives for consumers are weak. Many of the DSOs mention that automation is the only possible way to create substantial DSR volume, as opposed to having consumers reacting manually to price signals. Consequently, having third parties offering automation systems to end users is crucial to achieve DSR. Fourth, the market is currently not in place. The DSOs do not have a substantial need for DSR flexibility at the moment, since grids are generally over-dimensioned. Many of the DSOs expect that the demand for flexibility to grow in the future, and hence they are preparing by engaging in research and pilot projects.

When asked to describe their future plans in terms of DSR activity, the answers confirm the impression that the concept is in the early stages of development. Most DSOs reply that they see future potential for DSR activity. Pilot projects in which the DSOs are engaged, new technologies and communication platforms are being developed, and existing technologies and tariff structures are being tested.

1. Concept study

1.1 Introduction

Demand side response (DSR) is a question of mobilising potential flexibility in how and when end users chose to use energy. A commonly used definition of demand response is:

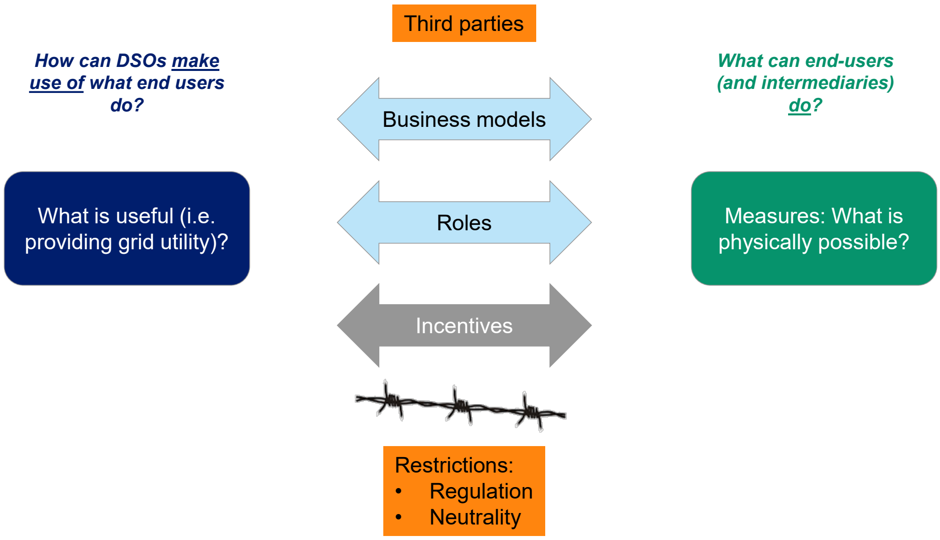
> "Demand response is a temporary change in electricity consumption by demand resources in response to market or reliability concerns."
>
> National Institute of Standards and Technology

There are various ways of exercising flexibility. For example, load shifting implies using the same amount of energy over a period of time, but changing the time of use in order to reduce the maximum load during that period of time. Peak clipping implies reduced load during peak hours, but without using the same energy at other times. A starting point in this concept study is to look into characteristics of the possible end user responses, and relate them to possible benefits seen from the Distribution System Operator (DSO) side. The critical element in the study is to discuss and evaluate what measures can ensure that useful demand side response is realised. In this regard, both business models, roles (DSO, end users and third parties) as well as the possible range of various incentives or market solutions are discussed. In addition, existing regulatory restrictions and barriers are considered. Aggregator roles and sale of demand side response into (TSO) organised markets for systems services are briefly mentioned, but the discussions of new market models and TSO/DSO relationship are outside the scope of this report.

Hence, the two focal questions in this study are:

- What is the potential supply of demand side flexibility – from what sources, and with what characteristics?
- How can DSOs transform end user flexibility into real value, i.e. actually make use of end user flexibility?

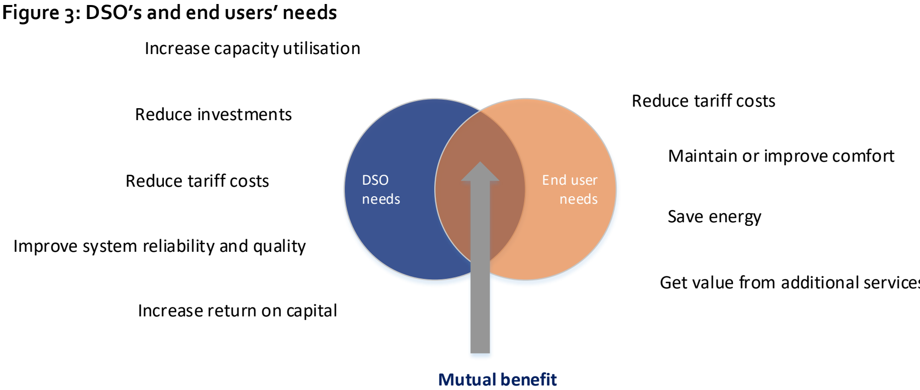
Figure 2: The concept study main issues



Demand side response has no value in itself – it is only when it enables realisation of real benefits that it should be encouraged. However, real value at individual level does not necessarily mean real value at system or society level. For example, redistribution of tariff costs between customers with no related reduction in network costs would give value to one end user at the expense of others. While redistribution of costs could be fairer, it does not necessarily provide any DSO or network benefits.

In order to understand the link between end user motivation and DSO and network benefits, it is important to gain insight into the main preferences and objectives on each side. These are illustrated below.

Figure 3: DSO's and end users' needs



The main needs and objectives for the DSO are related to reducing costs, increasing capacity utilisation and avoiding stranded investments, improve ROI[2] while upholding system quality, and avoid reputational challenges due to high tariffs. On the end user side, it is reasonable to assume that electricity is a low-interest product in the Nordics. End users would desire low costs, unaffected comfort levels, and possibly to get benefit from additional services. Given the strength of climate policy, some end users would also be concerned about saving energy and contributing to reducing greenhouse gas emissions.

In addition, there are societal benefits to reduced network costs and investments – for example, fewer investments mean reduced environmental impacts, and using available resources for other purposes with possibly higher benefits to society. Such issues are out of the scope of this study.

Within the scope of this study, we are concerned about areas where end user flexibility leads to network benefits. This is not necessarily a bilateral relation – third parties are very likely to play a material part in any business model for mobilising demand side response. However, in order to gain value and thus have a willingness to pay for a third party intermediary, either the DSO, the end user or both need to realise the value of demand side response. Logically, as the focus is on how DSOs can utilise demand side response to reduce network costs, the value of DSO benefits will dominate the concept study.

1.2 Concepts for utilising demand side flexibility in a DSO's network business

The amount of available information, publications and research on possible technical solutions, benefits, business models and market models regarding demand side response is overwhelming. In this study, we do not purport to give any detailed status or forecast of possible technical solutions and models. Rather, we suggest a categorisation of relevant types of measures.

First, we explore the physical characteristics of DSR and recent references and work on the probable potential of flexible capacity from households. Second, we look into the flexibility needed and its characteristics in terms of time, predictability and volume. Third, we explore possible benefits to the DSO from increased access to end user flexibility.

1.2.1 Physical characteristics of DSR

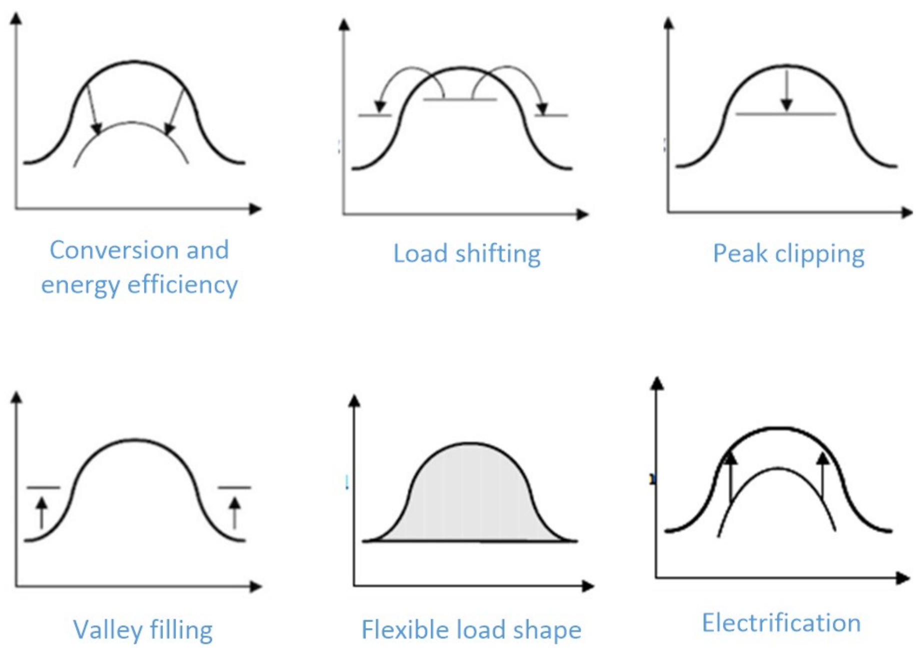
Demand side response can take many forms, depending on the type of end users in question. The Norwegian TSO has for many years offered contracts for flexibility both on energy (longer periods) and load (shorter periods) to large, industrial end users.

[2] ROI: Return on Investment.

Small end-users, being the focal point in this study, will have different physical possibilities to offer flexibility than large industry. The ability to offer flexibility depends on both the physical installations at end user level, and on the end user's behavioural preferences (Eurelectric, 2015). For example, an end user with electric heating (air and water) will have the physical ability to provide flexibility that an end user with district heating supply would not.

There are six typical ways of demand side response (World Bank, 2005).

Figure 4: Main types of load shape objectives



Source: World bank (2005).

- Conversion and energy efficiency typically involves long-term substitution of electricity with another energy carrier, or installing more efficient equipment;
- Load shifting is the short-term shift of load over the day to reduce the peak load, while consuming the same amount of energy over the day;
- Peak clipping is reducing the peak load, but without consuming the same amount of energy in other hours. This can be achieved both by reducing comfort, or by short-term substitution by other energy carriers;
- Valley filling is exploiting unused capacity during off-peak hours, e.g. by charging batteries or heating water;
- Flexible load shape is making the load shape dynamically responsive to reliability conditions;
- Electrification is general increase of demand for electricity, including conversion from other energy sources to electricity.

From the perspective of this study, the three first load shape objectives are of most interest, as the objectives are all aimed at load reduction and hence at reducing capacity needs in the electrical grid.

Load reduction and flexibility possibilities at end user levels are linked to five main sources:

- Heating (and cooling) system – being electrical, combined electrical and other source (heat pumps, combined boilers), or fully other source like district heating. In addition, some other uses like electric cables in driveways may demand significant loads and flexibility
- Household appliances, like refrigerators, washing/drying, cooking etc.
- Local generation of electricity, like PV systems
- Local storage, either in the form of hot water or electricity (batteries)
- Transportation, i.e. electrical vehicle (EV) charging).

The importance of each category in terms of available flexibility depends on end user structures and preferences. In a UK study (Drysdale, 2014), electric space and water heating was found to provide flexibility between seasons, while appliances accounted for little of available flexibility – except to some extent wet appliances (washing/drying).

In the Nordics (possibly except Denmark), the relative heating needs are obviously higher than in GB. In the UK, about 30% of electricity consumption in households is for heating purposes, while in Norway the share is approximately 70% (SSB, 2012). In Denmark households use little electricity for thermal purposes, and have around a 25% share (Odyssee-Mure, 2015). In Sweden, heating in small family homes (SFH) mostly uses electricity (and wood) for heating, while apartments generally have district heating supply (Statistiska Centralbyrån, 2015). In Finland, less than 25% of space and water heating in the household sector is supplied by electricity (Statistikcentralen , 2016). Hence, Norway stands out as the country where potential flexibility from space and water heating is substantial, while it is more limited in the three other countries. Nevertheless, Fortum has introduced a product called Fortum Fiksu where one of the elements is the sale of ancillary services from aggregated water heaters into ancillary markets.

Flexibility from other household sources is most likely still significant. In Germany, a study on the technical potential for demand response concludes with a total potential of 7.3 GW, of which 3.8 is in the tertiary sector – including both services and households. Half of this potential is related to ventilation in commercial buildings, but a significant share is still related to households (Gils, 2014)

Consequently, in terms of volume, the main source of flexibility from existing consumption is likely to be electric space and water heating, while wet and cold appliances also account for some potential flexibility. In a Nordic context, this means that the technical potential is significantly higher in Norway than in the three other Nordic countries. Nevertheless, technological developments like IoT (internet of things), automation etc. may affect this picture in the future.

EV charging and local generation (PV and others) are rather new and small categories in the Nordics. In Norway, EVs and plug-in EVs now account for 30% of new car sales. Corresponding numbers for Denmark and Sweden are 3.7% and 5.6%, respectively (Opplysningsrådet for veitrafikken, 2017). However, even with high new car market share in Norway, EVs still account for less than 4% of total private cars in Norway (SSB, 2017), and their impact on load shapes is still very small in most areas. With growing numbers of cars, combined with increasing battery capacity and charging power, the EV charging needs may become very significant in the distribution grid.

Household PV installations are growing in numbers in all the four Nordic countries, but still account for very little of total capacity. The exception is Denmark, with approximately 600 MW installed capacity, or approximately 100 MW installed in small panels (<6kW) (EnergiNet, 2017). However, with an anticipated cost reduction for PV installations, including battery systems, domestic generation is likely to increase in volume in all four Nordic countries. In grid-connected PV systems with no local battery, it is a possible scenario that on sunny summer days the load from PV systems exceeds the distribution grid capacity designed to handle winter loads. Evidence from Germany, having the highest share of PV installations in Europe, indicates that this is not yet a problem of any significance (Fraunhofer, 2017).

Hence, it is likely that flexibility in demand from both EV charging and from PV (and other decentralised) electricity generation will grow in importance in the next years. In an EU report on DSR (EC DG Energy, 2016), the EU-wide potential demand response potential in 2030 is summarised (based on (Gils, 2014). Flexibility from EV and battery storage makes up for approximately two thirds of total potential, while wet and cold appliances (fridge, washing machine etc.) and heating (space and water) share the rest of the potential.

In summary, the main categories of physical sources of flexibility are space and water heating, EV charging and PV systems. The latter two, EV and PV represent both new, significant demand for flexibility, as well as possible sources of flexibility.

Across all potential sources of flexibility in households, the duration of possible load shifting in existing and future installations *once they are installed* is limited to hours rather than days, and may be of limited use in the case that the need for flexibility extends over longer periods, e.g. due to prevailing cold weather. Hence, the discussion on demand response must be divided into two phases:

- How end users utilise their potential flexibility in *existing* equipment;
- How end users make decisions when acquiring or installing new equipment.

This is further discussed in chapter 1.2.2.

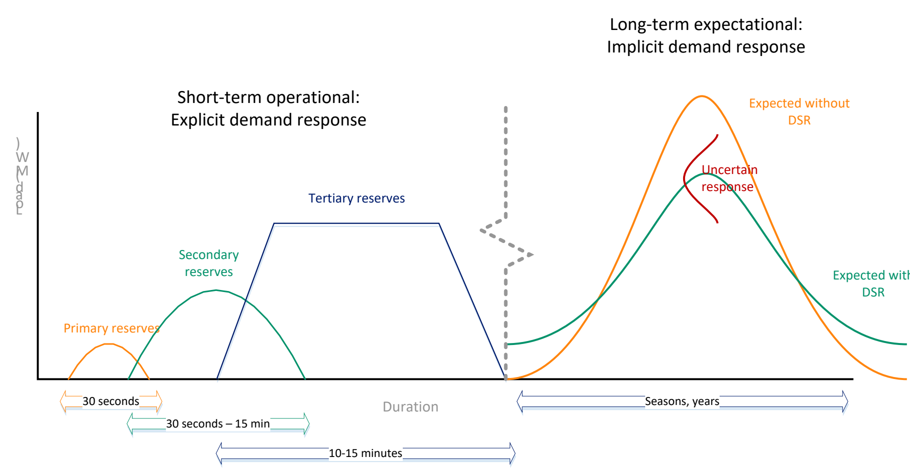
1.2.2 *Flexibility characteristics*

Flexibility can be characterised in terms of mobilisation time, duration and volume. Mobilisation time can range from less than seconds to minutes or hours. Duration could range from seconds to days or even weeks, and volume could be anywhere from kW to many MW.

Existing markets for flexibility typically concern *explicit flexibility*, i.e. flexibility that can be mobilised on command by the system operator. Examples of existing products are primary, secondary and tertiary reserves, all required to keep real time system quality and stability in place. In contrast, *implicit flexibility* is based on customers' response to price signals, where the system operator does not have direct control on availability, mobilisation time or volume (SEDC, 2016).

Figure 5 illustrates the main characteristics of explicit and implicit flexibility reserves.

Figure 5: Main characteristics of flexibility



For handling a real-time capacity restraint, explicit flexibility is a necessity. However, implicit flexibility may reduce the need for explicit flexibility over time, as well as reduce the expected dimensioning capacity requirement. Currently, explicit flexibility is offered by generators and large industry and traded on TSO organised marketplaces. Today, DSOs are not participants in these markets. The question of the DSO role in system operations and use of explicit flexibility markets, as well as system services market design, are important and challenging issues but outside of scope for the questions we address in this report. Nevertheless, we include explicit flexibility in the discussions below, as it is potentially important for future end user behaviour.

Implicit flexibility will always have an uncertain response. Incentives for implicit flexibility may take several forms; e.g. price signals, technical requirements for new equipment, information campaigns etc. In particular, price incentives may affect normal behaviour in such a way that end users tend not to use their full capacity. However, there is no guarantee that it will actually happen when flexibility is needed in the system. While explicit flexibility provides the system operator with a tool to handle short-term situations, implicit flexibility provides the grid owner with an option to postpone capacity expansions.

The same physical measures at end user level may provide both explicit and implicit flexibility. Automation systems may be linked to respond to price signals, or they may be remotely controlled by an aggregator under agreed limits and circumstances. Hence, the nature of the flexibility is depending on the contractual setting, rather than the underlying, physical flexibility in itself. However, only explicit (controllable) flexibility satisfies the need for predictability for system reserves.

With reference to chapter 1.2.1, the main household sources of flexibility with regards to explicit and implicit flexibility are summarised below. By down-regulation we mean reduced demand, while up-regulation is increased demand.

Table 2: Main possible household sources for explicit and implicit flexibility

Source	Explicit flexibility	Implicit flexibility
Heating (and cooling) system	Suitable for down-regulation for shorter periods, up to hours	Price signal to trigger substitution with other energy carriers, or to flatten demand curve over the day.
Household appliances	Limited flexibility, except refrigeration that can provide down-regulation	Flatten demand curve with systematic shift in time-of-use of wet appliances
Local generation of electricity, like PV systems	Limited capability, may up-regulate (reduce generation)	May increase need for flexibility, but also reduce long-term need for capacity depending on technology
Local storage, hot water or electricity (batteries)	May shift load from hours up to days. May provide both up- and downregulation	Flatten demand curve for all usages (el or heating hot water)
Transportation, i.e. electrical vehicle (EV) charging)	Suitable for down-regulation, may provide up-regulation (cost issue)	Flatten demand curve with controlled charging behaviour

Heating and cooling systems are slow loads, and may be switched off for periods from minutes to (a few) hours without significantly affecting comfort. While electricity usage for heating in households varies significantly between the four Nordic countries, cooling is in most instances electrical. However, cooling machines in households are relatively rare, except for heat pumps. Further, cooling is a summer load, when distribution grids normally have substantial free capacity.

For *explicit flexibility*, remote control to switch off electrical heating is possibly a significant source for down-regulation of demand. If alternative (back-up) heat sources are available, down-regulation can extend over longer periods of time, i.e. days or weeks. If electricity is the only source of heating, down-regulation time is limited to a few hours at most. In most households, this is likely to be the dominating situation.

For *implicit flexibility*, price signals can lead to substitution of electrical heating with other energy carriers, like district heating, heat pumps etc. Substitution in itself does not create more flexibility, rather the opposite: The less volume of heating supplied by electricity, the less short-term (real-time) flexibility will be available in absolute terms. However, substitution will contribute to lower peak load demand for electricity over time, all other things being equal.

Price signals may also lead to changed consumption patterns. In the absence of load-based price signals, end users do not have economic incentives to reduce other loads at typical peak hours, like turning the water boiler off when other heating or equipment load is high. Systematic changes in behaviour will have a similar impact on peak load as substitution, albeit possibly less certain and without the same reduction in electricity consumption in MWh.

Household appliances and equipment in general use little energy, and are becoming ever more energy efficient. However, as appliances are becoming more intelligent in the sense of "internet of things", automated load management would be possible. Cold appliances are especially suitable for within-day load shifting. However, with modern refrigerators and freezers consuming less than 300 kWh per year (approx. 150 W), the aggregate potential for flexibility is obviously limited. For a typical small family home with electrical heating, cold appliances would account for 1-2% of at total peak load requirement of 8-10 kW. For buildings with other heating, peak demand is 3–4 kW and cold appliances could account for up to 5% of total load (Pöyry, 2017). Within appliances, cold appliances account for approximately 23% of energy consumption and possibly similar share of load requirement (Xrgia, 2011).

Wet appliances account for approximately 14% of total household appliance energy consumption, and a higher proportion of load. Typical load for washing machines is 2 kW, and driers 1kW. Using wet appliances at night would be a source of load shifting; however, there are also concerns about fire safety when using wet appliances unattended.

Technological development in itself contributes to lower peak demand for most appliances. There are two distinct exceptions:

- Inductive cooking has higher power (25A instead of 20A fuse on 230V) than traditional cooking;
- Tankless water heaters that range from 10–30 kW for small house application.

Both these technologies contribute to energy savings, but have significantly higher load than traditional solutions. Also, cooking and hot water consumption was found to have little flexibility in (Drysdale, 2014). However, both cooking and hot water have short duration time and low diversity factor. Consequently, these technologies are likely to have little impact on load profiles on HV grid level, but may significantly impact capacity requirements on LV level. This is especially the case in the Norwegian 240 V LV system.

In summary, appliances have limited volume and flexibility to contribute to *explicit end user response*. The aggregate load is relatively low, and much of the consumption is time critical and therefore not flexible. Cold appliances appear to be the only relevant source for explicit flexibility. However, for *implicit response*, appliances may be significant in the sense that consumers avoid investing in load-demanding appliances like tankless water heaters, and systematically shift load from day to night for wet appliances.

Local generation of electricity, like PV systems, are generally without much regulating capacity unless a separate storage system is installed. For households, the current technology of choice would be PV. For a typical installation, the PV system would cover up to the annual electricity consumption of the building in question, and would (in the absence of a battery) export electricity to the grid in surplus periods.

PV systems can down-regulate generation (equivalent to up-regulation of demand), but without (or with full) batteries at the cost of lost production. In most Nordic regions, peak load is during winter when PV production is low. Reducing PV generation as an *explicit flexibility* reserve would be relevant only where PV export in summer exceeds the winter demand in MW. As a source for *implicit flexibility*, PV may have value in areas where summer cooling demand represents the annual peak. In general, flexibility from distributed generation in itself is limited. However, if PV system concentration in certain areas is high, explicit reduction of PV generation may be relevant.

Local storage, hot water or electricity (batteries) may be combined with local generation of electricity, but this is not a prerequisite. Electricity from the grid may be stored in batteries, or used to increase water temperature for heating or hot tap water. Obviously, batteries or water storage used by PV systems during the sunny seasons may also be charged from the grid during winter, and thus provide flexibility over the day during the winter season.

Storage in batteries can provide both explicit up- and downregulation for electricity, while hot water storage requires a water-borne heating system and is most suitable for up-regulation. Hot water storage would often be installed in conjunction with heat pumps, allowing electricity demand to be shifted from normal peak hours to off-peak running of the heat pump.

Battery technology is still expensive, but recently commercial solutions like Tesla Powerwall have come into the market. Current specifications are storage capacity of 14 kWh and maximum discharge at 7 kW (Tesla, 2017). Consequently, batteries are already able to supply flexibility in the magnitude of a small family home max load. Current investment costs are around EUR 900/kW, but battery storage costs are expected to fall significantly the next few years while performance improves.

There is little doubt that batteries represent the technically most efficient source of end user flexibility. It can be used for systematic flattening of the load curve, as well as explicit, controlled up- and downregulation. Costs remain an issue, and batteries are so far not a significant source of flexibility.

The obvious alternative cost to batteries is grid capacity investment. Based on Pöyry experience and assessments done in conjunction with capacity tariff studies, new grid capacity costs in the order of EUR 1,000–1,400/kW. However, as the expected lifetime of grid assets is 40 years or more, the investment per kW for grid and batteries are not directly comparable. Based on the current cost of batteries, battery storage solutions will on average be at least 50% more expensive than grid expansion. However, in locations where the load is low and the grid is more expensive per kW, battery storage is already a viable option. From DSOs, we have heard examples of grid expansion projects that could be postponed with installing as little as 80 A battery capacity. In these instances, regulatory barriers as discussed in chapter 1.5 are of importance.

There are numerous studies on historical and expected future battery cost development. It is a common expectation that battery costs will continue to fall. In a study done by Professor Daniel Kammen at Berkley University, it is argued that there is a clear relation between R&D spending in battery research and cost development. His analysis concludes that battery packs for energy storage (and electric vehicles) will fall by approximately 40% from 2016 level to 2020 (Kammen, 2017). At this cost level, batteries would be a cost-efficient alternative to grid investments in many instances.

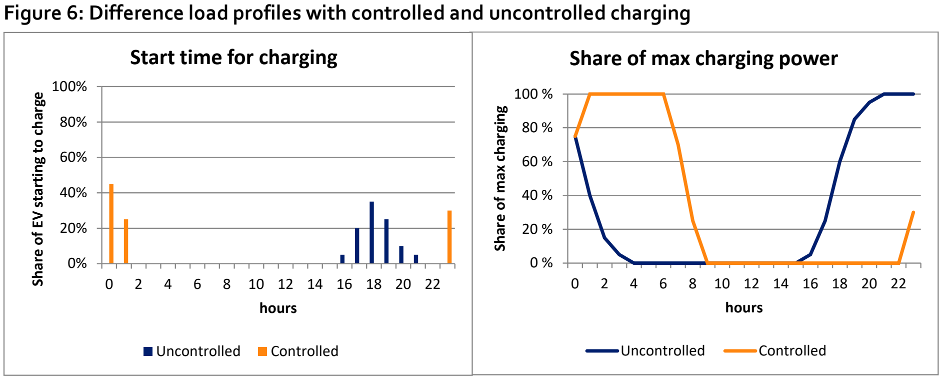
Electrical vehicle (EV) charging is possibly the most significant, new load emerging from the household sector. While charging up until now generally has been on 16A fuses, i.e. 3.6kW load, increased battery capacity and substantially longer range also imply higher charging power. High-power charging may exceed 100kW, while even at household level 10kW (32A) is becoming common (7 kW in the Norwegian 230V system). This means that EV home charging load is becoming similar in magnitude to peak winter load from a small family home.

The total amount of EVs and hence the total energy and power requirement for these cars decide whether EV charging is a substantial load contributor or not. Currently, EV charging is not important in any of the Nordic countries due to low EV car stocks. However, in the case that EV becomes a dominant technology and the stock of EVs becomes substantial, two questions arise:

- How and when are EVs charged, and can charging behaviour be controlled?
- Can EV batteries be used as a load reserve in the grid, i.e. discharge instead of charge at charging points?

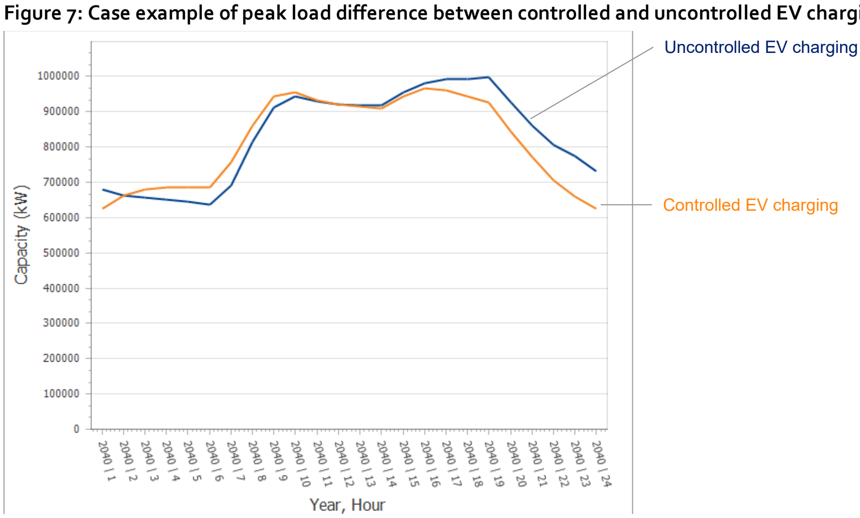
The time of charging in relation to other loads is important. In a recent Pöyry report (Pöyry, 2017), different charging patterns of home charging are analysed. The two typical patterns are uncontrolled and controlled. In the first the EV starts charging when the owner returns home from work. In the second, charging is controlled to start after midnight. In both cases, charging time is 8 hours. Representative profiles for each charging behaviour are shown below, start time for charging to the left and corresponding load profile to the right.

Figure 6: Difference load profiles with controlled and uncontrolled charging



With a normal load curve with peak in the morning (around 8–10am) and early evening (5–9pm), uncontrolled charging will very likely increase the peak load and potentially trigger grid capacity investments. In contrast, controlled charging may use free grid capacity during off-peak hours. A case example from one of the larger Norwegian cities illustrates this point. In a forecast with anticipated substantial EV sales up to 2040, the car stock in 2040 consists of more than 50% EVs. Forecasts are run in two EV charging behaviour cases; uncontrolled and controlled. The total load demand curve represents all electricity demand on the coldest day (dimensioning temperature), close to 1,000 MW (Pöyry, 2017).

Figure 7: Case example of peak load difference between controlled and uncontrolled EV charging



In this case, uncontrolled EV charging gives a new dimensioning peak load demand in the evening, about 50 MW (5-6%) above the peak load with controlled charging. As the case is drawn from a Norwegian city, the share of electrical heating is high compared to the other three Nordic countries. Hence, the relative impact of uncontrolled charging would be significantly higher in the other three countries in the same case forecast.

If EVs become a dominant transportation technology, load management of EV charging will possibly be the single most important demand side response issue. The typical private car runs around 15,000 km per year, or around 300 hours, leaving more than 8,000 hours available for charging. It is also fair to assume that the household utility or comfort loss from controlled charging will in most cases be negligible.

We would conclude that EV charging is one of the most attractive and easily achievable DSR areas, not least given that EV market penetration is in its infancy and adequate control technology can be (and to a large extent is) introduced at an early stage.

The other main issue concerning EV demand side response is using the EV battery for discharge to support the grid, so-called vehicle-to-grid (V2G) models or even EV virtual power plant (VPP). The idea is that EV batteries can supply grid support and even energy during critical periods. While a stationary Tesla Powerwall can supply 7kW, max output from a Nissan Leaf EV battery is over 90kW (Electric vehicle Wiki, 2017). Hence, relatively few EVs could potentially supply significant loads in the distribution grid. There are, however, both some behaviour and cost issues that complicate the picture.

First, owners buy EVs to use them for transportation, often time-critical and sometimes unplanned. Finding a discharged car in the morning is obviously not attractive to the end user. Defining rules around the use of EV capacity for grid purposes is clearly possible, but may be rather complicated. Further, even though an EV battery may have very high output (Nissan Leaf battery package can supply 90 kW), the LV grid at household level will not be dimensioned for anywhere near that output, at least not in small family homes. Intake in apartment blocks may be more suitable, where EV charging is located in common parking spaces near the substation. In any case, dimensioning of the actual charging points must be increased for systematic discharge systems to be possible. This is predominantly a cost issue.

A second concern is the reduction of EV battery lifetime. A battery's lifetime is related to the number of cycles of charge and discharge. Using the battery pack actively for grid support clearly reduces the usable lifetime for the EV before the battery pack needs to be replaced. Tesla CTO, Jeffrey B Straubel, states that the degradation cost to EV owners is very high (Shahan, 2016) and that he has no belief in the V2G concept "perhaps ever, but certainly not in the near term". In addition to degradation costs, he also points to the additional grid capacity costs as well as system costs to manage a V2G system. The same arguments would apply to an EV-based virtual power plan (VPP) model.

In the best of cases, V2G or EV VPP models seem very distant. However, a simpler hybrid model may be more realistic, where EV owners use their charging point and battery for local load flattening only. Simple, local power management systems could switch off EV charging while wet appliances or cooking is using power, or even supply load when using a tankless water heater. Being inside the end user main fuse, additional grid capacity costs would not be an issue, but degradation costs to the battery would still be relevant.

In summary, the most interesting potential DSR from EV seems to be on charging control. Active use of the battery pack seems distant at best, and also raises a range of complications of both technical and behavioural nature.

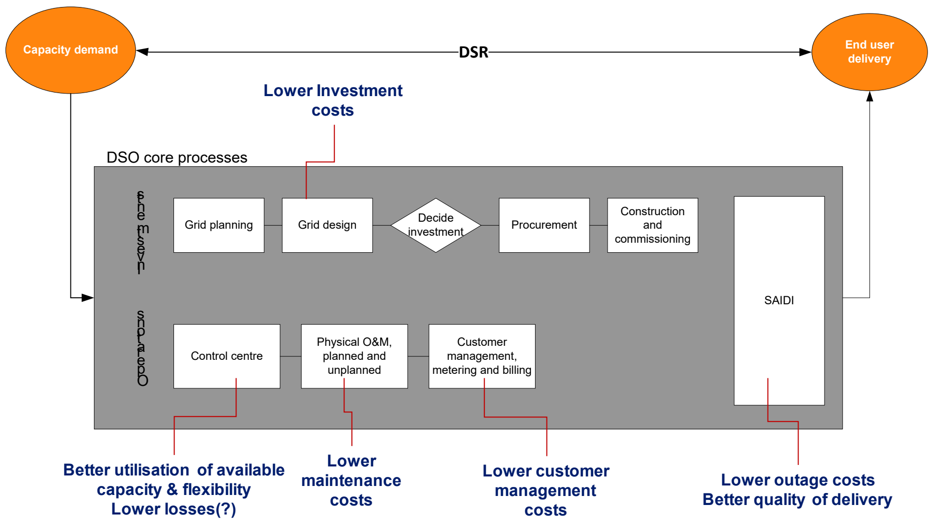
1.2.3 DSO value from DSR

Demand side response does not have any value in itself, unless it leads to resource savings or quality improvements in the electricity system. In this report, we focus on DSO benefits, but DSR may also have benefits for system operations at TSO level, as well as for generation. As stated before, value from DSR in relation to organised system services markets is not covered in this report.

The DSO value chain incudes two main processes: Asset planning and management (investments), and Operations planning and management. There are obvious links between the two: the design and capacity of the grid clearly affects operations. The capacity demand is determined by end user needs and behaviour, meaning that DSR is an important part of both the Asset and Operational processes.

In Figure 8, the main, potential DSO benefits are related to the different activities in the value chain.

Figure 8: Areas of potential DSO benefit and value from DSR



Investments are required both to meet the anticipated, dimensioning load over time, and to provide sufficient system reliability in the form of physical capacity reserve, so-called N-1. This means that the system will have alternative capacity in case of a possible outage in the system, e.g. alternative routing possibilities. Both purposes drive DSO investment costs. Hence, the main benefits from demand side response are linked to either systematic flattening of the demand curve, or to cheaper solutions that provide system reliability other than building redundant networks.

Distribution grid is capital intensive and capital costs (return on capital and depreciations) make up for a substantial share of total DSO costs. On average in Norwegian DSOs, capital costs at book value account for 42% of total costs (NVE Income cap, 2017). It is reasonable to assume that the cost structure is similar in the other Nordic countries. Over the last years, investment levels have increased substantially, and the capital cost share in DSOs is likely to rise.

Investments can broadly be categorised in two:

- Reinvestment, replacing existing assets without significantly increasing capacity or other technical characteristics;
- New investment, building new assets or replace and significantly increase the capacity in existing assets.

From an economic point of view, existing assets should be replaced when the marginal operating expense, including quality and outage costs (SAIDI), exceeds the replacement cost. In general, DSOs and their customers will gain economically by postponing the replacement time as long as possible.

If capacity demand exceeds the existing capacity, expansion often involves both new investment and early refurbishment before the normal, expected lifetime of existing capacity.

The common view is that postponement of investments has significant grid value. This view is supported by several studies, e.g. (Schachter, 2016). This UK based study shows that the option value of postponing investments using DSR is substantial. Two Norwegian studies, one report on dynamic tariffs (Kanak AS, 2012) and work for analysing the impacts of load tariffs for two Norwegian DSOs in 2014–2015 (Kanak AS, 2014) reach the same conclusions on both a quantitative and qualitative basis.

In the two latter studies, postponing capacity expansion at sub-station and low voltage grid level is found to reduce overall network costs in the order of 5–7%. In these studies, the analyses were made based on real, hourly-metered data at end –user level, and physical location of each end user linked to individual sub-stations and low-voltage lines. The potential flexibility of each individual end user was estimated based on the end user's duration curve (kWh/kW). In order to determine the urgency of capacity increase investments, actual peak load on individual sub-stations and low-voltage grid sections was used. The cost saving was calculated based on marginal investment costs for a realistic, step-wise capacity increase.

One interesting finding in these two studies was that a substantial network cost saving could be realised with access to flexibility from less than 10% of the total end users. Information we have been shown from other Norwegian DSOs supports this finding: Releasing flexibility from a very limited number of end users enables the DSO to avoid new capacity investments. This finding has implications for how incentive design could be more effective: Targeted incentives may yield much better results at a lower cost than general incentives. Obviously, introduction of targeted incentive schemes also has a regulatory side; this is further discussed in chapter 1.5.

The potential saving is linked to deferring investments rather than reducing the capacity expansion once a decision is taken. Down-scaling is broadly regarded to have limited economic value. The arguments are that the civil works and engineering part of grid capacity expansions are unrelated to capacity and makes up for a large share of total investment costs. Further, especially for overhead lines and cables, equipment costs for increments of capacity are rather low, while transformers and substation costs are quite proportional to capacity (see (Kanak AS, 2012), p13).

Hence, the option value of building some excess capacity once a decision is taken is most probably high, and downscaling capacity in new investments due to anticipated DSR would be less relevant. An additional argument is the risk aspect; while expected lifetime of grid assets are at least 35–40 years, estimating the impact of DSR over the same period would be speculative at best. In contrast, *deferring* reinvestment and capacity expansions in existing grids is a continuous option evaluation.

Real time grid management concerns issues like balancing, the stability of the system (frequency, voltage etc.), congestion control as well as optimal grid utilisation in order to minimise losses (EDSO, 2014). Explicit demand response can contribute with both up- and down-regulation (although demand down-regulation is the most obvious), and some potential sources can respond on very short notice given adequate control and automation systems.

System operation is a TSO responsibility. DSO grid control typically involves congestion management and local load control including thermal excess load. In addition, DSOs will handle local outages or network failures, utilising redundancy in the network (N-1) to maintain power supply. An example of DSR that has been in operation for a long time, is interruptible contracts with end users are also used for the same purpose.

While systematically flatter load curve can provide a basis for deferring or reducing investment levels, real-time demand response can in principle replace investments in redundancy in the network without reducing security of supply, or supplement network redundancy to improve security of supply.

In a Danish report exploring the development of a DSO market for flexibility services (iPower, 2013), a number of different, possible flexibility products are discussed. The products range from planned outage to very urgent situations. The report discusses the value of various products, which is linked to the alternative cost for the DSO to provide the same service. The alternative value may be either the cost of buying the same service from traditional flexibility providers (e.g. generators), or by investing in more grid assets. In both cases, the alternative cost is observable – at least to a reasonable degree. Increase of distributed generation may increase the value of local DSR, as grid capacity between traditional flexibility providers and the local grid may be insufficient and grid investments are required to access flexibility from more remote sources.

The case of using demand side response to secure real-time system operations and redundancy at distribution grid level is significantly more complex and critical than the case of adapting and deferring grid capacity investments for normal situations. The costs to society of system failures are high, and a very high degree of reliability must be achieved in order to rely on demand side response instead of physical redundancy in the network. Any benefit would depend on whether or not the total cost of supplying, but the alternative costs from traditional flexibility providers may or may not be higher than DSR.

DSOs do not currently use the ancillary markets organised by the TSO to provide explicit flexibility in the system. However, to avoid additional investments in a future system with significant distributed generation, use of local DSR can be a cheaper and more efficient solution than expanding redundancy through grid investments. However, local or regional system services markets raise a number of complex questions, including the complexity of (i) organising aggregator models to achieve sufficient volume, (ii) organising well-functioning marketplaces for DSR flexibility, and (iii) design system operation responsibilities and roles between TSO and different DSOs when using DSR flexibility; all represent complex issues that need to be resolved in order to make DSR accessible and useful in real-time DSO operations. These issues are not covered in this report.

Other, potential benefits to the grid include reduced losses, reduced maintenance and better security of supply. However, these benefits are not directly related to DSR, but rather a co-benefit from increased instrumentation and automation.

In a work published by Chalmers, a reduction in technical losses ranging from 0.6% to 13.4% due to DSR was demonstrated (Andersson, 2016). As losses increase by the square of load within a given grid system, load reductions will give a high, marginal benefit in terms of loss reductions. The value of technical losses is a function of the power price. In the Norwegian distribution network, losses make up for 7% of total network costs. Based on the result from Chalmers, active use of DSR for reducing losses would have a potential well below 1% of network costs.

The impacts on operation and maintenance costs as well as SAIDI and customer management costs are more indirect, and not depending on use of real-time flexibility from DSR. Introduction of DSR services is likely to lead to a higher degree of automation and instrumentation at end-user level. Smart meter installation is a case in point, valid for all end users. Access to more information about the grid will contribute to a number of potential, operational benefits. Smart meters and other grid and demand related data will improve the access to real-time or near real-time data:

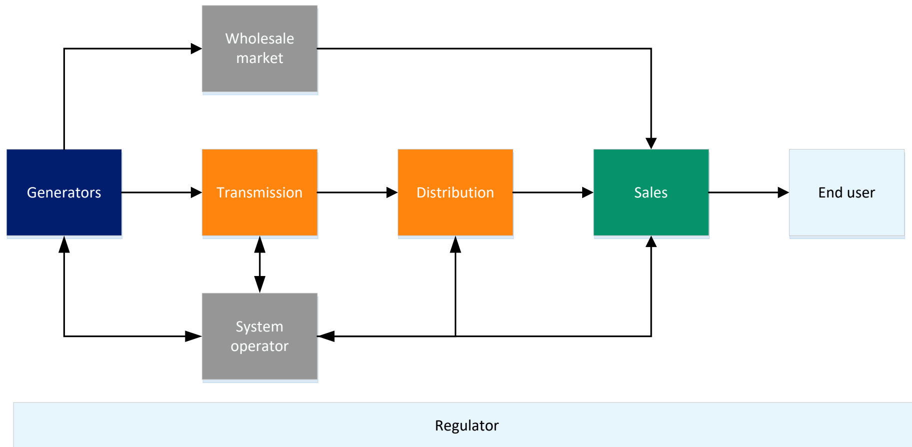
- Better data on grid utilisation will give the DSOs additional tools to improve evaluation and prioritisation of grid maintenance.
- More detailed, real-time data enables faster location of faults, lower repair costs and lower outage costs (SAIDI).
- Better customer information reduces the manpower need for customer management.

Operating costs (including salaries) account for approximately 45% of total DSO network costs, and savings in maintenance work and manpower could potentially reduce network costs significantly. We have found concrete references to studies on potential savings; however, the potential is likely to be significant.

1.3 Models for mobilising demand side flexibility

The prevailing electricity business model is to a large extent a one-way street. Large, centralised generators sell their production in the wholesale market, electricity is dispatched, transmitted and distributed under the control of the system operator, sales companies buy wholesale and sell to end users. System services and balancing power are mostly supplied by generators and a few big industry customers, and financed via the grid tariff. The regulator sets rules and oversees compliance.

Figure 9: Simplified value chain of traditional business model

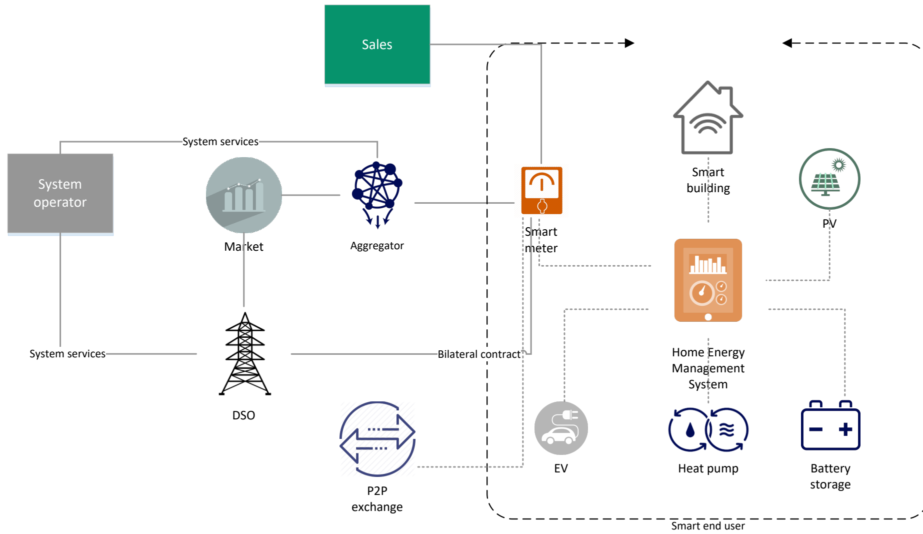


The traditional business model is challenged for several reasons:

- First, the growth of distributed generation shift electricity feed-in from the transmission grid to the distribution grid;
- Second, most renewable energy generation cannot be regulated, thus increasing the need for flexibility elsewhere in the system;
- Third, digital technology enables unprecedented information access and control and management systems down to end user levels;
- Fourth, new consumption like EVs create both new demand for and access to flexibility.

In summary, both growth of distributed generation and technological development of digitalised solutions are driving forces to shift the focus downwards in the value chain. Consequently, there are good reasons why the end user part of the value chain will grow in importance. Based on results from IEA DSM task 17 (IEA DSM, 2016), the future value chain can be illustrated as shown in Figure 10.

Figure 10: Illustration of future end-user oriented value chain



Source: EA DSM task 17 (2016).

Today, the end user purchase grid services from the local DSO, and power from a sales company. With the developments listed above, the future end user may:

- sell surplus power to the grid;
- store own-produced electricity for own future consumption, or to flatten demand curve;
- sell flexibility directly to the DSO or an aggregator;
- sell power on a peer-to-peer (P2P) basis to neighbours;
- develop virtual storage in neighbourhood networks; and
- possibly many more opportunities that will emerge.

End users will face a complex situation with many options on what investments and decisions to take, and how to utilise those options. Bearing in mind that household end users are non-professional in all of these issues, there are two crucial questions to address on what models to use for mobilising demand side response:

- How can household end users be incentivised to make their flexibility available?
- What new business models and roles are needed to mobilise and operationalise demand side response?

1.3.1 End user incentives

From chapter 1.2.3, one can conclude that there is a significant potential for network cost savings from utilising DSR. However, from the end user perspective, this is of limited direct interest, and is unlikely to incentivise any action that promotes DSR. In order to actually mobilise DSR, one needs to understand the direct benefits to end users from providing flexibility.

DSR depends on different forms of automation and digitalisation being installed, as well as changed behaviour from the end user. Installing new equipment at end user level incurs costs at end user level. To justify these costs, the end user may see value in three areas:

- Financially, in the form of direct payments or reduced costs, for example on grid tariffs or on reduced energy consumption;
- Increased comfort, that are of subjective value to the end user in the form of a more well-functioning home;
- Increased security, which could be alarms or surveillance, health monitoring etc.

Without exploring this issue further in detail, we point out that identification of real benefits to the end users, other than financial, are likely to be very important both in terms of incentive design and future business models. Keywords could be comfort, automation, social responsibility, and exploration for early adapters (IRGC, 2016).

Many of the installations that are required for DSR services will also – fully or partly – be used for covering other needs for the end user. For instance, an energy management system designed to shift load will also provide a platform for energy savings or for increasing comfort. The communication platform in the energy management system can also be used for security products. Hence, there is a dependency between different stakeholders and service providers to jointly (and possibly independently) provide sufficient incentives to end users to actually install the required equipment and systems at home, and to start using them.

From the network side, much of the focus for end user incentives is on pricing models and price signals. Nevertheless, from our discussion with various stakeholders, the DSO role in making the necessary infrastructure available to third parties through smart meter and communication platform installations is a very important prerequisite for other business operators related to end user flexibility and energy management. This role, in addition to making relevant data available for third-party suppliers, is said to be crucial for mobilising end user interest and actions.

Limited by concessions, regulations and neutrality restrictions, the DSOs have a more limited set of available instruments and incentives towards end users than commercial stakeholders. The main instruments are grid tariffs and other direct, financial instruments, while services related to energy savings, comfort and security are outside of DSO scope. Hence, DSOs can be concerned about two issues:

- How should the price signal be communicated in order to produce desired DSR, and how strong will it need to be?
- How can the tariff be designed to optimise the potential grid benefit, so that DSR happens at times that are of value for the grid?

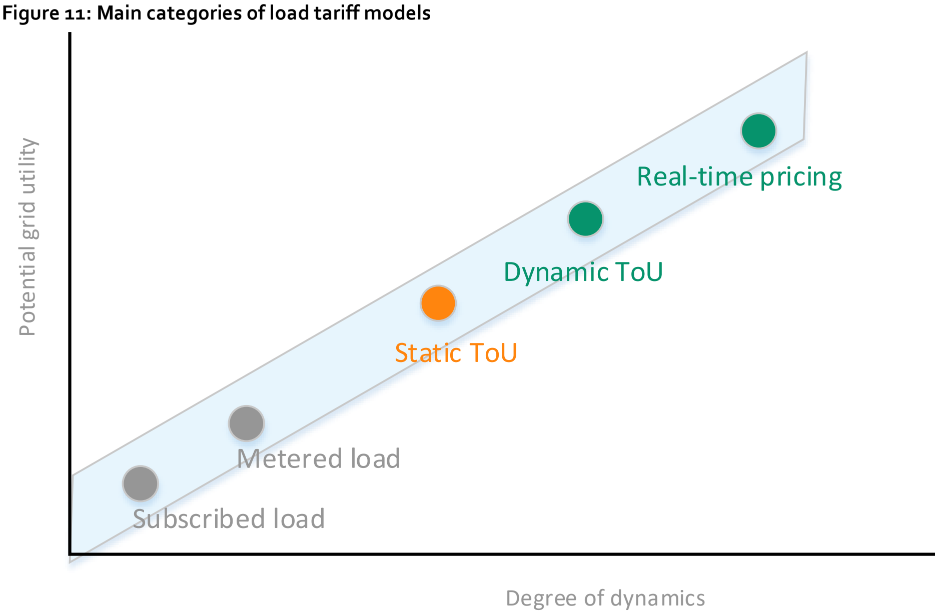
From the end user perspective, it does not matter whether demand response is useful for the grid or not – the end user reacts in what he finds is an appropriate way to the price signal, period. In that regard, it is the strength of the price signal that determines whether a tariff produces demand response or not. There are a few studies on this topic, but the majority of price sensitivity studies focus on energy price elasticity. These generally show that the demand for electricity is very inelastic. However, load shifting is different: Even significant load reductions can be realized with very small changes in energy consumption. In a typical small family home heated by electricity, a winter peak load shifting of 20% can be achieved by moving as little as 1–2% of that month's energy consumption.

Financial incentives will have to reach a certain level in order to motivate end users. There is limited research done in this area. A customer survey conducted by Norwegian DSO Skagerak Energi in 2012 indicated a minimum level of NOK1,000 (EUR 100) per year, a study in Finland (Annala, 2015) concluded with an amount in the same magnitude, depending on the type of load control. This study also found a relatively high willingness to provide demand side response and allow remote control of electric appliances that does not require changes in the everyday routines.

A small family home will typically have an annual consumption between 10–20,000 kWh (depending on heat source) and an annual, pre-tax grid tariff of approximately NOK 3–6,000 (EUR 300–600) per year. Given typical grid tariff costs, this means that a household customer would expect to save 15–30% on their grid tariff bill in order to focus on end user demand. Savings in this magnitude may be challenging to realise from tariff payments alone. However, combined with co-benefits in terms of energy savings, increased comfort etc. originating from other areas than payment for flexibility, annual savings in this magnitude appear much more realistic.

The most important design element for load tariffs is the relation between the system load and the individual end user's load. The more closely related the tariff is to the system load, the more likely it is to produce demand side response that is of value to the network. While there are a number of tariff design element details, the main tariff models and their impact on potential grid utility are illustrated in Models with subscribed and metered load have no direct relation to system load. However, they are relatively easy to understand for the end user, and there is a direct connection to load shifting measures that the end user can do in his own house. However, analyses related to load tariff design from DSOs at Hvaler and Ringeriks-kraft show that a customer-related and static tariff has low accuracy in giving price signal and load shifting that can be of value to the grid (see chapter 1.2.3).

Figure 11: Main categories of load tariff models



Static time-of-use (ToU) is a widely used model internationally. While the load is end – user specific, the tariff follows a normal grid capacity utilisation profile, so that the tariff is high at normal peak load times.

Dynamic tariffs (dynamic ToU and real-time tariffs) vary with actual system load rather than a normal profile, and are therefore closely related to actual system needs.

In an EU report on DSR (EC DG Energy, 2016), the past experiences from various forms of time-of-use (ToU) or load tariffs are discussed. Despite widespread use across Europe, there is limited evidence on how tariffs actually contribute to demand side response. In the Nordic countries, ToU tariffs have been most commonly used in Finland. As for other countries, France, UK and Germany are the most prominent cases. However, as digitalisation and smart systems are only recently becoming available in the market, the absence of past experience from price signals may be of limited relevance.

There is one prominent exception. The French Tempo tariff has been in place since the early 90s, and is an advanced dynamic tariff scheme with peak pricing determined by anticipated system requirement. The price difference between peak and off-peak prices is approximately 1:6. Studies of the Tempo tariff show that end users substantially shift consumption under peak prices, ranging from 15–45% shift. Average load reduction per household is 1 kW. The tariff is voluntary, and some 20% of end users (households and commercial) subscribe to this tariff. Shift in national load due to the tariff is estimated to be 4%.

The experience from France shows that households are willing to shift load due to price signals, and that the price model can be complex and sophisticated without "losing" the customer response. To what extent end users are willing to make investments in energy management systems, storage, and other physical measures that can provide flexibility is another question. It is likely that such investments will not be made on the basis providing flexibility in return for lower grid tariffs alone, nor will end users be motivated by economic gain alone.

A key issue is the interaction between end user tariff acceptance and the offering of automation or direct load control. A study on tariff acceptance in the UK (Fell, 2015) analysed a range of demand side response tariffs and how different solutions for direct control and automation affected end user acceptability. The results show that static ToU has high acceptance around 25–30% of respondents. The more complex dynamic ToU (similar to the French Tempo tariff described above) shows significantly lower acceptance. However, acceptance of dynamic ToU tariffs increased to the same level as static when automated response was introduced. Also, surprisingly and in contrast with other studies, the results show a high acceptance for the principle of direct control.

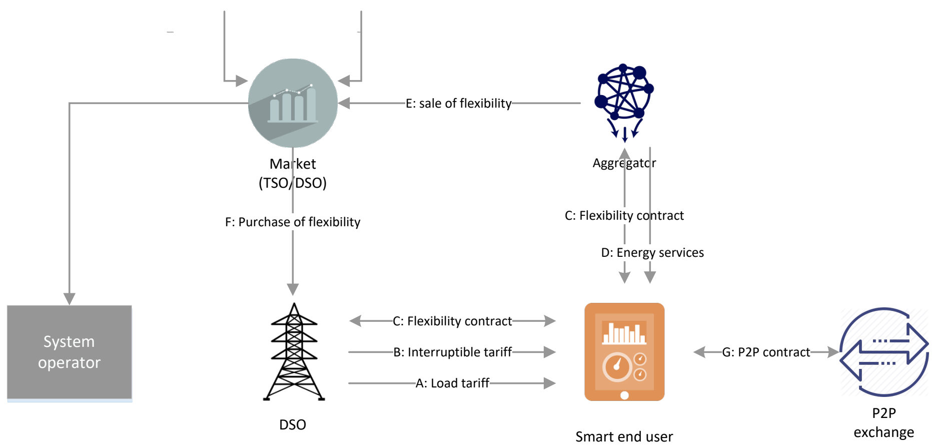
In summary, there is strong evidence that price signals, also in complex dynamic ToU tariff models, have high acceptance and affects end user behaviour. The presence of automated response appears to be very important. The on-going introduction and general instalment of smart meters, HAN interface (allowing third part access to smart meters), internet of things (IoT) and other digital platforms like communication via smartphones, all contribute to strengthen the role of automation. In addition to increasing the acceptance and impact of price signals, automation also enables the introduction of direct control through direct contracts or via aggregators in new business models.

1.3.2 New business models

With reference to Figure 10, there are three or four relevant counvterparts to the end user in a demand side response business model. These are the DSO, existing electricity retailers, new entrants like Smart Energy Service Providers (SESP), and possibly peer-to-peer (P2P) models with no intermediary between different end users. Both retail companies and new entrants can take the role of aggregator.

Figure 12 illustrates different demand response measures and business models, and the roles and parties involved. Generators and industry as suppliers of flexibility are included for completeness only.

Figure 12: Illustration of different demand response measures and business models



The measures indicated in the figure are not mutually excluding, on the contrary they may reinforce each other in innovative business models. In an IEA study on new business models (IEA-RETD, 2012), three different types of business models are identified:

- Product-Service-Systems or Energy Contracting Models, e.g. Energy Performance Contracting – Indicated as "D" in Figure 12;
- Business models based on new revenue models, like sale of flexibility products – Indicated as "C" in Figure 12;
- Business models based on new financing schemes, e.g. leasing of renewable energy equipment. This could be combined with "D" in Figure 12.

In addition to the above, development of more advanced digitalisation and innovative transaction systems alike Blockchain may enable P2P models – indicated as "G" in Figure 12.

The fundamental value proposition is important to the viability of any of these business models. Without elaborating the issue of socio-economic, sub-optimal solutions, we point to the importance that price signals reflect actual, underlying cost structures. Otherwise, demand response would lead to redistribution of costs only, rather than real socio-economic gains.

Several parties are directly or indirectly involved in creating new business models. All relevant business models depend on end users actually installing smart systems in their homes. Without sufficient economic incentives and gains, it is hard to envisage a market break-through of smart home solutions. The underlying potential value includes, but is not limited to, network cost savings. Smart homes can shift load, use energy more efficiently, increase comfort and provide security or health services that are of value to end users.

With a DSO perspective, there are two main categories of business models. The first is where the DSO has a direct end user relationship and role in the model. The second where the DSO utilises intermediaries to access demand side response.

Direct models include A, B and C in Figure 12. Model D, E and F include intermediaries and marketplaces. Model F includes neither DSO nor intermediaries, only end users.

In Table 3, the main value propositions, key responses and type of response are summarised.

Table 3: Main characteristics of different business models

Model	Value proposition	Key responses	Outcome	Presumed impact
A: Load tariffs	Flatten long-term growth in demand Flatten demand curve	Behaviour changes Installation of energy management systems Heat system conversion, energy efficiency Storage (PV)	Implicit response	Significant long-term price signal affecting end user behaviour and new installations Weak short-term impact due to low, short-term price elasticity Significant contribution to 3rd party market development
B: Interruptible tariff	Real-time operational benefit	Back-up energy source	Explicit response	Direct control in real-time congestion situations
C: Flexibility contract	Real-time operational benefit	Controllable, energy management system Utilise existing and invest in new flexibility	Explicit response	Direct control, similar use as (B) Direct purchase of flexibility instead of using 3rd party driven market (E)
D: Energy services	Reduce overall energy costs Load tariffs (A) increase underlying value	Installation of energy management systems Behaviour changes Heat system conversion, energy efficiency Storage (PV)	Implicit response	Smart energy management concepts, where load control is one element for savings Impact long-term demand development May also include direct control (C)
E: Flexibility markets	Economies of scale Make aggregated demand side flexibility available to TSO/DSO	Extend existing flexibility markets to aggregators Ensure suitable balance between TSO/DSO roles in use of flexibility	Explicit response	Aggregator organising DSR into larger packages to bid in TSO (or DSO) flexibility markets
G: P2P contract	Flatten local demand curve Virtual storage Local balancing	Efficient and secure transaction system (Blockchain?)	Implicit response	End users taking direct control of transaction, no DSO involvement Long-term flattening of demand curve

Note: Models A, B and C are DSO-centric models, where the DSO has a direct end user relationship.

Load tariffs (Model A) can be designed in several ways. All of the load tariff based models have weak explicit characteristics, but in various degree provide strong, long-term price signals that are likely to flatten the demand curve. In terms of providing short-term price signals, dynamic ToU tariffs (dToU) are obviously best suited. This tariff will reflect actual system needs, and be high during periods of high system load congestion. In addition, it will provide a long-term price signal affecting systematic behaviour and end user investments. Static ToU (sToU) provides the same long-term price signal, but will be less precise with regards to short-term system requirements. A simple load tariff based on measured end user load only will have mostly the same effects as sToU.

Models with subscribed capacity, and different pricing below and above that level, will give price signals similar to sToU in the short term during peak periods. However, long-term price signals will be weakened as the end user can adapt its subscription to a new, low-price level if his systematic demand increases. Also, end users will have weak incentives to exploit possible flexibility below the subscribed level, thus reducing the overall access to end user flexibility.

Introduction of load tariffs has a significant value in creating a market for third parties, offering energy management services. This is a very significant argument in favour of load tariffs, where the DSO incentivises third parties to introduce services that are of value to the DSO.

Within the current DSO business model, introducing load tariffs is relatively simple. System adaptation once smart meters are in place does carry a cost, but commercial solutions are already available. The main challenges for the DSO are related to detailed tariff design, cost redistribution between customers and acceptance, in addition to cash flow considerations over the year.

Model B is a commonly used, current DSO model, but normally only with larger customers with dual energy sources. The introduction of smart meters and automation at household level will make it possible to introduce similar contracts with smaller users. However, the DSO may not have systems that are suitable for handling a large number of interruptible contracts. Also, there may be challenges as to offering and procurement of such contracts: as not all household end user can be part of a discount system, communication and customer acceptance may be very challenging.

On the financial side, the model only redistributes tariff cost among customers, with no income effect for the DSO. Also, the model does not increase the cost base for the DSO in the short term, as there is no payment involved for the access to flexibility, only a tariff rebate.

Model C is a DSO operated flexibility contract, in practise similar to (B) but with direct payment for the flexibility. Hence, this model will increase the cost base of the DSO. The main advantage over (B) is that procurement is simpler, as tariff regulations do not limit the pricing and procurement process. Communication to end users and end user acceptance would possibly be less challenging. However, increased cost base will increase the total tariff cost in the short term, even though targeted flexibility contracts are likely to drive down investment and network costs. Also, depending on the income regulation regime, this model may negatively affect DSO return on capital.

The main advantage with this model is that it would allow DSOs to get access to flexibility where it is needed, but without the need for tariff discrimination between customers. The main disadvantage is that the model may be administratively and technically complex and costly. Another issue is whether a DSO direct model is compatible with a market offering of the same services. Prices set by the DSO in bilateral agreements would represent a ceiling price for any third-party offering. Hence, it is likely that a DSO-operated model and a market model are mutually excluding. The regulatory sides to model C are also discussed in chapter 1.5.

Model D and E are third-part based, market-driven models

The core of *Model D* is providing smart energy performance services. The provider could be different types of companies, ranging from current retailers to energy service companies, and other new entrants like Google, IKEA etc. For simplicity, we label them smart energy service providers (SESP).

The underlying value drivers include several elements; energy savings, comfort, load management to name the most important. The value of *load management* depends on the DSO offering a kind of load tariff, where load management contributes to lower end user total energy costs. The actual measures to achieve load management include automation, backup energy supply and storage. The interface between the end user and the SESP can be set at different point – e.g., both the SESP and the end user could own automation system, storage etc.

The focal point seen from the DSO side is that the business value of Model D depends significantly on the introduction of load tariffs, particularly if the marginal capacity cost is high. Without income from load management, the business rationale for end users and SESPs to enter into energy management arrangements is weaker.

An alternative approach to third party business models is *aggregator models, a combination of Model C and E.* Aggregator models do not depend on load tariffs, but rely on a marketplace where the TSO and/or DSOs buy short-term flexibility. While each household end user does not have enough flexibility to be able to bid into flexibility markets, an aggregator can operate enough flexibility contracts to be able to offer sufficient capacity. Currently, the TSOs operate flexibility markets, but only generators and larger (industrial) grid customers are active participants. Given access, aggregators may compete in these markets, providing the underlying cost structure for making flexibility available is competitive.

The DSO will have access to flexibility services through a marketplace, where several aggregators can bid in capacity (*Model F*). For the aggregator, flexibility demand from the DSO is not required to establish aggregated flexibility contracts, as long as they are able to bid into established TSO marketplaces.

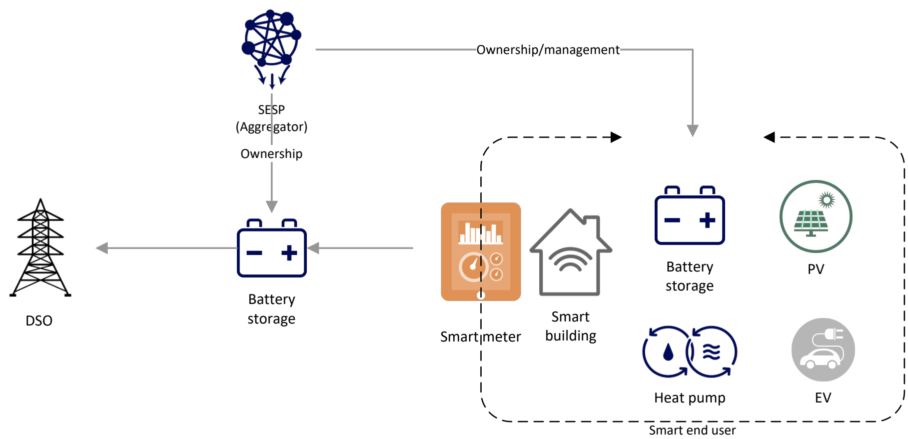
For the DSO, buying flexibility contracts adds to the regulatory cost base. Depending on the regulatory regime, increased costs may hurt financial results and return on capital. As long as model B (interruptible tariff) is available, this appears to be a simpler and less costly option for DSOs than buying flexibility in external markets.

Model F is purely consumer-centric. In its simplest form, it concerns sale of excess prosumer electricity to a neighbouring end user only. In addition to digitalisation, blockchain or similar peer-to-peer (P2P) transaction platform will be required.

While still an immature concept, the idea is that consumers make their own arrangements to flatten the demand curve in a local area, and to realise other benefits like RES integration or local system reliability. This is similar to the idea behind microgrids. For the DSOs, P2P models are similar to other implicit measures, but without the same degree of control over the design and incentives.

There are several roles the three main parties – DSO, SESP and (smart) end users could play in the business models. Roles are closely linked to ownership of the flexibility resources, i.e. the physical assets providing flexibility. Also, both the DSO and SESP could own assets outside of the end user that improves the value of demand side response.

Figure 13: Business model roles and flexible asset ownership



It is fair to assume that all end user flexibility resources are behind the end user's smart meter, which is owned by the DSO. Local assets could be owned by the end user, or owned (or financed) by the SESP. For the end user, external ownership or financing will contribute to lower risk, and one may argue that this lowers the threshold for entering into flexibility contracts with SESPs. Although covering commercial end users only, (the Energyst, 2016) provides some useful insight into well-functioning roles. Among the respondents in this study, approximately one third of respondents pointed to uncertainty of income, which in turn complicates financing of measures.

In contrast, in the absence of SESPs, the DSO-centric models A-C requires the end user to take the financial risk when installing systems or assets to provide flexibility. As all household end-users are by definition non-professional in this field, risk relief and certainty is very likely to be required in order to achieve wide-spread adoption of automation systems. SESPs will have professional capabilities with regards to risk assessment, and therefore are likely to play an important role as demand side response facilitators and players.

A secure income stream from sale of flexibility, combined with a reasonably certain cost reduction from energy savings, would ease end user investments in management systems, batteries or other flexible assets. It is also realistic that SESPs could own some of these assets, where the primary objective is to provide flexibility and energy usage optimisation.

Outside the end user domain, external battery storage may emerge as a valuable element in flexibility assets and measures. For SESPs battery storage may increase the value of end user flexibility. Also, for DSOs batteries may be a sensible alternative to grid capacity expansions; however, under current regulations such ownership is normally not allowed and may not be a generally available instrument for DSOs in the future. According to the EU winter package, "DSOs shall not be allowed to own, develop, manage or operate energy storage facilities".

1.3.3 Markets for ancillary services

Potential payments from aggregators to end users add to the financial incentives to install energy and load management systems and make other measures at home for the end user. Consequently, development of system services markets that are also open to aggregators (for instance by lowering the minimum bidding threshold into the markets) is likely to be an important enabler to achieve demand response from small end users.

One possible solution to include DSR into the system services market would be to use the existing TSO market. In this case, DSOs would not be involved in using the market, while the TSO would have more offering from possible providers of flexibility. However, in the case where both the TSOs and DSOs shall access the market and make use of flexibility, there are several options to consider. In an article from the Florence School of Regulation (Daan Six, 2017), five possible coordination schemes are identified:

- Centralized ancillary services market model: in this model, the TSO operates a market for both resources connected at transmission and distribution level, without extensive involvement of the DSO. This is the closest pattern to the traditional way of doing things;
- Local ancillary services market model: in this approach, the DSO organizes a local market for resources connected to the DSO-grid and, after solving local grid constraints, aggregates and offers the remaining bids to the TSO;
- Shared balancing responsibility model: Here, balancing responsibilities are exercised separately by TSO and DSO, each on its own network. The DSO organizes a local market while respecting an exchange power schedule agreed with the TSO, while the TSO has no access to the resources connected to the distribution grid;
- Common TSO-DSO ancillary services Market Model: the TSO and the DSO have a common objective to decrease the cost of the resources they need. This common objective could be realized by the joint operation of a common market (centralized variant), or the dynamic integration of a local market, operated by the DSO, and a central market, operated by the TSO (decentralized variant);
- Integrated Flexibility Market Model: in this scheme, the market is open for both regulated (TSOs, DSOs) and non-regulated market parties like balancing responsible parties (BRPs), which require the introduction of an independent market operator to guarantee neutrality. As a consequence, the boundaries between intraday markets and ancillary services could fade away.

The complexity of the issues raised in different coordination schemes is high. Local markets for demand response raise a series of questions related to market efficiency and neutrality, such as efficient price formation and abuse of market power. In addition, TSO/DSO coordination will have to be addressed, as demand response resources used locally will have to be coordinated with TSO system operations and use of central ancillary services markets. However, both a detailed description of the coordination between DSO and TSO, and use of flexibility for ancillary purposes is outside of the scope for this report.

1.4 Neutrality issues

DSOs are regulated, natural monopolies, and shall act as neutral market facilitators without discriminating among market participants. Also, DSOs are not allowed to be active in the power market, apart from buying electricity for grid losses and supplying end users with no retailer.

Principles for DSO neutrality are well established with regards to retail sales. The current regulations include rules on equal treatment of all retailers with regards to access to end user data, supplier changes, invoicing and customer service. Also, DSO neutrality requirements include regulations on non-discrimination between grid customers and customer groups. Finally, DSOs are subject to regulations on non-discriminatory procurement under the supply directive.

DSO neutrality is relevant for several issues concerning demand side response:

- Equal access to end user data to all relevant parties;
- Equal access to DSO procurement of services from all qualified parties;
- Level playing field between grid investments and flexibility mechanisms;
- Non-discrimination between grid customers with regards to connection and tariff terms.

The boundaries for regulated grid business are to some extent defined in current regulations, but in practise the boundaries may be difficult to determine. In relation to DSR, one may risk both that DSOs introduce activities that should be exposed to full competitions, and that limitations in current regulations prohibit sensible DSO activities.

Equal access to data is already secured in current regulations, however, the ownership and use of very detailed consumption data may cause problems for DSR business models. Data are owned by the end users, and use of those data for DSR purposes may require new agreements with each end user before data can be made available to third parties from the DSO. In contrast to current metering data, use detailed consumption data raises additional data privacy issues that are not necessarily resolved in current legislation.

As far as grid benefits are concerned, it is the DSO that makes the market for such services. As discussed in chapter 1.3.2, both DSO-centric and third party-based models are possible. The DSO may choose to enter into direct contracts with end users, or even cover their flexibility needs with interruptible tariff agreements, rather than buy flexibility from third party SESP companies. In that case, DSO-oriented flexibility markets will not exist, and the business foundation for SESP models is weakened. The DSOs preferences may be affected by the income regulatory regime, as discussed below.

This issue is raised also in ACER's white paper #3 (ACER, 2017), where the recommendations is that

> "The use of flexibility by DSOs should not be exclusive, and should allow the provider of flexibility to take advantage of other arrangements for valuing flexibility e.g. through participation in the balancing market."

In the same white paper, ACER stresses the need for granting equal access to ensure that

> "All flexibility sources should be able to participate in all arrangements for valuing flexibility whenever this participation is efficient".

The DSO has a central role in determining when participation is efficient, and when using flexibility mechanisms is an efficient mechanism instead of building more grids. In this regard, there is an obvious potential for sub-optimisation. To avoid sub-optimisation, the DSO will need to be neutral with regards to prioritisation between own investments and using third-party flexibility mechanisms. One particular concern would be where the DSO and third-party aggregators are part of the same business group. This is also closely linked to regulatory design as discussed in chapter 1.5

Under current EU regulations, DSOs and TSOs are not allowed to conduct power trading activities, except when buying power to cover grid losses: Buying electricity for storing and later selling electricity when depleting the battery. The only power purchases allowed for grid companies are those for coverage of grid losses.

Nevertheless, many argue that battery storage in many cases is an efficient alternative to grid investments, and that DSOs/TSOs should be allowed to own batteries. In a joint statement, EDSO, CEDEC, GEODE and EUROBAT calls for EU regulators to develop a clear regulatory framework that allows DSOs and TSOs both to procure flexibility services from batteries, and to fulfil such needs themselves through battery ownership (EDSO, 2017).

From a neutrality viewpoint, this is not straightforward. The joint statement underlines that the DSO should be allowed to use its own battery to replace purchase of flexibility only, and not sell flexibility. However, blocking sale of flexibility from the DSO to the TSO would be economically inefficient use of resources once a DSO-owned battery is in place. Such sales would clearly put the DSO in a competitive position in relation to third-party sellers of flexibility.

In contrast, strict regulations may also block DSOs from investing in battery storage when there are no commercial investors available, for example due to risk considerations. As a hypothetical example, consider peak demand requirement to a remote, industrial site with uncertain viability. With uncertain viability, getting either the industry itself or a third party to invest in battery storage and flexibility will be difficult. The default option is to build grid (that could be subject to claim for investment contribution from the industry, depending on regulatory framework). However, if the DSO could invest in a battery rather than new grid, that may both reduce risk and costs for the DSO.

Price signals and end user tariff design are subject to EU-wide and national regulations. In general, regulations require tariffs to be non-discriminatory and cost-reflective, but also that tariffs may be differentiated based on users' consumption level, profiles, voltage level etc. Geographical differentiation, except what follows from the borders between different DSOs, is generally not accepted. However, the actual value of demand response may well depend on geographical location; while sending a price signal for DSR in a constrained area may provide substantial grid cost savings, sending the same price signal in an area with no grid restraints risks creating a socioeconomic loss due to unnecessary DSR. In (Kanak AS, 2014) , the link between substations with constrained capacity and location of end users with incentives to shift load was analysed. The share of substations with constrained capacity that could actually benefit from DSR was approximately 10%, while the price signal is sent to all end users. This means that any load shifting from 90% of the customers would have no real value to the DSO, and may have a negative socioeconomic impact.

Thus, the effectiveness of DSR could potentially be improved by allowing geographical or other discrimination between end users. However, it is not difficult to see valid arguments against such discrimination, as fair treatment and customer acceptance. The challenge of adverse effects is smaller, however, the longer the time horizon: Lower load requirements become, eventually, a benefit for all parts of the grid.

1.5 Regulatory incentives and barriers for utilising demand side flexibility in the Nordics

DSOs are a natural monopoly and therefore under substantial public regulation. The main objectives for the regulation across the Nordic countries (and elsewhere) are threefold: First, ensure that a sufficient volume of grid capacity is established to avoid monopoly-style profit maximisation, second; protect customers from excessive pricing, and third, ensure a sufficient quality level. Typical regulatory measures to achieve these objectives are the introduction of connection rights, income or price caps, and minimum supply quality standards. Already at this stage, the number of objectives in regulation compared to available measures makes effective regulation difficult, and objective conflicts are a major issue in regulatory design and development.

None of the Nordic countries have explicit incentives aimed at promoting DSR in itself today, with the possible exception of interruptible grid tariffs. However, several regulatory elements affect the attractiveness of DSR as seen from the DSO side, as well as from end users and third parties. For the purpose of this study, we have explored current regulations in the four Nordic countries on the following five issues:

- Tariff regime, with regards both to design and use of price signals, and possibility to discriminate between customers on network benefit groundos;
- Access to and DSO involvement in flexibility markets for end users;
- Allowed DSO activities and roles, like ownership of certain assets and DSO involvement in flexibility markets;
- Income or profit effects of buying flexibility, e.g. that certain uses of DSO is to detriment of DSO profitability due to income regulation models;
- Access to and use of data from end users.

In the regulatory survey, each of these issues has been assessed for each Nordic country. The main findings are summarised in Table 4.

Table 4: Comparison of tariff regulations

Question	Norway	Sweden	Denmark	Finland
Are capacity tariffs for household customers allowed?	Capacity tariffs allowed, including ToU, metered load, fuse etc. Current regulations include minimum levels for fixed and energy elements, but no maximum	Capacity tariffs allowed, including ToU, metered load, fuse etc.	Not currently, but new regulations allowing capacity tariffs are likely to be introduced within a few years	Capacity tariffs allowed, including ToU, metered load, fuse etc.
Is tariff differentiation between customers and customer groups allowed?	Tariffs must be non-discriminatory within the same customer group- Load tariffs may be introduced stepwise as new customers get AMR installed	Tariffs must be non-discriminatory within the same customer group	Tariffs must be non-discriminatory within the same customer group	Tariffs must be non-discriminatory within the same customer group
Can the DSO offer interruptible tariffs, i.e. generally low tariffs for customers that are willing to reduce load at command from the DSO?	Yes, if justified with objective grid criteria	Yes, but limited usage	Not generally, but in certain cases as with electric boilers	Yes. If used, must be offered to every customer within a customer group
Can the DSO demand an investment contribution or connection fee from customers, in that case – shallow or deep?	Yes, shallow and limited upwards to actual, documented cost. Same rules apply to all customers	Yes, limited upwards to actual, documented cost. Can be both shallow and deep. Cost templates used for smaller connections	Yes, in the form of connection fee	Yes, in the form of connection fee

In general, load tariffs are currently not allowed in Denmark, but allowed in the other three countries. While advanced load tariffs are not commonly used in any of the countries, this is partly due to lack of smart meters and technology solutions rather than regulatory barriers.

All four countries have similar regulations on non-discrimination and objective criteria for tariffs. Consequently, none of the countries allow geographical or other differentiation of tariffs due to grid related criteria.

Interruptible tariffs are to various degrees allowed and used in practise in all four countries. However, due to the phasing-out of oil-fired boilers, interruptible contracts with customers having dual boilers are on the decline.

Also, all four countries have regulations that allow charging a connection fee or investment contribution from new connections. In Norway, Sweden and Finland the fee is based on actual connection costs. In Denmark, a standardised connection fee applies (see e.g. (Radius, 2017)). Of the other three countries, Sweden allows for both deep and shallow connection fees, while Norway and Finland only allow for shallow. This means that the price signals that are possible to send via connection fees and investment contribution are quite different between the four countries. The impact from connection fees is likely to reduce the required capacity of new connections, thereby strengthening implicit flexibility. Danish regulations clearly have the weakest incentives to DSR in this regard.

Currently, there are limited regulatory barriers to tariff setting in the Nordics, with the exception of Denmark. The current Danish regulation does not allow capacity based tariffs for household customers. Capacity based tariffs are expected to be introduced in a few years. Differentiation on geographical basis within concession areas are not allowed in any of the Nordic countries.

The incentives for demand response are much weaker with energy-based than with load-based tariff schemes. Across the Nordic countries, hourly metering has been possible for some years in Sweden and Finland, but to a very limited extent in Norway and Denmark. However, with existing technology the price signal transparency has been weak. The price has appeared on invoices rather than real-time information, and smart energy and load management systems in households have been very limited.

With new smart meters and other technological advances, as well as new communication platforms, price transparency and the possibility to react on price signals is becoming much better. Tariff design and price signals thus become very important incentives to mobilise automated energy and load management systems. If tariffs do not reflect the network savings and grid benefits of demand response, the commercial drivers for installing smart systems will be weaker. Hence, in the absence of price signals, the risk of demand response not becoming available is high.

Until now and possibly a few years ahead, the technology environment for "smart tariffs" has not been available. However, with new technology being developed, the need for tariff reform is high, and so is the need for tariff *regulatory* reform.

The main categories of load tariffs are briefly discussed in chapter 1.3.2. From a regulatory viewpoint, there are three main criteria that should be applied:

- Cost distribution: Grid tariffs should be cost-reflective, so that each grid customer pays a tariff that is representative of the costs for the customer's use of the grid;
- Price signals should only be used if they contribute to socioeconomic gains, i.e. the utility loss of changed behaviour (or customer investment in smart systems)

must be smaller than the savings in the grid. Otherwise, grid tariffs should affect the end user behaviour as little as possible.

Administrative implementation: The tariff must be possible to implement within reasonable resource use, across all involved parties (regulator, DSO, customer, metering and billing services).

Within the scope of this report, price signal design is the focal point. However, certain elements in current regulations in the Nordic countries limit the degrees of freedom for efficient price signal design. The most important barrier is the requirement for non-discrimination between customers, i.e. that all comparable customers shall face the same tariffs with in a concession area. In practice, this means that all customers will meet the same price signal, regardless of their ability to provide flexibility or their contribution to grid savings. A flexible approach, allowing differentiation between end users with specific consumption patterns, geographic location or ability to adapt could be more efficient. However, it is easy to see the counter-arguments related to equal treatment and non-discrimination.

Another barrier is specific, regulatory requirements for tariff structure. One example is the forthcoming, Norwegian tariff regulatory review. From preliminary presentations, it seems that the future model will be based on a customer-specific, subscribed load model with a surcharge for kWh/h consumption above the subscribed level. The model will apply to all customers, households and industry alike. Being non-dynamic, the price signals in the model will have limited covariation with grid system utilization. Also, the price signal will be effective above the subscribed level at individual customer level only, thus reducing the potential implicit demand side response volume.

Regulatory barriers to differentiation between customers and customer groups may limit the ability to send appropriate price signals. The implementation of load tariffs in Fredrikstad Energi Nett, a Norwegian DSO south of Oslo, provides some useful learning about regulatory barriers. The area was Hvaler islands, where there are as many summer leisure homes as households, and all customers have had AMR meters since late 2011. The tariff was designed to comply with current regulations, and was introduced as a simple, static load tariff. Load curves for households and leisure homes were very different. While households had a typical winter, weekday, morning and afternoon peak pattern, leisure homes peaked at Easter and summer, and during weekends. As many of the low voltage circuits were dominated by leisure homes, this customer group was first designed to have a high load tariff during summer, while households got a lower summer load tariff. This was clearly motivated by sending appropriate price signals to reduce the need for grid investments, but was judged to be illegal under current regulations by NVE.

Another area for regulatory barriers is the DSO access to purchase of flexibility, other than offering interruptible tariffs to eligible customers. A comparison of current regulations on the DSO purchase of other flexibility contracts than interruptible tariffs is listed in Table 5.

Table 5: Regulations of flexibility contracts

Question	Norway	Sweden	Denmark	Finland
Can the DSO enter into other bilateral agreements for purchase of capacity from customers or aggregators?	Only via organised market and from market participants. DSR aggregator participants do not yet exist	Yes, as long as purchase is justified with grid criteria	Yes, but based on a standardised model offered to everyone	Only via organised market and from market participants. DSR aggregator participants do not yet exist
What are the limitations, if any, for the DSO to buy flexibility services from organised markets?	No formal limitations. Non-discriminatory	No formal limitations. Non-discriminatory	No formal limitations. Non-discriminatory	No formal limitations. Non-discriminatory

In principle, DSOs could access end user flexibility either directly through bilateral contracts or via organised marketplaces. While none of these are actually in use today, the regulatory framework differs slightly between countries. In general, non-discrimination and grid criteria are required in order to use bilateral contracts.

Local flexibility could be offered both by flexible end users themselves, or – more likely – by third parties or aggregators with access to flexibility from many end users. Barriers in this area are more market-related and practical than regulatory. With current market rules, the volume threshold for participating in established flexibility markets (system services) is too high to allow for smaller bidders. The only example we are aware of in the Nordics, is LOS Energy in Norway.

Nevertheless, flexibility can in principle be offered on a bilateral basis to DSOs outside of the system services organised market. In order to be part of the regulatory cost base, purchase of flexibility from end users or third parties like aggregators will have to be justified by grid relevant criteria. One relevant criterion would be to avoid grid investments, and buy flexibility at a lesser cost instead. From discussions with representatives for the authorities in question, it seems likely that the cost of purchasing flexibility would be allowed as part of the regulatory cost base. Hence, purchase of flexibility from end users with batteries – either directly or via aggregators – seems to be a possible business model for DSOs. However, as discussed in the next paragraph on battery investments after Table 6, indirect models via aggregators may be more challenging to realise than direct models. Also, there is an open issue of whether an offer to provide battery-based flexibility will have to apply to all grid customers, or if the DSO can approach individual end users directly with a request.

One possible semi-regulatory barrier could be balance responsibility of aggregators. If flexibility providers were subject to balance responsibility, it would represent an additional cost element that would reduce the attractiveness of offering flexibility.

There is currently no room for local, organised flexibility markets at DSO level. The creation and use of local flexibility markets would require better coordination between TSOs and DSOs, as local use of flexibility could conceivably have adverse effects on higher grid levels. A regulatory response to any future coordination issue could thus be required.

Table 6: Use of solutions other than grid investments

Question	Norway	Sweden	Denmark	Finland
Can the DSO offer to invest in alternative solutions, other than grid, for a customer, or demand to supply a customer with an alternative connection & supply solution?	In principle yes, subject to regulatory approval. High threshold for approval	No, connection obligation prevails. Agreement on capacity limitations may be made	No, equality principle prevails	No, current interpretation is that only grid investments are sufficient and allowed

In general, grid companies are obliged to connect customers to the grid by means of grid investments. In Norway, there is a theoretical possibility to be exempted from the connection obligation. However, voluntary arrangements may be made, but with no obligation on the customer to accept such offers. In Sweden, there is a possibility to agree on limited capacity during peak periods, but no exemption from the grid connection in itself.

As referred to in chapter 1.2.3, even small batteries may replace grid investments to cover short-term peak challenges in the grid. Conceivably, DSOs could cover a required capacity increase by installing a battery, and (if other criteria are met) charge an investment contribution or connection fee for the cost of the battery. In the absence of connection fee, all grid customers would benefit from a battery solution through lower grid costs and lower tariffs. However, even though current EU legislation is unclear on the issue, storage facilities like batteries are generally regarded as a part of the generation system and therefore outside of allowed DSO activities. Italy has introduced an exemption for the TSO and DSOs. Hence, the inability to offer cheaper alternatives to grid investments to end users appears to be the most important regulatory barrier to DSR. The EU winter package explicitly introduces limitations on any DSO ownership of storage.

Alternatively, in case the DSO could demand an investment contribution or connection fee from the end user, this would be a strong financial incentive to that customer to install a battery at home, or engage a third party to do the investment. However, in many cases it would be a good solution to install batteries at (or close to) *other* end users than those demanding higher capacity. Consequently, a right for the DSO to purchase battery-based flexibility from individual end users (e.g. in the form of a negative investment contribution) appears to be an attractive source of DSR. However, there are possibly regulatory barriers to make such agreements directly with the desired end users without making the offer to all end users.

In a policy paper from Policy Department at the Directorate General for Internal policies, it is recommended that network operators should be allowed to own and control storage assets, i.e. batteries, but with regulated limitations for the use of such assets (Policy department, DG for Internal Policies, 2015). In Italy, the regulatory framework has been adapted to allow Terna, the TSO, to invest in a number of grid-scale batteries to supply ancillary services, balancing, power quality services and tertiary reserves (Terna, 2017). From a regulatory point of view, this is not very different from allowing DSOs to invest in batteries to avoid grid investments.

Regulatory barriers may be overcome if third-party aggregators offered location-specific flexibility from end users, and paid their customers to install home batteries. However, this business model is much more complex and harder to realise than a direct DSO battery investment model. One important element is that the DSO has a very different risk picture than commercial players: While a commercial player faces both volume and price risk for flexibility sales, the DSO has an alternative cost of grid investments only.

There are examples of existing business models where third parties invest in battery capacity at end user level. In the Netherlands, Eneco launched a home battery network concept in 2016. The plan is to create a network of Eneco-owned batteries located at households, and to provide ancillary services to Tennet, the TSO (Crowdnet, 2017). Like in the Nordics, there is no commercial basis for providing the flexibility or capacity service at DSO level.

The fourth regulatory issue concerns the possible impact of income regulation on use of DSR. Income regulation models in the Nordics all have some element of efficiency measurement. Hence, marginal cost recovery when taking on more costs in the DSO is likely to reduce the profit and return on capital.

Table 7: Impact on income regulation and return on capital

Question	Norway	Sweden	Denmark	Finland
Is the DSO income (income cap or other) affected by the way tariffs are set?	No	No	No	No
Will purchase of flexibility services affect the DSO income and profitability?	Purchase of flexibility will increase costs with limited income increase, thus hurting DSO return on capital	Purchase of flexibility will increase costs with limited income increase, thus hurting DSO return on capital	Purchase of flexibility will increase costs with no corresponding income increase, thus hurting DSO return on capital	Purchase of flexibility will increase costs and decrease efficiency, thus hurting DSO return on capital

First, the actual tariff design and converting today's energy based tariffs into capacity based tariffs has no impact on DSO income in either of the Nordic countries. Hence, in terms of implicit price signals and flexibility, income regulation is no barrier to DSR.

For purchase of explicit flexibility, the immediate effect is higher costs compared to using interruptible tariffs. The latter merely redistributes tariff costs among grid customers, while the former represents an additional cost to the DSO – at least in the short term. Consequently, income and return on capital are adversely affected in all four countries, albeit to varying degrees depending on the share of income determined by the DSO's efficiency score.

The potential impact on income and return on capital is not necessarily problematic. Using explicit demand side response is a real cost, and should therefore be reflected in the regulatory cost base with a realistic cost level. If anything, it is rather the use of interruptible tariffs with no visible price signal for the DSO that may over-incentivize the use of explicit DSR.

Finally, we have raised the issue of data privacy.

Table 8: Regulation of data privacy

Question	Norway	Sweden	Denmark	Finland
What limitations are there to the use of data from end users for the DSO and for third parties?	Individual data can be used for metering/ billing only. Third parties need separate end user agreement to use data	Individual data can be used for metering/ billing only. Third parties need separate end user agreement to use data	Individual data can be used for metering/ billing only. Third parties need separate end user agreement to use data	Individual data can be used for metering/ billing only. Third parties need separate end user agreement to use data

All four countries have similar data privacy arrangements. Individual data can be used for metering and billing, but not for other purposes. For third-part arrangements, individual agreements need to be made with each customer.

However, data privacy does not appear to be a barrier to DSR models. Any direct management of an end user's power consumption would in any case have to be agreed upon with the customer in advance.

2. Interview study

2.1 Issues and respondents

In line with the project scope of work, the interview study has focused on current DSO status, view on opportunities and barriers, and planned actions forward. In each of the four Nordic countries, three DSOs have been interviewed. In order to have substance in the information achieved, interviewees are DSOs that have already shown some activity or interest in the field.

The twelve DSOs interviewed are:

Table 9: Interviewees in the four countries

Norway	Sweden	Denmark	Finland
Hafslund Nett AS Norgesnett AS Agder Energi AS eSmart Systems (vendor)	Ellevio Skellefteå Kraft Elnät E.ON Elnät Sverige AB	Dansk Energi (not a DSO - interest organisation for DSOs and Generators) Bornholm Energi forsyning Radius	Caruna Elenia Helen

Most of the interviewees are part of groups with business areas other than grid business. Hence, DSR programmes are not necessarily anchored in the DSO part, even though they may partly be justified by DSO benefits and gains. Typically, the DSR programmes are managed either on group level or by the end user sales company of the group. The respondents in the survey are mostly either DSR programme or project managers, or strategy / business development managers in the DSO.

It is appropriate to raise the question whether current DSR initiatives are driven by DSO concerns, or by commercial drivers in the business development and/or sales units in the energy companies. Would this be a potential problem related to unbundling and conflict of interests? We believe that this is a minor issue. Any commercial-driven business development will have to acknowledge the importance of DSO and network value to build an attractive and profitable business model. Similarly, any DSO-driven concept development must acknowledge the importance of commercial drivers and the role of third parties to realise automation and installation of smart systems that are required to make DSR happen.

Due to the limited number of respondents, the results of the interview study are of a qualitative nature only, while statistics and other quantitative results would have little significance without a much broader survey data basis. To the extent possible, we point to apparent national differences, but we also cautiously underline that the responses are too few to allow for strong conclusions on that dimension.

The responses are not identified per company or in any fashion that the respondent can be identified, to ensure anonymity of all respondents. The questionnaire used in the interviews is attached in appendix.

2.2 Current DSO status

Most of the DSOs interviewed have already engaged in DSR activities, but only at a research and testing level. With one possible exception in Norway, there are no commercial driven initiatives on-going. Nevertheless, at R&D and pilot level, most of the respondents have initiated activities ether in the DSO itself or in sister companies.

The main reason for weak activity is twofold. First, respondents point to the fact that there is no market available. Direct involvement in the service provision is mostly out of bounds for the DSOs themselves, and as long as third party players are not present, the market will not develop. Second, the DSOs state that currently or in the near future, there is no need for DSR as the grid capacity is already sufficient.

Table 10: Overview of respondents replies on current status

Issue	Norway – 3 DSOs	Sweden –3 DSOs	Denmark – 3 DSOs	Finland – 3 DSOs
Respondents	Three DSOs, one technology vendor	Three DSOs	Three DSOs: The DSO association is in this context regarded as a DSO	Three DSOs
Current DSR activities	One DSO has commercial activities, all DSOs have research and demonstration activities	No current activities	Research and demonstration activities	Some experience with day and night tariffs for hot water boilers, otherwise nothing
Current DSO information on capacity restraints within their network area	Sufficient information at transmission level, little information at distribution level	Limited information. Best at transmission level	Limited information. System is over-dimensioned. No constraints. Some potential in DK2, which is not over-dimensioned	Good offline information. Online solutions are on the way
Sufficient systems to make use of available DSR flexibility	Sufficient systems at transmission level, not sufficient at distribution level	Not sufficient	Not sufficient. Only the newest generation SCADA systems are able to include such functionality	Some DSOs have systems sufficient for predictive DSR, but not real-time
Third party interest in DSR	Some interest but very few third party companies around	Only research organisations	Very few commercial third parties. Some more take part in research projects	Some interest, but very little activity

Drilling down into the two issues, a somewhat more diverse picture emerges. In both Finland and Norway, respondents point to the well-established system of interruptible load contracts – i.e., larger, flexible customers that pay a low grid tariff in return for providing flexibility to the DSO (or TSO) in situations with restrained capacity, typically tertiary reserves. Also, flexibility from electric boilers is mentioned by one of the Swedish DSOs that we have interviewed. Although a different market, the existence of the interruptible contracts demonstrates that there is a willingness to provide flexibility at end user level. However, this kind of contract is typically for commercial customers (or larger housing associations) and not for smaller households. Another factor, and a more fundamental difference from DSR markets, it is the DSO that sets the price and buy capacity without any commercial risk: the loss of income from interruptible customers are simply recovered by raising tariffs from other customers to reach the same income cap or level. Hence, the risk is much higher for new, commercial entrants and DSOs when it comes to creating a DSR market. As discussed in relation to batteries above, risk differences give a tendency to favour DSO-driven models.

At a general level, this question should be further explored. The simple question is whether local DSR should be part of the local, natural monopoly or be a competitive market. Current regulations favour the local monopoly option, and represent a barrier to new entrants in this area.

In Finland, respondents state that time-of-use tariffs for smaller end users have been in place for a long time. The ToU tariff is said to most likely affect the load profile, but not necessarily in a way useable for DSR.

The DSOs state that there is enough flexibility in the grid, but at the same time state that they have little information available on the actual capacity utilisation at low grid levels. Further, some respondents state that there is little or no need for such information systems at the time being. Nevertheless, most respondents acknowledge that the need for DSR may increase in the future due to new patterns of consumption, like EV charging, and distributed generation.

2.3 DSO view on value of flexibility

In a European perspective, the need for end user flexibility can be driven by an ever larger balancing need at the wholesale power market level created by high renewable penetration levels. This is only partly true in a Nordic perspective, where the renewables share is already high, and the wholesale power market balancing needs are lower due to the flexibility of hydropower. There is a clear difference between countries, though: In Denmark, the respondents see wholesale level fluctuation as a major driver, while respondents from the other countries more see local issues as being the main driver for increased levels of end user flexibility. The answers from the DSOs regarding the value of flexibility are synthesised in Table 11.

Table 11: Questions and answers regarding value of flexibility

Issue	Norway – 3 DSOs	Sweden – 3 DSOs	Denmark – 3 DSOs	Finland – 3 DSOs
Main drivers for DSR increase	Tight situations to avoid outages	Batteries, PV and tightened situations due to increased level of intermittent generation	Primarily wholesale level imbalances due to RES and secondary local imbalances due to EV+battery	Flattening demand peaks. Voltage support from storage
Where in the DSO business process will DSR give most value	Operations and planning	Operations and planning	Operations and potentially planning	Planning
Main benefits to the grid	Buy regulating power instead of outage in tight situations	Lower costs	Buy regulating power instead of outage in tight situations. Lower costs	Stronger grid from lower dimensions
Short term vs long term benefits	Both, but short term is easier. Long term is a matter of trust	Long term but small potential	Short term and potentially long term	Long term
Main prerequisites for realizing value to the grid. Necessary work processes	Digitalization improves access to information about grid situation	Digitalization, automation and aggregators	Aggregator role providing flexibility from many end-users	Automation and change in regulation

From the table it can be seen that the Nordic DSOs mainly see the value of flexibility in a long-term perspective, as a possible means to avoid or mainly postpone otherwise necessary grid investments. Many of the respondents see a future where electric vehicles and distributed solar are dominating demand patterns in distributing grids creating high demand peaks that could be evened out by DSR instead of being tackled by a very high grid capacity.

None of the respondents have any experience from including DSR in the planning process so far. The DSO's see the potential benefits, but they are also sceptical. Several challenges are mentioned, that can reduce the benefit of utilising DSR in the long term planning process:

- Lack of experience creates high uncertainty as to whether DSR can actually be taken into account when planning future capacity requirements;
- Over-dimensioning is cheap: Cable dimension is a small part of grid investment costs, and the marginal cost of installing extra capacity once an investment decision is taken is low;
- Reliability: Will the necessary flexibility be available at the time it is needed?

Several of the responding DSOs mention that digitalisation is an important prerequisite for the success of demand flexibility, since this empowers the DSOs with a much greater overview of the grid at lower voltage levels, and hence makes the DSOs aware of their actual needs in stressed grid situations. Further, some DSOs mention that the combination of digitalisation and DSR could be especially powerful in the long term planning process, since much more detailed information of the state of the grid can be utilised and hence the potential DSR benefits can be assessed. As mentioned by Finnish and Norwegian DSOs this can be even further strengthened by a change of regulation also benefitting investment in software and not only physical assets.

2.4 Barriers to DSR

The responding DSO's were asked about barriers to DSR implementation in the following four areas:

- Technology – is the technology mature enough?
- Regulation – are the rules giving space for DSR?
- End user behaviour – are they willing to provide flexibility?
- Market – are there suppliers and buyers of flexibility?

Table 12 shows the DSOs answers to the questions related to barriers to DSR. In terms of technology all the DSOs respond that there is technology available, so this should not be considered as a barrier. However, several DSOs state that technology is at a pilot stage, and that robustness and experience is lacking. One of the Danish TSOs stresses the importance of robustness, stability and standardisation that they are experiencing in a current research project. Further, there is a concern among the DSOs that systems for grid operation are not advanced enough to be able to utilise DSR in an efficient way.

Table 12: Questions and answers regarding barriers to DSR

Issue	Norway – 3 DSOs	Sweden – 3 DSOs	Denmark – 3 DSOs	Finland – 3 DSOs
Technological barriers	There are some working technologies but standardization and robustness are major challenges	Little experience, but it seems existing technology is limited to use in pilot projects. DSO systems need to be upgraded	There are some working technologies but standardization, robustness and stability are major challenges. Scada systems need to be upgraded	Technology is coming. Not really a barrier
Regulatory barriers	Regulation is evolving and on the right track. Capacity tariffs are needed and a change in which investments to promote classic grid investment vs more risk based DSR based investments	Tariffs need to be changed. Price signals to the end users are too weak	Regulation promotes capex based investments and gives too weak price signals. Change is under way	Regulation promotes capex based investments and gives too weak price signals
End user behaviour – a barrier?	End user behaviour is a high barrier – very little attention towards flexibility and high uncertainty about the actual potential	Automation necessary to change end user behaviour, end users are not aware of the DSR concept	End user flexibility is virtually non-existant due to very high tax on power consumption destroying the price signal	End user behaviour is a barrier due to weak price signals
Market barriers	Market is not there yet. Little demand from DSOs and very few aggregators providing supply of flexibility	Market is not there yet, no commercial market players present	Market is not there yet. Little demand from DSOs and very few aggregators providing supply of flexibility	Market is at a pilot stadium

All the responding DSOs agree that classic regulation where tariffs are energy focused and income regulation is focused on CAPEX is a clear barrier to DSR development. In some of the countries though, change is under way. In Norway for instance, there has been a pilot project testing capacity tariffs, and in Denmark a new regulation is being developed where capacity tariffs and a mixed CAPEX/OPEX income regulation are expected to be included.

According to the DSOs, end user behaviour is a big challenge. Generally, end users are not very interested in this subject, or are unaware of "their" flexibility, and the economic incentives are weak. Many of the DSOs mention that automation is the only possible way to create substantial DSR volume, as opposed to having consumers reacting manually to price signals. Consequently, business models involving third parties that offer automation systems to end users are crucial to achieve demand side response. As one of the Norwegian DSOs responded out of experience from a research project; "Even though all the equipment was for free, a lot of persuasion was needed to get end users on board". The main point is that use of new equipment must be hassle-free for the end user to be accepted.

The DSOs claim that there is not really a market for DSR – yet. DSOs don't really need the flexibility since the grids are generally well dimensioned and hence there is no real capacity restraint. Many of the TSOs claim that they expect the demand for flexibility to grow in the future, and hence they are engaging in research projects to prepare. On the supply side, some of the responding DSOs in Norway and Denmark see aggregators coming in – but these are clearly very early days. Also, the growing market for power plant owned electric boilers in Danish power plants increases the potential for Denmark.

2.5 DSO planned actions

The DSOs were asked about future plans in terms of demand flexibility. The answers are summarised in Table 13 and confirm the impression that we are in the early stages of development. Most of the DSOs see future potential, and at least in Norway and Denmark the DSOs are engaged in research and pilot projects. In these projects, new technology is being developed and existing technology is being tested along with the development of communication platforms for end users and automation controlled by aggregators. Apart from pilots and research projects, no concrete plans are mentioned by the DSO's.

Table 13: Questions and answers regarding DSO planned actions

Issue	Norway – 3 DSOs	Sweden – 3 DSOs	Denmark – 3 DSOs	Finland – 3 DSOs
Price signals	One DSO has had a pilot on capacity tariffs	One DSO is trying new pricing models in a pilot project	Danish DSOs want capacity tariffs and regulation is on the way	Pilots on capacity tariffs
Communication platforms	At a pilot stage	One DSO develops platforms within current pilot projects	Aggregators should develop this	Some DSOs have plans
Bilateral agreements with end users	No concrete plans	No concrete plans	No concrete plans	No concrete plans
Procuring market solutions	Maybe within the next few years	No concrete plans	Maybe within the next few years	No concrete plans, but market is the only way longer term

Most of the responding DSOs are considering tariff structures without having decided the future structure. Many DSOs mention capacity tariffs. All respondents see a need for giving stronger economic incentives for end user flexibility in the future.

Finnish DSO respondents are as interested in voltage support and active power reduction from DSR as an interesting feature, especially from distributed solar power.

2.6 Concluding remarks

The interview study has focused on current DSO status, views on opportunities and barriers, and planned actions forward. 12 Nordic DSOs have been interviewed.

Most of the DSOs interviewed have already engaged in DSR activities, but only at a research and testing level. With one possible exception in Norway, there are no commercially driven initiatives on-going.

Nordic DSOs mainly see the value of flexibility in a long-term perspective, as a possible means to avoid, or mainly postpone, otherwise necessary grid investments. Many of the respondents see a future where electric vehicles and distributed solar are dominating demand patterns in distributing grids creating high demand peaks that could be evened out by DSR instead of being tackled by a very high grid capacity.

All the responding DSOs agree that the classic DSO role and current regulation are barriers to DSR development. Traditionally, building more grid has been the answer to any capacity issue, and regulations have been designed for that purpose. End user perception is a major challenge. Generally, end users are not very interested in DSR, and the economic incentives are weak. The DSOs claim that the market for DSR is either missing completely, or is at a pilot stage where volumes are low. However, the respondents emphasize that change is under way in the form of new smart technology, and the risk of high investments costs pushing end users to adopt off-grid solutions.

Most of the responding DSOs are considering tariff structures without having decided the future structure. Many DSOs mention capacity tariffs. All respondents see a need for giving stronger economic incentives for end user flexibility in the future.

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Sammendrag på norsk

Etterspørselsfleksibilitet (Demand side response, DSR) handler om å mobilisere potensiell fleksibilitet med tanke på *hvordan* og *når* sluttbruker velger å bruke energi, og hvorvidt denne fleksibiliteten kan være verdifull for nettet. Mulige gevinster for nettet kan være reduserte eller utsatte investeringer, bedre pålitelighet eller reduserte systemkostnader.

Denne studien er todelt. Første del beskriver ulike konsepter innen etterspørselsfleksibilitet, diskuterer modeller for realisering og regulatoriske forhold ved modellene. Andre del beskriver intervjuer av utvalgte DSOer i fire nordiske land. Studien beskriver status, hvordan DSOene vurderer den potensielle verdien av fleksibilitet i deres nett, hva de ser på som barrierer og hvilke aktiviteter de planlegger innen DSR.

Rapporten ser på DSR hos små sluttbrukere, spesielt hos husholdninger. Motivasjonen for dette er utrullingen av smarte målere som gir muligheter for smarte løsninger hos husholdninger. Nytten for nettet finnes dessuten hovedsakelig i distribusjonsnettet, ikke i transmisjonsnettet.

Konsepter innen etterspørselsfleksibilitet

Det er utfordrende å samle ulike muligheter og ideer innen DSR til meningsfulle konsepter av etterspørselsfleksibilitet. På husholdningsnivå har vi valgt fem kategorier for samle mulige tiltak:

- Varme (kjøle-) systemer
- Husholdningsapparater apperater
- Lokal produksjon av elektrisitet, som PV systemer
- Lokal lagring, varmtvann eller elektrisitet (batterier)
- Transport, elbil (EV) lading

Med referanse til flere nordiske og internasjonale studier, diskuterer vi potensiale for fleksibilitet innen hver kategori. Det finnes to typer fleksibilitet:

- Eksplisitt fleksibilitet som kan bli mobilisert raskt hvor varighet og volum kan kontrolleres. Denne typen fleksibilitet kan benyttes i drift og flaskehalshåndtering i nåtid og på kort sikt.
- Implisitt fleksibilitet er knyttet til forventning om reduksjon av effektetterspørsel på lang sikt som følge av systematiske endringer i adferd hos

sluttbruker. Slik fleksibilitet kan benyttes i langsiktig planlegging, men ikke i driftsbeslutninger i nåtid.

Vi finner varme- og kjølesystemer og lagring av elektrisitet og varmt vann er de mest lovende kategoriene for å utnytte DSR. Vi finner videre at den største potensielle verdien av DSR finnes i reduserte og utsatte investeringer i nett.

Sluttbruker kan motiveres til å gjennomføre tiltak som realiserer etterspørselsfleksibilitet av finansielle insentiver, økt komfort eller økt sikkerhet. DSOer er naturlig monopoler og kan kun drive nettvirksomhet, så det kan være behov for andre aktører enn DSOen for å gi sluttbruker insentiver til å gjennomføre tiltak som utløser etterspørselsfleksibiliteten.

Intervjuer med DSOer

Vi intervjuet representanter fra tre DSOer per land. DSOene har enten pågående eller planlagte tiltak innen etterspørselsfleksibilitet. Vi har også intervjuet et norsk teknologiselskap. Intervjuene dekket følgende temaer:

- Status på tiltak innen DSR hos selskapet.
- Verdien av og behovet for DSR i det nordiske nettet.
- Muligheter og barrierer for implementering av DSR tiltak i et nordisk DSO perspektiv.
- Planer for DSR tiltak i selskapet.

De fleste av DSOene i var involvert i aktiviteter innen DSR, hovedsakelig innen forsknings- og testnivå. Respondentene tror i hovedsak at verdien av DSR i det nordiske nettet finnes på lang sikt gjennom utsatte eller unngåtte investeringer, og at behovet for DSR vil være størst for å løse utfordringer i distribusjonsnettet. Mulige barrierer for å ta i bruk DSR er manglende teknologi, reguleringer, usikkerhet rundt sluttbrukers villighet til å endre adferd og usikkerhet om det er aktører til å skape marked for fleksibilitet. Planene DSOene har for DSR tiltak viser at konseptet fortsatt er under utvikling.

Appendix – Questionnaire

Interview guide

The interviews should focus on four main topics:

- Current status:
  - DSOs use of flexibility today
  - DSO knowledge of network needs and potential costs or quality issues
- Value of flexibility:
  - What kinds of flexibility (duration, volume, predictability)
  - Short-term (operational benefits): Quality, outage management, grid losses
  - Long-term: Postponed or reduced investments
- Barriers:
  - Technology
  - Market
  - Regulations
  - End user behaviour
- Planned actions:
  - Price signals, tariffs
  - Communication platforms
  - Bilateral agreements with end users
  - Procuring market solutions
  - Smart technology solutions

Detailed questions are provided below. Please use the table to provide your feedback, to the extent possible. For each main topic, there are two extra columns – one for comments/information from the DSOs that does not fit elsewhere, and one for "summing up" the key learnings. There is also a summary section at the very end, where you are asked to provide your impressions/key take aways from the discussion, including subjective comments on whether DSR appear to be a priority issue for the DSO, how knowledgeable and prepared they appear to be, etc.

Table 14: Interview guide

Question	Reply
Status	**Current use and knowledge**
Is DSR used by the DSO today? If yes, in what form and for what purpose? If no, why not?	
What information does the DSO have about current capacity restraints in the network? Is this judged to be sufficient to make good capacity management and expansion decisions?	
Does the DSO have sufficient systems today to make use of available DSR flexibility?	
Has there been interest from end users and/or third parties to establish DSR services in the DSO area?	
Other comments from DSO	
Pöyry key take-aways	
Value of flexibility	**Potential benefits from mobilising end user flexibility and DSR**
What would be the main drivers behind increased access to (and need for) demand side flexibility?	
Where in the DSO business processes would DSR potentially give most value?	
What are the main benefits to the grid, e.g. cost reductions, quality improvements or other?	
Are short- or long-term benefits most important to you? I.e. real-time operational flexibility or long-term investment reductions?	
What are the main prerequisites for realising network value from DSR? What systems or work processes must be in place at the DSO to exploit DSR?	
Other comments from DSO	
Pöyry key take-aways	
Barriers	**Most important impediments to realising potential grid benefits**
Technology: Are technological solutions available in the market, including competent vendors? Is integration of new solutions with existing systems possible / realistic? Systems to link between DSR and grid operations / planning	
Regulations: Barriers represented by.. Tariff regulations, including the possibility to differentiate between customers according to DSR criteria Asset ownership, e.g. DSO owned storage DSO neutrality regulations Data ownership, privacy and distribution of data Economic (income) regulation Right to buy system services, bilateral agreements Role division with TSO (system responsibility)	
End user behaviour Response to incentives (tariffs, other) Perception of possible benefits (other than cost savings) Unwillingness to invest in local solutions Actual availability of physical flexibility	
Market Third party / service provider appetite to invest in new business models Many small end users, fragmentation of flexibility, cost of aggregation Real value of using end user flexibility – DSO's ability to transform flexibility into value	
Other comments from DSO	
Pöyry key take-aways	

Question Status	Reply Current use and knowledge
DSO planned actions *Price signals, tariffs* Change current tariff model to incentivise DSR Stronger differentiation of tariffs Other incentives, bilateral agreements? *Communication platforms* Develop advanced or real-time communication platforms Other communication platforms? Bilateral agreements with end users Direct control – DSO-end user agreement Nature of contracts (duration, volume, response time) Procuring market solutions Direct control via third part / aggregator Nature of contracts (duration, volume, response time) Other comments from DSO *Pöyry key take-aways*	**Initiatives/plans to increase DSOs access to end user flexibility**
Pöyry overall impressions/key takeaways	

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Demand side flexibility in the Nordic electricity market

The organisation for the Nordic energy regulators, NordREG, has ordered this study to explore status of demand side flexibility among Nordic distribution system operators (DSOs). Demand side response is a question of mobilising potential flexibility in how and when end users choose to use energy, and how such flexibility can provide value to the network. Network value can be reduced or deferred investments, better system reliability or other system cost reductions. This report addresses concepts for utilising demand response and related regulatory issues. The report also includes an interview study among selected DSOs in the Nordic countries. This addresses current status, how flexibility can be a value for their business, what they see as barriers and planned activities relating to demand response.

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