Nordic Energy Research

Demand side flexibility in the Nordics

Lessons learned from 10 case studies



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Foreword

The Nordic countries share a vision of becoming the most sustainable and integrated region in the world. Large-scale deployment of renewable energy is a key enabler for this and for building a green and competitive region.

Smart and flexible use of electricity reduces costs, strengthens security of supply, and is essential for integrating renewables while maintaining system stability.

Drawing on ten Nordic case studies focused on demand-side flexibility (DSF), the study highlights market barriers and enablers for the effective use of smart appliances.

In many ways, the report reflects the "chicken-and-egg dilemma": without consumer participation, flexibility markets lack liquidity; without robust incentives, consumers hesitate to invest.

One of the key messages is that complex local flexibility markets are not the only way to utilise DSF to address grid challenges. Conditional connections, bilateral agreements, and grid tariffs are examples of alternative solutions.

While specific product-related policy measures are not analysed, the authors recommend developing a roadmap with clear milestones for appliance standardisation and interoperability.

Klaus Skytte
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Summary and conclusions

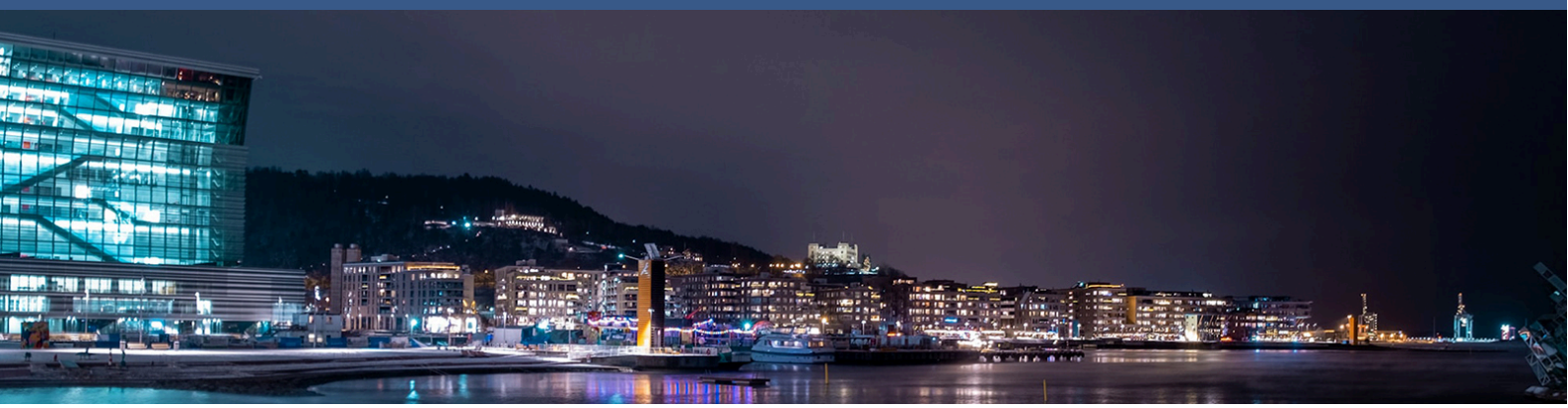


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Project aim: Knowledge basis for regulation to facilitate and promote demand-side flexibility

Flexibility from smart appliances can contribute to ensuring a stable power system, along with the accelerating adoption of renewable energy sources. To succeed, the product design of smart appliances must be developed alongside the procurement solution, including both technical solutions and market design. The main aim of this project is to provide an updated knowledge basis for Nordic government authorities' and policy makers' efforts to develop regulatory approaches that may facilitate and promote the adoption of efficient flexibility solutions, and thus, to inform national Nordic and European legislative activities. The analysis is based on a mapping of different initiatives to develop local flexibility mechanisms that exploit demand-side flexibility (DSF) and in-depth studies of the experience from 10 such cases across the Nordics. A particular focus is devoted to barriers and enablers for the efficient use of local demand-side flexibility from smart appliances.

Current utilisation of demand-side flexibility in the Nordics

Flexibility can be incentivised and procured in different ways. Conditional connections are used or piloted in all countries. Time-of-use or power-based grid tariffs are also being implemented. Local demand-side flexibility markets are the most sophisticated procurement method, and several versions of these are piloted or implemented in all countries. To account for the variety in scope, duration, and focus, we call these *flexibility initiatives*. In total, we have identified 45 finalised or ongoing demand-side flexibility initiatives across the Nordic countries. Norway is the most active country with 20 initiatives. Sweden is the only country with examples of permanent demand-side flexibility solutions. Most of the flexibility initiatives are technical demos that demonstrate that particular technical solutions work, or pilots that also include payment, verification of delivery, etc.

Whether a country has rolled out smart meters and implemented HAN portals and data hubs is affecting how demand-side flexibility can be procured. All the Nordic countries have rolled out smart meters. The roll-out of second-generation smart meters (AMR 2.0) has already started in Finland and is under preparation in Norway and Denmark. We also see that both HAN ports and data hubs have been or are being established, except for a data hub in Sweden.[1]

Utilising local flexibility is one of many ways DSOs can handle grid issues. The goal of the local flexibility initiatives can therefore be to find out if local flexibility can be a profitable solution to local grid issues, or to test the use of demand-side flexibility both technically and commercially. The main objective of 17 of the 45 initiatives was to solve specific grid issues, while the objective of 13 of the initiatives was to understand and develop solutions. We also identified some other purposes, including establishing a marketplace or a microgrid.

A range of different flexibility sources have been tested across the initiatives, although many of them only once. Smart appliances are included in most of the flexibility initiatives. The flexibility sources that have been tested the most are EV chargers (17) and heat pumps (8). PVs, ESWHs, and batteries have all been tested in six flexibility initiatives.

1. Home Area Network, enabling monitoring and control of energy usage

Barriers and enablers of demand-side flexibility are investigated through 10 case studies

We selected 10 of the initiatives for in-depth case studies. The main selection criteria were that they should focus on flexibility from a range of smart appliances, and that the solutions should have reached a certain level of maturity. We also wanted to study cases with innovative mechanisms that used smart appliances in novel ways, and with some variation across different products, flexibility sources, and providers. Moreover, all the Nordic countries should be represented. The selected case studies are:

1. **Byggfleks (Norway),** 2019-2023. Focus on testing technical solutions and systems. Loads from commercial buildings. Knowledge and results were transferred and continued in new pilots.
2. **Battflex (Norway),** 2019-2024. Demonstration of the potential of utilising flexibility to address grid issues. Loads include ESWHs and grid-connected batteries. Findings have been integrated into new initiatives and products.
3. **Norflex (Norway),** 2019-2023. Aimed to increase the use of flexibility to manage local grid bottlenecks via market-based solutions. Loads from households and industrial, and commercial buildings. Followed up by the ongoing Euroflex project.
4. **Sthlmflex (Sweden),** 2020-2023. Focus on a lack of grid capacity in the Stockholm region. Privately owned loads, mainly EV chargers but also heat pumps. Discontinued due to low market liquidity and low demand from DSOs.
5. **Effekthandel väst (Sweden),** Permanent market-based solution. Established as an alternative to investments in grid capacity to handle future grid issues due to increasing electricity demand. Loads include batteries, EV chargers, fridges, and freezers. The DSOs plan to expand the solution to new loads.
6. **E.ON Energidistribution's flexibility markets (Sweden),** Permanent from 2023/2024. Nine local demand-side flexibility markets are established to solve grid issues. Loads include heat pumps, EV chargers, battery storage, ventilation units, backup generators, and lighting systems.
7. **FUSE (Denmark),** 2020-2023. Established to integrate smart EV charging into the energy system, exploring how dynamic charging management can help stabilise the grid. Loads include home, workplace, and semi-public chargers.

8. **EcoGrid (Denmark),** 2016-2019. Exploring and developing a market-based approach to demand-side flexibility in an isolated energy system (Bornholm). Loads from household customers, like electric heating systems.
9. **Helen and Fingrid's marketplace (Finland),** 2025-2027. A live common marketplace for congestion management. Loads include generation, consumption, and storage. The long-term target is to establish a common national marketplace.
10. **Elenia's smart meters (Finland),** from 2020. DSOs offer a service where loads of household customers with smart meters are adjusted according to the spot prices. The load control solution will be commercialised in 2026 and built into the data hub. Flexibility providers can then control aggregated loads for use in electricity and local demand-side markets. Includes loads from single-family and two-family homes like ESWHs and underfloor heating.

Table 1 summarises the estimated potential per appliance, case study, and country. The potentials are in the same order of magnitude as the installed capacities in some of the largest power plants in the Nordic countries.

Table 1: Rough Estimates of the National Overall Potential of Different Smart Appliances

	Potential	ESWH	Ventilation	Underfloor heating	EV - charging	Heat pumps	Freezers and fridges
ByggFleks*	~ 1 GW	X	X	X			
BattFlex	2,5 GW	X					
Norflex/-Euroflex	1-6 GW				X		
Sthlmflex	2-8 GW					X	
Effekt-handel Väst	0,6 GW						X
E.ON Energi-distri-bution's flexibility markets	N/A						
FUSE	0,9 GW				X		
EcoGrid	0,2 GW					X	
Helen Electricity Network	1,7-3 GW					X	
Elenia	~ 1 GW	X		X			

Barriers related to smart appliances and market design are intertwined and should be considered collectively.

A host of barriers can hinder the provision and use of economically profitable demand-side flexibility sources in helping solve grid challenges. The result is that DSOs choose more expensive alternatives like grid investments or using flexibility from more expensive sources. This makes grid costs, paid by the grid customers, higher than they need to be. It is crucial to remember that we do not necessarily want to achieve the full flexibility potential of all the different flexibility sources, but we do want to exploit the economically profitable flexibility. This implies identifying and removing barriers related to market and regulatory failures along the value chain.

In the majority of case studies, the actors report that it is difficult to make the provision of demand-side flexibility from smart appliances profitable. Aggregators need to make various investments and other efforts to be able to aggregate and offer a portfolio of loads to the marketplace. The remuneration is usually not very high. Thus, one of the main findings from the case studies is that the lack of profitability is a general and significant barrier.

Other barriers are mainly related to the flexibility of and operation of smart appliances, the market design, including access to the marketplace and to the DSOs' platforms. We emphasise that the barriers are intertwined and should be considered collectively. We see that identified issues can be solved by improving the abilities of smart appliances or by changing the requirements to participate in the market. From the case studies, we have identified enablers and learnings that can address the barriers.

Several policies and industry standards are under development and address many of the identified barriers. The Nordic countries should take action to help accelerate their progress.

A comprehensive set of rules and regulations that aims at efficient utilisation of DSF in the Internal Energy Market (IEM) is (still) on the drawing board. The challenge of unleashing demand-side flexibility is approached from several angles – from the market angle by facilitating market access (and reducing transaction costs) for flexibility providers and strengthening the incentives (or requirements) on TSOs and DSOs demand for DSF, and from the flexibility product design angle by developing technical requirements and industry standards for potentially smart appliances.

However, a comprehensive and harmonised EU regulatory framework for DSF is still under development. Early regulations tend to be broad and evolve as technologies mature. The Code of Conduct (CoC) for smart appliances is a key initiative promoting interoperability, but it remains voluntary and lacks a clear timeline for integration into binding EU regulations. The absence of standardised requirements for appliance flexibility and communication protocols poses a risk to DSF development. Despite slow regulatory progress, EU rules do not prevent proactive member states from advancing DSF. Nordic countries, with their experience from pilots and demos, are well-positioned to lead. To accelerate progress, we recommend developing a roadmap with clear milestones for appliance standardisation and interoperability, including defining flexibility criteria and setting minimum requirements.

Policy Recommendations: Six *"Messages"* to the Nordic Authorities and Policy Makers

Increasing demand-side flexibility (DSF) requires investments from both providers and users, which will only occur if there is a viable business case. Profitability can be improved by reducing costs, such as making appliances smart and responsive to market signals. The ultimate goal is a standardised "plug-and-play" solution. However, premature standardisation may hinder innovation in a still-maturing market. Remuneration for flexibility provision can be increased by DSOs using local DSF markets more actively. DSOs have traditionally relied on grid investments alone, and the economic regulation was developed according to traditional grid operation. During the transition to also trusting market measures to deliver necessary flexibility at the right time and place, excess grid capacity and uncertainty about future revenues represent barriers. Profitability can also be improved by enabling value stacking across platforms and recognising that flexibility providers can also earn income from adapting to spot prices and grid tariffs, not just from explicit TSO and DSO markets.

The 10 case studies highlight both barriers and enablers for demand-side flexibility (DSF) in the Nordic markets, offering valuable insights for future regulation, though the fragmented knowledge base makes it premature to propose concrete measures. Effective policy development should consider the larger picture, including both explicit and implicit flexibility, address the lack of standardised appliance requirements, and ensure access to all relevant market platforms to reduce uncertainty and improve profitability.

Corresponding to the recommendation that the Nordic countries take a lead in developing a roadmap with clear milestones for appliance standardisation and interoperability in the EU, a similar roadmap and work plan should be developed for the other elements necessary to advance the use and provision of flexibility. Our recommendations for the focus of such a road map and for the principles or factors that should guide its development are:

1. DSO regulation should be technology-neutral. DSOs should be incentivised to choose the most cost-effective solutions, whether grid investments or operational measures. Current economic regulations have been identified to favour infrastructure investments over demand-side flexibility.

2. Stronger DSO commitment to use flexibility solutions. When deciding to establish a local DSF market or mechanism, the DSO's commitment to its development is crucial. DSOs must invest in building market liquidity by guaranteeing minimum compensation and long-term engagement. Sweden's E.ON case exemplifies this approach.

3. Focus new initiatives on the strengthening of coordination among actors. The cases we have studied show that barriers experienced in early pilots are being addressed in subsequent and ongoing flexibility initiatives. However, the pilots are often fragmented and limited in scope and time. We see improved TSO-DSO and DSO-DSO coordination as essential for enabling value stacking, harmonising market designs, and addressing technical barriers like rebound effects.

4. Simplify verification requirements for small loads. DSOs and TSOs should consider simplifying verification requirements for smaller loads like smart appliances in buildings, where complex requirements related to baselining, individual measurement, and verification requirements would make participation in flexibility markets too costly. Incentivising readiness to respond to signals can be more effective for small loads. For these loads, the most effective strategy may be to incentivise their ability to respond to market signals rather than verifying each activation. This could involve compensating all qualifying resources registered in a flexibility register, with forecasting models later helping estimate actual availability for activation.

5. Rethink risk in grid operation. Accepting calculated risks – enabled by digitalisation – can improve grid utilisation and reduce costs. This includes tolerating some uncertainty in DSF activation.

6. Consider alternatives to market-based procurement. Conditional connections, bilateral agreements, and grid tariffs may be more efficient than complex markets in certain contexts. Such alternatives do not generally involve bidding and activation, eliminating many important barriers. The main goal should be to develop demand-side flexibility to make the system more flexible, not whether it is offered through explicit or implicit flexibility.

Definitions and Abbreviations

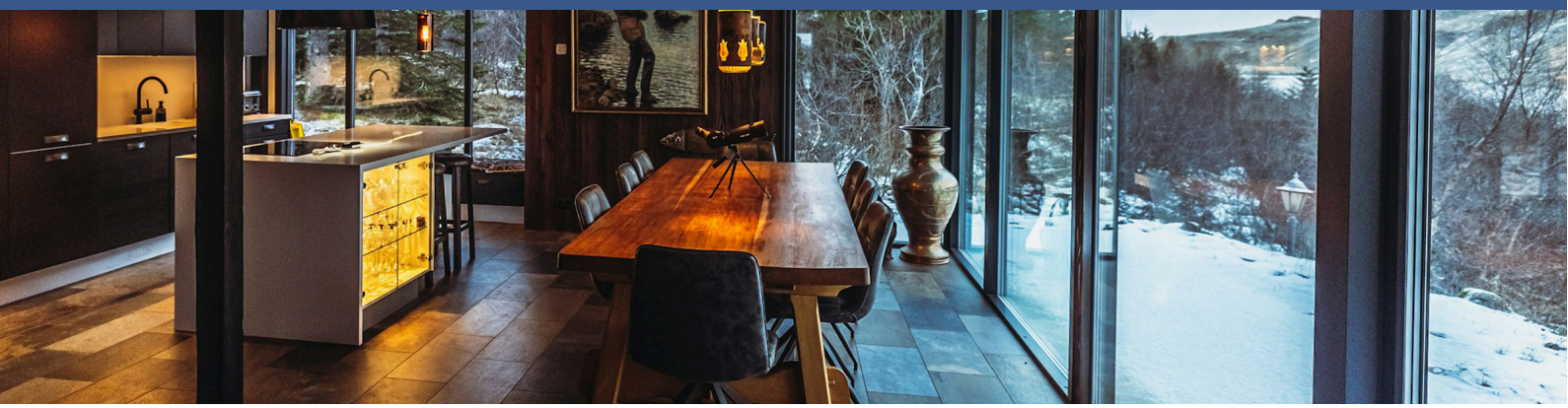


Photo: Unsplash.com

Definitions[2]

Energy Smart appliances – an appliance that is able to automatically respond to external stimuli, e.g., price information, direct control signals, and/or local measurements (mainly voltage and frequency)

Flexibility – response to an external stimulus in form of a change of an appliance's electricity consumption pattern

Aggregator – intermediary bundling small, distributed energy resources (DERs)

2. Definitions follow the Preparatory study on Smart Appliances: https://eco-smartappliances.eu/sites/ecosmartappliances/files/downloads/Task_7%282%29SEC2_22102018_FINAL.pdf

Abbreviations

DSF - Demand side flexibility

DSO – Distribution System Operator

TSO – Transmission System Operator

IEM – Internal Electricity Market

CoC – Code of Conduct

mFRR – Manual Frequency Restoration Reserve

aFRR – Automatic Frequency Restoration Reserve

FCR-N – Frequency Containment Reserve - Normal

FCR-D – Frequency Containment Reserve - Disturbance

FFR – Fast Frequency Reserves

BRP – Balancing Responsible Party

BSP – Balancing Service Party

AMS – Advanced Metering System

AMR – Automatic Meter Reading

HAN – Home Area Network

IoT – Internet of Things

SPU – Service Providing Unit

SPG – Service Providing Group

Introduction



Photo: Unsplash.com

About the project

The main aim of the project is to provide a knowledge basis for Nordic government authorities' and policy makers' development of regulatory approaches that may facilitate and promote the adoption of efficient flexibility solutions, and thus, to inform national Nordic and European legislative activities. The overarching question is how the design of the regulatory framework can facilitate and promote efficient use of local demand-side flexibility from smart appliances, linked to ongoing national and European policy processes. To achieve this, the task is to map and characterize demand for and supply of demand-side flexibility (DSF), focusing on flexibility from smart appliances, and the experience with procurement solutions (contracts, market mechanisms) that are currently used, tested or developed in the Nordic market, and provide recommendations on regulatory approaches to the development of demand and supply, and market mechanisms.

The report is done as a collaboration between THEMA in Norway, COWI in Denmark, CIT Renergy in Sweden, and Motiva Services in Finland. Together, we have identified barriers and possible solutions through 10 case studies in Norway, Sweden, Denmark, and Finland.

About the report

The report is structured in three main parts:

1. Overview of current utilisation of flexibility in the Nordics

In Chapter 2, we present an overview of the current utilisation of flexibility. For each of the four countries, we present key information on why demand-side flexibility is needed, how flexibility is currently procured and give an overview of parameters affecting which solutions can be implemented, such as how many DSOs there are, the status of rollout of smart metering, whether a datahub is established and if they have access to HAN (Home Area Network). We also account for which countries have grid tariff structures based on capacity use or time of use, and whether conditional connections are being used.

Furthermore, we have mapped all flexibility initiatives by DSOs, and present key information on these. This includes the purpose of the flexibility initiative (technical demonstration, pilot, or commercially mature and permanent solutions), characteristics of flexibility procured, and procurement mechanism. Special focus has been put on flexibility from smart appliances. A database with contact information from these initiatives was delivered along with this report.

2. Presentation of 10 case studies

From the list of mapped flexibility initiatives, we have picked 10 of them to investigate and present as case studies. These were picked so that they together met several criteria. They should focus on flexibility from a range of smart appliances and have reached a certain level of maturity. Furthermore, they should have a certain variation across different needs from the DSO and have an even distribution between the countries. The chosen case studies are presented in Chapter 3 and consist of:

1. Byggfleks (Norway)
2. Battflex (Norway)
3. Norflex (Norway)
4. Sthlmflex (Sweden)
5. Effekthandel väst (Sweden)
6. E.ON Energidistribution's flexibility markets (Sweden)
7. FUSE (Denmark)
8. EcoGrid (Denmark)
9. Helen and Fingrid's marketplace (Finland)
10. Elenia's smart meters (Finland)

Each case study includes a general case description, the value chain for demand-side flexibility, an estimation of overall flexibility potential from smart appliances included, and finally barriers and suggested enablers. Chapter 3 starts with an overview of the main lessons from each case study and a table summarising estimated overall flexibility potentials from the 10 case studies.

3. Barriers, existing relevant policy, and industry standards, and finally our policy recommendations

In Chapter 4, the barriers identified in the case studies are first summarised and presented. Secondly, the existing relevant policy and industry standards are presented and assessed. These include:

- EcoDesign for Sustainable Products Regulation and Energy Labelling
- Code of Conduct (voluntary industry standard)
- Network Code on Demand Response
- RED III art. 20 (a)
- The Electricity Market Directive and the Electricity Market Regulation

Finally, we present our policy recommendations. These are based on the barriers and enablers identified in the case studies, a maturity assessment of demand-side flexibility, and the current regulations and industry standards.

Current utilisation of flexibility in the Nordics



Photo: E.on

In this chapter, we present relevant information about the power/grid sector in each country, in addition to information on how demand-side flexibility is utilised today. We first present a cross-Nordic overview comparing the four countries, before going into detail on each country (called *country context)*.[3]

Information included in country contexts

We have identified relevant parameters and how they facilitate the use of local demand-side flexibility from smart appliances across the four countries. These are summarised in three categories:

1. Need for flexibility.
    - What are the **main drivers for the use of flexibility** (from the DSO's point of view)?

3. Norway, Sweden, Denmark and Finland.

2. Current use of flexibility, including:
    - The TSOs' use of aggregated flexibility resources today
    - Other **DSO flexibility mechanisms** in place or under implementation
    - End-user **tariff design** in the distribution grid (grid and energy) that may affect the consumption profile

3. Context affecting the adaptation of new flexibility
    - The **number of DSOs locally and regionally,** which can affect coordination, standardisation, etc., for each country
    - Technology requirement for connections, including status and functionality for **smart meter roll-out** (AMS), affecting the technical possibilities such as measurement and access to HAN (Home Area Network)

Comparative Analysis and Cross-Nordic Overview

Before we take a deep dive into the different countries, we first show a cross-Nordic overview to make it easier to compare how the different countries utilise local flexibility today. In the figure below, we see that the number of DSOs differs quite substantially, from 40 in Denmark to 170 in Sweden. All countries have rolled out smart meters. Finland has started the roll-out of the second-generation smart meters (AMR 2.0), and it is also under preparation in Norway and Denmark. We also see that both HAN ports[4] and data hubs are being implemented, except for data hub in Sweden. Conditional connections are used or piloted in all countries, and time-of-use or power-based grid tariffs are being implemented.

4. Home Area Network, enabling monitoring and control of energy usage

Table 2: Comparison of key elements

	Number of DSOs	Smart meter roll-out	Next generation smart meter status	HAN port imple-mented?	Datahub imple-mented?	Conditional connections in use?	Time of use or power based grid tariff?
Norway	85	100 %	Under deve-lopment	✓	✓	✓	✓
Sweden	170	100 %	×	By 2025	×	✓	Imple-mented by some DSOs. Required by 2027.
Denmark	40	100 %	Under pre-paration	Optional	✓	✓	×
Finland	77	100 %	Roll-out started	✓	✓	Piloted	Small customers: some Large customers: all

Identified demand-side flexibility initiatives

In total, 45 demand-side flexibility initiatives have been identified across the Nordic countries in this study. Norway is the most active country with 20 projects. Sweden is the only country with permanent demand-side flexibility solutions. In the table below, the initiatives are sorted according to maturity, where a technical demo only demonstrates that the solutions work technically, while a pilot also involves payment, verification, etc. A commercialised solution is integrated into the DSO's daily operation of the grid and is not dependent on financial support.

Table 3: Number and maturity of identified demand side flexibility initiatives

	Commercialized solutions	Technical demos	Pilots	Total
Norway	0	12	8	20
Sweden	7	0	7	14
Denmark	0	1	3	4
Finland	1	2	4	7

Purpose of flexibility initiatives

Utilising local flexibility is one of many ways grid companies can solve or reduce grid issues. The goal of the local flexibility initiatives can therefore be to increase knowledge on whether using local flexibility can be a profitable way to solve issues, and to get closer to employing it both technically and commercially. As shown in the table below, the purpose of 13 out of 45 of the initiatives was to understand and develop solutions, meaning they were not initiated to solve a grid issue present today. The purpose of 17 of the initiatives was to solve specific grid issues. We also identified some other purposes, including establishing a marketplace or a microgrid.

Table 4: Maturity of identified demand side flexibility initiatives

Purpose	Norway	Sweden	Denmark	Finland	Total
Understand and develop solutions	5	2	1	5	13
Solving specific grid issues	4	9	3	1	17
Marketplace	3	0	0	1	4
Microgrid	4	0	0	0	4
Other	4	3	0	0	8

Flexibility sources involved (all initiatives identified)

Finally, we have studied which flexibility sources have been involved in the different initiatives. We see that a range of flexibility sources have been tested, although many of them only once. The flexibility sources that have been tested the most are EV chargers (17) and heat pumps (8). PVs, ESWHs, and batteries have all been tested in six flexibility initiatives.

Table 5: Loads involved in demand side flexibility initiatives

	Norway	Sweden	Denmark	Finland	Total
EV chargers	9	4	3	1	17
Heat pumps	0	6	1	1	8
PVs	4	0	0	2	6
ESWHs	5	0	0	1	6
Battery	0	5	0	1	6
Floor heating	3	0	1	1	5
Ventilation	1	1	0	0	2
Cooling systems	0	2	0	0	2
Heat panels	2	0	0	0	2
District heating	1	0	0	0	1
Electric radiators	0	0	1	0	1
Electric boiler	0	0	0	1	1
Data centre	0	0	0	1	1
Aggregate	0	1	0	0	1
Refrigerator/-freezer	0	1	0	0	1

In some of the initiatives, the type of household appliance was not specified. These are not included in the table above.

Norway country sheet

Country context

The primary driver for flexibility in Norway is the lack of capacity in the high voltage grid, which prevents electrification of both existing and new industries, as well as the transport sector. Furthermore, large volumes of distributed PV are expected to be installed over the next few years, which can cause more frequent voltage disturbances in the low-voltage grid. Addressing these issues through grid reinforcements is often costly, highlighting the need for enhanced flexibility usage.

Queue management

Queue management for grid connections operates on a "first-come, first-served" basis. For capacities under 5 MW, no capacity availability assessments need to be conducted, ensuring no waiting time for smaller customers. For larger capacities (≥ 5 MW or ≥ 1 MW in specific areas), approval from the TSO is required. Projects demonstrating maturity, with defined timelines, licensing, and financing in place, are prioritised in the approval process. As of 2023, 11.5 GW of consumption requests were in the queue, of which 5.2 GW were mature projects. For production, 9.5 GW of capacity was queued, of which 1.8 GW were mature projects.

Current use of flexibility

The TSO employs balancing markets that engage large consumers and producers. The DSOs have initiated several flexibility pilots, but they still have to reach commercial maturity. Conditional connections and interruptible loads are in use on all grid levels for wind and hydro power. Similar arrangements for demand are slowly being implemented, but are still limited in comparison.

Previously, the TSO offered discounted tariffs for DSOs that provided interruptible loads to address significant grid disturbances. These arrangements were discontinued in 2021. Some DSOs do, however, have interruptible contracts with customers.

For end-users, grid tariffs are structured differently for small and large customers. For small customers, the grid tariff comprises a capacity and variable component. Most grid companies implemented a new grid tariff model in 2022 for households and businesses with a yearly consumption < 100 000 kWh to motivate these consumers to use electricity in a “smarter” way. The incentive to lower consumption

peaks lies in a fixed monthly charge, which in most grid areas is determined by the average of the consumer's three highest daily maximum hourly consumptions within the previous month. A daily peak is defined as the hour with the highest electricity consumption within 24 hours. Customers can therefore save money by avoiding high electricity usage at the same time / within a single hour during the day. The variable component is based on the consumer's actual consumption and may vary depending on the time of use. In 2024, the Norwegian Energy Regulatory Authority (RME) was tasked by the Ministry of Energy to evaluate the grid tariff model through two subprojects. Key findings from the first project[5] are

- 74 out of the 77 grid companies mapped use the capacity-based charges to calculate the fixed charge. There are variations in how the tiers of the capacity models are structured
- 71% of grid companies differentiate the variable energy component between day and night, while 79% differentiate between weekdays and weekends.

Large consumers (> 100,000 kWh/yr) often have more complex tariff structures than households. The tariff includes an energy component and a fixed component and may also include a capacity charge. The structure of each of these components varies depending on the grid company in question[6].

Context affecting the adaptation of new flexibility

As of 2024, there are approximately 85 grid companies in Norway. These companies manage various grid levels, from high-voltage transmission grids to low-voltage distribution networks. The TSO, Statnett, is responsible for the high-voltage transmission system, while regional DSOs manage the regional and local grids, which again consist of both high and low-voltage networks. The size of the grid companies also varies significantly. The smallest grid company has a few thousand customers, while the largest DSO, Elvia, has more than 900,000 customers.

Smart metering and data hub

All Norwegian electricity consumers have a smart meter (AMS) installed. The meters offer two-way communication between the metering point and the DSO and register electricity consumption on an **hourly** basis, that is automatically sent to the DSO. The next generation of smart meters, AMS 2.0, is expected to be rolled out over the next ten years.

Through the smart meter, the consumer also has the option to receive time-of-use information about consumption and prices. To receive this information, the HAN

5. RME (2024)
6. Elhub (2021)

port must be activated. The HAN port is a physical port on the smart meter that, by default, is closed for use. Before it can be used, the customer must ask the DSO to activate it. This is usually done remotely through the DSO's data systems. On a national level, only a few per cent of customers have activated their HAN ports.

Activation of the HAN port is in many instances a prerequisite to utilise smart appliances in households. By connecting external reading equipment to the HAN port, the customer can access real-time information about their own electricity consumption. This information can be used by smart appliances to adjust the customers' electricity consumption. Multiple commercial providers offer services based on information from the HAN port. Other providers can utilise consumption data directly from the appliances to monitor and optimise their usage based on different price signals.

The customers can view their historical data in the data hub, Elhub. The customers can also give third parties permission to access their data through the hub.

Current utilisation of DSR in Norway

Amongst the Nordic countries, Norway has conducted the highest number of flexibility projects. A total of 20 flexibility initiatives were identified in our mapping. The initiatives primarily focus on demonstrating and validating flexibility potentials from different end users and appliances, and the technical solutions necessary to realise flexibility from these sources. In some projects, the main goal is to solve specific grid-related issues through tariffs, while others focus on bilateral agreements with larger customers and technologies that allow for more dynamic grid utilisation.

There are also variations amongst the projects in terms of what type of flexibility resources they aim to activate and what value chains they propose to do so. **NorFlex**/EuroFlex focus on a pure market-based approach and aims to build a working marketplace for all types of demand-side flexibility services, including household appliances. **ByggFleks** and **BattFlex**, on the other hand, primarily focus on specific building and household appliances and direct activation of assets without a marketplace to mediate a transaction.

Sweden country sheet

Country context

The future electricity grid in Sweden, as well as other Nordic countries, will feature a higher share of small-scale variable electricity production, a higher degree of electrification, and thus an increasing need for flexible resources to keep the grid balanced. Other than flexibly dispatchable electricity production and energy storage, demand side flexibility will be needed to fulfil this task. Several of Sweden's around 170 DSOs have already seen increased capacity challenges in their local and regional grids, and many foresee similar problems in the future.[7]

Smart metering and data hub

The rollout of smart meters was finished by January 1st, 2025. Requirements for smart meters include 15-minute data logging, remote data collection and updates, and an open standard customer interface. For this, a HAN port is often used, but other solutions may be applied as well: The relevant statute[8] merely demands an open standard customer interface, which the DSO is only allowed to activate if requested by the customer.

Sweden's participation in defining a common data hub has been on hold since 2020 due to an unclear legislative background.[9]

Queue management

The management of connection queues is defined in the Swedish Electricity Act (Ellagen), which requires grid concession owners to connect applicants objectively and non-discriminatorily, which is oftentimes done in a first-come, first-served manner. However, the Swedish TSO also gives non-binding recommendations to DSOs on how project maturity should be considered when handling the connection queue.[10] In 2024, a common set of industry recommendations on the topic was published by Swedenergy, the interest organisation for Swedish energy companies.[11]

7. Flexibilitet i distributionsnäten
8. Förordning om ändring i förordningen (1999:716) om mätning, beräkning och rapportering av överförd el | Svensk författningssamling
9. Data hub project on hold | Svenska kraftnät
10. Svenska kraftnäts rekommendationer till nätföretag gällande hantering av anslutningsärenden
11. Branschpraxis Mognadsgrad för anslutning till regionnät och lokalnät - Energiföretagen Sverige

Current utilisation of DSR in Sweden

The Swedish TSO Svenska Kraftnät manages and operates several ancillary services markets, where both larger and aggregated smaller FSPs can participate. Svenska Kraftnät has also been an active participant in the local flexibility market Sthlmflex, see Chapter 3.6. Several DSOs have since then been engaged in local flexibility markets, some of which are analysed below. The main issue these markets are supposed to solve is local bottlenecks in local and regional grids, but also production peaks.[12] To facilitate a more flexible grid use, the TSO employs joint subscriptions to its grid ("Summaabonnemang"), which enables moving capacity between different connection nodes. In the special case of Sthlmflex, the exchange of transmission capacity subscriptions ("Abonnemangsväxling") between connection nodes was made possible, enabling DSOs to purchase flexibility services both in their own and other regional grids.

The TSO also offers temporary subscriptions to its grid, which can be activated by the DSO to cover peak loads. However, this is only possible in the event of an available surplus TSO grid capacity and can thus not be guaranteed.

End-user grid tariffs for small consumers are not uniform: Power-based tariffs are obligatory to be introduced until 2027, with many companies already introducing a power component earlier than that. DSOs enjoy a high degree of freedom in designing these tariffs.

Selection of case studies

The first larger pilot in Sweden was CoordiNet (2019/20), developed within the Horizon 2020 program and with local markets in Uppsala, Skåne, Gotland, and Jämtland/Västernorrland. The market platform used in this project, SWITCH, was mainly developed by E.ON, which chose to develop further local markets as CoordiNet ended.[13]

Sthlmflex was operational from 2020/21 and in part intended as RnD project to assess, among others, different market designs and the effect of standardised communication standards. As of winter 2024/25, no trade is foreseen to take place on the market anymore. As a lot of data and valuable lessons learned are available for this project, it was chosen as a pilot case study.

12. Kartläggning av lokala flexibilitetsmarknader
13. Another project, BeFlexible, was started after the end of CoordiNet and builds upon its results.

Just as Sthlmflex, Effekthandel Väst uses NODES as the market platform, but focuses on solving potential future grid issues, as opposed to pressing current ones. The market was started in 2022 and thus had the chance to use the first learning from Sthlmflex. To analyse these, and because Effekthandel Väst actually left the pilot stage, it was chosen as the second case study.

Of the above-mentioned CoordiNet project, Swedish grid company E.ON chose to continue some markets and added several more, reaching a total of 9 different market areas to date. In 2023, Energimarknadsinspektionen concluded that current flexibility markets are in an early stage and cannot be regarded as completely functioning yet. However, the underlying data for this statement is around 2 years old by now, and the expansion of E.ON's markets was a reason to choose these as a collective case study.

Denmark country sheet

Country context

The primary drivers for flexibility in Denmark are the increasing electrification of district heating[14], the growing demand from the transport sector, and new industrial loads. Additionally, the significant expansion of decentralised renewable energy sources poses challenges for the operation and development of the electricity grid at all voltage levels. These challenges vary among DSOs, depending on regional differences in consumption and generation patterns.

Electricity consumption in Denmark is expected to grow by 65% by 2030 compared to 2020[15], primarily driven by the transition to electric solutions in heating and transport. Decentralised generation has also increased, with annual renewable energy production reaching 19 TWh in 2020[16], creating a greater need for adaptation in local grids.

Trends and development

Electrification of district heating has added approximately 400 MW of flexibility capacity from electric boilers and large heat pumps between 2015 and 2020. These

14. A Transition Perspective on Demand-Side Flexibility in the Integrated Energy System Insights from the Danish ISGAN Annex 7 Project 2017-2021
15. Danish Energy Agency, Development and Role of Flexibility in the Danish Power System 2021
16. Green Power Denmark, *Elnet til meget mere – Analyse*, 2023

units can deliver up to 1,000 GWh of heat annually and are actively used to absorb surplus production from wind and solar energy.

The electrification of the transport sector, including the deployment of electric vehicles and charging infrastructure, creates new demands on the distribution grid. Smart charging has become a key method to reduce peak loads and make better use of surplus production from renewable energy sources.

The growing share of local wind and solar energy increases the need to manage variable energy flows and bidirectional power flow in the electricity grid. This requires optimisation of local grid capacity and more precise monitoring of grid loads.

Past experiences and current approach

In the years between 2005–2015, Denmark explored the potential for establishing local markets for flexibility through pilot projects such as EcoGrid and DREM. These experiences demonstrated that economic incentives alone, especially at the household level, were rarely sufficient to significantly change consumption patterns without advanced automation. Local flexibility markets were deemed complex and economically challenging to scale.

More recently, Denmark has focused on structural solutions. Limited grid access requires new connections to reduce or disconnect consumption during peak situations, minimising the need for grid expansion. Time-differentiated tariffs have been introduced to encourage shifting consumption away from high-load periods.

Current utilisation of DSR in Denmark

Denmark's demand-side response (DSR) strategy has evolved through both structural measures and pilot projects, focusing on integrating flexibility to address grid challenges. However, the implementation of DSR in Denmark remains constrained by technical, regulatory, and practical barriers.[17]

Denmark employs time-differentiated tariffs to encourage consumers to shift electricity usage to off-peak hours.[18] These tariffs are designed to reduce grid strain during peak demand, providing economic incentives for more balanced electricity consumption patterns. A notable example is the exploration of tariff harmonisation between TSOs and DSOs to ensure cost-reflective and transparent pricing mechanisms. Such efforts aim to optimise socio-economic grid expansion and promote demand-side flexibility across various grid levels.

17. Danish Energy Agency, Analyse af markedsudviklingen for fleksibilitet i lokale elnet 2021
18. Energinet, Possible solutions for electricity needs – Energinet's long-term development plan 2022 – Solution catalogue

The concept of conditional grid connections has also been implemented to manage demand-side flexibility[19]. New connections, including large-scale energy users such as electric vehicle (EV) charging infrastructure and industrial facilities, often face restrictions that allow grid operators to limit consumption during periods of high demand. These measures reduce the need for immediate grid upgrades while ensuring operational stability.

Several pilot projects have explored the feasibility of market-based local flexibility solutions. For instance, a project on Lolland tested geographically tagged bids in the existing balancing market to manage local congestion. The results revealed both potential and challenges, including issues with communication protocols, market liquidity, and the integration of local flexibility into existing market structures. Such projects have highlighted the need for further development of IT systems, better communication frameworks, and standardised operational procedures.

The FUSE project and other initiatives on smart EV charging have aimed to demonstrate the potential of integrating EVs as flexible grid resources. While these projects showed technical viability, they also uncovered significant barriers, including the lack of standardised data exchange protocols, high costs for advanced metering systems, and challenges in verifying billing accuracy, as verified in an interview with DTU Electro. These factors have prevented widespread adoption of smart charging solutions.

In practice, DSR in Denmark remains heavily reliant on structural measures, such as dynamic tariffs and restricted grid access, rather than fully developed local flexibility markets. Distribution system operators (DSOs) and the transmission system operator (TSO) continue to explore ways to enhance coordination and unlock the full potential of demand-side flexibility. However, significant work is required to overcome barriers, particularly in aligning regulatory frameworks, improving data accessibility, and addressing technical constraints.

Denmark's approach reflects a pragmatic progression towards integrating DSR while balancing technical feasibility and socio-economic considerations. Continued investment in technology, regulatory development, and stakeholder collaboration will be crucial to further advancing demand-side response in the Danish electricity system.

19. Energinet, Green Power Denmark – Net til Tiden, 2023

Need for flexibility

DSO perspective

Increasing electrification, including heat pumps and EVs, puts pressure on grid capacity, while integration of decentralised renewable energy sources like wind and solar causes congestion and local bottlenecks[20].

Flexibility is prioritised to avoid costly grid expansions and to address voltage instability challenges in areas with high penetration of distributed generation.

Queue management

Connections are managed on a first-come, first-served basis, but prioritisation may apply for mature projects with secured financing and necessary permits.

For larger connections or those impacting grid stability, coordination with the TSO is required.

The TSO reports that it increasingly uses flexibility solutions to accommodate new connections and reduce delays in areas with congestion or limited capacity.

Applications to the transmission grid

There are no available data on the average waiting time for TSO connection. Data concerning TSO grid capacity is related to production only.

The agreement for grid connection is estimated to be 12 months or less. However, this is purely the agreement and not concerning the actual connection.

Current use of flexibility

TSO balancing markets: Energinet uses European platforms like PICASSO (aFRR) and MARI (mFRR) to manage imbalances in the transmission grid, integrating flexibility from large producers and industrial consumers.

DSO flexibility mechanisms: Danish DSOs are developing solutions like conditional connections in congested areas and pilot projects to leverage local flexibility and avoid costly grid expansions.

Interruptible loads: Conditional connections and interruptible contracts are increasingly used to manage high-demand periods, with some DSOs offering discounts to incentivise flexible consumption.

Local flexibility projects: Initiatives focus on integrating decentralised resources into flexibility markets, creating incentives for small and medium-sized actors to contribute to grid stability.

20. Energistyrelsen, Analyse af markedsudviklingen for fleksibilitet i lokale elnet 2021

End-user grid tariffs

Incentive programs and tariffs: Energinet's previous discount program for interruptible loads ended in 2021. New efforts centre on dynamic tariffs and market models to encourage flexible energy use and production.

Context affecting the adaptation of new flexibility

Number of DSOs: 34 DSOs currently operate in Denmark, primarily managing low- and medium-voltage grids (<100 kV), with fewer handling high-voltage or transmission-connected grids.

Smart metering

- 100% rollout completed, providing 2-way communication.
- 1-hour time resolution is standard.
- Customers can access historical data online.
- Both summation meters and phase meters are used for billing purposes, ensuring accurate energy measurement.

Datahub: Fully implemented by Energinet, allowing third-party access to customer energy data with explicit customer consent.

Finland country sheet

Country context

Need for flexibility from the DSO's perspective

The main drivers for flexibility are a lack of capacity in the high and mid voltage grids for electrification of district heating, both existing and new industry, and transport. The increase in decentralised power generation affects the grid development in all grid voltage levels. The growth in the number of active customers participating in the energy market also increases the capacity needs. The situation varies significantly between DSOs.

For the whole of Finland, transmitted energy in DSOs' distribution networks is estimated to grow by nearly 8,000 GWh, almost 15% from the 2021 level until 2031.

The percentage growth for DSOs operating in urban environments is estimated to be about 20%, for DSOs with a predominance of conurbation areas about 13% and for DSOs with a predominance of sparsely populated areas about 6%. Energy received from customers is projected to decrease for DSOs operating in urban environments, but to double for DSOs operating in predominantly conurbation areas, and triple for DSOs operating in sparsely populated areas over ten years. In the future, electricity storage and various flexibility solutions and services are expected to increase in importance and be an integral part of grid maintenance and management, which must be taken into account in grid development[21].

Queue management

The first-come, first-served principle is used for new grid connections in the transmission grid. Other formal principles for queue management are not in use. The queue management has been possible to organise by negotiating so far.

TSO connection applications (waiting)

There is no available data on the average waiting time for TSO connection. In total, Fingrid has received approximately 400 GW of requests to connect to the transmission grid for electricity production, approximately 60 GW for electricity consumption, and approximately 20 GW for electricity storage[22]. Fingrid's main challenge is the transmission grid capacity from northern and central to southern Finland and from western to southern Finland.

Current use of flexibility

TSO's mechanisms for transmission management: Fingrid uses mFRR energy bids for congestion management by ordering mFRR special regulation. From 2023, Fingrid has made it a permanent practice to trade on the intraday market to perform the congestion management measures required by cross-border interconnector faults (more info)[23]. According to the analysis of the case study in the trial period, the procurement of energy from the intraday market enhances the operational security, is fluent to execute by the grid control room operators, and the expenses are reduced compared to procurements from the balancing market.

At the end of 2024, Fingrid introduced a transmission management agreement (bilateral agreement), which agrees on the flexibility of production or consumption

21. Summary report of the 2022 electricity distribution network development plans.
22. https://www.fingrid.fi/en/news/news/2024/fingrid-group--managements-review-1-january30-september-2024/
23. https://www.fingrid.fi/en/news/news/2023/intraday-market-trading-for-congestion-management-during-faults--continuation-as-a-permanent-practice/

for the needs of transmission management. The agreement sets out the terms of flexibility in advance before the situation arises. Transmission management agreements are suitable for capacities of at least 10 MW, which are not technically compatible with the balancing markets (more info)[24].

There are currently no market-based flexibility services available for DSOs. The amount of FSPs' (aggregators') flexible capacities suitable for local flexibility is still quite limited and widely distributed. The first live pilot marketplace of local flexibility will start in the winter of 2025. The target is to harness capacities, which are not technically compatible with the balancing markets, for the use of transmission management of the DSO (Helen Electricity Network) and TSO.

There are no rules on conditional/flexible connections in the Finnish legislation. Some DSOs have applied temporary flexible connections. The first implementation of a flexible connection (temporary dynamic connection) was implemented in 2023 by DSO (Caruna) for the connection of an electric boiler[25]. TSO offers temporary, flexible connections as an option[26]. Flexible connections have not yet been implemented in the transmission grid.

The national tariff structure does not allow dynamic network tariffs. Different tariffs according to the time of use and peak consumption are implemented (e.g., night and day tariffs and power tariffs), but not according to the congestion situation. Interruptible tariffs have not been implemented.

At the end of 2023, electricity exchange-based contracts accounted for 31 per cent of all electricity retail sales contracts.

End-user grid tariffs

For small customers, DSOs use volumetric (eur/kWh) and fixed charge (eur/month). Some DSOs have a power capacity charge (eur/kW) also for customers with the main fuse size ≤ 63A. For large customers, the DSO tariffs include volumetric (eur/kWh) and fixed charge (eur/month), power capacity charge (eur/kW), and reactive power charge (eur/kvar). Tariffs and their structures vary significantly depending on the DSO. The government proposal suggests the harmonisation of distribution network tariff structures.[27]

24. https://www.fingridlehti.fi/en/what-is-a-transmission-management-agreement/
25. https://caruna.fi/ajankohtaista/ensimmainen-dynaaminen-sahkoliittyma-kytkettiin-verkkoon-espoon-suomenojalla
26. https://www.fingrid.fi/en/news/news/2024/fingrid-proposes-reforms-to-the-structure-of-grid-service-fees/
27. https://finlex.fi/en/government-proposals/2024/197

Context affecting the adaptation of new flexibility

Number of DSOs

There are a total of 77 DSOs in Finland[28]. The 15 largest DSOs cover approximately 70 per cent of distribution networks, electricity users, and the companies' turnover[29]. The smallest DSOs operate in one municipality and serve a few thousand customers.

Smart metering

The roll-out status of smart meters with one-hour resolution is 100 %. The next generation smart meters are called AMR 2.0 meters. All meters must have a 15-minute resolution by the end of 2028. A control relay is included in AMR-2.0 meters. All meters must include the HAN port by May 2031. Web-based access to historical data (15 min resolution) is accessed from Fingrid's data hub and from DSO's service.

Data hub

The centralised information exchange system (datahub) for the electricity retail market was commissioned on 21.2.2022. The system is maintained by Fingrid Datahub Ltd, a subsidiary of Fingrid. Datahub is used by approximately 80 DSOs and approximately 80 electricity sales companies, and more than 20 service providers.

The Datahub service includes third parties that provide services to DSOs, electricity suppliers, and end customers through delegations and authorisations. Third parties must be authorised to access the data, either on delegation from an electricity supplier or DSO or with the authorisation of an end customer. The end customer gives the authorisation through the customer portal provided by the data hub[30]. The authorisations and delegations are explained further in *Electricity retail market business process in Datahub*[31].

28. https://energiavirasto.fi/siirtohinnoittelun-valvonta
29. https://energia.fi/
30. Guidance for third parties within the scope of the Datahub service. Fingrid Datahub. 22.6.2023.
31. Fingrid (2023): Electricity retail market business process in Datahub. 6.7.2023, Chapter 3.9

Current utilisation of DSR in Finland and chosen cases

In Finland, only a few DSOs have so far carried out pilot demonstrations for local DSF. The use of flexible electricity consumption as an alternative to expanding the capacity of the distribution network is still in its early stages, but the first steps are being taken, e.g., towards the local flexibility markets.

Chosen case studies

The chosen two case studies from Finland represent live implementations, which are both in the preparation phase to some extent. The method to map barriers and opportunities here has reflected the requirements connected to the case studies of FSPs' experiences and capabilities with a focus on home appliances.

1. The first live pilot marketplace in Finland starts in the winter of 2025 by Helen Electricity Network and Fingrid. Pilot tests the functioning of the local DSF market, products, and the market's liquidity. Prior knowledge for the marketplace gained from technical pilots with simulated market design in INTERRFACE and OneNet projects.

2. The DSF possibilities of smart electricity meter control relays. As a pilot case: DSO Elenia's experiences of DSF capabilities of home appliances connected to electricity meters' load control relays'. The possibilities of load control relays were piloted in 2018-2020 with 76 household-clients in Elenia's grid. Elenia launched the service for controlling the relays automatically according to spot prices in 2024 for all households with loads connected to the new AMR 2.0 meter. The loads connected to the relays are typically ESWHs and electric underfloor storage heating. In the near future, the load control relays will be commercialised for the use of FSPs. The load control of AMR 2.0 meters has significant DSF potential suitable for the evolving local DSF markets (referring to case study 1).

The other mapped initiatives, which included local DSF

In addition to the chosen case studies, the following flexibility initiatives, including local DSF, were mapped:

- OneNet project (2020-2024, Horizon 2020): The scope of OneNet was to create an architecture that enables the whole European electrical system to operate as a single system in which a variety of markets allow the universal participation of stakeholders regardless of their physical location. The Finnish

technical demonstration tested the market-based and coordinated flexibility procurement with relevant network situations for the Finnish environment to learn how congestion can be solved using flexibility and how the combination of flexibility from DSO and TSO networks interacts. Demonstration showcased the functioning of the proposed market design. More information about the Finnish case study can be found on the project's website (7.6 Final Northern Cluster demonstrator evaluation report)[32].

- INTERRFACE project (2019-2022, Horizon 2020): The Finnish operational congestion management demonstration piloted the end-to-end IEGSA (Interoperable pan-European Grid Service Architecture) process in the planned scenarios to validate its functioning in different situations. The IEGSA solution provided the FSPs a possibility to manage their resources, offer them to markets through the connected market operator, and get activation requests from the respective marketplace. For the SOs, the solution introduced a possibility to procure flexibility in a coordinated manner based on the location of the resources.
  The project included a technical congestion management demonstration in a simulated grid model in Elenia's (DSO) grid. FSP (Kapacity.io) aggregated heat pumps in 6 residential apartment buildings. The demonstration included TSO-DSO coordination in grid disruption situations. The project also demonstrated the use of intraday market for TSO's congestion management. Intraday pilot case proved that congestion management can be part of an international and liquid intraday market with relatively small system-level exceptions and modifications. More info on the report on Fingrid's website.[33]
- SysFlex project (2017-2021, Horizon 2020). The project aims to offer new solutions for the integration of consumption and production flexibility to the electricity market to enable more wind and solar power to the system. The Finnish demonstrations connected to the local DSF:
  - The demonstration showcased the increase in control ability of reactive power by a market-based approach, where inverter-based resources connected to the distribution system are used as controllable assets. This development benefits the DSO and opens opportunities to asset owners and aggregators. The project demonstrated a reactive power

32. https://www.onenet-project.eu/use-cases/
33. https://www.fingrid.fi/contentassets/99d3e79bf5a542839102e15e95fed106/interrface-hankkeen-pilotoinnin-loppuraportti.pdf

market solution. The presented approach builds upon the development of various market-based flexibility services. The development of these applications is challenging for the FSPs, since controlling various kinds of assets requires various technical solutions that may be case dependent[34].

- Project included a case study of the electric vehicle charging control in office buildings. The case study was conducted in an office with eight
- EV charging points and a battery energy storage system (BESS). The BESS's peak shaving application was successfully applied to cut the increased power demands[35]

34. https://ieeexplore.ieee.org/document/9543338/metrics#metrics
35. https://ieeexplore.ieee.org/document/9583092

In-depth case studies of flexibility initiatives

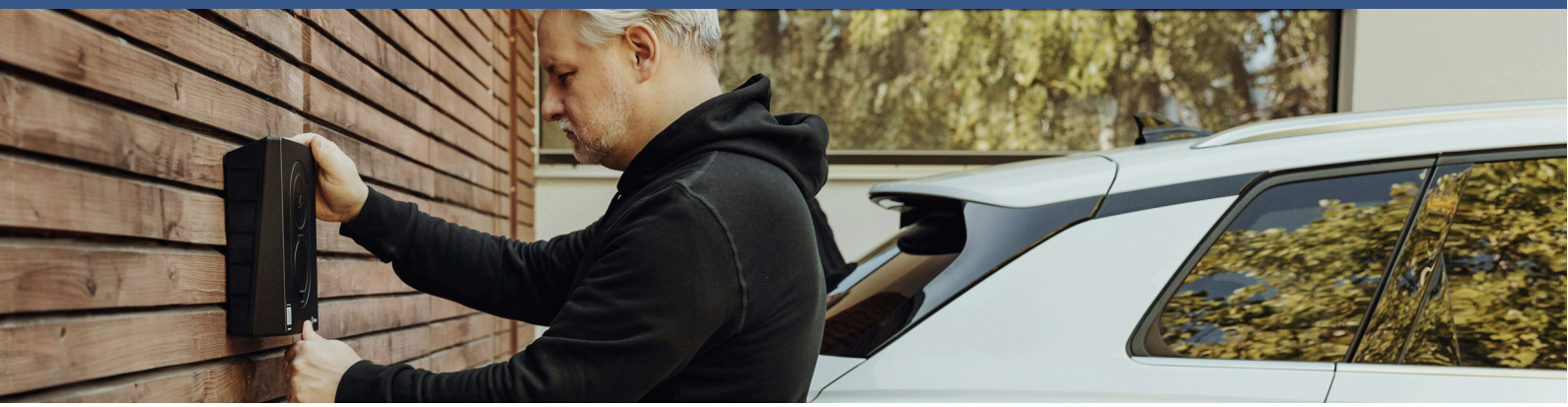


Photo: Unsplash.com

In this chapter, we present the 10 use cases. For each of them, we provide a case description, show the processes and actors involved in the value chain, and describe barriers and suggested ways to overcome the barriers. We also provide a rough estimate of the overall flexibility potential of the flexibility source in focus. Before we go into the specific use cases, we present the main learnings from the 10 cases and explain the value chain for flexibility.

Selected case studies

Several criteria were used when selecting cases to be studied in this project. They should focus on flexibility from a range of smart appliances like smart appliances with storage water heaters (continuous or night storage), thermal appliances (heating and cooling), electric radiators, electric boilers, electric and hybrid heat pumps, and air conditioners. The cases should have reached a certain level of maturity, i.e., how long they have been implemented. Newer cases were also preferred. The design choices in new solutions may be interesting even if the mechanism is not mature, and new mechanisms were expected to draw upon

learnings from earlier solutions. It was also desirable to study innovative cases to study mechanisms utilising smart appliances in novel ways.

In addition to the criteria, the selection should also have a certain variation across:

- Different products/DSO needs
- Different flexibility sources/load types
- Different providers (i.e., contractual arrangements, aggregation solutions)

10 flexibility initiatives were selected across the four countries. The cases are presented in the table below, highlighting previous work they build upon, their purpose and focus, the actors and loads participating, and plans going forward. Two of the cases are permanent solutions, while the rest are temporary pilots and demonstrations.

Table 6: Overview of selected case studies

	Builds on	Purpose and focus	Participants and loads	Plans
Byggfleks (2019-2023)	• Part of *Strømfleks,* demonstrating how flexibility from different sources can be utilised to manage issues in the distribution grid	• Byggfleks focused on testing the technical solution and systems for activation and aggregation of flexibility from commercial buildings • Aimed to reduce and distribute peak loads	• DSO Lede, Horten municipality, Vestfold and Telemark counties, Format Eiendom, SINTEF, and Aidon • Loads include room heating, water heating, and ventilation from commercial buildings with BACS	• Knowledge and results were transferred and continued in pilots on other types of commercial buildings
Battflex (2019-2024)	• Originates from KAFFI, evaluating the need for and potential of activating local flexibility • Builds on LEAFS and EffektPILOT	• Aimed to demonstrate the potential of utilising consumer flexibility to address grid issues • Focuses on grid-friendly flexibility	• DSO Elvia, the Norwegian Smartgrid Centre, NTNU, EPOS Consulting • Loads include ESHWs and grid-connected batteries. The case focuses on ESWHs	• Findings from BattFlex have been integrated into various initiatives and products
Norflex (2019-2023)	• Builds on learnings from various pilots and studies organised by Glitre Nett and Agder Energi Nett (both now Glitre), and Statnett	• Aimed to increase the use of flexibility through market-based solutions to manage local grid bottlenecks • Uses NODES as trading platform	• DSO Glitre, TSO Statnett, utility Å Energi • Loads include batteries, EV chargers, household appliances, and loads from industrial and commercial buildings. Our case focuses on EV chargers and household appliances	• Followed up by Euroflex (ongoing)
Sthlmflex (2020-2023)		• Established due to a lack of grid capacity and to stay within power subscriptions towards the TSO • Uses NODES as trading platform	• Svenska kraftnät, Ellevio, Vattenfall and E.ON (DSO) • Loads involved are mostly privately owned. A large share of loads was EV chargers. Our case study focuses on two heat pumps in office buildings	• Discontinued due to low liquidity. DSOs prefer other ways to acquire flexibility, e.g., bilateral agreements and conditional connections

Effekthandel Väst (permanent)	• Builds on learnings from CoordiNet and Sthlmflex	• Established to solve future electricity demand and grid capacity challenges • Uses NODES as trading platform	• Göteborg Energi, Mölndal Energi, industrial enterprises, small companies, aggregators, and large property owners • Loads include batteries, EV chargers, fridges, and freezers in supermarkets and warehouses. Our case study focuses on freezers and fridges	• The DSOs have plans to expand the market with new loads and to use flexibility along with grid investments to solve future grid issues
E.ON Energidistribution's flexibility markets (permanent from 2023/ 2024)	• Builds on CoordiNet (developed the market platform)	• E.ON owns and operates 70 Swedish grid areas, and has established local DSF markets at nine of them • Markets are established where the local grid faces capacity issues, usually active between Nov-March • Uses market platform SWITCH	• E.ON Energidistribution, home owners (via aggregators), property owners, municipalities, and industrial/commercial actors • Loads include heat pumps, car charges, battery storage, ventilation units, backup generators, and lighting systems	
FUSE (2020-2023)		• Established to integrate smart EV charging into the Danish energy system • Explores how dynamic charging management can provide DSF and help stabilise the distribution grid	• Frederiksberg municipality, DTU Wind and Energy Systems, Radius Elnet, Danish e-Mobility, and Spirii • Home charging, workplace charging, and semi-public chargers	• Further refinement of interoperability standards, addressing regulatory barriers, and improving real-time measurement capabilities remain key areas for future research and development
EcoGrid 2.0 (2016-2019)	• Builds on EcoGrid 1.0 (EU initiative)	• Large-scale research and demonstration project at the island of Bornholm (isolated energy system) • Exploring and developing a market-based approach to DSF • Uses market platform FLECH	• Bornholms Energi & Forsyning, Energinet, Insero, IBM, DTU, Uptime-IT, Krukow and CBS • Loads from residential electricity consumers. Our case study focuses on electric heating systems	

Helen Electricity Network and Fingrid (2025-2027)	• Builds on INTERFACE and OneNet (both technical pilots with simulated market design)	• Live common marketplace for congestion management to test the market, products, market rules, and market liquidity • Uses market platform NODES	• Fingrid, Helen Electricity Network • Production, consumption, or storage	• The long-term target is a common national marketplace. The goal is to develop product specifications based on this pilot	
DSO Elenia (2020à)	• Builds on learnings from pilots of smart meters 2018-2020	• DSO Elenia offers a service where loads of household customers with AMR 2.0 are adjusted automatically, e.g., according to the cheapest day-ahead prices. The legislative amendment will commercialise load control from 1 September 2026, and a load control interface will be built into the data hub. Due to the amendment, FSPs can use the smart meters to control aggregated loads for use in electricity and local DSF markets	• DSO Elenia, Aidon, Vattenfall, Empower (FSP), Datahub • Loads from single-family and two-family houses. ESWHs and underfloor electric storage heating	• Commercialisation of the solution from fall 2026	

Main learnings from the 10 case studies

Norwegian DSO Lede: Byggfleks - Validating DSF technology for grid operation (2019-2023)

The pilot successfully tested a technical solution and systems for the activation and aggregation of flexibility from commercial buildings. Lede found that activation limited to 1-2 hours did not affect user comfort.

Feedback from building managers suggests that complicated control systems should be avoided, and if not, guidance and knowledge-building should be prioritised. Lede also experiences challenges related to variations in appliance smartness and interoperability. Older appliances had a limited ability to integrate and communicate with top control systems. However, once an integration was set up, the logic could be reused to integrate new assets.

Norwegian DSO Eidsiva (now Elvia): Battflex - Voltage control in weak grids (2019-2024)

Smart ESWHs were installed in a selection of households to assess how market-based optimisation impacts grid voltage levels and whether smart automation can mitigate potential grid voltage issues in local grids. The pilot found that pure price optimisation could lead to rebound effects. Controlling the ESWHs based on a combination of voltage control and price optimisation, on the other hand, led to reduced electricity costs without affecting the voltage level negatively. Only implicit flexibility was tested (optimising the water heaters based on Nord Pool spot prices).

No technical barriers were reported by the interviewees. This may be related to the flexibility provider (OSO) was also the supplier of the smart appliances and the technical system for activating flexibility. The flexibility provider only had to integrate with a single type of appliance, for which they had designed the interface themselves.

Norflex (Euroflex) - Large-scale demonstration project – flexibility market (2019-2023, 2023-2026)

Several important issues have been identified in Norflex, where possible solutions are being tested in Euroflex. One example is baseline estimation. The flexibility providers experienced difficulties estimating the baseline for the different smaller flexibility sources, especially for household appliances. As a response to this, a new

product is being developed and tested in Euroflex, called *MaxUsage.* This product lets the flexibility providers bid on a total maximum capacity being used for their portfolio as a whole.

Another example is coordination and value stacking (letting flexible resources participate in several markets). Participants experienced coordination as essential to ensure efficient usage of flexibility sources. This concerns coordination between TSO and DSO, but also between local and regional DSOs. It is important to develop solutions allowing flexible resources to participate in both TSO and DSO markets. If market liquidity is split between markets, the worry is that much-needed profitability is lost. An easy solution for forwarding bids was tested briefly in Norflex. This leads the participants in the direction of a Flexibility register, providing an overview of distributed flexibility assets and their properties. Participants in Euroflex will pilot such a register and also determine rules on how and by whom the resources can be activated across markets.

Finally, building a functioning flexibility market takes time. Participants state the importance of predictability and using similar solutions and market setups for different local markets. It is also important to remember that household customers are primarily incentivised to be flexible due to volatile power prices (implicit flexibility). Explicit flexibility is something they engage in as an add-on, often after being informed by their utility company (flexibility provider).

Sthlmflex - R&D project with common market design and products (2020-2023)

The grid issues (restricted grid capacity) that the pilot was established to solve turned out to be significantly smaller than expected. This was due to two main reasons: i) mild winters and ii) high electricity prices. The need for flexibility is strongly dependent on weather conditions. A mild winter gave a smaller need for flexibility than anticipated. Furthermore, the Russian invasion of Ukraine led to electricity price spikes, resulting in lower consumption and decreased need for flexibility.

The case study identified several regulatory matters that can prevent well-functioning use of local flexibility in Sweden. Grid tariffs favouring a flatter consumption curve can decrease the profitability of offering flexibility. Furthermore, Swedish DSOs have stronger incentives to invest in grid capacity than to solve grid issues with operational measures, like flexibility. Finally, the structure of subscriptions Swedish DSOs pay towards the TSO also disfavours using local flexibility.

The pilot also revealed important learnings regarding the loads and procurement solution. Domestic heat pumps showed promise as they are numerous, and their

electricity consumption is easy to predict. These loads respond too slowly to participate in reserve markets, but can participate in local DSF markets where a longer response time is acceptable. However, all the flexibility that was purchased was not actually delivered. This raised questions about the reliability of FSPs and discussions on how to validate deliveries in a proper way. Finally, an important learning from Sthlmflex was that tight communication between the aggregator and DSO prevents misunderstandings and redundant work.

Effekthandel Väst - Permanent DSF Platform (Permanent from 2022)

Previous pilots have shown that market liquidity is essential to ensure FSPs invest in technology, routines, and competence-building needed to participate in the market. The DSOs "invested" in the market by choosing to solve grid issues through the market, even if they had other alternatives to solve an issue. Still, the DSOs preferred bilateral agreements to use the local market to solve grid issues. This is seen as a barrier to sufficient market liquidity.

An important learning is that baselines should be adjusted according to the appliance. This is, for example, important for fridges and freezers, as food hygiene rules restrict their flexibility potential. Rigid baselines could prevent profitability for loads. If communication protocols are to be standardised, it is important that the standards give room for the baseline to be adjusted to the loads' unique consumption profile.

It is important that flexible loads are located where the grid issues are. Loads located in areas with high population density are more likely to help solve a grid issue. This makes loads like fridges and freezers at supermarkets interesting.

E.ON Energidistribution's flexibility markets (Permanent from 2023/2024)

E.ON owns and operates 70 local grids in Sweden and has established local flexibility markets in nine of its grid areas. E.ON experiences grid issues in several of its grid areas due to increased electricity demand and a higher degree of intermittent power generation, combined with low available flexibility potential from large industrial customers. Before establishing a new flexibility market, E.ON investigates whether flexibility can solve the grid issues at hand, whether a local DFS market is the best way of procuring flexibility, and whether this is the most cost-effective tool. After deciding to establish a new market, E.ON invests in the market by guaranteeing a number of years the market will be operated. They also set minimum availability payment levels. Ensuring market liquidity from the start is seen as essential to make potential participants trust that it will be profitable for them to go through with the necessary investments.

E.ON moved the management of its flexibility markets to its line organisation in 2022 and considers flexibility as an integral part of handling the grid in the future. They use the same processes and guidelines throughout the organisation. This includes the definition of baselines, prequalification of resources, and sanctioning of failure to deliver.

E.ON has also focused on developing automated solutions for the calculation and publication of flexibility needs, making it possible for FSPs to integrate with the API and enabling a smoother validation process. They have experienced that aggregators are crucial due to their know-how, hardware, and software regarding integration towards different market platforms and appliances. Aggregators also play an important role in defining viable baselines, increasing how much of the flexibility potential of the resource is being used.

FUSE project - Research pilot/potential study (2020-2023)

The FUSE project showed that it is technically feasible to shift charging demand to align with grid constraints without impacting user convenience. More specifically, it was shown that controlled smart charging can reduce peak loads by 20 per cent. This has a significant impact in high-density urban charging environments.

Another important learning is that latency issues in data transmission can significantly affect the responsiveness of charging control. Delays exceeding 500 milliseconds in load adjustment can reduce system efficiency. Standardised communication protocols will help ensure real-time interoperability between chargers, aggregators, and grid operators.

Different metering approaches to validate load reductions were tested in the project. As expected, sub-metering at the charging station level provides more accurate verification than aggregated household consumption data. Sub-metering is, however, more costly.

Bornholm's Energi og Forsyning (DSO): EcoGrid 2.0. Full-scale pilot/research study (2017-2019)

The EcoGrid 2.0 project demonstrated that heat pumps and electric radiators can provide flexibility, but response times and control precision varied significantly. Furthermore, heat pumps exhibited delayed activation and rebound effects, making them less suitable for fast-response flexibility services. 9.7 per cent of flexibility activations failed due to lost signals or delayed data transmission. The issues could have been avoided with optimised control algorithms, standardised communication protocols, and full access to APIs.

Consumer engagement was limited due to low financial compensation. Households were compensated through reduced electricity costs. The average annual reduction was, however, only 100 DKK per household.

Both the DSO and the TSO used the flexible resources to solve issues in their grids. A lack of market mechanisms for resource allocation and coordination frameworks resulted in conflicts where the same resource was sometimes needed for both system-wide balancing and local congestion management.

Finnish DSO Helen Electricity Network and Fingrid: Pilot of marketplace for DSF (2025 – 2027)

DSO Helen Electricity Network's and TSO Fingrid's common marketplace for congestion management goes live in Q1 2025. The marketplace is mainly used for predictable congestion situations. Many flexible loads can't be used for reserve markets, e.g., due to the reaction time requirements. The new marketplace will harness these loads, especially for congestion management, both for DSOs and TSOs. In case of a sudden grid fault situation, Fingrid will first use other congestion management methods, and the common marketplace comes in later if the congestion continues.

Value stacking (being able to participate in several markets) has been mentioned in many case studies as needed to ensure profitability for resources participating in local DSF markets. The common marketplace in Finland has enabled the necessary TSO-DSO coordination and gate closure times to allow for value stacking. In practice, the bids that are not accepted for DSO's ShortFlex product can be used automatically for TSO's ShortFlex product. The gate closure times also take into account the gate closure times of other markets, especially mFRR/aFRR capacity and energy markets.

Finnish DSO Elenia: DSF service for the day-ahead market based on smart meters (2023 à)

A significant number of loads, such as ESWHs and electric underfloor heating from single and double-family houses, are already connected to smart electricity meters' control relays and have good demand response potential, without any need for additional devices or installations. Today, the loads are mostly controlled according to a simple day/night grid tariff, but the second-generation smart meters offer possibilities to develop services responding to DSO tariffs, spot prices, intraday, and local DSF markets.

The solution for controlling the relays according to spot prices was piloted by Elenia, and most of the customers who participated report that their living comfort was

not affected. The next generation of smart meters can respond fast, but the communication infrastructure limits participation in the reserve markets. However, Elenia's second-generation smart meters (Aidon's meter) are capable of controlling loads also according to frequency.

Overall flexibility potentials

A rough estimate of the overall national flexibility potential of the flexibility source in focus is provided per case study. These estimates should not be interpreted as exact calculations but rather as indicative numbers on aggregated flexibility potentials from smart household appliances in the Nordic countries. The estimate and hence the extent of smart appliances' ability to support the power system can help inform policy discussions on how far policies and regulations should go in terms of facilitating demand response from the appliances in question.

Table 5 summarises the estimated potential per appliance, case study, and country. The potentials are in the same order of magnitude as the installed capacities in some of the largest power plants in the Nordic countries. The method of estimation varies somewhat between the case studies. The values are therefore not directly comparable. For more details, the reader is referred to the subchapters below.

Table 7: Estimated potentials per appliance, case study, and country*

	Potential	ESWH	Ventilation	Underfloor heating	EV charging	Heat pumps	Freezers and fridges
ByggFleks*	~ 1 GW	X	X	X			
BattFlex	2,5 GW	X					
Norflex/-Euroflex	1-6 GW				X		
Sthlmflex	2-8 GW					X	
Effekt-handel Väst	0,6 GW						X
E.ON Energi-distri-bution's flexibility markets	N/A						
FUSE	0,9 GW				X		
EcoGrid	0,2 GW					X	
Helen Electri-city Network	1,7-3 GW					X	
Elenia	~ 1 GW	X		X			

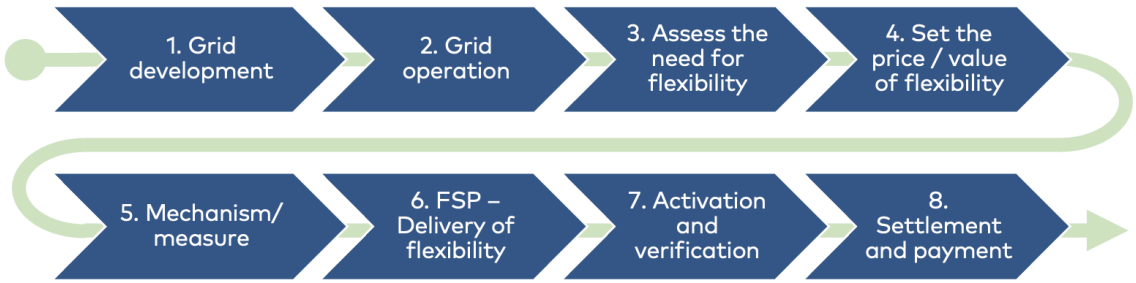
*For Byggflex, the estimated amount refers to commercial buildings. Since E.ON Energidistribution's flexibility markets are analysed primarily from a market perspective, the potential of single appliances was not determined.

Value chain for flexibility

Before entering the case studies, we provide an overview of the value chain for flexibility, including all aspects that need to be in place for DSOs to procure flexibility as a solution to grid issues. The description of the value chain makes it easier to understand the processes and systems used in the different case studies, and it also makes it easier to see where the barrier lies.

We have defined the value chain for flexibility according to 8 steps, shown in the figure below. In addition, there is a need for i) platforms and systems, ii) regulation, and iii) TSO-DSO coordination along the whole value chain. The case studies typically do not cover the whole value chain but focus on steps 5-7. Each of the case studies includes a flexibility value chain, explaining the process and systems used in the specific case study.

Figure 1: Value Chain for Flexibility



Explanation of the 8 steps:

1. **Grid development.** For the TSO/DSO to be able to use flexible sources as a part of their service, they need to plan for it. This means including flexibility when planning/developing the grid. This requires that the TSO or DSO can trust that the necessary flexibility is available when needed (time, location, volume, etc.). It also requires that grid developers have the relevant data available.
2. **Grid operation.** This step includes the necessary actions to make it possible to use flexibility as part of operating the grid. This can, e.g., be related to including information on flexibility in operating systems (SCADA/NIS/GIS).
3. **Assess the need for flexibility.** The TSO or DSO assesses when and for what they need flexibility, meaning which situations in the grid and when this

happens. This will, in many cases, require analysis tools and/or operation planning.

4. **Set the price/value for flexibility.** Usually, there are different ways a specific situation in the grid can be solved, where some will include using flexible sources. The TSO or DSO should have incentives to choose the cheapest solution that solves the problem and will to an assessment on the price they are willing to pay for the needed flexibility.
5. **Mechanism/measure.** Establishing a mechanism/measure enabling the procurement of flexibility. This can be a marketplace, bilateral agreements, conditional connections, etc. Prequalification of resources is necessary when using a marketplace as a mechanism.
6. **Delivery of flexibility from FSP.** The flexibility service provider takes action to be able to provide their flexibility (because they expect it to be profitable). For this to happen, you need:
    a. A willing Balancing Responsible Party (BRP) for aggregators
    b. Sufficient income potential and profitability for the end-user, flexibility service provider, and balancing responsible party
    c. Sufficient information and understanding
7. **Activation and verification.** Establishing systems that make sure loads are activated and that can verify that they were, and that there is a standardised way to do this. Important parts of this are:
    a. Availability - loads actually being available when they are needed
    b. Baseline - what would the power consumption/production have been without activation
    c. Verification – systems for verifying activation
8. **Settlement and payment.** Establishing systems for settlement and payment, in addition to penalties to actors who do not fulfil their market obligations.

Norway: ByggFleks

General case description

ByggFleks was a part of a project called StrømFleks, led by Norwegian DSO Lede. StrømFleks demonstrates how DSF from different sources can be utilised to

manage local issues in distribution grids. Apart from Lede, stakeholders included Horten municipality, Vestfold and Telemark County, property developer Format Eiendom, research institution SINTEF, and smart meter supplier Aidon. The entire project was conducted from 2019 to 2023 within a limited grid area. The knowledge and results from the project were transferred and continued by Lede in other flexibility projects in other types of commercial buildings. Important information sources for ByggFleks are the project's final report[36] and interviews with Lede, Vestfold, and Telemark County, as well as various technology providers.

In ByggFleks, the focus was on the grid customers' side of the value chain, corresponding to steps 6 and 7 in the value chain outlined in Chapter 3.1, and to test the technical solutions and systems for activation and aggregation of **flexibility from commercial buildings**. The project aimed to reduce and distribute peak loads from various appliances. No grid issues were specified, as the main focus of the project was system testing and to gain a better understanding of commercial buildings' flexibility potential.

Four commercial buildings with Building Automation and Control Systems (BACS) installed participated in the pilot[37]. The type of buildings and the appliances tested per building are specified in the table below. In total, the maximum available flexibility for activation from these buildings was 1.09 MW. Over the project period, the maximum flexibility activated simultaneously was 115 kW. Total energy volume removed through flexibility activation was 10.2 MWh.

Table 8: Flexibility resources in ByggFleks

Building type	Appliances made available for DSF	BACS status
High school 1	Room heating, water heating	New building, fully integrated BACS
High school 2	Room heating, water heating	Older building, partly integrated BACS
Elementary school	Room heating, ventilation, and water heating	Partly integrated BACS
Sports hall	Room heating, ventilation, and water heating	Partly integrated BACS

36. *Prosjekt «Storskala uttesting av forbrukerfleksibilitet»* (Lede & Menon Economics, 2024). Project ID 18/16282
37. Information regarding capacities per load and ByggFleks-specific numbers obtained from dialog with Lede

Value chain for DSF

Systems in use

The DSF value chain is illustrated in the table below.

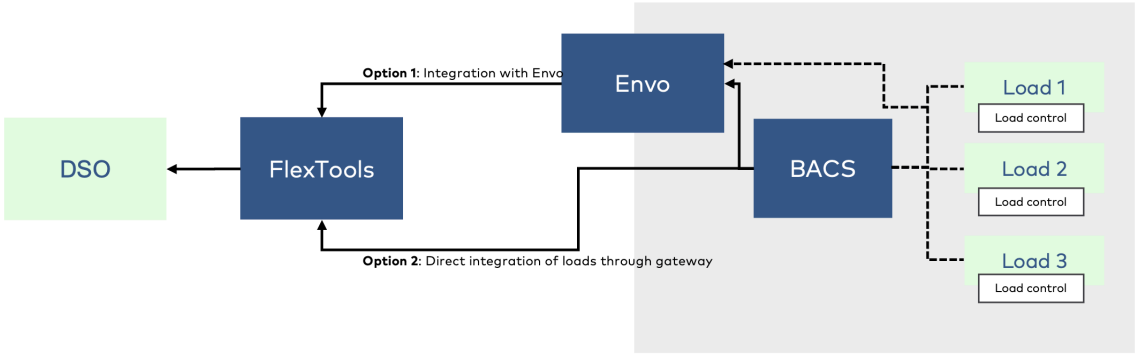
Table 9: Physical value chain for DSF in ByggFleks

Step in value chain	Stakeholders and systems in use		Function
4	DSO	*Lede*	
6/7	Interface DSO/top system	*FlexTools*	Registers (prequalifies) flexibility assets to DSO. Activation signal to smart appliances.
6/7	Top control system	*Either BACS or Envo control system*	Aggregates and control loads in the commercial building. Integrated with FlexTools either through top system or direct gateway connection. Integrated with smart appliances either through hardware connection or APIs (on load control unit).
6/7	Smart appliance with load control	*Room heating, ESWH, ventilation*	Integrated with top system (BACS/Envo) through hardware connection or APIs.

Load control is a unit installed on an appliance to allow it to connect and communicate with a central control system, either through a hardware connection or cloud-to-cloud integration. In ByggFleks, some appliances were already equipped with a load control, while other appliances were not, and local adjustments had to be made to integrate these appliances.

Building Automation and Control Systems (BACS) are systems used to control and automate loads or systems within buildings. A single BACS can manage all loads in a building, or a building may feature multiple BACS or independent loads operating without a BACS. BACS is usually operated by a building manager, and various sorts of interfaces exist to monitor and control the connected loads. A **separate top control system** is another option for integrating building appliances and/or BACS. In ByggFleks, a top system from Envo was utilised to connect some of the appliances and to merge separate BACS systems. The Envo control system had all the required protocols for integrating the appliances (HAN, Modbus, Enbus, Bacnet, etc.), enabling control and overview of production/consumption of all building appliances within a single system. The different routes taken to integrate the building loads are illustrated in Figure 4. To integrate existing loads that do not have standardised interfaces via a local integrator such as BACS and/or Envo is necessary to make these loads available for flexibility purposes.

Figure 2: Integration of building appliances through various routes in ByggFleks



The DSO used a platform called the **FlexTools Platform** to aggregate flexibility from the end-users by integrating with the BACS and/or top control system. The platform could integrate with the BACS and/or the Envo control system through a hardware connection (RTU channels[38]), cloud-to-cloud integration, or API integration. The DSO organised the building portfolios based on the localisation in the grid structure and activated flexibility directly through the platform.

Customer management and involvement

For each building, a schedule indicating at what time periods DSF would be available was developed in collaboration between the DSO and building managers [39]. Within these hours, the appliances could be activated by the DSO. Since the focus of the project was system testing, the appliances were never deactivated for more than 1-2 hours at a time, and no more than two times per day. The building managers were notified in advance of activation, but did not play any part in the actual activation. The limited activation time meant few negative consequences for the users of the buildings, primarily staff and students, in terms of air quality and temperature. No further testing was done to see how long the loads could be activated without significant changes to user comfort.

Feedback from building managers and owners suggested some areas of improvement, primarily related to user-friendliness and further incentives to utilise flexibility. In buildings where it was deemed necessary to install a separate top system to aggregate all the appliances, building managers had to deal with dual control systems and interfaces in parallel to manage the various appliances.

38. Flextools offers a Remote Terminal Unit (RTU) with controllable outputs that collects measurement data and acts as an interface, compatible with various Building Management Systems/BACS. RTU is an electronic hardware device that can be used to directly connect various electronic devices to an external system.
39. Lede

Further, as there were no market mechanisms or payments for DSF, the users expressed limited interest in further participation in the project without further incentives.

Barriers and enablers for DSF

The main challenges encountered in ByggFleks were related to variations in appliance smartness and interoperability. According to the interviewees, older appliances had a limited ability to integrate and communicate with top control systems. Some interviewees suggested that appliances in older buildings may use proprietary protocols and, therefore, cannot be programmed for load control or accessed. In newer assets, however, BACS integration was deemed manageable despite various interfaces. Once integration is done, the logic can be reused to integrate new assets. For interface standardisation not to be an issue, buildings should operate on the most common communication protocols. Apart from interoperability, no barriers related to the appliances themselves were identified in the project.

Integration and interoperability issues: At the Delivery-Activation stage (steps 6 and 7) of the flexibility value chain, many older building appliances cannot readily connect to overarching control systems because they use proprietary protocols or lack load-control units. This technical mismatch means device "smartness" and interoperability vary widely, curtailing the demand-side flexibility that commercial buildings can offer and risking lock-in between customers, original-equipment manufacturers, and balancing-service providers. Work-arounds, such as installing extra gateways or interface modules, do exist and can be reused once set up, but they add cost for building owners and demand time from service providers. Because today's appliances rely on a multitude of protocols, gateways, and APIs, interviewees view the resulting complexity as a systemic hurdle. The most effective enabler is forward-looking standardisation of appliance-to-system communication, ensuring new equipment ships with open, harmonised interfaces that eliminate bespoke integrations and unlock greater flexibility potential.

Lack of mandatory load-control provisions in building regulations: At the Delivery stage (step 6) of the flexibility value chain, current rules do not require that appliances installed in new commercial buildings come equipped with load-control capabilities. Without this regulatory push, many devices enter service unable to respond to external control signals, which sharply limits the DSF that building operators can provide to the grid.

Unclear stakeholder roles and dual-selling risks: Across the Implementation-to-Settlement stages (steps 5 through 8) of the flexibility value chain, multiple parties

can be involved in installing, integrating, and operating building appliances, each of whom might technically act as a flexibility service provider and bid the same resource into different markets. While this was not a problem in the ByggFleks pilot, which confined itself to technical tests of integration and activation, interviewees flagged it as a potential challenge if the project scales into a market-based arrangement. Without clear lines of ownership and control, the same kW of flexibility could be "sold" twice, undermining market integrity. The enabling measure is to establish explicit, transparent rules that define who owns each asset, who is authorised to dispatch it, and how participation across multiple flexibility markets is monitored and enforced.

Lack of compensation for flexibility activation: At the Settlement stage (step 8) of the flexibility value chain, building owners received no payment when their appliances were activated to provide DSF. Without a direct economic reward, owners quickly lose interest in taking part in further pilots, and the overall pool of commercial-building flexibility remains underutilised. The most effective enablers are (1) clear bilateral contracts in which the DSO and asset owner spell out the terms under which availability and activations will be paid for, or (2) migrating the assets onto a competitive market platform where transparent price signals automatically remunerate each activation.

Complex, multi-interface control systems: During the Delivery-Activation stages (steps 6 and 7) of the flexibility value chain, many commercial buildings relied on several overlapping control installations and user interfaces. This patchwork made it hard for facility managers to obtain a clear, real-time view of energy use and appliance status, hampering day-to-day optimisation and limiting the building's DSF potential. Without systematic training or onboarding for building managers when new systems or concepts are introduced, the knowledge gap widens over time, discouraging deeper DSF engagement. The key enabler is a structured competence-development program that equips building managers and operators to exploit their systems' full flexibility.

Overall potential for DSF from commercial buildings

Electric System Water Heaters (ESWHs) were the resources that provided most of the flexibility in ByggFleks. The buildings investigated in the project were schools and a sports hall, and thus, most of the hot water goes to showers. The ESWH capacities were 30- 105 kW[40]. A load control had to be installed on some of the tanks to make them available for flexibility. If properly isolated, ESWH tanks can be

40. Information regarding capacities per load obtained from dialog with Lede.

activated and still store hot water for several hours without any significant temperature reductions. In this case, the maximum activation duration was set to two hours; however, interviewees indicate that the appliance could have been activated for much longer without reducing the comfort. The overall availability of the ESWHs for flexibility was high, as the hot water consumption in the schools was relatively low.

Electric underfloor heating consists of electric heating cables cast in concrete and can be fully turned off for flexibility purposes without harming any components. The thermal inertia in the concrete allows for activation for at least one hour without users noticing. Beyond one hour, the availability depends on how densely the heating cables are packed in the flooring, how many people are in the building, and the outdoor temperature. Despite being installed at different times following different building stages, most of the heating cables already had load control and were integrated with a BACS. Their installed capacities and flexibility potential ranged from 35 to 300 kW.

The flexibility potential of **ventilation** depends on the air quality requirements of the users and the general air quality within and surrounding the building. In ByggFleks, some of the schools were located near garbage dumps or in areas with higher Radon levels, which meant that the ventilation system had to maintain a certain air quality level. Furthermore, parts of the testing were conducted during the COVID-19 pandemic, where hygiene and air quality requirements in schools were elevated. In contrast to other appliances tested, ventilation cannot be cut directly. Instead, the energy consumption is reduced by setting the system in recirculation mode or reducing the air flow temperature. Recirculation can only be done in short sequences without affecting the air quality. In this case, the maximum duration was set to one hour. In a building with multiple smaller ventilation systems instead of a few larger ones, the flexibility potential is expected to be larger, as you can rotate between zones. The ventilation system tested in ByggFleks had a total capacity of approximately 210 kW.

The DSF potential of commercial buildings is highly dependent on the building in question. For instance, the age of the building may determine how long room heating may be deactivated before it starts affecting the comfort of the users. The limited activation time for all appliances tested in the pilot leaves the question of how long the appliances can be activated without affecting user comfort open. The interviewees' reflection is that the user comfort, especially hot water and room temperature, would be unaffected for a longer period than the time tested here. However, they also note that longer activation periods would result in rebound effects, which would coincide with other loads in the building. As newer buildings usually are more energy efficient than older ones, there also might be a limited

potential for further energy optimisation efforts. Lastly, the BACS setup and the complexity level of integrating appliances with a top system will determine whether it is economically feasible to utilise the flexibility from the building's appliances.

Overall potential

ByggFleks demonstrates that ventilation, room heating, and water heating can be flexible, provided that it is feasible to integrate these appliances with a sort of top system. Assuming that all schools have some form of ventilation system, water heating system, and heating, we can make the following assumptions regarding the theoretical flexibility potential in Norwegian school buildings from different energy appliances (Table 7).

Table 10: Overall potential estimation based on ByggFleks.

Appliance	Capacity per unit kW for different school sizes*	Number of buildings [41]	Theoretical potential
ESWH	Small: 30 kW Large: 105 kW	In 2024, there were 2692 elementary and middle schools and 418 high schools in Norway. Large (>300 students in elementary school, >900 in high school): **953** schools Small: **2157** schools	164,7 MW
Ventilation	180 kW		484,6 MW
Room heating	Small: 45 kW Large: 350 kW		430,6 MW
Total potential			**1080 MW**

*Based on documented appliance capacities in ByggFleks. It is unclear how representative these capacities are of the entire appliance portfolio.

The size, age, and energy usage in schools vary significantly. The above estimates should thus be considered as rough. A study from Multiconsult[42] on the technical state of ventilation, heating, and cooling systems in Norwegian schools concluded that almost 40 per cent of the building area was TG2 or worse[43], and would need rehabilitation within the next 10 years. We assume that the technical potential to integrate older appliances with a top system is less than in a newer building with a BACS system. For how long heating appliances and ventilation can actually be

41. Utdanningsdirektoratet
42. Tilstand skolebygg (Multiconsult, 2022)
43. TG scale from 0 – 3, where 0 = as good as new, and 3 = significant rehabilitation needed

disconnected without affecting the usage of the building depends on the building. In well-isolated, newer buildings, the duration for which loads can be activated is expected to be much longer than what was tested in ByggFleks. For ventilation, on the other hand, indoor climate requirements limit how long ventilation systems can be activated for flexibility purposes.

Norway: Battflex

General description

The BattFlex pilot was led by the Norwegian DSO Elvia and was one of four initiatives under a large-scale demonstration project, IDE – Intelligent Distribution of Electricity. The project was conducted from 2019 to 2024 and led by The Norwegian Smartgrid Centre in collaboration with a consortium of partners, including the grid companies BKK, Elvia, Tensio, Agder Energi, Norgesnett, and Lede, as well as the NTNU university and EPOS Consulting.

The Battflex pilot aimed to demonstrate the potential, as well as evaluate the impacts and benefits, of utilising consumer flexibility from smart electric storage water heaters (ESWHs) and grid-connected batteries to address voltage quality issues in weak or vulnerable low-voltage networks. The project sought to verify that such solutions could provide a cost-effective alternative to traditional grid reinforcement.

The BattFlex pilot originated from the KAFFI project, conducted by Eidsiva Nett (now Elvia) in 2018 in collaboration with THEMA Consulting. The KAFFI project aimed to evaluate the need for and potential of activating local flexibility in the distribution grid. The study analysed alternative solutions for 17 selected transformer circuits, demonstrating that such measures could reduce costs by 75% compared to conventional grid reinforcements. The Battflex pilot was further shaped by insights from the Austrian LEAFS project and Ringerikskraft Nett's EffektPILOT. Findings from the LEAFS project emphasised the importance of activating consumer flexibility in a "grid-friendly" manner rather than relying solely on price signals. This became central to the development of control algorithms for flexibility activation in BattFlex, optimising activation of ESWHs based on both price signals and dynamic voltage parameters.

As part of the pilot, 72 ESWHs from OSO Hotwater were installed in households across two chosen transformer circuits in Elvia's grid area. In addition, three grid-connected batteries were deployed across three chosen transformer circuits in the low-voltage grid, also within Elvia's grid area. The developed and tested solution for smart ESWHs incorporated control algorithms that automatically and autonomously optimise activation of the appliances based on both price signals and dynamic voltage parameters, testing how price optimisation impacts voltage issues in vulnerable low-voltage networks (more on this below). Since the focus of this report is on end-user appliances, the following sections highlight findings regarding the flexibility offered by ESWHs.

Findings from the BattFlex pilot have since been integrated into various initiatives and products. OSO Hotwater continues to sell smart water heaters with functionalities developed during the pilot, including the control algorithm for flexibility activation and a customer app, as further described in the sections below. Additionally, Enova's support scheme for smart ESWHs was developed in collaboration with Elvia following the Battflex pilot, confirming that such a scheme would provide significant added value and that smart ESWHs could deliver the desired functionality. Insights from the battery solution in Battflex were also applied in the IDE project's FBI pilot, which explored how voltage boosters, combined with batteries, can defer investments and help mature the technology for broader use.

For Battflex, important information sources include the pilot's final report[44] and interviews with representatives from Elvia, OSO Hotwater, and EPOS Consulting.

44. Battflex Pilot Report "Nytteverdier fra smarte varmtvannsberedere" (Elvia, OSO Energy & EPOS Consulting, 2022)

Value chain for DSF

The DSF value chain is illustrated in the table below.

Table 11: Physical value chain for DSF in Battflex

Step in value chain	Stakeholders and systems in use		Function
3/4/5	DSO	*Elvia*	
6/7	Interface DSO/FSP	*Bilateral agreements*	The interface between the DSO and FSP consisted primarily of bilateral agreements regarding the management of customer data. Since the pilot tested implicit flexibility, autonomously and automatically optimized based on individual customer consumption profiles, spot prices, and grid voltage, it did not include a market or activation signals from the DSO.
6/7	Flexibility provider (FSP)	*OSO Hotwater*	OSO Hotwater was both the supplier and the provider of flexibility from smart household ESWHs in the pilot.
6/7	Interface FSP/customer	*OSO Charge and OSO's inCharge app*	OSO Charge hardware, installed on the ESWH to allow for smart control, features an open, cloud-based API and communicates via Wi-Fi/LTE. The inCharge app provides customers with a complete overview and control of their ESWH's consumption
6/7	Smart ESWH		

Systems in use

In the pilot, smart ESWHs were delivered to the participating end customers with a hardware unit, the OSO Charge smart control unit, pre-installed on the ESWH. When installed, this hardware enables both the activation and measurement of flexibility from the water heater. For OSO water heaters manufactured from 2017 onward, the OSO Charge unit can be installed on the ESWH to retrofit it with smart functionality, even if it was not originally included.

Each OSO Charge unit is equipped with an internal measurement circuit that meets the Nordic resolution standards[45], enabling it to locally measure frequency, voltage, and current on the heater. By measuring temperature at three different heights, OSO Charge controls both stored capacity and consumption. OSO Charge uses cloud-based communication via Wi-Fi or LTE/4G, allowing for efficient integration with open APIs. LTE-enabled hardware costs an additional 200 NOK compared to Wi-Fi. While industrial units typically use LTE/4G, households generally rely on Wi-Fi due to cost considerations, as it provides reliable connectivity at a lower cost without scalability issues. For home ESWHs, cloud communication from the unit occurs every 10 minutes via Wi-Fi. Each unit has a digital twin that stores data from the water heater (temperature, voltage, and power consumption). Data

45. Technical Requirements for Fast Frequency Reserve Provision in the Nordic Synchronous Area v.1.1

from each unit over the past seven days is used by OSO's machine learning model to forecast the next day's consumption, predict available flexibility, and optimise energy usage for each ESWH in the OSO portfolio.

As mentioned initially, OSO smart ESWHs were developed in the pilot to assess how market-based optimisation impacts grid voltage levels and whether smart automation can mitigate potential grid voltage issues. The pilot found that pure price optimisation could lead to rebound effects, in this context referring to a sudden surge in load when multiple water heaters reconnect simultaneously, exacerbating voltage issues in vulnerable low-voltage grids. In contrast, optimising for both price and voltage provided significant voltage support and added value for customers through reduced grid tariffs and electricity costs. To achieve this, OSO Charge incorporates so-called 'grid-friendly activation,' using control algorithms that optimise the ESWH's power consumption based on both local voltage and Nord Pool spot prices. OSO Charge autonomously activates flexibility according to predefined optimisation parameters, enabling operation without external control or customer involvement. The pilot tested only the activation of implicit flexibility. The algorithms are designed to prioritise safety (e.g., temperature control to prevent health risks), followed by primary performance (ensuring a consistent hot water supply), price optimisation, and, finally, system-level optimisation.

For price optimisation, market prices are retrieved from the Nord Pool API at 1 PM the day before. The machine learning algorithm then considers the price optimisation alongside the estimated future consumption of the appliance to plan heating for the next 24 hours, with optimisation occurring twice daily: between 2-3 AM and at 12 PM. The updated control profile is received by OSO Charge and runs locally on the device, meaning it does not rely on an internet connection to function.

Voltage optimisation enables grid-friendly activation by adjusting the setpoint for each appliance based on historical voltage data. The algorithm is dynamic and adjusts based on factors such as seasonal variations, providing voltage support based on the appliance's grid location. OSO Charge enables the appliance to respond to voltage levels with a reaction time of 1.3 seconds, an accuracy/resolution of 5 MHz, and a reporting frequency of 10 Hz. Additionally, a fleet of OSO Charge-enabled water heaters can coordinate to reduce load during local voltage disturbances, ensuring a balanced aggregation of available flexibility.

As mentioned above, the algorithm prioritises price optimisation over system optimisation. However, grid constraints can override price-based optimisation to ensure grid-friendly activation at the local level (power and voltage levels). In the event of a significant voltage drop, OSO Charge attempts to deactivate to prevent instability. OSO has specific terms that allow for temporary disconnection of

devices to support grid stability. However, if the ESWH remains within the acceptable voltage range, it continues to be controlled based on price optimisation.

Oso Charge also has the functionality for explicit activation of ESWHs, such as activation for delivery into FFR markets, although this functionality was not tested in Battflex. The internal measurement circuit in OSO Charge is technically approved for FFR, as its resolution and response time meet the requirements for participation in these markets.

Customer management

Through the OSO inCharge app, customers gain access to detailed consumption data and full control of their ESWHs' consumption. The app offers multiple modes, including automatic, manual, third-party control (which offers the ability to control water heating via OSO's open cloud-based API), sleep mode, and renewable energy mode, enabling customers to choose how their ESWHs operate based on their preferences. In the app, customers can define their flexibility preferences and determine the level of risk they are willing to accept regarding how aggressively the ESWH optimises based on price, with a slightly increased risk of reduced comfort. When connected to the app, OSO has access to individual-level data for the ESWH and, as previously mentioned, can explicitly activate the appliances; however, this is only available with the user's approval and was not tested in the Battflex pilot.

As part of the smart water heater rollout in the pilot, Elvia developed a digital process for managing customer communication and flexibility agreements. Customers also received compensation in the form of free smart ESWHs when participating in the pilot. While the customer relationship was owned by OSO, Elvia handled both compensation and the management of agreements for participation in the pilot. The pilot demonstrated that smart ESWHs, optimised for both price and voltage, provided value to customers by reducing both grid tariffs and electricity costs.

Barriers and enablers for DSF from ESWHs in Norway

The interviews identified several barriers to utilising consumer flexibility from smart electric storage water heaters (ESWHs) in Norway, as summarised below. Notably, no significant technical barriers were reported in the Battflex case. The interviewees indicated that integrating, aggregating, and activating ESWHs for flexibility did not present technical challenges. However, this finding should be seen in the context of the pilot, where the flexibility service provider (OSO) was also the supplier of the appliances and the technical system for activating flexibility from these. Hence, the FSP only needed to integrate with a single type of appliance, for which they had designed the interface themselves.

Rebound effects: Interviewees highlighted that 'rebound effects,' in this context specifically referring to a momentary surge in load when multiple water heaters are reconnected, and resulting voltage issues, as potential consequences of utilising flexibility from ESWHs. The project found that pure price optimisation led to rebound effects and negative impacts on grid voltage levels, which further aggravated voltage issues in vulnerable low-voltage grids.

In Battflex, the issue of potential rebound effects was mitigated through implementing an automatic and autonomous voltage control algorithm in the smart control unit of each appliance. Combining this with price optimisation, grid-friendly activation was achieved, and rebound effects were prevented.

As an enabling measure, the project therefore recommends avoiding large-scale installation of solutions on the customer side that cannot be activated/controlled based on voltage parameters and do not have the necessary autonomy to prevent exacerbating issues related to voltage quality and voltage levels in the low-voltage grid. The project suggests that ensuring that suppliers of local flexibility solutions implement "grid-friendly activation" can be achieved through various means, including technical or regulatory requirements, collaboration with suppliers, and economic incentives.

Although the interviewees did not specifically address the cost of implementing voltage control compared to a solution based solely on price optimisation, the report and interviews suggest that there are no significant technical or economic barriers to implementing such solutions. The approach primarily involves programming control algorithms to activate based on both dynamic voltage parameters and market prices. Like price optimisation, this method also provides value to customers through reduced grid fees and lower electricity costs.

Regulatory restrictions hindering market access: Interviewees highlight that unlocking significant flexibility from end users in Norway requires that more flexibility providers participate in the market. So far, local flexibility in Norway has mainly been demonstrated through pilot projects, and there is a lack of scalable, commercially viable solutions that incorporate profitable and efficient business models for delivering flexibility.

Several interviewees noted that current regulatory restrictions for participation in TSO markets (see paragraph below) make it challenging for independent Balance Service Providers (BSPs), such as OSO, to offer flexibility from their customers in both TSO and DSO markets and thus discourage such providers from developing effective, scalable business models for flexibility.

In the FCR markets, current regulations require that the flexibility provider also hold balance responsibility for the regulated

asset[46]. This means that an independent BSP role is not allowed in these markets. As a result, actors like OSO, which do not have balance responsibility, cannot directly deliver flexibility from their assets into these markets.

In the aFRR and mFRR markets, interviewees highlighted that the minimum bid size required by current market regulations, which ranges from 1 to 5 MW in FFR depending on the contract type, makes it difficult for actors providing flexibility from small household appliances to participate. For OSO, this minimum bid requirement means they cannot aggregate enough loads to deliver flexibility directly into these markets. Instead, a larger aggregator would need to take responsibility for submitting bids on behalf of OSO's ESWHs in the reserve markets, adding administrative burden for OSO.

While OSO's ESWHs are technically approved for reserve markets, under current regulations, this was deemed too complex to make participation worthwhile for OSO. Moreover, current TSO market regulations prevent BSPs from participating in both local flexibility markets and reserve markets with the same capacities. More on this will be discussed under the Norflex pilot, which is mentioned later in the report.

The interviewees highlighted that utilising flexibility from appliances is easier when there is a certain level of homogeneity in the market (homogeneous appliances). This suggests that unlocking the flexibility potential of household appliances in Norway might be challenging if one single actor (for instance, a BRP) needs to integrate, aggregate, and manage a diverse range of appliances.

Looking at potential enabling measures, changing the current regulations to allow independent BSPs to more easily sell flexibility from their end customers directly into both local and reserve markets could promote entrepreneurship and facilitate the entry of new flexibility providers. This would unlock flexibility from a broader range of loads and support more profitable business models for both providers and end users.

Interviewees highlighted that regulations better suited to providers offering flexibility from aggregated and small household appliances would be particularly beneficial. They pointed out that the regulatory barriers faced by BSPs in delivering flexibility present a greater challenge to unlocking the flexibility potential of ESWHs than the lack of standardisation and 'smart readiness.' Additionally, the pilot project demonstrated that overcoming technical barriers may be more achievable if the flexibility provider is also the supplier of the appliances and/or the flexibility

46. A new model for balance responsible parties and providers of balancing services is planned to be introduced by the end of 2024 (Statnett, 2024) https://www.statnett.no/for-aktorer-i-kraftbransjen/nyhetsarkiv/ny-modell-for-balanseansvarlige-og-leverandorer-av-balansetjenester-planlegges-innfort-ved-utgangen-av-2024/

solution. This suggests that such regulatory changes could help mitigate both regulatory and technical barriers.

Specifically, interviewees emphasised that BSPs should be allowed to deliver flexibility in the FCR-D and FCR-N markets without requiring an agreement with a BRP, as is currently the case for FFR markets, given that the potential imbalance costs for the BRP would be minimal also in these markets. One interviewee further suggested that participation in the mFRR CM market should also be permitted if the activation price is set sufficiently high.

Additionally, it was proposed that the minimum bid size requirement in the reserve markets should be adjusted to allow for aggregated loads as an exception, thereby enabling smaller actors to participate. It was also suggested that making reserve market bid data publicly available could help new entrants establish themselves in the market. Providing access to market data, also for actors who are not yet participating in the market, could give them valuable insights into market dynamics and the potential earnings from participating in these markets, enabling them to better position themselves and develop viable business models.

Inefficient customer incentives for providing flexibility: Based on interviews, commercialising flexibility solutions requires business models that facilitate end-user participation without complex prequalification processes and are perceived as simple and reliable. Furthermore, these models should enable efficient digital compensation and management of end users, eliminating the need for direct communication between the flexibility provider or DSO and each end user.

According to interviewees, the current Enova scheme, which provides support for end-users purchasing smart water heaters, may be too complex to effectively incentivise the adoption of smart ESWHs over non-smart ones. The application process is handled on an individual basis, and it requires, among other things, that the ESWH be compatible with smart home systems.

As for enabling measures, interviewees highlighted that it might be beneficial if equipment suppliers could pre-qualify their products for participation in the support scheme, streamlining the process for end users and making it a 'no-brainer' to choose smart appliances. One could imagine that such a process might be easier to streamline if the appliances followed a standardised code of conduct and had an energy label indicating their smart readiness.

Overall potential for DSF from ESWHs

According to OSO, a typical water heater has a capacity of 2–3 kW. With around 2.7 million private water heaters in Norway, ESWHs collectively represent over 5,000

MW of potential capacity, assuming an average of 2 kW per unit. Of these, 200,000 are OSO units with smart functionality potential, contributing 400 MW to the total capacity.

Test results from BattFLEX indicate that approximately 50% of the installed capacity in a fleet of ESWHs can be aggregated for flexibility during peak load hours. This means up to 2,500 MW of flexibility could be activated at any time, with 200 MW coming from OSO's smart-enabled units. ESWHs provide instantaneous flexibility, as they can be easily switched on and off without any issues.

BattFLEX results indicate that ESWHs can remain off for most of the day without users noticing, allowing for up to 18 hours of downtime within 24 hours. OSO estimates that each unit provides an average daily flexibility of 12 kWh, resulting in a total estimated potential of approximately 32.4 GWh per day from all Norwegian water heaters, with 2.4 GWh coming from OSO's units alone.

Norway: Norflex

General description

The purpose of the Norflex project was to increase the use of DSF through new market-based solutions to manage local grid bottlenecks. In total, 31,470 trades were carried out, amounting to 1.39 GWh from over 4,000 assets spread across southern Norway[47]. The participants in the project were the DSO Glitre, TSO Statnett, market platform service provider Nodes, and the utility company Å Energi [48]. Additional stakeholders included flexibility service providers (FSPs) and FlexTools. Norflex was conducted from 2019-2023 and followed up by the ongoing Euroflex project, where seven additional DSOs and various FSPs participate[49]. We include findings from both projects in this report, but the primary focus is on the Norflex pilot. For this study, important information sources include interviews with one of the grid companies, Nodes, and two FSPs.

The asset portfolio spans from industrial and commercial buildings to batteries, EV chargers, and household appliances. For the scope of this report, the following

47. Whitepaper Norflex (2020-2023)
48. Sluttrapport Storskala demonstrasjon av fremtidens energisystem (Norflex, 2023)
49. History Euroflex

sections will primarily focus on aspects related to EV chargers and other household appliances.

Value chain for DSF

In Norflex, the focus was on developing a functioning marketplace for local flexibility trade, corresponding to steps 4-8 in the value chain outlined in Chapter 3.1 above. The value chain and main stakeholders are illustrated in the table below.

Table 12: Value chain for DSF in Norflex

Step in value chain	Stakeholders and systems in use		Function
4	DSO	*Glitre Nett, +7 other DSOs in EuroFlex*	
4	Interface DSO/market	*GridTools*	Defines areas (nodes) in the grid, automatic submission of bids to market platform
5	Marketplace	*NodesMarket*	Mediate bids between DSO and FSP. Facilitates reservation and activation of flexibility, baseline estimation, and.validation and settlement of trades. Different products.
6/7/8	Interface market/FSP	*FlexTools*	Prequalification of flexibility asset portfolios. Submission of bids. Activation signal to FSPs.
6/7/8	Flexibility provider	*Flexibility service providers (both BRPs and BSPs) FSPs' own set-ups for integration and management of loads*	Aggregates and manages flexibility from portfolio. Responsible for all customer contact.
6/7/8	Interface FSP/customer		FSP platform may include cloud-based data management, prognosis tools and integration logics. Direct control of appliances: Integrate smart appliances with communication protocols through open APIs (cloud-to-cloud) or through direct hardware connections. May or may not use metering data to optimize consumption across multiple appliances.
6/7/8	Smart appliance	*Primarily EVs*	Integrates with FSP platform through open APIs

Market Platform and Market Participants

The demand for flexibility from DSOs and the supply of flexibility from flexibility providers are matched through the market platform NODES. NODES acts as the intermediary for buyers and sellers, which facilitates the reservation and activation of flexibility. The platform also allows transaction automation, including trade signals for activation, validation of delivery, and settling of the transaction. There is no direct contact between the DSOs and flexibility providers. Both DSOs and flexibility providers connect to the platform through open APIs.

Flexibility providers include both large individual actors selling their own flexibility (>1kW) and aggregators who mediate aggregated flexibility from smaller customers. The FSPs are responsible for all customer contact and recruitment and are not required by NODES to disclose their business models and profit strategies. In the Norflex project, only aggregators with balance responsibility (BRP) could

participate, but in Euroflex, independent aggregators (BSP) are also allowed to participate[50]. In a commercial setting, these BSPs will most likely be required to have a balancing agreement with a BRP to be able to participate in a market; however, in Euroflex, that will not necessarily be a requirement.

Registration of Flexibility Resources and Bidding

Flexibility providers prequalify their resource portfolios in NODES using Flextools, where information such as the main metering ID and capacity per asset is registered. Grid companies use this information to allocate the assets to various nodes in their network.

Following prequalification, flexibility providers can submit bids to the platform. A bid includes information about volume, duration, time, location (allocated through prequalification), price, and direction (up/down regulation). Each bid must have an associated baseline in the event of a matched trade (more on baselines below). Flexibility is reserved for two hours before delivery, and the flexibility provider receives a signal to activate. The delivery of flexibility is validated and settled on the platform two hours later. If there are deviations between the reserved and measured capacity, the payment is reduced accordingly. However, lack of delivery does not result in further penalties for the FSPs.

Products

The flexibility products in Norflex were[51]:

- **ShortFlex:** Physical delivery of flexibility. Market opens for trading 7 days ahead of physical delivery, and bids are cleared 2 hours ahead of delivery. The orders had a duration of one hour. The minimum bid size was 1 kW. FSPs were paid for activation.
- **LongFlex:** Reservation of flexibility. LongFlex contracts were offered with different durations, either weekly contracts (LongFlex week) or contracts that spanned over multiple weeks (LongFlex season). FSPs were paid for both availability and activation (ShortFlex).

Additionally, a third product, MaxUsage, is under development and is being tested. This is in response to FSP feedback indicating that estimating the baseline in the other products is challenging, particularly for household

50. In Euroflex, a FSP can be either a BRP or a BSP. A BRP is responsible for managing any imbalances from their customers. Large BRPs can also prequalify for Statnett's reserve markets. A BSP is an independent aggregator that does not hold any balancing responsibility but instead offers technical solutions to aggregated end-user flexibility. BSPs were recently granted access to Statnett's mFRR and aFRR markets, proviso that the BSP has a balancing agreement with a BRP.
51. Whitepaper Norflex (2020-2023)

flexibility[52] [53]. Instead of bidding on a specific capacity that can be disconnected, the flexibility provider in MaxUsage bids on a total maximum capacity for their portfolio (more on baseline estimation below).

For both ShortFlex and LongFlex, the traded quantities increased over the pilot period as more FSPs prequalified their asset portfolios and started to bid in flexibility on the platform. In total, 1395 MW of flexibility was traded. The trades had a total value of 12.5 million NOK[54]. The invoiced amount is lower than the traded volume due to adjustments for partial and non-delivery. The payment percentage ended at 69% in accordance with NODES's marketplace rulebook[55].

DSO-TSO coordination

To ensure efficient usage of flexible assets and to handle local bottlenecks, coordination between Statnett and DSOs is seen by the interviewees as an important prerequisite to establishing functioning local markets for flexibility. Equally important as the coordination between TSO/DSO is the coordination between local distribution grid companies and regional DSOs. Without any clear framework on how bids can be forwarded from one market to another, or through simultaneous access, interviewees remark that it will be challenging to avoid the splitting of liquidity between markets. Furthermore, limited market access for smaller FSPs may limit their income potential and thus also their interest in developing and offering solutions to aggregate flexibility from small assets.

A central part of the ongoing workstreams in Euroflex is therefore to investigate how different markets should be integrated and how products and services must be designed to make it easier for FSPs to offer services to multiple markets. In Norflex, forwarding of uncleared bids from the local market to Statnett's mFRR market was briefly tested[56]. The stakeholders involved saw the need for clearer cross-market rules and an asset overview before multiple market participation can be implemented. In Euroflex, Statnett, together with Elhub, will therefore map out and pilot functionality for a **national flexibility register**[57] [58]. The purpose of such a register is to provide an overview of distributed flexibility assets and their properties, and to determine rules on how and by whom these resources can be activated across markets.

52. Whitepaper Norflex (2020-2023)
53. Flexibility from Electric Vehicles (CIRED, 2022)
54. Whitepaper Norflex (2020-2023)
55. Whitepaper Norflex (2020-2023)
56. NorFlex project demonstrate integration to Statnett's mFRR market (nodesmarket, 2022)
57. Sluttrapport Storskala demonstrasjon av fremtidens energisystem (Norflex, 2023)
58. Euroflex (Statnett, 2024)

Customer involvement

Household customers were recruited to the pilot by the FSPs directly. FSPs were also responsible for all customer communication and support. In Norflex, most of the flexibility came from private EV chargers, which were integrated with the FSPs' own cloud-based data hubs. Similar set-ups are being used by other technical aggregators in Euroflex to aggregate flexibility from more EV chargers, as well as other household appliances such as heat pumps and heat panels. Some customers integrate their entire house into the platforms, while others only integrate one or two appliances.

The communication between the FSP and customers happens through an app, where the customers can monitor their own consumption and define how they wish to be flexible. Depending on what appliances are connected to the hub, the customer can define how they want these assets to be used. These settings can be dynamically changed or overruled by the consumer.

According to the interviewees, most household customers were incentivised to become flexible due to higher spot prices and price volatility, especially in southern Norway after 2020. The price variations and information campaigns from the FSPs made customers aware that there was money to be saved if they became flexible. The FSPs have different business models, where customers either achieve lower energy bills by allowing the FSP to optimise their consumption based on grid tariffs and spot prices, or by receiving points or discounts to use on services or products provided by the FSP, allowing the FSP to trade their flexibility in other markets. The compensation the consumer gets for participating in balancing markets or local flexibility markets is thus not directly related to the prices quoted in the markets. The FSPs report that even though many customers are willing to participate in the flexibility markets, the spot price signals are so strong that most of the capacity activated through their platform is implicit flexibility.

Other important learnings from the project

The key learning point from Norflex is that it takes time to build a functioning flexibility market, both from a technical, economic, and regulatory perspective. The interviewees emphasise the need to establish more permanent solutions and market set-ups across geographical regions to increase predictability for customers, FSPs, and DSOs going forward. The Network Code allows member states to assign the responsibility of setting up and organising local flexibility markets, and a national decision on how local flexibility markets are to be organised is not expected before closer to 2030. Thus, some interviewees suspect that many potential FSPs and flexible resources are pending their participation until such a national decision has been made.

Secondly, on the technical side, a lot of resources went into establishing cohesive, digital value chains. Automated solutions in the interfaces between buyer and marketplace, and marketplace and seller, are necessary to scale activities.

Lastly, as mentioned previously, baseline estimations for smaller loads, such as household appliances, were a challenge in Norflex. Several FSPs reported that the baseline estimation methods could be improved, as there were, in some cases, significant deviations between the estimate and what was actually delivered. For some loads, such as EVs, the unpredictable consumption pattern of the load was partly to blame for the deviation. However, for most loads, the main reason was that data was collected through the customer's main metering device instead of from the dedicated metering devices installed on the appliances, and the loads are stochastic in nature. The household appliances tested constitute only a small portion of the customers' total energy consumption. Thus, it was tricky to verify whether flexibility from the assets had in fact been activated due to "noise" from the rest of the household consumption.

Without reliable baseline models, there is a risk that FSPs will be either overpaid or underpaid for their deliveries. The value of flexibility in the short term is thus highly dependent on adequate baseline calculation and forecast models. Currently, the task of defining and calculating baselines is the responsibility of the system operators. The Norflex project, therefore, recommended several measures to improve the estimations going forward, including:

- Stricter requirements for dedicated submeters for individual loads and more granular data collection to verify delivery
- Linking the baseline estimation model to the pending flexibility register for more accurate forecasts
- Allowing all interested parties, including FSPs, to submit new calculation methods for approval
- Developing new products, such as MaxUsage, for appliances where baseline estimation has proved to be more challenging than for other appliances

Barriers and enablers

The following enablers and barriers were identified, both from the literature and from interviews with relevant stakeholders.

Unresolved national framework for local flexibility markets: At the Mechanism/Measure stage (step 5) of the flexibility value chain, the EU Network Code lets each member state decide who will set up and run local flexibility markets, yet Norway's final decision is unlikely before 2030. This regulatory limbo

discourages DSOs from planning such markets, while lingering uncertainty over future market design disincentivises FSPs from investing in new solutions.

Lack of coordination for dual-market participation: At the Mechanism/Measure stage (step 5) of the flexibility value chain, FSPs cannot offer the same capacity in both local flexibility markets and the TSO's balancing markets because no framework yet exists for forwarding bids or aligning activation rules across market layers. This set-up fragments liquidity, and the limited on-ramp to reserve markets especially sidelines smaller FSPs, reducing their appetite to aggregate distributed resources. The main enablers are two ongoing initiatives: Euroflex, which is designing market products that span local and national platforms, and the Statnett–Elhub national flexibility register, which will catalogue assets, codify activation priorities, and give FSPs streamlined access to participate in multiple markets with the same resources.

Fragmented communication protocols and APIs: At the Delivery stage (step 6) of the flexibility value chain, there is still no common standard for how appliances expose data or accept control signals. Each FSP therefore has to build a bespoke integration for every new device, the effort and cost varying widely with the underlying API. Sluggish interfaces can, in some cases, even bar an appliance from fast-response markets. While FSPs treat integration know-how as part of their value proposition and reuse connection logic once it is in place (often opting for cloud-to-cloud links to bypass on-site hurdles), they stress that harmonising rules, such as the forthcoming Code of Conduct for Energy Smart Appliances, would sharply cut onboarding time and expand the pool of controllable loads.

Spot-price-driven optimisation undermines grid-needs flexibility: Throughout the Delivery, Activation, and Settlement stages (steps 6 – 8) of the flexibility value chain, sharp volatility in the day-ahead spot market makes it more profitable for customers to time-shift smart-appliance use, particularly EV charging, purely on wholesale-price signals. Interviews reveal that EVs are connected for less time than earlier estimates assumed, and during those limited hours, customers earn more by chasing spot-price spreads than by answering DSO requests. Consequently, implicit flexibility based on spot prices crowds out explicit flexibility procured via DSO signals, reducing the controllable capacity available for local grid relief. A practical enabler would be to align or stack incentives, for instance, through local flexibility premiums or tariffs that reflect grid constraints and can be combined with spot-price optimisation – so that serving the grid is at least as lucrative as riding wholesale-price swings.

Voltage fluctuations from abrupt EV-charging ramps: At the Activation stage (step 7) of the flexibility value chain, simultaneous start-and-stop behaviour in

low-voltage networks, for instance, when many EVs chase day-ahead spot prices, may cause sharp load swings that trigger local voltage dips and spikes. FSPs can smooth the profile by introducing a "slow-release" strategy, gradually ramping charging power over consecutive intervals, and by co-optimising all controllable household appliances (where customers permit), so total demand stays within voltage-friendly limits.

Inaccurate baselines for small, distributed loads: Across the Mechanism, Delivery, Activation, and Settlement stages (steps 5 – 8) of the flexibility value chain, the Norflex pilot showed that baseline estimates for household appliances often differed from their actual use. The main reasons were drawing data from main meters instead of dedicated submeters and the naturally variable behaviour of the devices involved. When baselines are off, FSP payments can be misaligned, which lowers the appeal of providing flexibility and reduces settlement accuracy. Installing higher-granularity meters and adopting a standardised baseline method would improve reliability and help ensure fair compensation.

Fragmented financial incentives for smart appliances: Across the Nordic countries, national support schemes for smart-energy devices differ in size, eligibility rules, and application procedures. This patchwork leads to uneven deployment of controllable appliances, so the pool of flexible loads grows at different speeds in each market. For FSPs that operate cross-border, the lack of a consistent incentive landscape complicates scaling their aggregation and service models. A clearer, more harmonised set of financial measures would encourage households to adopt smart appliances at a similar pace everywhere and thus make it easier for FSPs to expand region-wide.

DSO revenue regulation discourages flexibility: At the Market-design and Procurement stages (steps 3 and 4) of the flexibility value chain, the current revenue-cap model ties a DSO's allowed income mainly to its asset base, so grid investments boost revenues more reliably than operational expenditures such as procuring flexibility. Interviewees therefore feel the framework gives DSOs little motivation to weigh demand-side flexibility as an alternative to grid investments.

Household appliances as resources for DSF

In Norflex, the primary household flexibility resource was private EV chargers. FSPs integrated the EVs with their own cloud-based data hubs. Similar set-ups are being used by other technical aggregators in Euroflex to aggregate flexibility from more EV chargers, as well as other household appliances such as heat pumps and heat panels.

Any device that can receive and respond to external signals can, in theory, be operated flexibly. Most electric household appliances sold over the past ten years can communicate with external systems through WiFi, 4G, or radio signals. Appliances can also be made flexible by the installation of a local hardware device that is directly connected to the appliance in question and acts as an intermediate between the appliance and the external system.

Most appliances were integrated with the FSPs' data hubs through cloud-to-cloud integration. The FSPs are responsible for setting up the integration, which happens over various APIs. The interviewees remark that even though some API integrations are challenging, once it is completed, the logic can be reused. Therefore, finding solutions to integrate new appliances into their platforms is seen as part of their value proposition. Since the appliances and business models are still under development, standardisation of APIs and communication protocols is perceived as limiting further innovations instead of being helpful. On the other hand, the FSPs mentioned that some APIs are too slow for the appliances to participate in fast-response markets, which may potentially become an issue in the future.

In the data hub, consumption forecasts for both individual customers and the FSPs' customer portfolio are made with AI based on a combination of historic consumption data, customer settings, and weather forecasts. These forecasts are used by the FSPs to plan their trading activities.

Once integrated, the customer can give the FSP permission to control the loads based on various signals through their app solution. For EV charging, for instance, the customers can specify that they want their car charged to X% within a certain time. Then, day-ahead prices are used to plan the charging cycle. If there is further room to manage the charging cycle, the FSP can trade the customers' flexibility in other markets. For most customers, the largest part of their flexibility is activated based on spot prices, and not price signals from the flexibility markets.

EV charging as a resource of DSF

EVs are well-suited to provide short-term flexibility services by rapidly starting and stopping charging according to the needs of the power grid[59]. The flexibility potential of a single EV is highly variable, as it depends on how that particular car is utilised on a daily basis. The average availability is "shorter than one might expect", according to one interviewee.

In Norflex, the FSP Tibber participated with approximately 1500 EV chargers[60]. The charging was made flexible by either connecting the charging box or the EV itself to

59. Flexibility from Electric Vehicles (CIRED, 2022)
60. Flexibility from Electric Vehicles (CIRED, 2022)

Tibber's platform. A third option, if neither of these units were compatible with smart charging, was for the customer to invest in a local hardware device that could be integrated instead. Few issues with starting and stopping the charging cycle were observed. Interviewees report that the activation response time of most chargers was less than 10 seconds.

One observation made about flexible EV charging in both Norflex and other projects is that it can pose challenges to the grid if not managed properly. If a lot of EVs start and stop their charging simultaneously from one hour to another, it may cause large voltage fluctuations locally[61]. These challenges can either arise from uncoordinated charging driven by consumer behaviour or when smart charging is solely based on spot price optimisation. To avoid damage to the fuse box, FSPs can do a "slow release" of the assets, where they gradually ramp up the consumption from one hour to another.

DSF from other household appliances

Though not the focus in Norflex, other household appliances are being set up to deliver flexibility services to the grid in Euroflex, by both Tibber and other household FSPs.

According to another FSP, an average household can deliver 7.5 kW of flexibility, of which most comes from smart EV charging. Other smart appliances include heat panels, ESWHs, and underfloor heating. These appliances can be integrated using similar logic as the ones developed for EV smart charging. The flexibility potential of these loads is summarised in Table 8. The potential, especially the thermal flexibility, is dependent on thermal characteristics of the house, installation topology, and, most importantly, the comfort preferences of the residents.

Table 13: Flexibility potential from other household appliances[62]

Appliance	Capacity, kW	Response time, seconds	Max activation duration, hours	Minimum recovery time, hours
ESWH	2.5 kW	< 10 s	4-6 h	1-2 h
Heat panel	0.7 kW	< 60 s	1 h	1 h
Heating cables	1 kW	< 30 s	3 h	1 h
Other appliances	3 kW	< 30 s	-	-

61. Flexibility from Electric Vehicles (CIRED, 2022)
62. Based on information provided by interviewed FSPs.

DSF potential from EV charging in Norway

As newer EVs can be smartly charged, a significant portion of the Norwegian EV park of nearly 790,000 cars has the **potential** to deliver DSF services to the grid[63]. Towards 2030, we expect that the number of EVs will increase, which, over time, could increase the DSF potential from this segment even further.

Depending on the EV and charging box, most EVs charge with a capacity of 3.7 – 22 kW, and need, on average, 2 to 10 hours to be fully charged[64]. How often and at what time of day a car is charged depends on the user of the car. On average, we assume a car needs to be charged every third day. Thus, we can assume that 1/3 of all EVs could be made available for daily DSR. If we assume that all these cars are indeed flexible and are connected to the charging point for a longer period of time than what is required to charge them to a certain level, the total DSR potential from domestic EVs in Norway is estimated to be **1-6 GW.**

Sweden: Sthlmflex

General description

In 2018, the Greater Stockholm region had been facing local and regional grid challenges for years, with more connection requests than grid expansion alone could handle. Also, since a tax on combined heating and power (CHP) was announced to be introduced in 2019, a higher electric heating demand was projected as district heating prices were expected to increase.

Sthlmflex was thus established as a local flexibility market to deal with these challenges and set up as a collaboration project with Swedish TSO Svenska Kraftnät as project owner and the DSOs Ellevio and Vattenfall (later joined by DSO E.ON) as participants. The concrete issue the participants hoped to address was the risk of exceeding power subscriptions[65] towards the TSOs' national grid, and the project was planned as a pilot with a clear research focus.

63. Tilnull.no
64. Elbil.no
65. In Sweden, every customer to the national grid signs a usage agreement, which governs how much transmission capacity the customer subscribes to. This agreement states the payable fee according to the grid tariff's capacity fee. On top, it is possible to apply for a temporary subscription, which is added to the annual subscription and applies to one single week.

Sthlmflex was operative starting in 2020. In 2022/23, the last active season as a research project, 4.641 flexibility resources participated through 10 providers. Of these, around 95% of resources were privately owned, mostly EV chargers.

Project results

An important result of the pilot market was that the need for flexibility is strongly dependent on weather conditions, with ambient temperature being the most important contributor, especially when these lasted for longer periods of time. The winter of 2020/21 was relatively mild in the Stockholm area, resulting in fewer call-offs than initially anticipated. On top of that, external factors like the spike in electricity prices caused by the preparation and execution of Russia's full-scale invasion of Ukraine decreased the baseline consumption and thus the need for flexibility further[66].

Another learning point was that all flexibility purchased by the DSOs had not been delivered, raising questions about the reliability of FSPs and the proper ways to validate deliveries.

In the end, the market was discontinued, mainly due to low liquidity. While the need for flexibility is still present and growing, the DSOs viewed other flexibility measures as more promising, such as bilateral contracts or conditional connections in the near term.

Value chain for DSF

Sthlmflex was conceived in part as a research project to demonstrate the different steps to be taken for flexibility deliveries. However, the project was also designed to solve a real and pressing underlying grid issue in a transition period until physical grid reinforcements came in place, thus covering steps 2-8 in the value chain described in Chapter 3.1.

66. Ellevio | Sthlmflex: Lärdomar och resultat från ett banbrytande flexibilitetsprojekt

Table 14: Flexibility value chain for DSF in Sthlmflex

Step in value chain	Stakeholders and systems in use		Function
2-4	DSO	*Ellevio/Vattenfall, later E.ON*	
5	Market platform	*Nodes*	Market platform
6/7/8	Market aggregator	*Entelios*	Aggregates resources into different portfolios
6/7/8	Interface market/FSP	*FlexTools*	Prequalification of flexibility asset portfolios. Submission of bids. Activation signal to FSPs.
6/7/8	Flexibility provider	*Vasakronan*	Owner of flexibility resources.
6/7/8	Technical aggregator	*Ngenic and ProptechOS*	Ngenic equipped heat pumps with smart controls and monitoring units, ProptechOS aggregated the building stock
6/7/8	"Dumb" appliance	*Example: legacy heat pump*	

The market platform used was NODES, with their products "**LongFlex"** (risk handling with long time horizon, not unlike bilateral contracts), "**ShortFlex"** ("free bids" used for short-term cost optimisation and "**VeckoFlex/ShortFlex Availability"** (2-3 days' time horizon, including an availability fee). The product characteristics are displayed in Table 9.

Table 15: Product characteristics in Sthlmflex

	Short Flex	LongFlex	VeckoFlex/ ShortFlex availability
Endurance	60 minutes		
Market close	2h before delivery	-	-
Lowest bid	0,1 MW		
Granularity	0,01 MW (2022/23)		
Payment	Activation Pay-as-bid	Activation Pay-as-bid Availability Pay-as-bid	Activation Pay-as-bid Availability Pay-as-bid
Availability requirements	During hours covered by bids	Days with -5°C or colder	Predefined number of hours per week

Case study description: heat pumps as a flexibility source

The analysed case study consisted of two heat pumps in office buildings in Stockholm. They are owned and operated by Vasakronan, one of Sweden's largest property owners. During Sthlmflex, Vasakronan used both heat pumps, car chargers, and ventilation as flexibility resources. NODES was used as trading platform, and communication with the heat pumps' control units was handled by FlexTools. ProptechOS was utilised to model and aggregate several buildings for participation in the marketplace.

As a general result, less trading than expected occurred on the market, mainly caused by high electricity prices, which decreased the overall need for flexibility. More results are incorporated in the Section "Barriers and enablers".

Overall potential of heat pumps as a flexibility source

Especially for single-family dwellings, heat pumps have a high market share in Sweden. According to Energimyndigheten's statistics database, around 60 % of these houses are heated by different kinds of heat pumps. Table 10 shows the numbers for different kinds of heat pumps and building types.

Table 16: Number of installed heat pumps in Sweden

Number of installed heat pumps (1000s, 2023)	Ground source	Air-to-water	Air-to-air	SUM
Single-family dwellings	478	443	745	1667
Apartment buildings	20	15	2	37
Commercial	13	7	8	28
Total	510	466	756	1732

Source: Energimyndigheten 2024: Ny energistatistik för byggnader

Assuming an average electric power input of 4 kW for smaller and 20 kW for larger heat pumps, this would yield a theoretical potential of 8 GW flexibility from heat pumps if all were available as FSPs. As most heat pumps to date do not fulfil the requirements to be used as FSP (mainly due to a lack of connectivity, which in part could be solved by retrofitting), and because not all heat pumps are situated in

areas with a need for local flexibility, this number would have to be reduced in reality. Also, not all heat pumps in the country will always operate at nominal power at the same time, which further reduces the potential.

In a recent publication[67], the total flexibility potential from residential heat pumps in Sweden in 2030 is estimated to be around 1000 MW on a minute scale and up to 3250 MW on an hourly scale, assuming that 50% of all installed power can be made available to the grid by then. This is well in line with the estimate given above. The flexibility potential is limited by the activation time for short time scales (air-to-air heat pumps can deliver flexibility in a matter of seconds, while water-borne systems have longer reaction times) and by the thermal inertia of the building for long ones. The latter limit could be delayed by encouraging larger accumulator tanks in the case of air-to-water heat pumps, while air-to-air heat pumps lack this possibility. Concerning activation times, frequency-controlled heat pumps can ensure both faster response to external signals and smoother operation than on-off controls, which used to be state of the art or smaller heat pumps.[68] In 2021, around half of all installations of ground-source heat pumps in Sweden used frequency-controlled heat pumps.[69]

Summing up, the total flexibility potential from heat pumps in Sweden can be assumed to be several gigawatts, with the spatial distribution in the country and the ability to retrofit remote control and measurement technologies as important issues to take into consideration.

Barriers and enablers

Enablers:

- **High market penetration of heat pumps** in Sweden enables considerable potential for demand flexibility, which can be unlocked by new standards when upgrading
- **Demand characteristics:** Heat demand dominated Sthlmflex and is easy to predict. Different demand profiles in different appliances can be complementary: heat pumps have a different flexibility profile compared to EV chargers or other appliances.
- **Activation times:** In local markets, the use of resources with longer activation times compared to balancing markets is possible since the market rules on

67. Flexibilitetspotentialer till år 2030, Power Circle
68. Smart styrning av elanvändning - Analys av tekniska förutsättningar för utrustning samt rekommendationer för ökad efterfrågeflexibilitet, Energimyndigheten 2023
69. Pulsen 2021, Svenska Kyl- och Värmepumpföreningen

activation times are usually less strict.

- **Reusable integrations**: Digitalising legacy equipment is costly, but the installed hardware and implemented integrations can still be used for other marketplaces or services.
- **Tight communication** between DSO and aggregator when building integrations prevents misunderstandings and redundant work.
- **Green leases** enable landlords to vary temperatures within certain limits.

Barriers:

- **High entry threshold**: The setup cost for administration and integration can exceed the benefits if the flexibility demand (and thus market liquidity) is low.
- **Future power tariffs** may promote a flatter power consumption curve. Since flexibility resources such as heat pumps or batteries need to run on higher power before and/or after having delivered flexibility, their power profile becomes more volatile when they are used flexibly. This volatility results in higher power peaks, and the cost incurred by these in a power tariff can decrease the profitability of using the resource flexibly.
- **Low temporary subscription prices:** In Sweden, DSOs and regional grid companies can apply for a temporary subscription to the TSO's grid, which is added to the annual subscription, see section 3.6.1. In the case of Sthlmflex, the prices for these subscriptions were often lower than the flexibility bids, which were thus outcompeted. It should be mentioned, however, that temporary subscriptions are not guaranteed and thus cannot be seen as adequate replacements for flexibility.
- **Low incentives to participate in flex markets:** The Swedish regulation on the revenue of grid operators (Intäktsregleringen) defines the economic framework for investments in electricity grids and defines a cap for DSOs' revenue. In connection with this, the Swedish Electricity Act (Ellagen) states that the revenue cap should take into account the extent to which flexibility services are used and improve the efficiency of network operations. However, interviewees expressed that this definition is insufficient and that making investments in physical grids is still considered more economically appealing.
- Complicated prequalification process:
    - Prequalifications for both regional and local grids.
    - Baseline- and measurement problems: Different appliance types feature different power consumption profiles and follow more foreseeable or completely stochastic patterns, which makes it harder to fit pre-defined baselines as suggested by market platform

operators for certain appliances.

    - Data availability and ownership: in Sthlmflex, the grid companies (rather than the FSPs) communicated with NODES and thus needed power-of-attorney for every resource to relay measurement and verification data. This added an administrative burden and led to discussions about what the recorded data can and cannot be used for
    - Information disadvantage for actors other than the DSOs, who don't have access to data such as customers' power demand profiles for baseline optimisation through other channels, since there is no data hub
- **Multiple communication interfaces and integrations** towards different proprietary systems in appliances.
- **High participation cost per unit** for appliances, mainly due to requirements for individual measurement per unit, especially when no measurement hardware is present in the existing hardware.
- **Endurance was more important for local markets** than TSOs' flex markets: In a cold wave, flexibility from heat pumps and other heaters may be used up after day 1, when room temperature moves below an acceptable threshold. Without reheating the building in between (e.g., when the grid situation relaxes during nighttime), flexibility cannot be delivered after that time.
- **Low baseline consumption** in modern office buildings: Newer office buildings typically adhere to stricter standards than legacy buildings, meaning that heating, ventilation, and air conditioning are optimised towards low energy consumption. This results in a comparably low amount of flexibility landlords can offer from appliances in these buildings.

Sweden: Effekthandel Väst

General description

Effekthandel Väst is a local flexibility market in the Gothenburg region, established to address the region's future electricity demand and grid capacity challenges. On this market, DSOs Göteborg Energi and Mölndal Energi purchase flexibility services from connected customers. Participants in Effekthandel Väst include industrial

enterprises, small companies, and private persons via aggregators, and large property owners. Among the flexibility sources traded are batteries, EV chargers, and fridges/freezers in supermarkets and warehouses.

Since NODES is used as trading platform, the same products are traded as in Sthlmflex (ShortFlex/LongFlex), except for the new product "MaxUsage", which limits power use and thus circumvents the need for a baseline calculation, with lower administration efforts as a consequence. Effekthandel Väst is active during winter (November 1st to March 31st), when electricity demand is highest. Minimum endurance is 1 hour, and the lowest bid size is 50 kW (single source or aggregated).

Learnings from other markets

Before starting the market, both CoordiNet and Sthlmflex were analysed. A key learning was that a market needs a sufficient number of trades to be interesting to market actors for them to invest in both technology, routines, and competence building. This was especially important since the market needed to work without external research funding. To achieve this, direct communication lines with potential customers were established, rather than choosing a top-down approach where mainly the needs of the DSOs were communicated publicly and widely. Also, the pricing scheme was designed to be more attractive from the start, with a price that considered the alternative cost for flexibility on the customer side and prices in competing markets (e.g., balancing markets). Purchasing flexibility was prioritised over other possible solutions to solve the capacity problem. This leads to more flexibility being purchased than strictly necessary and stimulates market activity.

Since Effekthandel Väst, unlike Sthlmflex, only needs to consider the local grid (and not the regional grid), the extra administrative burden for filling in power-of-attorneys can be eliminated. Also, fewer different kinds of appliances are currently in use on the market, which enables a slimmer prequalification process of flexibility resources.

Future development

Göteborg Energi is determined to expand the market in the coming years and believes that flexibility will be an important tool to handle the challenges its grid will need to handle in the future, alongside grid upgrades. The total estimated need for flexibility is about 100 MW. Also, new forms of flexibility resources are planned to be integrated with the market, mainly larger battery storage and, when available, aggregated electric cars via V2G.

Value chain for DSF

As mentioned above, Göteborg Energi and Mölndal Energi foresee a growing demand for flexibility in their grids in the future and plan the grids accordingly. Since flexibility is considered an integral part of handling the grid in the future, and because the market can be seen as mature after several operating seasons, all steps 1-8 in the value chain defined in Chapter 3.1 are covered by the project.

Table 17: Physical value chain for DSF in Effekthandel Väst

Step in value chain	Stakeholders and systems in use		Function
1-4	DSO	*Göteborg Energi/Mölndal Energi*	DSOs
5	Market platform	*Nodes*	Market platform
6/7/8	Market aggregator	*Ambidex*	Ambidex also acts as a market aggregator and integrates directly with Nodes
6/7/8	Flexibility provider	*Supermarkets*	Owner of flexibility resources.
6/7/8	Technical aggregator	*Ambidex*	Ambidex adds hardware for control and monitoring of fridges and freezers in supermarkets
6/7/8	"Dumb" appliance	*Example: fridge/freezer system*	

Systems in use

As mentioned above, NODES is used as market platform, with an API that can be accessed for all relevant market activity, such as registering resources, placing bids, or sending baselines and measurement data. For validation, the FSP can choose to upload their own data to NODES or let the DSO use the electric meter data directly. There are no specific requirements for communication protocol standards because the DSO neither communicates directly with nor controls the flexibility resource.

Instead, all communication takes place via the market platform. Buying and selling bids are matched, and the winning flexibility provider either receives an SMS containing all necessary details on the trade or chooses to integrate with the API.

Resources

The DSOs running Effekthandel Väst do not prescribe which types of resources can be used on the flexibility market, as long as they fulfil the requirements stated above.

In total, around 30 FSPs managing roughly 700 flexibility resources provided 30 MW of available flexibility in 2023/2024. On the appliance side, EV chargers and non-residential fridges/freezers can be mentioned, with heat pumps being added at a later stage.

The minimum bid size for the local market is 50 kW, which means that most resources need to go through an aggregator to participate. Minimum endurance is set to 1 hour. Separate measurements on the appliance level are not a requirement today, but this will probably change in the future. In the following, a case study for flexibility from freezers and fridges in supermarkets is described.

Case study description: fridges and freezers in supermarkets

Ambidex was founded in 2023 with a business idea founded upon research from Chalmers University of Technology. The company installs control modules in the PACs (Programmable Automation Controllers) of supermarkets' cooling systems that both monitor and control the refrigeration system's power consumption. Communication usually takes place via the open Modbus/Modbus-TCP protocols.

In Effekthandel Väst, Ambidex also acts as an aggregator, bundling together several supermarkets in the Gothenburg region in different portfolios which can be activated separately or together depending on where and how much the grid needs to be supported, and handling the integration towards NODES via an API. On the marketplace, the aggregated resources are traded in the LongFlex market (see Chapter 3.6). A typical supermarket in the portfolio can have an installed electrical capacity of around 150 kW, of which 50 kW are potentially flexible for longer periods of time, and 35 kW effectively brought to market.

Before being eligible to participate in Effekthandel Väst, the resources need to be prequalified, which is done by an activation test and reporting of the results, a simpler procedure as compared to the Swedish TSOs' ancillary service markets.

The NODES default baseline calculation only considers the last 4 weeks' power consumption. As fridges and freezers feature a power consumption profile that, among others, factors change with ambient temperature, week, day, and time of day, the match between the default and actual baselines is imperfect. Part of the integration into the market platform was thus to negotiate an adapted baseline procedure based on Ambidex's data, which takes the flexibility resources' unique consumption profile into account. This enabled Ambidex to deliver more flexibility than had been possible otherwise. In the future, Ambidex will look into both additional markets such as SvK's ancillary service markets[70] and other resources

70. In the interview, it was pointed out that a sufficiently low response time to meet these services' requirements was possible to reach from a technological point of view.

such as HVAC systems in the same supermarkets, which are good complements to fridges and freezers from a power consumption point of view: In summer, cooling of goods consumes more power, while space heating demand is low (although air conditioning might be needed), which is reversed during winter.

Overall potential of fridges and freezers as a flexibility source

One way of calculating the total flexibility potential, i.e., the sum of implicit and explicit flexibility, from fridges and freezers is to create an annual consumption profile based on previous data, which leads to the assumptions that cooling demand is 1.4 times higher during high-demand hours (07-19) than at night and that the total annual electricity consumption lies around 575 GWh for cooling of goods in the service sector.[71]

The subsequent calculation yields a total flexibility potential of 75 MW for Sweden, with an endurance of 1h and a recovery period of 2h. It is worth noting that the same report quotes a potential of 564 MW in *residential* white goods, i.e., fridges/freezers and washing machines/tumble dryers in households.

Another article[72] found that in Germany, the average supermarket's power demand is around 30 kW, with roughly half of that being used for refrigeration. In Sweden, with around 3200 supermarkets, assuming a similar power demand, this would mean a flexibility potential of roughly 48 MW.

Barriers and enablers

The following enablers and barriers were identified, both from literature and from interviews with DSOs, technology providers, and aggregators.

Enablers:

- **Implementation of the demand response network code** (see Chapter 4), which is set to standardise market-specific parameters such as bid sizes, call-off periods, and communication protocols between different local markets. The main points interviewees want to see answered by rules in the demand response network code are standardised communication protocols,

71. 2021 numbers; Method and numerical results are presented in Energimarknadsinspektionens report Främjande av ett mer flexibelt elsystem
72. Funder, T. (2015). *Supermarkets as an Important Smart Grid Application.* In 16th European Conference, Technological Innovations In Refrigeration And In Air Conditioning

prequalification rules, validation and payment solutions, and harmonised baseline registration methods.

- **Local gateways owned and operated by the aggregator** relay information from and to the flexibility resource and ensure secure data transmission.
- **Flexible baseline definitions:** The possibility to discuss the definition of appliance-specific baselines with the market platform operators and agree on said baselines is seen as a huge advantage; without this possibility, it is questionable if fridges and freezers could have been brought to the local flexibility market while maintaining economic profitability.
- **Spatial distribution of supermarkets in the grid**: Unlike large industrial flexibility resources, supermarkets exist in most places and are correlated with population density, which in turn can drive the need for flexibility. Fridges and freezers are present in most of these supermarkets. Thus, the even distribution of these resources aligns well with the need to address grid issues locally.
- **Existing communication protocols** such as Modbus (as standardised in IEC 61158) enable quick integration towards different builds and generations of fridges and freezers, or their control systems, respectively. In Sweden, this is enhanced by a high market share of control systems from the same company (Danfoss). A future research question might be whether the current level of standardisation is sufficient for this application or not. If not, a solution might be to amend initiatives like the Code of Conduct for Energy Smart Appliances (see chapter 4.3.2) to include industrial-size freezers and fridges as smart appliances.
- **APIs:** When appliances are aggregated, manual activation of flexibility resources is not an alternative. The presence of an API, as when integrating with NODES, ensures that activations and market transactions can be automated.

Barriers:

- **Food hygiene and respective legislation:** temperatures in fridges and freezers are heavily controlled by food hygiene rules. When used as a flexibility resource, these appliances will not be able to deliver in situations where decreasing their power intake could mean a risk of exceeding temperature thresholds. In the current case study, this was handled as previously described by fine-tuning the resources' baselines, meaning that no deliveries had to be cancelled.
- **Missing communication standards for market platforms**: As an aggregator,

being present on different local flexibility markets with different rules and market platforms usually means high integration costs, which do not benefit from economies of scale. The definition of common standards could lower the threshold for participation in multiple markets. However, when defining these standards, it is important to ensure enough flexibility in questions such as baseline definition, see section on enablers.

- **Market liquidity** was also mentioned as a potential issue for Effekthandel Väst, although liquidity is higher than it was for Sthlmflex. For details, see the chapter on Sthlmflex.
- **Limited testing infrastructure** towards market platform: As of now, aggregators cannot test their entire code up to a bid being called, but have to rely on NODES' test call. An extended test infrastructure could help avoid this problem.
- **The Swedish regulation on the revenue of grid operators (Intäktsregleringen)** defines the economic framework for investments in electricity grids and defines a cap for DSOs' revenue. As was the case for Sthlmflex, interviewees in this case study also expressed the view that making investments in physical grids is more economically appealing than investing in flexibility measures.
- **Lack of expertise:** Resource owners, in this case owners of supermarkets, are often unaware of their own ability to participate in flexibility markets. Targeted information campaigns could be useful in tapping this potential.
- **Non-aligned trading deadlines on different markets:** Ancillary markets and local flexibility markets are not always synchronised in their closing times, which is especially important when bids from the local markets shall be forwarded to an ancillary market.
- **Power tariffs:** As described in the chapter on Sthlmflex, power tariffs can hinder the roll-out of flexibility markets since the power consumption profile will become more volatile. On top of that, interviewees pointed out that there are a lot of different power tariffs present in Sweden, since the DSOs have some freedom in designing them, and that there is no easily automated way to import data on the different tariffs. Keeping the optimisation algorithms for flexibility resources up to date is therefore a challenge. Dynamic power tariffs are being developed in research projects right now and will probably solve this problem.
- **DSOs not favouring market solutions over bilateral contracts:** DSOs might be overcautious and instead of implementing flexibility markets, cover their flexibility needs by bilateral contracts with single FSPs, which excludes a large number of potential FSPs.

Sweden: E.ON Energidistribution's flexibility markets

E.ON Energidistribution has opened different commercial markets in its grid areas in Sweden. In order to analyse what the drivers behind this development were, a general description of the company's flexibility markets, rather than one specific case study description, is performed in this chapter. The potential of single appliances on a national scale was therefore not determined. The information is based on publicly available sources, a stakeholder webinar[73], and interviews with E.ON employees.

General description

The German energy company E.ON entered the Swedish market as a DSO in the early 2000s by acquiring Sydkraft, which itself had previously bought several Swedish DSOs. Today, E.ON Energidistribution owns and operates 70 local grids in 139 municipalities, with a focus on southern and middle Sweden. Most of the company's grids are situated in grid areas SE3 and SE4. The grid situation in these southern Swedish areas is challenging at times due to an increased electricity demand. Also, they feature a higher degree of intermittent power production and lower available flexibility potential from large primary industrial sites as compared to the northern Swedish grid areas SE1 and SE2. Also, E.ON Energidistribution's grid tariffs are in the higher range of the Swedish DSOs. This is in part caused by the long distances between large-scale power generation in northern Sweden and the company's grids in southern Sweden, and the losses resulting from the required long-range electricity transmission. To enable customers to connect faster and use the grid more efficiently, which can also keep down costs for electricity and tariffs for the customers, E.ON Energidistribution works strategically with both implicit and explicit flexibility. The work on explicit flexibility includes the setup of flexibility markets, whereas implicit flexibility is encouraged by flexibility mappings, which unveil existing flexibility potential for companies and property owners and help them to lower both electricity and grid tariff costs.

Local flexibility markets

Based on learnings from the EU-funded project CoordiNet, E.ON Energidistribution established its first local flexibility markets in 2023 in Bålsta, Vaxholm, Hässleholm,

73. *"E.ON Energidistributions flexibilitetsmarknader"*, September 12th, 2024

and Southern Skåne[74]. During season 2024-2025, these are expanded with markets in Enköping, Kallhäll, Kungsängen, Northern Örebro, and Northeastern Skåne, for a total of 9 commercial markets. The markets are established where the local grid faces capacity issues and are usually active between November and March, and range from 1 MW to 30 MW in estimated flexibility need. In total, E.ON Energidistribution estimates a need for around 700 MW in their combined grid areas within the next years[75].

E.ON Energidistribution addresses both homeowners (via aggregators), property owners, municipalities, and industrial/commercial actors as participants in their local markets. The tech-neutral market approach enables resources such as heat pumps, car chargers, battery storage, ventilation units, backup generators, and lighting systems to participate.

As a market platform, but also as a planning tool for both FSPs and DSOs, SWITCH, which was developed within CoordiNet and is owned by E.ON Energidistribution, is used. Three products are traded:

- **"Direktorder"** (direct orders) with a pay-as-bid activation fee
- "**Tillgänglighetsorder"** (availability orders), which adds a fixed availability fee and
- **"Säsongstillgänglighet"** (seasonal availability), which is comparable to availability orders, but focuses on longer time spans. The smallest bid is limited to 100kW, and an endurance of 1 hour needs to be guaranteed.

If the FSP fails to deliver at least 75% of their bid, no payment is made. Above 75%, the payment scales linearly with the percentage of delivery from 75 to 100%.

Although some resources are aggregated, a handful of industrial and commercial customers are big enough to participate on their own, their size ranging from the minimum bid size of 0.1MW up to 15MW, where the larger resources could, for example, be industrial-size heat pumps or steam turbines.

Value chain for DSF

E.ON Energidistribution expands the number of local flexibility markets and runs them on a commercial basis. Since the company considers flexibility an integral part of handling the grid in the future, and because the markets can be seen as mature after several operating seasons, all steps 1-8 in the value chain defined in Chapter 3.1 are covered by the market.

74. Southern Skåne, Bålsta and Vaxholm had previously been run as a part of CoordiNet since 2019/2020
75. See network development plan: https://www.eon.se/content/dam/eon-se/swe-documents/swe-eon-natutvecklingsplan-2025-2034.pdf

Table 18: Physical value chain for DSF in E.ON's flexibility markets

Step in value chain	Stakeholders and systems in use		Function
1-4	DSO	*E.ON*	DSO
3-4	Planning tool	*Switch*	Planning tool for grid companies
5	Market place	*Switch*	Market place
6/7/8	Flexibility provider	*Switch*	Tool for FSPs, integration via API
6/7/8	Aggregators	*Multiple actors*	Aggregating resources
6/7/8	Appliances	*Heat pumps, car chargers, battery storage, ventilation units, backup generators and lighting systems*	

Learnings and status of new markets:

While E.ON Energidistribution participated in both CoordiNet and Sthlmflex, the management of their flexibility markets has moved from a project form to be handled in the company's line organisation since 2022, meaning that the same processes and guidelines are used throughout the organisation. Among other things, this means that the definition of baselines and production plans, prequalification of equipment, and sanctioning of failure to deliver are handled more strictly now than in previous research projects, which is reflected by new and uniform market design and rules.

The opening of a new market is preceded by an analysis of whether a local flexibility market can solve the grid issues at hand. E.ON Energidistribution's network development plan estimates the total flexibility need, and a team analyses whether a local flexibility market or other solutions are the most cost-effective tools to address the grid issues.

When scaling up from single projects to a larger number of markets, automation plays a crucial role since manual interventions scale badly. An automated calculation and publication of flexibility needs and the possibility for FSPs to integrate towards an API have therefore been a focus of development work and resulted in fewer manual interventions than in the project phase. Concerning the Switch platform, an iterative product definition and more accurate prediction algorithms have led to better demand forecasts, higher trust in flexibility deliveries,

and smoother validation processes. Random samples are analysed to ensure that the reported baseline is in accordance with the actual delivery. The service provider also provides meter data, which can either be based on the billing meter or a submeter directly metering the flexibility resource. For aggregated resources, the aggregator is responsible for sending measurements for the whole group of resources.

Barriers and enablers

In line with the other Swedish case studies, interviewees pointed out liquidity issues, regulation on the revenue cap of grid operators, missing communication standards for market platforms, and a lack of expertise as barriers. Since these points have already been analysed in Chapters 3.7 and 3.8, they are not mentioned separately in this section.

Enablers:

- **Aggregators:** E.ON Energidistribution describes the aggregator's role as crucial for successful flexibility markets. In part, aggregators own the know-how regarding integration both towards different market platforms and a wide range of appliances, often using their own hardware for measurement and communication. As described in the case study for Sthlmflex and Effekthandel Väst, aggregators also play a fundamental role in defining viable baselines, unlocking the flexibility potential a resource might have. A steep learning curve concerning baseline procedures has led to better matches between baselines, flexibility demand, and validated deliveries.
- **Clear and consistent rules:** Market rules, but also policies, laws, and regulations that shift quickly and unpredictably, can hinder the implementation of local flexibility markets because both DSOs and FSPs will shy away from necessary investments in an uncertain situation. E.ON Energidistribution has therefore tried to standardise the rulebook between their individual markets and stresses the importance that the same is done on a national and European level, e.g., by swift implementation of the Network Code on Demand Response (see chapter 4)
- **Long-term planning certainty:** When starting up a new market, E.ON Energidistribution states a minimum number of years the market will be guaranteed to operate alongside minimum availability payment levels. This reduces planning uncertainty for FSPs and lowers the threshold for market participation.

Barriers:

Political decisions on a municipal level might hinder certain flexibility resources from being brought to the market. A notable example mentioned in the interviews is power generators, which technically could be used as flexibility resources, but are not allowed to run on fossil fuels other than in crises due to guidelines the owner (a municipality) defined.

Long ramp-up to build markets: In the more mature local flexibility markets managed by E.ON Energidistribution, market liquidity was an issue at first, but became less problematic after the first couple of operating seasons. Ensuring market liquidity from the start should therefore be a focus for further market design efforts. Also, the aforementioned lack of competence falls in the category of ramp-up issues.

No intrinsic motivation for local flexibility markets: As opposed to the TSO's ancillary markets, local flexibility markets are not an exclusive solution: Whereas ancillary services are critical to the operation of an electrical grid, and cannot be easily replaced by other measures, local flexibility markets need to justify their existence in competition with other solutions to grid issues such as bilateral contracts or conditional connections.

Inflexible leases: Many lease conditions for commercial buildings contain service descriptions defining acceptable windows for office temperatures or ventilation system operating times. These conditions can prevent the landlord from using the HVAC system flexibly, since this usually means that a wider temperature corridor needs to be accepted. A solution to this can be found in so-called *green leases*, as used by Vasakronan, see Chapter 3.6.

Appliances' warranty conditions: Appliance manufacturers might add terms and conditions forbidding the end user from controlling the appliance by using external signals, with the threat of voiding the warranty if this is ignored. Warranty conditions should therefore be written in such a way that allows for flexible use.

Internal barriers: External factors, like the discontinuation of other local flexibility markets or the recent drop in prices for ancillary services, can lead to internal resistance against this solution, both in DSOs and potential FSPs.

Denmark: FUSE

General case description

The FUSE project was initiated in 2020 as part of Denmark's efforts to integrate smart EV charging into the energy system, with funding from EUDP (2020-I). The project was designed as a three-year initiative, running from 2020 to 2023, with a focus on real-world testing and market integration of EV flexibility. The project is aimed at integrating smart charging of electric vehicles (EVs) as a flexibility resource in the power grid. FUSE was deployed in Frederiksberg Municipality, a dense urban area with high EV adoption and limited space for charging infrastructure. The project specifically explores how dynamic charging management can provide DSF and help stabilise the distribution grid, particularly in urban environments.

Objectives

The increasing adoption of EVs introduces significant new electricity demand, often concentrated in specific time periods, such as evening hours when people return home from work. Without coordination, uncontrolled charging could lead to localised grid congestion and increased peak loads. To mitigate this, FUSE investigates how flexible charging strategies can:

- Shift charging to off-peak periods, aligning with lower grid load and higher renewable energy production.
- Enable EVs to act as a controllable load, responding to price signals and grid conditions.
- Integrate EV charging into local flexibility markets, allowing it to compete with other distributed energy resources.

The project explored the flexibility potential from various charging settings, including:

- Private home charging: Studying how residential users respond to dynamic pricing.
- Workplace charging: Evaluating how daytime charging can provide additional flexibility.
- Semi-public chargers: Testing flexibility integration from shared EV charging stations.

Technical and market mechanisms

FUSE employs a multi-layered approach to studying and implementing smart EV charging:

- Dynamic Charging Management: Charging power is regulated in real-time to prevent grid overload and optimise energy use.
- Aggregator-Based Control: A centralised control system manages multiple EV chargers, ensuring coordinated demand response.
- Integration with Spot Prices: EV charging is optimised based on day-ahead electricity prices, ensuring cost-effective charging for users.
- Grid Load Balancing: Charging is dynamically adjusted to prevent local distribution grid bottlenecks, particularly in areas with high EV density

Stakeholders and participants

FUSE was conducted as a collaborative project involving stakeholders from grid operators, research institutions, mobility providers, and policymakers.

- DTU Wind and Energy Systems (Project Leader)
  Conducted grid impact analysis and demand modelling.
- Radius Elnet (DSO)
  Assessed grid constraints and charging flexibility integration.
- Danish e-Mobility
  Worked on policy recommendations and industry dissemination.
- Spirii (Aggregator and Charge Point Operator)
  Managed dynamic charging and real-time market integration.
- Municipality of Frederiksberg
  Provided test areas and urban mobility insights.

In preparation for this report, several stakeholders were contacted for supplementary interviews to qualify the findings and provide further context to the Danish cases. While no responses were received from most of the stakeholders, partial interviews were successfully conducted with Danish e-Mobility on 26 November 2024, as well as with DTU Elektro, which served as the primary project lead. These inputs are reflected in the references and analysis where relevant.

Value chain

The FUSE project aims to integrate smart charging infrastructure into the electricity system by enabling dynamic load management and leveraging

demand-side flexibility. The value chain in FUSE consists of several components, including electric vehicle (EV) charging stations, energy management platforms, grid operators, and market mechanisms that facilitate flexibility services.

Table 19: Physical value chain for DSF in FUSE

Step in value chain	Stakeholders and systems in use		Function
2	DSO	*Radius Elnet*	Assesses grid constraints and ensures EV charging does not overload the network
3	Planning tool	*DTU Wind & Energy Systems / Charging Point Calculator*	Models EV charging flexibility potential and its impact on grid operations
5	Flexibility provider / Aggregator	*Spirii*	Manages and optimizes EV charging schedules to balance grid impact and user costs
6-7	Appliances	*EV chargers at homes, workplaces & semi-public locations*	End-user appliances delivering flexibility

Systems in use

The FUSE project utilises multiple systems to enable demand-side flexibility through smart charging infrastructure. Unlike a dedicated market platform, FUSE relies on existing market mechanisms and infrastructure to manage flexibility.

Grid Operations and Monitoring: Radius Elnet assesses grid conditions and determines when flexibility is needed to avoid local congestion issues.

Planning and Forecasting Tools: DTU Wind & Energy Systems' Charging Point Calculator models EV charging flexibility potential and forecasts grid impact based on usage patterns.

Aggregation and Control Systems: Spirii serves as the flexibility aggregator, coordinating charging schedules based on grid demand and price signals from the existing market structures.

End-User Appliances: Smart chargers at homes, workplaces, and semi-public locations dynamically adjust charging power based on real-time signals.

All communication between these elements follows standardised protocols to ensure interoperability. Aggregators interact with charging infrastructure through APIs and cloud-based platforms, enabling remote optimisation of charging behaviour.

Resources

The flexibility resources in FUSE consist primarily of EV chargers deployed at various locations. These resources contribute to grid flexibility by shifting charging demand to off-peak periods. Unlike market-based flexibility programs, where resources are traded, FUSE leverages demand-side management to optimise energy usage for consumers rather than generate direct financial revenue.

Flexibility Service Providers (FSPs): Spirii aggregates and optimises flexibility without introducing new financial transactions on dedicated platforms.

End-User Participation: Consumers benefit from lower electricity costs due to optimised charging, but do not actively trade flexibility as a revenue source.

Data and Control Infrastructure: EV chargers are connected to management platforms that allow automated control and optimisation based on price signals and grid conditions.

The approach in FUSE focuses on cost savings through smart energy management rather than trading flexibility as a market product.

Learnings from the FUSE project

The FUSE project has provided key insights into the practical implementation of demand-side flexibility through smart EV charging. One major learning point is the technical feasibility of shifting charging demand to align with grid constraints without impacting user convenience[76]. Data from the project indicates that it is possible to schedule and coordinate charging in a way that avoids critical peak hours without compromising daily mobility needs. Using the analytical framework outlined in the project report, the theoretical potential for demand shifting can be estimated as:

*Flexibility capacity (MW) = Average flexible capacity per unit * Number of units * Utilisation factor*

Assuming 900,000 residential charging points, each with 11 kW charging capacity (as specified in the report), and using simulated charging profiles from Table 3 in Section 2.4, approximately 40% of charging occurs during peak hours (17:00–20:00) without intervention. If a conservative utilisation factor of 25% is applied—representing the share of chargers in use and technically controllable during peak windows—the potential for flexible load shifting is:

76. Dansk ELBIL ALLIANCE, DTU - Smart fra start Anbefaling til fremtidens ladestandere

900.000 x 11kW x 40% x 25% = 900 MW. This suggests that nearly 1 GW of demand could theoretically be shifted away from peak hours under optimal—but realistic—conditions. Such a level of flexibility could significantly ease grid congestion, particularly in residential areas with high EV adoption, and contribute to deferring costly grid reinforcements.

FUSE has demonstrated that demand-side flexibility from EV charging is technically feasible and, when effectively managed, contributes to reducing grid congestion. Further refinement of interoperability standards, addressing regulatory barriers, and improving real-time measurement capabilities remain key areas for future research and development.

Barriers and enablers

Regulatory challenges: The project has also identified key challenges in regulatory frameworks[77]. Current market structures are not fully adapted to widespread EV participation in flexibility services. One significant barrier is the lack of financial incentives for demand-side response at the distribution level. While TSO-level markets exist, DSOs currently have limited or no mechanisms to procure local flexibility services. Regulatory changes are necessary to enable DSOs to actively integrate EV flexibility into their network planning. An important aspect is ensuring that regulatory incentives align with operational needs, as DSOs often lack structured flexibility procurement mechanisms.

Communication and data integration issues: Ensuring real-time interoperability between chargers, aggregators, and grid operators has been a notable challenge. Standardised protocols are required to maintain effective communication between different system components[78]. The project found that latency issues in data transmission can significantly affect the responsiveness of charging control. For instance, in high-demand periods, delays exceeding 500 milliseconds in load adjustment can reduce system efficiency[79]. Furthermore, variations in data formatting across different platforms have made integration more complex, necessitating further standardisation efforts. If interoperability between chargers (EV users), aggregators, and grid operators is not ensured, then the message might not be interpreted correctly (e.g., kWh could be read as Wh).

77. Dansk ELBIL ALLIANCE, DTU - Smart fra start Anbefaling til fremtidens ladestandere
78. Dansk ELBIL ALLIANCE, DTU - Fremtidens ladestander - Smart fra start - Anbefalinger til den smarte ladestander, 2020
79. Dansk ELBIL ALLIANCE, DTU - Fremtidens ladestander - Smart fra start - Anbefalinger til den smarte ladestander, 2020

Measurement and verification constraints: Reliable measurement and verification are crucial for ensuring that flexibility services are effectively delivered. The project tested different metering approaches to validate load reductions. Initial findings indicate that sub-metering at the charging station level provides more accurate verification than aggregated household consumption data[80]. However, implementation costs for high-resolution metering remain a limiting factor, particularly for widespread deployment. The project has also highlighted the need for improved verification frameworks that account for different charging behaviours and load profiles.

Peak load reduction and capacity: FUSE demonstrated that smart charging strategies can effectively shift charging demand away from peak hours, reducing local grid strain[81]. The project included 1,500 charging points, with individual charging capacities ranging between 3.7 kW and 22 kW per charger. Given a typical charging session duration of 2 to 10 hours, coordinated load shifting at scale has the potential to shift several megawatts of demand in peak periods. However, quantifying the exact impact requires further analysis of activation patterns and participation rates among users.

Denmark: EcoGrid

General case description

EcoGrid 2.0 was a large-scale research and demonstration project in Denmark that aimed at exploring and developing a market-based approach to demand-side flexibility (DSF). The project builds upon the success of the previous EcoGrid EU initiative[82] and sought to demonstrate how households' electricity consumption could be aggregated and traded as a flexibility resource in electricity markets. The project was conducted from 2016 to 2019 on the island of Bornholm, an isolated energy system with a high penetration of renewable energy sources (wind and solar). The project tested real-time market integration of flexibility from residential electricity consumers, particularly focusing on electric heating systems.

80. Dansk ELBIL ALLIANCE, DTU - Fremtidens ladestander - Smart fra start - Anbefalinger til den smarte ladestander, 2020
81. Dansk ELBIL ALLIANCE, DTU - Fremtidens ladestander - Smart fra start - Anbefalinger til den smarte ladestander, 2020
82. http://www.eu-ecogrid.net/ecogrid-eu

Objectives

The project aimed to:

- Develop and test an open flexibility market where households could sell their demand-side flexibility.
- Demonstrate automated demand response in residential homes without affecting user comfort.
- Reduce grid congestion and balance the system by integrating decentralised flexibility resources.
- Investigate business models for aggregators to bundle and trade household flexibility.
- Enhance digitalisation and forecasting through smart meters, machine learning, and data analytics.

By transitioning from a pilot project (EcoGrid EU) to a market-driven system (EcoGrid 2.0), the project sought to prove that demand-side flexibility could be a commercially viable solution for grid balancing and congestion management.

Market-based approach and aggregation model

How the Flexibility Market Worked

- Consumers' energy consumption was adjusted automatically based on price and grid signals.
- Aggregators pooled flexibility from multiple households and sold it to TSOs, DSOs, and balance-responsible parties.
- A Flexibility Clearinghouse Market (FLECH) was established, allowing both TSOs and DSOs to procure demand-side flexibility services.

The market supported two primary service types:

1. Scheduled Services: Consumers agreed to shift consumption at predefined times.
2. Conditional Services: Consumers provided on-demand flexibility when requested by the market.

Technical implementation and digitalisation

- Smart meters: Provided 5-minute data for accurate consumption monitoring.
- Machine learning algorithms: Predicted household flexibility potential based on historical data.
- IoT-based Home Energy Management Systems (HEMS): Automated electric heating control via cloud-based optimisation.

- Real-time market platform (IBM Bluemix): Enabled automated trading and settlement of flexibility services.

Stakeholders and participants

EcoGrid 2.0 was a collaborative effort involving multiple stakeholders from research, industry, and the energy sector.

- TSO: Energinet.
- DSO: Bornholms Energi & Forsyning.
- Aggregators:
    - IBM: Developed automation tools and market integration strategies.
    - Insero: Focused on consumer engagement and aggregator operation models.
- Technology & Research Partners: DTU (Technical University of Denmark), IBM, Uptime-IT, Insero, Krukow, and CBS.
- Private Consumers: 800 households participated, primarily with heat pumps and electric heating panels.

Value chain

EcoGrid 2.0 contributes steps (4)5 to 7 on the DSF value chain described in chapter 3.1, focusing on market integrations, activation, and verification. It demonstrated how household flexibility can be traded and utilised in real-time markets.

- Step 4/5: Establishing market mechanisms
    - EcoGrid 2.0 developed and tested a market-based approach for demand-side flexibility.
    - It included a dedicated market platform (FLECH) for aggregators to trade flexibility.
    - TSOs, DSOs, and BRPs could procure flexibility services through scheduled and conditional bids.
- Step 6: Delivery of flexibility from providers
    - Aggregators (IBM & Insero) managed flexibility from 800 households.
    - Smart meters and automation enabled real-time load shifting of heat pumps and electric radiators.
    - Consumers' energy use was adjusted automatically based on market signals and system needs.
- Step 7: Activation, verification, and settlement

- Flexibility activations were tracked using smart meters with 5-minute resolution.
- Baseline models ensured accurate verification of delivered flexibility.
- Market settlement was automated, ensuring payments to aggregators based on actual performance.

Table 20: Physical value chain for DSF in Ecogrid 2.0

Step in value chain	Stakeholders and systems in use		Function
2	DSO	*Bornholms Energi & Forsyning*	DSO managing grid operation and planning
3-4	Planning tool	IBM Bluemix (Flexibility Analytics)	Modelling and prediction of flexibility needs
5	Market place	*FLECH*	Market platform for pre-defined flexibility activation
6-7	Flexibility provider	*Insero & IBSM*	Aggregating and optimizing flexibility resources, incl. smart metering and control
6-7	Aggregators	*IBM & Insero*	Smart metering, API integration, and communication protocols
7-8	Appliances	*Heat pumps & electric radiators*	End-user appliances delivering flexibility

Core mechanisms

The EcoGrid 2.0 project functioned as a real-time flexibility market, where household electricity consumption—primarily from heat pumps and electric radiators—was adjusted based on system needs. The market operated on the Flexibility Clearing House (FLECH) platform, where aggregators submitted bids for flexibility, and the TSO or DSO Bornholms Energi & Forsyning procured this flexibility for balancing or congestion management purposes.

The bidding and activation process was structured in hourly cycles. Aggregators collected and forecasted available flexibility based on temperature, historical usage, and real-time consumption patterns. The market cleared within 15 minutes, selecting the most cost-efficient offers, after which flexibility activation was initiated. The cost-efficiency of an offer depended on factors such as the aggregator's estimated cost, the expected energy rebound effect, and the location-specific needs of the TSO/DSO.

Flexibility forecasting

Aggregators used machine learning algorithms that incorporated historical household consumption data, weather conditions, and time-of-day factors to predict available flexibility. Load reduction potential varied based on outside temperature, with greater flexibility available on colder days. At -5°C, the average household could deliver 1.1 kW of load reduction, while at 0°C, this dropped to 0.8 kW[83]. The highest flexibility was generally available at midday rather than early morning, as homes retained residual warmth from overnight heating, making short-term load reductions more feasible at these hours.

83. EcoGrid 2.0 - Main Results and Findings, September 2019

Consumer compensation

In the EcoGrid 2.0, consumers did not get directly compensated for the delivery of flexibility. Instead, financial benefits were realised through reduced electricity bills, as households could shift consumption away from high-price periods[84]. However, the financial incentive was relatively small, averaging less than 100 DKK per household annually, which limited active consumer engagement.

DSO-TSO market coordination

The DSO played a crucial role in determining when and where local flexibility was needed, particularly for preventing grid congestion. Unlike TSO activations, which responded to frequency deviations in real time, DSO activations were often scheduled days in advance based on congestion forecasts. This occasionally led to conflicts between TSO and DSO activations, as the same flexibility pool could be requested by both parties[85].

Activated flexibility volumes and market performance

Over the course of the project, aggregators initiated a total of 102,458 activations, distributed between the two main aggregators:

- Siemens: 19,682 activations
- GreenWave: 82,776 activations

Despite the high number of activations, approximately 9.7% of attempts failed, primarily due to communication errors between the platform and household devices. In terms of flexibility capacity, the participating households delivered up to 1 MW per activation, with individual heat pumps providing between 0.8 and 1.1 kW per event, depending on outdoor temperature and home insulation levels. The estimated total energy shifted during the project was over 5 GWh, with activations typically lasting 30–60 minutes[86].

Economic aspect

One of the key findings of EcoGrid 2.0 was that the economic incentives for household participation were limited. Consumers did not receive direct payments for their flexibility but instead saved on their electricity bills by shifting consumption away from peak-price hours. However, the average annual savings per household amounted to less than 100 DKK, which did not create a strong financial incentive. From a market operations perspective, aggregators generated revenue by trading flexibility in both TSO and DSO markets. However, price volatility and limited liquidity in the flexibility market restricted the overall profitability. The evaluation

84. ibid.
85. ibid.
86. ibid.

suggested that a more structured compensation model could enhance aggregator participation and market scalability[87].

Rebound Effects and Technical Constraints

A major challenge in EcoGrid 2.0 was the rebound effect[88], which refers to the increase in energy consumption following flexibility activation. This is particularly relevant for thermostatically controlled loads (heat pumps, electric radiators), where reducing consumption temporarily results in a compensatory surge in demand afterwards.

Key findings on the rebound effect:

- Uncontrolled rebound effects resulted in a load increase exceeding the initial load reduction, negating part of the benefits of flexibility activations.
- Smart control algorithms were implemented in heating season 3, successfully mitigating rebound effects by gradually restoring heating instead of allowing a sudden power surge.
- Rebound effects were particularly pronounced on very cold days, where indoor temperatures dropped faster than expected, requiring more energy to restore comfort levels.

The final assessment recommended that future flexibility programs incorporate advanced load recovery strategies to minimise rebound effects, ensuring that flexibility services remain net beneficial to the grid.

Technical and infrastructure overview of EcoGrid 2.0

EcoGrid 2.0 relied on a combination of hardware, software, and communication infrastructure to facilitate real-time demand-side flexibility from residential consumers. At the heart of the system were heat pumps and electric radiators, which acted as primary flexibility resources, complemented by smart metering, cloud-based aggregation platforms, and real-time communication networks. Despite the success of the technical implementation, the project also highlighted key challenges related to device interoperability, data communication reliability, and standardisation.

Heating appliances

Heat pumps, used in 85% of participating homes, proved to be particularly effective due to their thermal storage capabilities. Depending on outdoor temperatures and insulation levels, heat pumps could deliver between 0.8 kW and 1.1 kW of flexible load per activation, providing a scalable and predictable source of

87. ibid.
88. ibid.

demand response. Electric radiators, used in 15% of participating homes, provided an alternative flexibility source, with individual power capacity of 0.5–1.5 kW per unit. Unlike heat pumps, radiators did not benefit from thermal storage, meaning short-term flexibility activations had a more direct impact on indoor comfort. This resulted in higher override rates, where participants manually adjusted their settings to counteract flexibility activations, reducing overall effectiveness.

Metering and data collection

Participating homes were equipped with smart meters capable of recording high-resolution energy consumption data. While standard Danish smart meters provide hourly data, EcoGrid 2.0 required higher resolution (5-minute intervals) to allow real-time tracking of flexibility activation and settlement. These meters fed consumption data directly into the market platform, allowing aggregators and system operators to monitor the impact of activations and compare real-time reductions against baseline consumption models. One of the critical advantages of high-resolution metering was the ability to accurately verify delivered flexibility, ensuring that aggregators were only compensated for actual load reductions. However, the project also revealed challenges in data processing and integration, particularly in cases where communication failures resulted in missing or delayed metering data. Approximately 9.7% of flexibility activations failed due to loss of communication between smart meters and the central platform, highlighting the need for improved data reliability in future implementations.

Communication and control systems

A core component of EcoGrid 2.0's technical implementation was the communication infrastructure that connected household appliances to aggregators and the market platform. Heating appliances were controlled via a mix of Wi-Fi, Zigbee, and proprietary cloud-based manufacturer interfaces, allowing real-time activation signals to be transmitted to and from consumers. While most modern heat pumps supported remote control, many older models lacked standardised API access, requiring aggregators to develop custom software layers to bridge these gaps.

The lack of standardised communication protocols across different manufacturers posed a significant barrier to seamless integration. While some devices used MODBUS or BACnet protocols, others relied on proprietary cloud platforms, making uniform control difficult. This fragmented technology landscape meant that aggregators had to develop multiple parallel integration methods, increasing the complexity and cost of system operation.

Key learnings from EcoGrid 2.0

EcoGrid 2.0 demonstrated the technical feasibility of household demand-side flexibility but also highlighted several challenges that need to be addressed for

large-scale deployment. One of the key findings was that heat pumps and electric radiators can successfully provide flexibility, but response times and control precision varied significantly. Heat pumps exhibited delayed activation and rebound effects, making them less suitable for fast-response flexibility services without better control mechanisms[89].

Reliable communication infrastructure proved to be critical, yet 9.7% of flexibility activations failed due to lost signals or delayed data transmission. The use of multiple communication protocols across different appliances led to integration issues, and some devices had limited API access, requiring custom software solutions for market participation. The lack of standardisation in communication created barriers to automation, increasing the cost and complexity of aggregator operations.

From a market and economic perspective, EcoGrid 2.0 successfully demonstrated real-time flexibility trading, but low financial incentives for consumers limited engagement. Households did not receive direct payments, instead benefiting from reduced electricity costs, but with annual savings under 100 DKK per household, motivation remained low. Furthermore, the coordination between TSO and DSO activations revealed conflicts, as the same flexibility resource was sometimes needed for both system-wide balancing and local congestion management, leading to suboptimal resource allocation.

Overall, the project confirmed that household flexibility can play a role in future energy markets, but success will depend on improving device interoperability, strengthening data communication reliability, optimising financial incentives, and refining market coordination mechanisms.

Overall potential of heat pumps as a flexibility source

The project's scalability assessment estimated that, if rolled out nationwide in Denmark, demand-side flexibility from residential heat pumps could contribute up to 200 MW of flexible capacity, mainly during winter months when heating demand is high. This represents approximately 2–3% of Denmark's peak electricity consumption. Further analysis suggested that, under optimal market conditions, automated flexibility activation could reduce the annual peak demand by 5–8%, helping to delay grid investments and improve renewable energy integration[90].

89. ibid.
90. ibid.

Barriers and enablers

Table 21: Barriers and enablers in Ecogrid 2.0

Category	Barrier	Enabler	Potential solution
Appliance response	Heat pumps had slow reaction times and rebound effects, limiting fast flexibility.	Thermal storage in buildings mitigated rapid temperature drops	Optimised control algorithms to gradually restore load and reduce rebound peaks
Communication	9.7% activation failures due to lost signals and protocol inconsistencies	Standardised APIs and improved cloud-based control	Industry-wide adoption of common communication standards to enhance compatibility
Market and economy	Low financial incentives reduced consumer engagement	Aggregators successfully traded flexibility in real-time markets	Higher compensation schemes or dynamic pricing structures to improve consumer participation
Coordination	TSO and DSO competed for the same flexibility, leading to inefficiencies	Flexibility successfully tested for grid balancing and congestion relief	Clearer market mechanisms for resource allocation and better coordination frameworks
Integrations and standardisation	Lack of uniform protocols increased integration costs	Machine learning-based forecasting improved bid accuracy	Regulatory push for standardisation in device control interfaces

Finland: Helen Electricity Network's and Fingrid's marketplace for congestion management

Flexibility markets have been seen in Finland as a necessary tool for congestion management. Prior knowledge for preparing the markets has been gained from technical pilots with simulated market design in INTERFACE and OneNet projects. TSO Fingrid and the DSO Helen Electricity Network are launching together the first pilot of the live marketplace for congestion management with a go-live target in Q1 of 2025.

General description

The project creates and pilots a common marketplace for congestion management for Fingrid and Helen Electricity Network (DSO). Although it is a pilot project, the market will be used operationally by the system operators to solve congestion. The pilot project tests the functioning of the flexibility market for congestion management, defined products and market rules, and the market's liquidity. The plan is to continue the piloting phase until the end of 2027. The longer-term target is to develop a common national marketplace by the experiences gained from the pilot.

About Helen Electricity Network Ltd. (DSO)

Helen Electricity Network is part of the Helen group (included as a sub-group in the Helsinki city Group) and has 430,000 customer measurement points and 36,000 connection points. Further information about the network can be found in the Electricity distribution network development plan of Helen Electricity Network Ltd [91].

Grid Issue

Fingrid's main challenge is the transmission grid capacity from northern and central to southern Finland and from western to southern Finland. The case study of Fingrid in the project is to solve 400 kV grid congestion in normal, fault, and disturbance situations. Fingrid uses the congestion management market as part of other congestion management methods.

91. https://www.helensahkoverkko.fi/globalassets/hsv/tietoa-meist%C3%A4/helen-s%C3%A4hk%C3%B6verkko-kehitt%C3%A4missuunnitelma-2024_en.pdf

Helen Electricity Network is challenged by rapid changes in the electricity production (shutdown of CHP power plants) and consumption (e.g., electric boilers and electrification of transport), which might create a deficit in the 110 kV network. The problems could occur rather seldom and infrequently, e.g., in an N-1 situation. The maximum loading of the area is expected to double by 2030, up to ca. 1600 MW. This challenges the capacity of the local 110 kV network. In addition to maximum loads, energy transmitted to customers is estimated to increase from 4,436 GWh in 2023 to 8,294 GWh in 2033[92]. In the same period, local production of electricity is estimated to decrease from 1,071 GWh to 152 GWh.

Value chain for DSF

The value chain of flexibility of the marketplace with the main stakeholders is presented below.

Table 22: Physical value chain for DSF in Helen Electricity Network's and Fingrid's marketplace for congestion management

Step in value chain	Stakeholders and systems in use		Function
4	DSO, TSO	*Helen Electricity Network, Fingrid*	
5	Marketplace	*NodesMarket*	Mediate bids between DSO and FSP. Facilitates reservation and activation of flexibility, baseline estimation, and validation and settlement of trades. Different products.
6/7/8	Flexibility provider	*Flexibility service providers*	Aggregates and manages flexibility from portfolio. Responsible for all customer contact. Registers the resources and delivers the measurement data and baselines on Nodes platform.
6/7/8	Interface FSP/customer	*FSPs' own set-ups for integration and management of flexible resources*	FSP's platform may include cloud-based data management, prognosis tools and integration logics.
6/7/8	Flexible resource	*Various resources*	The flexible resources can be production, consumption or storage. The marketplace will offer more possibilities to participate also for such flexible resources that are not capable to participate in reserve markets, e.g. resources with slower reaction time.

Flex Mechanisms

Fingrid has defined five congestion zones, i.e., procurement areas of flexibility, for the marketplace (North, Central, South, Southwest, Uusimaa)[93]. The marketplace will offer more possibilities to participate for such flexible resources that are not capable of participating in reserve markets, e.g., resources with slower reaction time. The flexible resources can be production, consumption, or storage.

92. Helen Electricity Network Ltd. Electricity distribution network development plan 2024.
93. Fingrid's and Helen electricity network's presentation in the project's stakeholder meeting 17.12.2024

The DSO's main solution is temporary flexible connections, but the market-based congestion management opportunities are an additional possibility. Helen Electricity Network Ltd. has created four congestion zones for the marketplace for congestion management.

Brief description of the marketplace for congestion management

Fingrid and Helen Electricity Network have submitted the terms and conditions of the marketplace to the Energy Authority for approval in October 2024. When the terms and conditions have been approved, trading in the marketplace will begin, estimated in Q1 of 2025. The description here is based on the situation in December 2024, and the information is based on Fingrid's and Helen Electricity Network's info event on 17.12.2024 and interviews of Fingrid's and Helen Electricity Network's representatives.

The marketplace responds mainly to predictable congestion situations. In Fingrid's case studies, in a sudden 400 kV network fault situation, other congestion management methods, such as mFRR special regulation, are used first, and the marketplace comes in later if the congestion continues. Also in Helen Electricity Network's case study, in addition to forecasted congestions, e.g., the exceptional switching status caused by a sudden fault and the ensued, prolonged repair work might cause flexibility needs. The project aims to harness especially such flexibility resources that are not capable of participating in the TSO reserve markets.

The chosen market platform is NODES, which facilitates the trading of flexibility between grid operators and flexibility providers. The market products are LongFlex^{TM} for capacity and ShortFlex^{TM} for energy markets. The capacity product LongFlex^{TM} allows system operators (SO) to reserve flexible capacity in a capacity market auction to ensure that flexibility is available when it is needed. The accepted bid for LongFlex obligates to give an offer to the ShortFlex product. Both LongFlex and ShortFlex bids are given separately for the up- and down-regulation. The market operates on a pay-as-bid principle. The idea is to make it possible to develop product specifications based on experiences gained during the pilot project. The bids are selected per flexibility area in price order, starting with the most cost-effective from the network company's perspective. The system operator can set a price cap for the product.

Helen Electricity Network aims to use the capacity product LongFlex^{TM}. Helen Electricity Network's ShortFlex product's trading happens by an auction at D-1 10:00 (EET/EST) before the day-ahead market closes, and thus the trade is not reported to eSett for the imbalance settlement. The DSO accepts the ShortFlex bids needed at 10:00 the day before the delivery. Since the trade is not reported to

eSett for the imbalance settlement, the balance responsible party (BRP) and the electricity supplier need to take into account the trade done with the system operator in their trading activities, e.g., in the day-ahead market.

Fingrid's ShortFlex product is continuously traded after the day-ahead market closes, from D-1 at 15:00 (CET+1/CEST+1) until 60 minutes before the delivery (T-60 min). Fingrid reports the energy trade for eSett. The reporting is planned to be implemented latest 13 days after the transaction. In both products, the invoicing of the transactions between the SO and the flexibility service provider (FSP) is managed by NODES. The bids not accepted for Helen Electricity Network's ShortFlex product can be used automatically for Fingrid's ShortFlex product.

Participation in the new TSO-DSO congestion management market and reserve markets of the TSO with the same flexible resource is possible. However, the same capacity of a resource cannot be bid to the congestion management market and to a reserve market (mFRR, aFRR, FCR-N, FCR-D, or FFR) for the same hour. A flexibility service provider decides which markets to participate in with its flexible resources. The need for flexibility in the new congestion management market will be significantly lower compared to the reserve markets, where flexibility is needed every day for balancing.

The gate closure times of the TSO-DSO congestion management market are set taking into account the gate closure times of other markets, especially mFRR/aFRR capacity and energy markets:

•The DSO's congestion management energy market auction is held D-1 at 10:00 (EET/EEST) for all hours of the next day. The auction is held after the results of the mFRR and aFRR capacity markets that have been received earlier in the D-1 morning.

•The trading in the continuous congestion management energy market ends 60 minutes before delivery, and thus, the flexibility service providers know the result of the market before the gate closure time of the mFRR (45 min before delivery) and aFRR (25 min before delivery) energy markets.

The market time unit is planned to be 60 minutes, and the minimum bid size would be 0,1 MW for the ShortFlex and LongFlex products. However, some FSPs have expressed that there would be more flexible resources available for shorter bids. The FSP defines the preparation time required for its flexible resources and can set an expiry time for its offer in the ShortFlex product. The verification of the traded flexibility by the measurement data happens after the transaction.

The FSP could use the baseline provided by NODES based on the measurement data and calculation methods of NODES, or send its own prognosis of the baseline.

The future EU-level network code for demand response is expected to include top-level principles for baseline and the process for defining it.

FSP must agree with the BRP and the electricity supplier of the flexible resource to participate in the marketplace. The FSPs are first pre-approved before their trading is accepted. The FSPs are queried about the technical information of the flexible resources, but prequalification tests of the flexible resources are not performed.

DSF potential from household heat pumps

DSF potential and possible barriers connected to household heat pumps and electric heating were mapped by interviewing flexibility service providers (FSPs).

A very indicative estimation of the number of heat pumps in Finland at the end of 2024 is as follows:

- Ground source heat pumps: 160,000 pcs.
- Air-to-water heat pumps: 90,000 pcs.
- Exhaust air heat pumps: 40,000 pcs.
- Air-to-air heat pumps: 1,040,000 pcs.

The estimate is based on the sales statistics of the Finnish Heat Pump Association.

Heat pumps in Finland are mostly installed in residential buildings. Based on Finnish energy performance certificate (EPC) database statistics, around 75% of ground source heat pumps are installed on single-family residential buildings, and below 5% on other than residential buildings.

If assumed that in winter months the average power demand of ground source, air to water and exhaust air heat pumps, together with their electric resistance heaters, would be around 2,5 kW, the total power demand would be around 700 MW. If assumed that the average power demand of air-to-air heat pumps would be around 1 kW in winter months, the total average power demand of air-to-air heat pumps would be around 1,000 MW.

During the coldest days (average temperature under -20 °C), the average power demand of heat pumps is a lot higher, and the differences of the heat pump types grow wider. If simplified and assuming that the average power demand of ground source, air to water, and exhaust air heat pumps together with their electric resistance heaters would be around 5 kW on the coldest winter days, their total power demand would be around 1,400 MW. If assumed that the average power demand of air-to-air heat pumps on the coldest winter days would be around 1,5 kW, the total power demand of air-to-air heat pumps would be around 1600 MW.

With these assumptions, a very rough theoretical estimation for the power demand of heat pumps in Finland could be somewhere around 1,700 MW on a normal winter day and around 3,000 MW on the coldest winter days. These numbers are indicative estimates including significant uncertainties, and, therefore, they should not be taken as trusted results. The demand response potential is weakened by, for example, the fact that older heat pumps are not easy to connect to FSPs' services.

The demand response potential of heat pumps varies a lot according to outside temperature and the properties of the building, heat distribution system, additional heating sources, and the heat pump itself. On very cold winter days, air source heat pumps use more complementary heating (usually electric resistance heaters integrated to a heat pump or other electric heating) to support the heating with a compressor than ground source heat pumps, which increases air source heat pumps' power demand on the coldest winter days. Fireplaces (masonry heaters) are also widely used as complementary heating on the coldest days, which affects DR potential. On the coldest winter days, the room temperature drops more quickly when the heating stops, especially if the insulation of a building envelope is weak, the ventilation system doesn't include heat recovery, and there is low thermal mass on the heat distribution system and on the building itself.

The heat pump heating in Finland's building stock is increasing, and electric heating is decreasing. The estimated development of electricity consumption from 2020 to 2030 expressed in the long-term renovation strategy, is presented in the table below.

Table 23: The estimated development of electricity consumption of electric and heat pump heating in Finland's building stock from 2020 to 2030

Building type	Heating method	Consumption in 2020	Consumption in 2030
Detached and semidetached houses	electric heating heat pump heating	9 607 GWh 4 958 GWh	7253 GWh 7115 GWh
Terraced houses	electric heating heat pump heating	1,385 GWh 591 GWh	1 132 GWh 824 GWh
Apartment houses	electric heating heat pump heating	1136 GWh 81 GWh	810 GWh 836 GWh
Non-residential buildings	electric heating heat pump heating	2106 GWh 183 GWh	1810 GWh 953 GWh

Source: Finland's long-term renovation strategy

Project learnings: Barriers and enablers

Barriers and enablers were mapped by interviewing FSPs connected to the DSF of residential buildings. This review was not restricted only to the marketplace for congestion management but also included a wider DSF context.

Barriers: household heat pump solutions

Finnish FSP Kapacity.io was interviewed for the use of home-sized heat pumps as a DSF resource. Kapacity.io provides services to energy companies and property owners through their DSF cloud platform for heat pumps and electric heating. The company operates internationally and participates in many DSF markets across Europe. The DSF resources are connected to the Kapacity.io cloud. Kapacity.io's service gives control commands directly to the device manufacturer's cloud platform without an intermediary to harness the extensive control capabilities provided by each manufacturer. Kapacity.io was acquired by North American FSP EnergyHub at the end of 2024.

The home heat pumps are connected to the Kapacity.io cloud via an internet connection (LAN or Wifi), so additional devices are not needed. Most homeowners can bring the service into use independently. A wide range of heat pumps in the market is supported.

The identified barriers and respective opportunities:

- The local DSF marketplace pilot: FSPs' DSF resources are spread over a wide area. Difficulty in achieving a significant capacity for local DSF from a

specific area in Helsinki. The condition that a bid can include only resources from one BRP could also limit the opportunities.

- The possible duration of DSF with heat pumps varies a lot according to the weather conditions (e.g., weak DSF potential in -30°C) and when the previous activations have taken place (when and how long). For heat pumps, DSF for two hours could be possible, but for six hours, it is not feasible. However, the potential duration depends strongly on weather conditions and building properties.
- Verification:
    - Measurement of the heat pump's electricity consumption should be accurate enough to fulfil verification requirements. There is some variation in the accuracy of the electricity consumption measurement integrated into heat pumps. The interviewee estimated that there could be some variation in the accuracy between heat pump manufacturers. There is also variation in the measurement accuracy between different installations (different operating conditions) with the same heat pump model. The accuracy could not be verified, but one manufacturer's representative estimated that the measurement error could roughly be inside the tolerance of +-10%.

A weak accuracy can be seen as a barrier to fulfilling verification requirements. The accuracy can be solved with external electricity consumption measurement, but this raises costs for smaller household size heat pump installations. Harmonisation of the methods to estimate heat pumps' electricity consumption and requirements for minimum accuracy could be seen as a possible opportunity to remove these barriers.

- The verification requirements for DR differ between different DSF markets. Harmonisation of requirements and conditions in general would help FSPs' operation in different DSF markets.
- Internet connectivity:
    - Heat pumps' internet connectivity depends on the model. The connection is often as an additional module in cheaper models, which increases the adoption threshold. Requirements for internet connectivity are a possible opportunity to remove the barrier.
- API interfaces: There is a lot of variation in API-interface arrangements among heat pump manufacturers, and also, bad API practices exist. Variation complicates and increases the work for connecting DSF services to the cloud services. Kapacity.io has published a "wish list" for the HVAC device

cloud compatibility, which includes an example on how to build an industry-standard API for controlling heat pumps by third parties[94]. The following control and monitoring possibilities of the heat pump via the manufacturer's cloud service must be enabled to ensure compatibility with the service:

- Control the supply temperature setpoint
- Control the domestic hot water temperatures (if the heat pump provides domestic hot water)
- Monitor heat pump domestic hot water temperature (if heat pump provides domestic hot water)
- Monitor heat pump supply temperature
- Monitor alarms of the heat pump

Based on the above, harmonisation of heat pump manufacturers' API-interfaces for controlling heat pumps via the manufacturer's cloud by third parties and minimum requirements for control and monitoring capabilities could be seen as an opportunity.

- Information about device manufacturers' software updates in time for the FSPs. A software update of a heat pump model may cause a need for an update to the DSF service. If the FSP doesn´t receive information about the software update of the heat pump model in time from the manufacturer, the heat pump's compatibility with the DSF service could be disturbed. In the worst-case scenario, this might cause disturbances to the operation of the heat pump.
- The installation and connecting the device to the internet: Some installers could benefit from training on the DSF possibilities of heat pumps. The ease of connecting the heat pump to the Internet varies between manufacturers. Some residents need help connecting the device to the internet.

Barriers: home ESWHs, electric heating, and air-to-air heat pumps

Finnish FSP Optiwatti was interviewed for the use of home ESWHs, electric heating, and air-to-air heat pumps as a DSF resource. Optiwatti has "dozens of megawatts" of DSF resource in its service. The brief introduction of the service and systems in use:

- OptiWatti controls home heating equipment centrally: Electric radiators, underfloor heating, ESWHs, and air source heat pumps. In addition, car heating, electric car charging, and solar panel production information can be integrated into the same control system.

94. https://kapacity.notion.site/Requirements-For-Device-API-e7b0d34ebafc4e3da67c87bc5ae2374e

- The heating of each room can be controlled separately, and the room temperature can be programmed with an hour granularity.
- The service automatically optimises heating based on indoor and outdoor temperature, weather forecast, and electricity exchange price. Aggregated control of the resistive load-based resources for the FCR-D (up) market at the development stage (as part of Horizon Europe STREAM project).
- Equipment assembled to provide the service:
    - Sensors: measure the temperature and humidity in each room
    - Smart central unit: controls the heating and connects to the internet (Optiwatti cloud)
    - Smart radio-controlled relays: control heating devices
    - Accessories: Air source heat pump ir-controller, hot water boiler control relay

The identified barriers and respective opportunities:

- It is assumed to be more economically feasible to offer fast responding DSF service with resistive load to e.g., FRC markets than for the local DSF market. If FSP is accepted in yearly FCR markets, there is no possibility of taking part in the local DSF market in the same period with the same DSF resource. However, FSP could take part in the local DSF market together with the hourly FCR markets.
- FSP has some difficulties in obtaining customers' information, e.g., on the electricity supply point, electricity supplier, and BRP. The information is needed for FCR and local DSF markets.
    - Suggested solution when FSP utilises the electricity meter's control relay: FSP would obtain the customer information from Datahub through the customer's authorisation. The Government's bill suggests that a load control interface for electricity meters load control relay, would be built to the Datahub, but the project has not yet started, and the information FSPs could obtain from the Datahub in this context has not been defined.
- ESWHs: FSP doesn't have real-time information about the temperature or electric current/power consumption of the ESWH. The information would help the FSP to estimate the DR capacity of ESWHs and to verify the fulfilled flexibility. A readable signal from ESWH, whether electric current is being consumed, and the hot water temperature information from the ESWH would help here. Possible requirements for the minimum information obtained from the ESWH could be seen as an opportunity.

- Air-to-air heat pumps: It is difficult for FSP to obtain information straight from the air-to-air heat pump, because heat pumps lack an easy standard communication interface for this (e.g., Bluetooth, USB-C). A two-way communication should be easily enabled, and the beneficial data points from the heat pump should be available: e.g., target temperature, fan speed, and the power consumed. The information would help to know if the control commands for the heat pump are functioning, to estimate the demand response capacity, and to verify the fulfilled flexibility.

Communication protocols of air-to-air heat pumps are manufacturer-specific. The harmonisation of the communication protocols would help connect air-to-air heat pumps to the FSP's service.

- Electric radiators: A variety of connectivities exist. Standard connectivity would help to connect radiators to the FSP's service (e.g., Bluetooth, USB-C, or standard Wifi). The information on the power consumed would be beneficial on the same basis as in air-to-air heat pumps.

The development of the Code of Conduct for Energy Smart Appliances (ESA) can be seen as an opportunity here. In the mapping of use cases of the Code of Conduct (version 1.0), the monitoring of power consumption is defined as a mandatory feature for heat pumps, local space heaters, water heaters, and ventilation. The implementation of the capabilities of Energy Smart Appliances can be, e.g., realised physically in the ESA or represented as a digital twin in the manufacturer's cloud[95]. It depends on the flexibility service provider's service, which kind of implementation is the most suitable.

Finnish FSP Cozify was interviewed for additional information on communication and controllability of electric heating and heat pumps. The key takeaways:

- The problem with the lack of two-way communication properties of the devices was also verified by Cozify. E.g., the MODBUS communication module for a single heat pump could cost around 300 EUR. A basic example for the importance of information from the device controlled: if known when the radiator heats up and the heat pump cools the air, the service could, e.g., prevent the heating when the cooling is on. The information also helps to estimate the DR capability of the device at a specific moment.
- Heat pumps have not been designed with demand response in mind, and the requirements for controllability for DSF purposes are a somewhat new issue for the manufacturers.

95. Code of Conduct on energy management related interoperability of Energy Smart Appliances (V.1.0)

- The interviewee has seen some challenges in controlling devices via the manufacturers' cloud services: if, e.g., the user's password expires, the service might not work before the password has been changed.

Finland: DSF possibilities of smart electricity meters load control relays, case Elenia

General description

About Elenia

Elenia is the second largest DSO in Finland with 440,000 customers and 76,600 km of electricity network[96]. The Elenia Group consists of energy sector services provider Elenia Oy and electricity network services provider Elenia Verkko Oyj. The available capacity of the network varies significantly according to the network area. The free capacity of low, medium, and high-voltage networks is found in Elenia's online map service[97].

Today, smart electricity meters' load control relays are used to control electric loads mostly according to the DSOs' night tariffs. The next generation of electricity meters, which are currently being installed by DSOs, are called AMR 2.0 meters (AMR = Automatic Meter Reading). The Government Decree mandates load control functionality as a mandatory feature also in the new 15-minute resolution AMR 2.0 meters for single-family and two-family houses. Electricity meters must be changed to AMR 2.0 meters by 4.7.2031.

The government bill proposes the commercialisation of the load control of DSOs' AMR 2.0 meters for use by FSPs. The regulation would enter into force on 1 September 2026. Residents could authorise FSP to issue load control commands via the load control interface, which would be built to the Datahub. The role of DSOs is seen as an enabler and procurer of local demand side flexibility, not as a main FSP.

Elenia has carried out extensive development work together with Aidon (producer of smart electricity meters) to enable the feasible use of load control relays in AMR

96. https://www.elenia.fi/en/elenia/company/operational-area
97. https://avoin.aws.elenia.fi/kartta/

2.0 meters for demand response. Elenia piloted the DSF possibilities of smart electricity meters in 2018-2020. Elenia today offers free of charge DSF service, where household customers are able to control the loads connected to the AMR 2.0 meter's control relays automatically according to the cheapest day-ahead market prices. In the future, the AMR 2.0 load control relays could also be used for the evolving local DSF markets and for optimising the loads according to the DSOs' power tariffs.

Estimated development in the grid area and grid issues

In the future, the population is estimated to decrease in Elenia's network area, but electricity consumption is estimated to increase significantly, especially due to the electrification of industry and transport. Production is estimated to increase significantly due to the increase in solar and wind power. The number of new electricity storage connections is expected to continue to grow. Increasing consumption and production will require significant investments in the network. The key indicators of the electricity network over the next ten years are shown in Table 23.

Table 24: Key indicators of the electricity network over the next ten years[98]

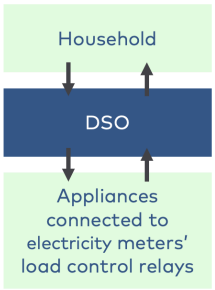
	Current state, 31.12.2023	Forecast, 31.12.2033
Energy transmitted in the network area, MWh		
Energy transmitted to network service customers	5 789 601	7 902 000
Energy received from network service customers	2 928 679	12 170 000
Number of places of use	440 025	450 000
Distributed generation		
1) Nominal power, kW		
1.1) Connected to the high-voltage network	1 246 000	3 986 000
1.2) Connected to the medium-voltage network	150 800	642 000
1.3) Connected to the low-voltage network	16 026	401 000
2) Number of production sites		
2.1) Connected to the high-voltage network	26	75
2.2) Connected to the medium-voltage network	89	526
2.3) Connected to the low-voltage network	16 026	43 053
Number of connections used in public charging of electric vehicles	266	602

Value chain for DSF

A simple physical value chain of utilising Elenia's AMR 2.0 meters' load control relays as they are utilised today is presented below.

98. Elenia's Network Development Plan 2024

Table 25: Physical value chain for DSF in Elenia's control relay service

Stakeholders and systems in use		Function
	*Elenia's system with customer interface*	Household customer chooses the control settings of the relays in the Elenia's web-service: day-night control, setting the relays "on" at the selected time, setting the relays "on" during the cheapest spot prices or turning the control off.
	Elenia's system sends the control calendar to the AMR 2.0 meter's Head End System	Elenia's system sends the control calendar based on the control relay's settings to the AMR 2.0 meter's Head End System (HES) via the mobile network (LTE-M or NB-IoT).
	Primarily ESWHs and electric underfloor heating	The electricity meter's load control relay is swiched on/off by the control calendar sent to the meter's HES. Appliances are connected to AMR 2.0 electricity meter's control relays by professional electrician.

The following example describes a possible general, not DSO-specific value chain in the future, in a case where load control relays of AMR 2.0 meters would be commercialised, the control interface would have been built to Datahub, and the loads connected to the AMR 2.0 meters' load control relays would be aggregated by FSP to the DSOs' marketplace for congestion management. Today, Helen Electricity Network Ltd. is the only DSO in Finland, which is piloting the marketplace for congestion management, but the longer-term target is to develop a common national marketplace by the experiences gained from the pilot (the marketplace pilot is described in Chapter 3.10).

Table 26: Physical value chain for DSF in Elenia's case with commercialised control relays

Step in value chain	Stakeholders and systems in use		Function
3/4	DSO, TSO		DSO (and TSO) estimates the need for congestion management and places requests for quotations on the marketplace. Sets a possible price cap for the flexibility bids.
5/6/7/8	Marketplace and interfaces (DSO/market and FSP/market)	*e.g. NodesMarket and interface tools*	Mediate bids between DSO/TSO and FSP. Facilitates reservation and activation of flexibility, baseline estimation, and validation and settlement of trades. Different products.
6/7/8	FSP		Aggregates and manages flexibility from portfolio. Responsible for all customer contact concerning the offered flexibility service.
6/7	Datahub	*Load control interface*	Conveys the control commands between FSP and DSO. Customer (household) authorizes FSP in the Datahub.
6/7	DSO	*DSO's system connected to Datahub's load control interface, AMR 2.0 meter's Head End System (HES)*	DSO's system conveys the control commands from the Datahub's load control interface to electricity meter via mobile network (LTE, NB-IoT). Also DSO itself would offer control services for exploiting the control relays for e.g. day-night control, but household could always procure the control services from FSP. DSO's role would be to act as an enabler of utilization of load control relays for flexibility markets, not to act as an aggregator.
6/7/8	Appliances connected to AMR 2.0 meters' load control relays	*Primarily ESWHs and electric underfloor heating*	The AMR 2.0 electricity meter's load control relay is swiched on/off by the control calendar sent to the meter. Appliances are connected to control relays by professional electrician.

The flexibility mechanisms and capabilities

Elenia today has the service for utilising the AMR 2.0 control relays in day-ahead markets. The household customer with AMR 2.0 meters' load control relays can choose to use the spot-price control in Elenia's cloud service. The end user is responsible for verifying that there is a controllable load connected to the meters' control relay. The cloud service chooses the next day's cheapest spot prices and sends the control calendar to the ARM 2.0 meter, which activates the control relay(s) and the appliance(s) connected to the relay(s) according to the calendar. The most typical loads connected to the relays are ESWHs and underfloor electric storage heating.

AMR 2.0 meters' load control relays will be commercialised in the near future. The government bill proposes the commercialisation of the load control of DSOs' AMR 2.0 meters for use by FSPs. The regulation would enter into force in September 2026. The load control interface would be built for the Datahub. FSPs would send the control commands (e.g., a control calendar) to the common Datahub's control interface. Each DSO would integrate its electricity metering system into the interface. The control interface would send the control commands onward to the DSO's system, which activates the AMR 2.0 meter's control relay. The end user (household) would authorise the FSP in the data hub for controlling the AMR 2.0 meter's relays.

It is expected that the load control interface will be used first, mostly in the day-ahead market. In the day-ahead market, the required reaction time is easy to fulfil, economic potential is high, most household customers understand the principle, and there are no challenges concerning verification, baseline definitions, or balance management.

In terms of technical reaction time, the local DSF markets have good potential, but economic potential is expected to be somewhat weaker than in the day-ahead market. Using the load control relays in the intraday markets requires faster reaction time, which is still reachable with AMR 2.0 control relays, and the economic potential is good. In the legislation, the load control request's turnaround time is set to a maximum of six hours. However, in most cases, the turnaround time of control commands is practically no more than a few minutes, and at its fastest, only tens of seconds. The control commands will be implemented in the DSOs' systems on a "best effort" basis to reach a faster reaction time than legislation obligates.

The use in reserve markets challenges the reaction time of the AMR 2.0 control system and, therefore, doesn't seem to be feasible in the short term.

The systems in use

Elenia's AMR 2.0 meter's load control system includes the following systems:

- Elenia uses Aidon's AMR 2.0 meters with Aidon's head-end system (HES)
- Elenia's metering data management system (MDM)
- Elenia's smart grid platform with a user interface, including the control of load control relays
- The signals are sent to the AMR 2.0 meter using a mobile network connection (LTE-M or NB-IoT)

Today, only DSOs can send control commands for the AMR meters control relays, but according to the government's bill, control relays will be commercialised in September 2026. The FSPs would be authorised by residents in the Datahub to issue the load control commands. FSPs would send the control commands via the load control interface, which would be built into the Datahub. The control interface conveys the commands to the DSO's system.

DSF potential from loads controlled by AMR 2.0 meters

Technical potential of the AMR 2.0 meters' load control relays – ESWHs and electric underfloor storage heating

In Finland, the new AMR 2.0 meters are obligated to have the control relay when they are installed in detached and semi-detached houses. The rough estimations of DSF potentials connected to the relays are presented below. The loads connected to the control relays consist mainly of ESWHs and underfloor electric storage heating.

The DR potential of ESWHs and electric underfloor storage heating in Elenia's grid

Elenia's 70,000 customers have the time-based tariff (day-night tariff), and the maximum DR potential of the electric load connected to load control relays in the grid area is estimated to be around 125 MW. The controllable capacity connected to the load control relays of the meter is estimated to be 75 MW in summer and 120 MW in winter. The controllable load per customer is estimated to be 3 kW on average[99].

National DR potential of ESWHs and electric underfloor storage heating connected to electricity meters' control relays

The estimated number of detached and semi-detached houses with electric heating in Finland is around 506 000 and terraced houses

99. Vanguard Consulting, 2024.

26,000[100]. Evaluated on this basis, the estimated total power of installed ESWHs in detached and semi-detached houses would be about 1500 MW, if estimated that the average power of the ESWHs would be 3 kW. If assumed that there are on average five apartments in a terraced house, there would be around 400 MW installed ESWH capacity in terraced houses with an assumption of 3 kW average power. However, the ESWHs in terraced houses can seldom be connected to the electricity meter's control relay, because all the meters are usually assembled in the common technical room of the housing cooperative.

Järventausta et. al. (2015) estimated that in total, there would be around 2,900 MW installed total capacity of electric heating, which can be controlled by electricity meters' load control relays. The electric load already connected to the relays was estimated to be 1800 MW. After the study, some of this load may have been disconnected from the meters.

The national flexibility potential of the devices installed in the load control relays today is estimated to vary as a monthly average between 950 MW in March and 540 MW in July[101]. The potential includes the relay controls that are used in DSOs' transmission products with a night tariff. The potential consists mainly of electric storage water heaters (ESWH) and underfloor storage heating in detached and semi-detached houses. Presumably, the potential in July (540 MW) represents ESWH's technical flexibility potential, which could be assumed to be constant in all seasons. With this assumption, the technical DR potential of electric underfloor storage heating connected to the electricity meters would be 950-540 MW=410 MW.

Typically, electric underfloor heating is combined with an air-to-air heat pump and often also with a heat-retaining fireplace. This brings uncertainty to the estimations.

The development of local DSF possibilities

Elenia today offers a free-of-charge DSF service, where homeowners in Elenia's grid with new AMR 2.0 meters can control the loads connected to the relays automatically according to, e.g., time of the day or cheapest day-ahead market prices. In the future, AMR 2.0 meters' load control relays could be used for the local DSF markets as they evolve, and for optimising the loads according to the DSOs' power tariffs. Elenia estimates that the DSF potential of AMR 2.0 meters for congestion management is growing significantly towards the end of the decade[102]
.

100. Statistics Finland.
101. Vanguard Consulting, 2024.
102. Elenia's Network Development Plan.

The industry estimates that the use of load control relays for local DSF will evolve and become more common in 2027-2028.

Coordination with DSO needed

There are many details that need to be agreed upon before the FSPs will be able to launch the services using the AMR 2.0 load control relays. If the meter breaks down, who will ensure that the customer has hot water? If the control command to the meter does not get through, is it the responsibility of the DSO or FSP to send the message again?[103]

Project learnings: Barriers and enablers

Elenia's pilot on electricity meters' DSF possibilities[104] [105]

Elenia piloted the DSF possibilities of new generation electricity meters' load control relays in 2018-2020 together with Vattenfall, Empower, Telia, and Visma Consulting. The loads involved were ESWHs and electric heating in 76 homes in Elenia's grid. The pilot homes were fitted with new electricity meters, enabling load control with a faster reaction time.

Electricity supplier Vattenfall controlled the loads according to the day-ahead market, and FSP (Empower) according to the mFRR, with part of the pilot group. When no more system changes and repairs were made, the throughput rate of control commands was high, 98%. The reaction time with 88% of commands was less than one minute, and of those commands 80% reached under 30 seconds reaction time. At its longest, receiving the message took about 42 minutes from sending the first control command due to poor signal coverage. The maximum controlled average power per customer varied from 2,6 kW in June to 4 kW in winter months (more info in the table below).

The pilot also tested how long the total time is from sending the control signal to receiving the power change message back from the electricity meter. When the first power change message was received successfully, in 90% of the controls power change message was received within 3 minutes after the control command was sent.

Customers responded monthly to a survey about the impact of the test controls on living comfort. Primarily, the test controls did not affect living comfort, and to the extent that they did, most of the perceived effects were positive.

103. Elenia's interview on 26.11.2024
104. The intelligent power grid as an enabler of the virtual power plant platform, Final report. 2020
105. Elenia's and Vattenfall's interviews on 26.11.2024 and 31.12.2024

Table 27: The controlled power in Elenia's pilot

Maximum monthly controlled power and average power per customer[106]

	Maximum total controlled power (kW)	Maximum controlled average power/customer (kW)
June	21	2,6
July	168	3,1
August	203	3,6
September	203	3,8
October	138	4
November	159	3,2
December	204	3,9
January	176	4
February	179	4
March	175	3,9
Maximum	204	4

Barriers and opportunities of DSF connected to the use of load control relays

To identify the barriers and opportunities of the DSF connected to the use of load control relays, representatives of Elenia, Optiwatti, and Vattenfall were interviewed. The recognised barriers and opportunities are presented below.

The barriers

- The reaction time of the service utilising AMR 2.0 meters' control relays today limits the use for TSO's reserve markets. In addition, the measurement resolution of the meter should be more frequent. Elenia's AMR 2.0 meters send metering data in 5-minute resolution for the measurement information system, which combines it to a 15-minute time series. It would be possible to program the meter to send the data, e.g., in 1-minute resolution, but the amount of data increases, and the speed of the transfer needs to be fast enough. Limitations to the reaction time could come from the capability of the mobile network (e.g., NB-IoT). If the data is sent to thousands of customers at the same time, the deviations could increase to some extent.

106. The intelligent power grid as an enabler of the virtual power plant platform, Final report

Elenia's AMR 2.0 meter (Aidon's meter) is capable of controlling loads also according to frequency. This means that the load would regulate up and down according to the frequency when the frequency control is "turned on". The frequency control is "turned on and off" by the control calendar sent to the meters' Head End System. The control calendar sent to the meter could, e.g., turn the frequency control on at 8 am, turn it off at 10 am, turn it on again at 2 pm, and off at 3 pm.

- In the future, it could be possible to use the loads connected to the control relays to the FCR market by sending the meter a frequency control calendar in advance. The calendar would tell the meter to control the loads of the relay, for example, between 12 noon and 8 pm based on the measured frequency. The development referred to above should be done to fulfil verification requirements of the FCR-markets (shorter metering resolution and sending the metering data for Fingrid almost in real time).
- Challenges with poor signal coverage in some areas. The load control function requires a better connection than traditional day-night control. Although the throughput rate of control commands to the ARM 2.0 meter has been high (98-99 %), some connection failures exist due to poor mobile network connection (NB-IoT or LTE-M) to the meter. It is possible to improve the connection with an additional antenna. Poor connection can prevent the use of LTE-M, which would be faster than NB-IoT, which has better signal reception.
- The operation of an electronic thermostat, with e.g. weekly program, may be disrupted if the heating is controlled too frequently by cutting the power directly with the electricity meter's control relay (e.g., the use for FCR-N markets). When the loads are controlled based on the hourly spot price, the control frequency has been estimated to remain at a relatively safe level for the electronic thermostats. The problem with frequent controls could be bypassed by implementing a control from the electricity meter to the thermostat, if the thermostat is compatible with the signal from the meter (usually a potential-free contact). However, physical wiring from the meter to each thermostat is expensive to implement.
- The space heating, which consists of many heating sources, could be challenging in DSF markets, because it is more complicated to estimate how electricity consumption behaves.
- Lack of information: Elenia conducted a survey for 1000 customers who had an AMR 2.0 meter and load control connected to the meter (night-tariff) and had not adopted the spot price control. Many respondents were not aware of the service despite the information sent to customers. 60% of customers

who were not aware of the service responded that they will adopt it.

- The weak knowledge of the household customers: The household customer needs to understand the principle of how the load control works and how he/she benefit from offering the resources for the local DSF. The service based on the local DSF could be more difficult for the customer to understand than the service based on the spot prices.
- Only the customer knows if there is a load connected to the relay suitable for the DSF service. Sending the electrician to ensure the electric connections and the loads/appliances connected to the control relays would be expensive for the FSP. This causes some uncertainty for the FSPs in estimating the DSF potential of their resources. The FSPs have a responsibility to inform the household customers what kind of devices can be controlled by their service.
- Some FSPs don't recognise AMR 2.0 control relays as an interesting way to control the electric loads, which have capabilities to react fast enough for the TSO's reserve markets, if controlled straight by the FSP's own control system.

Opportunities

- A good DR potential with the loads already connected to the control relays. The national DR potential is estimated to be 540 MW in July and 950 MW in March. No need for additional devices/installations. The expectation is that electricity suppliers will widely offer DSF services that utilise AMR 2.0 meters' load control relays when the use is commercialised.
- There is a lot of variation in electrical switchboards and couplings. Still, electricians have been able to install the loads correctly in the load control relay.
- Elenia's AMR 2.0 meters' control relays can offer the reaction time needed for local DSF and, e.g., for intraday markets.
- In Elenia's pilot, the test controls primarily did not affect living comfort (91% of respondents), and to the extent that they did, most of the perceived effects were positive (57%). In general, customer satisfaction with the load control was rated 4,5/5.

Cross-national policy recommendations



Photo: Pexels

According to basic economic theory, politicians and authorities should abstain from direct interventions in well-functioning markets. For a market to be well-functioning, though, a set of basic conditions must be met. Some of these conditions apply to flexibility markets and market-based utilisation of demand-side flexibility in particular:

- Markets may be missing, or market access may be limited
- Product definitions may not be sufficiently standardised
- Technologies/solutions may be immature
- Information may not be adequately available

In addition to such market failures, there may be regulatory failures, i.e., other regulations that effectively constitute barriers. An example of the latter is the economic regulation of DSOs that incentivise grid investments even if the use of flexibility is the more economical solution.

Another important basic economic principle is that, once a market or regulatory failure (barrier) has been properly identified and described, targeted policy measures should be specifically designed to address the nature of that market failure. Should several market failures be identified, each should be targeted individually, and measures should be implemented that ensure that the goal is

reached in a cost-effective way. Administrative costs and transaction costs associated with the measure should be considered, and the measure should only be implemented if the benefits are larger than the costs.

In this chapter, we first summarise and assess the barriers identified in the case studies as a basis for the policy recommendation (4.1). The development of flexibility solutions, both in terms of smart appliances' flexibility potentials, communication protocols, and market and product design, is still ongoing. In Section 4.2, we lay out how this may affect the regulatory approach. Finally, in section 4.3, before we present our recommendations to the Nordic regulators in section 4.4, we provide an overview of existing EU regulation and ongoing policy developments with ramifications for the development of efficient flexibility markets in the Nordic markets.

Assessment and summary of identified barriers

Various barriers can hinder the provision and use of economically profitable demand-side flexibility sources in helping solve grid challenges. The result would be grid customers paying too much for their grid connections and for their use of the grid. It is crucial to remember that the aim is not necessarily to realise the full flexibility potential of all the different flexibility sources, but to exploit the economically profitable flexibility. This implies identifying and removing barriers related to market and regulatory failures along the value chain that hinder the economically efficient provision and/or procurement of DSF services.

The main barriers are summarised in this section. In the majority of the case studies, the actors report that it is difficult to make demand-side flexibility from smart appliances profitable. Aggregators need to make various investments and other efforts to be able to aggregate and offer a portfolio of loads to the marketplace. The payment from the markets is usually not very high. Thus, a main challenge is the lack of profitability due to a combination of barriers that make costs too high and compensation too low.

Barriers related to smart appliances and barriers related to market design are intertwined and should be considered collectively. We see that identified issues can be solved by improving the flexibility abilities of smart appliances or by changing the requirements to participate in the market.

Table 12 gives an overview of the most important barriers we have identified from each of the case studies. We have selected the barriers that are reported from several case studies. The barriers are described in more detail below the table.

Table 28: Overview of main barriers and where they were identified*

	1	2	3	4	5	6	7	8	9	10
Low market liquidity		✓		✓	✓	✓		✓		
Low level of economic compensation	✓		✓	✓				✓		
Value stacking			✓		✓			✓	✓	✓
Differences between local DSF markets			✓		✓		✓			
Rebound effects		✓	✓				✓			
Lack of standardized communication protocols	✓		✓	✓	✓	✓	✓	✓	✓	
Non-smart appliances	✓								✓	
Consumption measurement and verification of activation							✓		✓	✓
Baseline issues			✓	✓	✓			✓	✓	
Incentives in economic regulation			✓	✓	✓	✓				
Reliability and stability in framework conditions					✓	✓				
Information and knowledge	✓			✓	✓	✓				✓

*Numbers in columns refer to: 1. Byggflex, 2. Battflex, 3. Norflex, 4. Sthlmflex, 5. Effekthandel väst, 6. E.ON's flexibility markets, 7. FUSE, 8. EcoGrid, 9. Helen, 10. Elenia.

Low market liquidity in local flexibility markets

Market liquidity was a reported barrier in Sthlmflex, Effekthandel väst, and in the first of E.ON's flexibility markets. Low market liquidity is a problem for the DSO procuring flexibility, as it can lead to high prices and even the absence of bids. This can result in a vicious circle, where the DSO lowers its demand even more because they do not trust that the market can deliver flexibility at the right time and in sufficient volumes. DSOs will then use other measures to fix their grid issues. However, low demand from the DSO can also occur from grid issues being smaller than expected. This happened in Sthlmflex, where mild winters and high power prices led to the forecasted grid issues being smaller than expected.

In some use-cases, e.g., Helen Electricity Network's and Fingrid's marketplace, a bid can only include resources from one BRP, limiting the opportunities to combine different loads. In this way, the market design (bid requirements) can prevent sufficient market liquidity. However, setting requirements like this might also be necessary if the flexibility is needed to solve grid issues in a specific area, e.g., solving a local bottleneck.

Achieving sufficient market liquidity can also be difficult when actors in practice have to choose between participating in the TSO reserve markets or the DSO local flexibility markets (more about this in the section on *Value stacking* below).

No or too low economic compensation for flexible loads

In several of the case studies, the economic compensation for flexibility was considered too low and/or uncertain. In some of the technical demos, no economic compensation was offered for the loads involved (e.g., Byggflex). In other cases, the offered compensation was seen as too small to incentivise participation (e.g., FUSE and EcoGrid). It was also stated that it is difficult for actors who are considering joining the market because they do not have insight into the market dynamics and potential earnings, making it difficult for them to develop business models.

Limited opportunities for value stacking

Profitability of flexibility provision, making flexibility provision more attractive, would be easier to achieve if providers could participate in both the TSO reserve market and the DSO local DSF markets with the same load. This is generally not possible today due to:

- There is no setup ready to coordinate between the markets. Finland is an exception, as participation in the new local DSF market and reserve markets

of the TSO with the same flexible resource is possible. However, even in Finland, the same capacity of a resource cannot be bid to the congestion management market and to the reserve markets (mFRR, aFRR, FCR-N, FCR-D, or FFR) for the same hour. Resources can, e.g., participate in the hourly FCR market at 2-5 PM and the local DSF market at 7-9 PM. In Euroflex, which is the follow-up project of Norflex, a possible solution for this lack of coordination is being developed and tested. The suggested solution is a flexibility register, where all prequalified FSPs and flexibility resources are registered.

- The minimum bid size in reserve markets (FFR) is too large for FSPs of small household appliances. FSPs can participate through a larger aggregator/BRP, but this would require agreements with each owner of the specific loads and the BRP. Requirements on how fast a bid should be activated are also a barrier for smaller loads from smart appliances.
- The trading deadlines between the different markets are not aligned. This is important if bids from the local markets shall be forwarded to a TSO reserve market, or vice versa.

Added value can also be achieved by delivering implicit flexibility, i.e., varying power consumption depending on the spot price. Generally, there is more money to be saved by adjusting your electricity consumption to the spot price rather than participating in flexibility markets. In theory, you can do both, but there are issues related to timing. Spot prices are announced the day ahead, which may result in actors not wanting to make bids in local DSF markets before they know the spot prices of the specific day.

Different requirements and designs of local DSF markets

Aggregators/FSPs that want to participate in different local DSF markets (with different loads) face different rules and market platforms for each market. This constitutes an entry barrier as they must go through integration of communication protocols for each market, while with a common, standard approach, they could have realised economies of scale. This is identified as a barrier in the case study of Effekthandel väst. Another example of such different rules is verification requirements related to the accuracy in electricity consumption measurement, identified in the Helen & Fingrid case study. The Norflex case study identified different financial support schemes in different countries as a barrier, making it more difficult for flexibility service providers to scale their business model.

Rebound effects causing voltage issues

Rebound effects are seen in mechanisms using only price optimisation, where fast upregulation after downregulation can result in voltage issues (this can also occur after implicit load shifting based on spot prices), which must be handled by the DSO. This implies a cost for the DSO. DSOs can give economic incentives to prevent such rebound effects through the grid tariff structure. Capacity-based grid tariffs promote a flatter power consumption curve and may encourage slower upregulation after downregulation. A barrier to enable consumption following both activation/price signals and the grid tariff today is the variation in capacity-based tariff structures among DSOs. Without an easily automatised way to import data on the different tariffs, it will be hard to keep the optimisation algorithms up to date.

Another possible risk is that other appliances are being turned on when the appliance offering flexibility is activated, e.g., floor heating vs heat pump heating. This makes it necessary to activate a larger volume because consumer adjustment counteracts the activation.

Lack of standardised communication protocols

Communication protocols and API solutions are not yet standardised across appliances. This means that FSPs have to integrate each appliance individually into their platforms. How difficult and time-consuming this is depends on the level of complexity in the API, but this setup cost represents an entry barrier. However, many FSPs see their integration solution as part of their business proposition. As an analogy, this can be seen as their "patent", or reward for being innovative. We grant actors patents for their innovations to ensure they have incentives to develop such solutions. According to interviewees, standardisation at this point risks limiting innovation as the markets, integration solutions, and business models are still immature. Following the same analogy, patents are only given for a certain amount of time. Having these entry barriers is not the desired end-situation but may be a necessary step to incentivise the development of innovative solutions necessary to realise the future where flexibility can be cheaply offered from smart appliances with easy "plug-n-play" features.

This is not to say that there are no issues today regarding the lack of harmonisation of manufacturers' API interfaces for load control and minimum requirements for control and monitoring capabilities. As stated above, developing solutions enabling demand-side flexibility can be time-consuming for the FSPs. Building managers with lacking knowledge and/or competence may also find it hard to operate and optimise intricate and/or multiple control system installations and interfaces.

Heterogeneity of communication systems in different loads is also a barrier if loads have to be aggregated, e.g., to fulfil minimum bid sizes in the reserve markets.

In FUSE, challenges were identified related to ensuring real-time interoperability between chargers, aggregators, and grid operators due to a lack of standardised communication protocols. Variations in data formatting across different platforms made integration more complex, suggesting a need for standardisation. If interoperability between chargers (EV users), aggregators, and grid operators is not ensured, then the message might not be interpreted correctly (e.g., kWh could be read as Wh).

Some appliances, e.g., electric radiators, are connected to the FSP service with a variety of connectivities and protocols (Bluetooth, USB-C, Wifi). This is seen as a barrier because it makes it more complicated for the FSP to connect radiators to their service.

Non-smart appliances

Older appliances have a limited ability to integrate and communicate with top control systems due to proprietary protocols and/or missing load control units. Requirements for individual measurement per unit lead to a high participation cost per unit for loads without measurement hardware. In Norway, there are no requirements to install load controls on appliances in new buildings. The Helen and Fingrid case study found that internet connectivity is often an additional module for cheaper heat pumps, even if they are brand new. Installing communication modules later is possible, but likely to be significantly more expensive.

Lacking harmonisation of electricity consumption measurement and verification accuracy

The accuracy of electricity consumption measurement varies, and this is a barrier to verification. There is no harmonised method to measure consumption nor harmonised requirements for minimum accuracy.

Sub-metering at the specific appliance provides more accurate verification than aggregated household consumption data (via the smart meter), but the costs for high-resolution metering are higher. Sub-metering can be more beneficial for loads like space heating, consisting of several heating sources, as it is then more complicated to estimate how electricity consumption behaves.

As explained above, the smart meter (AMS) reaction time is too slow for loads to participate in TSO markets (this is even true in Finland, with a 5-minute resolution of AMS). Many meters can be programmed to send data with a higher resolution, but the amount of data could then lead to limitations in reaction time due to the capacity of the mobile network.

Lack of information about resources and their current electricity consumption makes it hard to know which resources are actually available for activation (consumption increase or decrease). In the Elenia case study, it was stated that only the customer knows if a load is connected to the relay suitable for the DSF service, causing uncertainty for the FSPs in estimating the DSF potential of their resources. In the Helen Electricity Network's case study, the FSP had difficulties obtaining customer information (electricity supply point, electricity supplier, BRP). Such information could be obtained from a data hub through customers' authorisation. FSPs neither have real-time information about the ESWHs' temperature nor their electricity consumption, which they need to estimate DR capacity and verify fulfilled flexibility. The same problems were present for air-to-air heat pumps, as they lack a two-way communication interface. The Modbus communication module, enabling two-way communication, can cost up to 300 EUR for one heat pump. Communication protocols in air-to-air heat pumps are manufacturer-specific, and harmonisation of these would help. The same problem applies to electric radiators.

Baselining issues

Five of the case studies reported baseline issues as a barrier. One example is Norflex, where there were significant deviations between estimated and actual consumption. The deviations were primarily due to two issues: i) consumption data was collected from the main metering device, rather than from dedicated submeters, and ii) the behaviour of the tested loads was hard to predict. However, several of the other case studies have tested possible solutions to the issue of unpredictable behaviour. In the Ecogrid case, machine learning based forecasting was used to predict power consumption more accurately based on parameters like historical consumption data, weather conditions, and time-of-day factors.

Counteracting incentives in the economic regulation of DSOs

In Norway, the economic regulation of the DSOs favours solutions involving (grid) investments relative to operational expenses. Similar issues are reported from Sweden, where interviewees hold that the economic regulation of DSOs makes investments in physical grids more economically appealing than investing in flexibility measures. This perception prevails, although the Swedish Electricity Act states that flexibility measures should be reflected in determining DSOs' revenue cap. Another issue in Sweden is that the DSOs subscribe to a specific grid capacity from the TSO. If they need to temporarily exceed this capacity, they can apply for a temporary increase in the subscribed capacity. The price of this temporary subscription is generally lower than the cost of using local DSF to stay within their normal capacity limit. Generally, the regulation should incentivise DSOs to choose the cheapest way to solve grid issues, taking into account the total socio-economic costs.

Uncertainty about future market conditions and reliability

Actors need to know that they invest according to a market design that is going to last, and that the procurer (TSO/DSO) will use the market actively to solve grid issues, in order to trust that their investment will be profitable. The demand response network code says that member states are to assign the responsibility of setting up and organising local DSF markets, but this is not expected to be implemented until 2027 at the earliest. The pending decision may delay the establishment of local flexibility markets, which in turn can delay the development of solutions by FSPs and the procurement and use of smart appliances by customers.

A local DSF market with low liquidity might not be adequate for the DSOs, as they need to be certain that a sufficient power and energy volume will be available to solve their grid issues. It is therefore important to put enough emphasis on building the market in the beginning, to avoid low liquidity being an issue for a long time. Information to owners of suitable loads is an important part of this.

In some cases, the DSO does not yet trust local DSF markets to solve their grid issues and therefore uses bilateral contracts. EU directives state that market solutions should be chosen before, e.g., conditional contracts, but this is not always implemented in national legislation.

Lacking information and knowledge

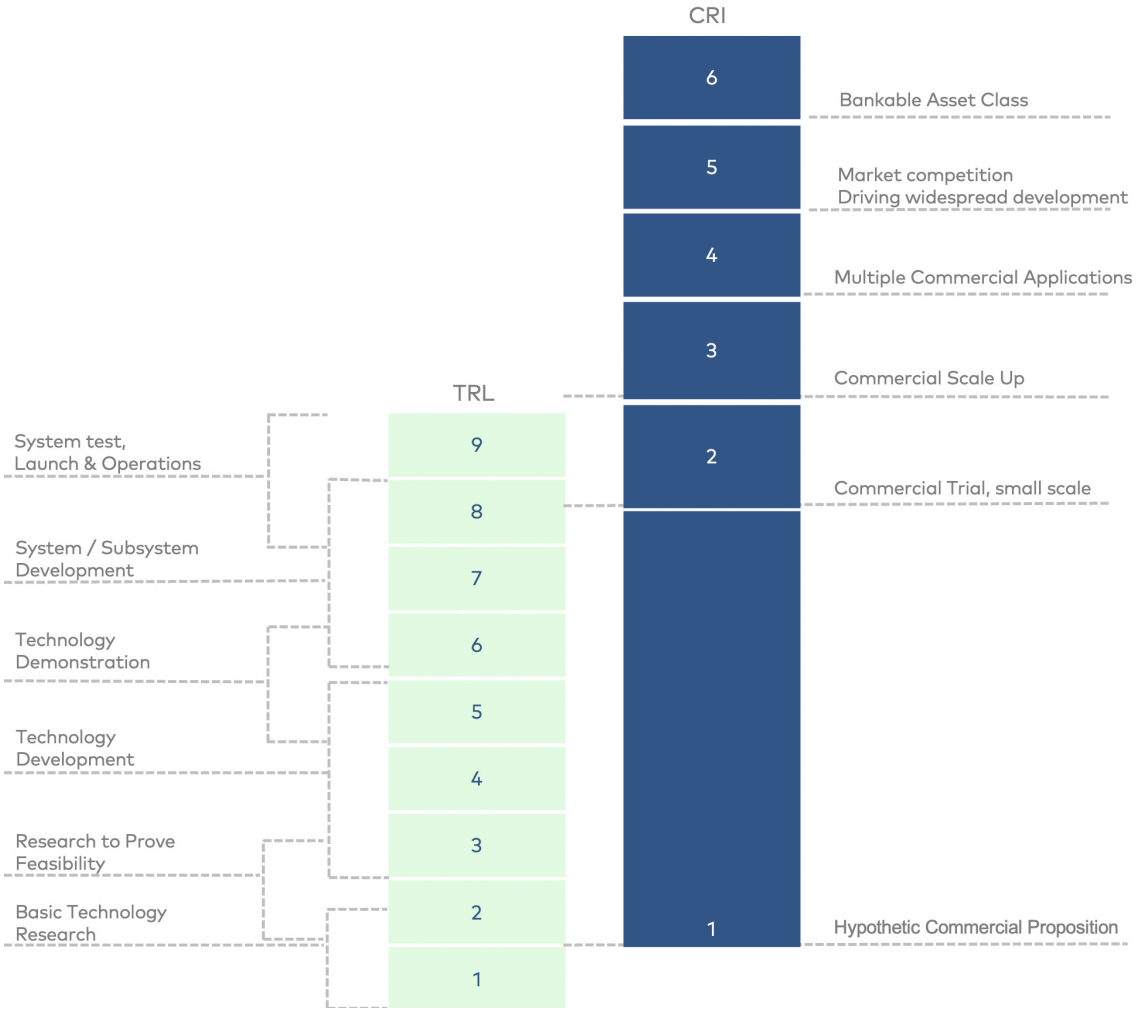
Owners of loads, e.g., the supermarkets in Effekthandel väst, are often unaware of their own ability to participate in local DSF markets. Lack of technical competence might also be a barrier, e.g., owners of smart appliances who need help to connect their devices to the internet. Both the lack of information that they can profit from their smart appliances and how to do it are seen as barriers to achieving sufficient liquidity in local DSF markets.

Level of maturity affects the choice of policy measures

The choice of policy measures or market intervention should be adjusted according to the technological and commercial maturity of the technology/solution at hand.

Policy measures should be based on the level of maturity, technologically and commercially. Technology development is measured by the Technology Readiness Level (TRL), while market change is measured by the Commercial Readiness Index (CRI). The connection between the TRL and CRI is shown in the figure below.

Figure 3: Technology Readiness Level and Commercial Readiness Index



Source: Commonwealth of Australia/ARENA (2014): Commercial Readiness Index for Renewable Energy Sectors[107]

107. The illustration is developed by ARENA (2014): https://arena.gov.au/assets/2014/02/Commercial-Readiness-Index.pdf

A range of indicators should be analysed when assessing the step on the commercial readiness index. These indicators include regulatory environment, stakeholder acceptance, technical performance, financial proposition (costs and revenue), industry supply chain and skills, market opportunities, and company maturity. In step 3, public support is given to technology development, while in step 4, the goal of the public support is to increase demand.

Our maturity assessment is based on information on flexibility use described in chapter two, and the 10 use-cases. We see some variation in maturity across the different countries. Even though the technology level should not differ between countries, different framework conditions can lead to different stages in commercial readiness. For instance, there are only permanent DSF solutions in Sweden. Even though we view the permanent solutions in Sweden as more mature, they have not reached CRI level 6.

We assess the commercial readiness of local DSF markets to be between stages 3 and 4. Although we see some permanent markets, most initiatives are still either technology demonstrations or pilots.

Existing relevant policy and industry standards

The extent to which end-user appliances can provide flexibility and the costs related to such supply are affected by technological developments, product design, and a host of EU regulations, initiatives, and industry standards. The incentives to provide such flexibility, on the other hand, depend on the demand for flexibility services and the value of flexibility that can be realised in the market. Hence, the regulation of grid companies and network codes affects the TSO and DSOs' incentives to use demand-side flexibility, and the requirements in the revised renewables directive (RED III) and even the electricity market directive may facilitate or work as barriers for the exploitation of DSF. To provide recommendations for the improvement of policies to promote DSF, it is important to understand and assess relevant framework conditions that already are or are expected to be implemented. In this section, we describe and discuss relevant elements of Ecodesign and Energy Labelling regulations, the Code of Conduct, the Network code on Demand Response, the Revised Renewables Directive (RED III), and the Electricity Market Directive.

Ecodesign for Sustainable Products Regulation and Energy Labelling

The Ecodesign for Sustainable Products Regulation (ESPR) entered into force in 2024[108]. The ESPR sets minimum requirements by defining limits or standards for energy efficiency for energy-using and energy-related products sold in the EU market[109]. The ESPR and the current product regulations under the Ecodesign Directive cover any final use commodities that use energy, such as household appliances and information technologies. The ESPR applies to most of the appliances that may potentially supply DSF, including refrigerators and freezers; heating, cooling, and ventilation appliances; light sources; and B2B products. It does not apply to EV chargers yet, but a preparatory study is being conducted with planned adoption in 2027. Currently, the ESPR does not set any requirements for the ability for smart operation of the appliances.

While the ESPR sets minimum energy efficiency and sustainability standards, the Energy Label informs consumers about products' energy performance and other environmental characteristics. The standards and requirements are set individually for each product. Requirements include information about the appliance's energy use, its energy efficiency relative to a product-specific energy efficiency index (EEI), in addition to other information relevant to its energy use and environmental footprint throughout the product's life cycle. The appliances' ability for smart operation is not included in the sustainability criteria. While the ESPR sets the minimum requirements, the Energy Labelling requirements range the allowed product characteristics.

Increasing the energy efficiency of an electrical appliance that may provide DSF is likely to affect the flexibility *potential* of the appliance. If the appliance needs less energy or capacity, it can also deliver less down- or upregulation (peak shaving). Better insulation that reduces losses may, however, make the appliance more flexible in terms of load shifting. In some cases, EE regulations may also reduce the appliance's *ability* to provide demand flexibility. For example, the Ecodesign regulation for water heaters sets maximum storage volumes for *electrical* storage water heaters (ESWHs) and limits to heat loss in storage, implying a stronger preference for directly gas-heated water heaters. In some countries, such as

108. Replacing the Ecodesign Directive 2009/125.
109. "The ESPR aims to significantly improve the sustainability of products placed on the EU market by improving their circularity, energy performance, recyclability and durability» (https://commission.europa.eu/energy-climate-change-environment/standards-tools-and-labels/products-labelling-rules-and-requirements/ecodesign-sustainable-products-regulation_en).

Finland, France, and Norway, however, where electricity generation is mainly based on hydro and nuclear power, households have traditionally installed relatively large ESWHs, rather than heating directly by natural gas. In these countries, ESWHs represent an important DSF potential that may be reduced by Ecodesign regulation. From an energy system perspective, the flexibility value of ESWHs should be included in the impact assessment of stricter energy efficiency requirements, limiting the storage volumes of ESWHs.

Code of Conduct

The Code of Conduct (CoC) for smart appliances was launched in April 2024 (EC, 2024). The CoC initiative develops an industry standard on "energy management related operability of Energy Smart Appliances". Work on the development of the CoC was initiated and is led by the EU (DG Energy and the Joint Research Center, JRC) based on a preparatory study, see text box 2. The CoC defines common standards for the smartness of energy appliances, with an aim to increase the number of interoperable energy smart appliances (ESAs). This means that appliances capable of flexible operation are to be designed with functionality capable of reacting automatically to machine-to-machine communication, enabling them to respond to external signals subject to user permission. The CoC includes electrical appliances that are subject to Energy Label requirements (see the previous section).

Moreover, the CoC specifies a number of use cases in terms of abilities and flexibility characteristics that the appliances should be able to provide:

- Flexible start
- Monitoring of power consumption
- Limitation of power consumption
- Incentive-table-based power consumption management
- Manual operation (providing users with the necessary information in case of user-driven manual operation)

The list of use cases is expected to be developed further. The second phase of the CoC was kicked off by a workshop in September 2024. Two of the agenda items were a discussion of the expansion of the CoC to cover energy management systems, photovoltaic inverters, and electric vehicle chargers, and to update the first version of the CoC to include new solutions and protocols.

Use-cases may be mandatory or optional, and this differs between different categories of ESAs (EU, 2022). For heat pumps, for example, monitoring of power

consumption is mandatory, while for heating, cooling, and ventilation appliances, monitoring of power consumption and limitation of power consumption are mandatory. The monitoring of power consumption use-case implies that information from the ESA is applied in an overall energy management concept.

Importantly, the CoC defines a common language for technical specifications (features, functions, devices, etc.) of ESAs, the Smart Application Reference ontology (SAREF). This is a necessary step towards a future in which appliances can be made plug-and-play, reducing the need for additional APIs to integrate appliances in smart management systems and enabling communication across relevant protocols.

The CoC also sets Active Power Limits for the maximum active (real) power consumption of an ESA. As with the Ecodesign requirements, this may limit the flexibility potential of the load, but is justifiable if the value of the energy saving is higher than the value of the (lost) flexibility potential.

According to press releases from some of the industry parties in the CoC, manufacturers who have signed the code are to prepare the performance of their products accordingly within a year, i.e., by April 2025. Thereafter, the CoC is to be reviewed once a year. Currently, 11 manufacturers have signed the CoC, including Miele, Mitsubishi, Panasonic, and Electrolux (EC, 2024).

According to the initiative's web page[110], while stricter regulation seems premature (at this stage, see text box), rapid technological developments could also lead to the consolidation of different product ecosystems, which will use proprietary solutions and will inherently be incompatible (i.e., not interoperable) with each other. Therefore, it was pointed out that there is a case for action to be taken by the European Commission "for securing coherent development on the market, adherence of industry to open standards, and promotion of Smart Appliances REFerence (SAREF) as a general ontology (language) underpinning product interoperability".

Prior to reaching the ultimate goal of the CoC, which is "regulation ensuring interoperability across the board", "technological readiness for manufacturing energy-smart appliances", and "natural market convergence towards interoperable products" must be promoted and achieved. While the first stage points to the development of mature technologies, the second stage points to the commercial readiness of the solutions (cf. Section 4.3).

110. https://ses.jrc.ec.europa.eu/development-of-policy-proposals-for-energy-smart-appliances

Network Code on Demand Response

The Network Code on Demand Response (NC DR) includes provisions related to the grid companies' use of and facilitation of DSF, in particular the facilitation of DSF supply from smaller customers, "... including load, energy storage and distributed generation, individually or aggregated, ..." through market-based procurement of flexibility services by DSOs and TSOs. The revised draft has been subject to public consultation, and ACER submitted its proposal to the Commission in March 2025.

The regulation focuses on[111]

- effective participation of small system users in all markets, by setting clearer requirements for the implementation of aggregation models and establishing a European registry for baselining methodologies,
- easier access to balancing and local markets, by rules for product verification and by simpler and shorter prequalification, and by establishing a flexibility information system,
- a transparent process to ensure the establishment of local markets, by making market-based procurement the default and requiring justification of deviations, and setting clearer requirements for the interaction between markets, and
- ensuring overall efficient operation, through TSO-DSO and DSO-DSO coordination.

Provisions relevant for the use of DSF include, *inter alia*:

- **Baselining.** The national system operators are to define, calculate, and validate terms and conditions for baselining methods according to a process commonly proposed by all TSOs, according to minimum requirements. ENTSO-E and EU DSO are to publish and update annually a baselining method register.
- **Aggregation models.** According to the Electricity regulation, all market participants are responsible for their own imbalances, either directly, as BRPs, or by contractually delegating their responsibility to another BRP. The regulation sets clear rules for the correct allocation of balance responsibility.
- **Lower minimum bid sizes and bid granularity of balancing products.** To facilitate the participation of smaller resources in balancing services,

111. According to ACERs presentation of the draft NC DR on October 1st, 2024: ACER webinar: draft network code on demand response | www.acer.europa.eu

including by means of aggregation, the minimum bid size, defined in the TCMs of the NC DR, is set at 1 MW for standard energy and capacity products for balancing, frequency restoration, and replacement reserves (as defined by other EU regulations, including Regulation (EU) 2017/2195).

- **Product prequalification.** To lower entry barriers, while ensuing system security and safe grid operation, the regulation establishes EU-wide methodologies for the technical requirements for service providing units (SPUs) or service providing groups (SPGs) providing balancing or local services. The specific product attributes shall be defined in a table of equivalence, determining, among other things, availability window, preparation period, ramping period, validity period, mode of activation, and location. A proposal shall be developed by each member state.
- **Obligations of market-based procurement of local services.** All service procurements should be made in a process where either the selection or activation of the service provider is based on a bidding process.
- **Criteria for application of flexible connection.** Any activation of flexible connection agreements shall not lead to market distortions, for example, through agreements that limit the system users' (with such an agreement) provision of balancing and local services in the relevant markets.
- **Ownership of energy storage facilities by system operators.** As all energy storage services shall be market-based and competitive, the NC DR sets out under which criteria system operators may own, develop, or operate such a facility.
- **Requirements for Distribution Network Development Plans (DNDP).** In pursuit of art. 32(3) of Directive (EU) 2019/944, DSOs shall publish transparent DNDPs at least every two years. The NC DR sets out the content and requirements of the plans. The plans should, *inter alia*, include an overview of local services and local energy strategies.
- **TSO-DSO and DSO-DSO coordination**. Member states shall develop a proposal for national terms and conditions for TSO-DSO and DSO-DSO coordination. These shall ensure that, e.g., actions to solve balancing, congestion, or voltage issues are coordinated.
- **Reporting and monitoring.** At least every two years, ENTSO-E and the EU DSO entity are to publish a report on demand response.

According to the draft, the grid companies will be obliged to regularly consider whether system services can be procured more efficiently through market mechanisms, and to implement such mechanisms if they are deemed more efficient.

The Commission will review the ACER proposal and initiate a process to get the Demand Response (DR) Regulation established and the three related regulations amended. Once adopted by member states, the policies will become legally binding across the EU.

RED III art. 20(a)

The objective of the Renewable Energy Directive is to facilitate efficient integration of increased shares of renewable electricity in the power system. Access to flexibility sources is seen as crucial to achieving this.

Significantly, Article 20a of the revised Renewable Energy Directive (RED III) is about measures to facilitate system integration of renewable electricity, and hence, about ensuring efficient development, procurement, and use of flexibility sources. Its five paragraphs cover:

1. Customers' access to information
2. Interoperability and harmonised approach for access to the data from paragraph 1
3. Access to basic battery information
4. Smart and bi-directional charging
5. Non-discriminatory access for small and mobile storage assets to electricity markets, including capacity markets and local flexibility markets

Article 20a is an amendment to the previous version of the Renewable Energy Directive. Member states are to implement their provisions by 21 May 2025. The Commission has published a guidance document (C(2024) 5041 final) to help member states in the implementation of Article 20a. This document explains and details the paragraphs, including their interlinkages and overlaps with other EU legislation.

The provisions imply requirements regarding *data and market access* for different actors:

- *TSOs and (if possible) DSOs* to increase transparency of and access to relevant data to electricity market players, aggregators, consumers, and end-users, including EV users. Specifically, information about RES share and GHG emissions is to be made available in real-time and with a maximum granularity of one hour in each bidding zone.
- In addition, DSOs are to provide anonymised and aggregated data on the demand response potential and injected generation from self-consumers and renewable energy communities.
- *Battery and EV manufacturers* must enable access to information on battery

owners and users, including access to such data for third parties acting on their behalf.

- Member states are to
    - ensure that DSOs are fully informed about flexible load assets in their systems, e.g., through a permitting or notification procedure if necessary,
    - ensure smart recharging, and, where appropriate, interface with smart metering systems, if deployed by MS, and bidirectional recharging functionalities for non-publicly accessible normal power recharging points, and
    - non-discriminatory access for small and mobile storage assets to the balancing and flexibility services markets.

Appliances explicitly mentioned in Article 20a are PVs, Heat pumps, EV charging, small storage assets, and Building management systems, but the provisions cover most relevant appliances as they are not technology specific.

Regarding interoperability, the guidance advises Member states to use specific existing, commonly agreed data exchange formats and standards for standardised data exchange between system operators. Advice is also offered on how member states can achieve the required interoperability and a harmonised approach for access to data.

The Electricity market directive and the Electricity market regulation

The Electricity market directive and Electricity market regulation, whose general objective is to ensure a well-functioning electricity market, also contain provisions relevant to the utilisation of demand-side flexibility. Significantly, the Regulation sets out that DSOs should be incentivised to procure flexibility services and gives the EU DSO entity the task of "facilitating demand side flexibility and response, and distribution grid users' access to markets". Article 3 sets basic rules on non-discriminatory access to flexibility markets, Article 13 is about possibilities for (independent) aggregation, and Articles 15-17 are about the role of active customers (that own an energy storage facility) participating in the market.

The Regulation says that consumers should have the possibility of participating in all forms of demand response and sets out incentives for the use of flexibility in the distribution networks (Article 32) and the integration of electromobility into the electricity network (Article 33). The provisions imply that DSO regulations that

incentivise the DSOs to procure flexibility services should be put in place, and that procurement should be market-based, transparent, and non-discriminatory. Similarly, EV charging points should be regulated with a view to facilitating connection to the distribution networks. DSOs are not allowed to own, develop, manage, or operate charging points (unless they are strictly for their own use).

Assessment and implications for the Nordic regulators

The EU regulations and processes approach the challenge of unleashing demand-side flexibility from several angles – from the market angle by facilitating market access (and reducing transaction costs) for flexibility providers and strengthening the incentives (or requirements) on TSOs and DSOs demand for DSF, and from the flexibility product design angle by developing technical requirements or industry standards on potentially smart appliances. These provisions and processes should indeed create stronger incentives for the use of flexibility and the development of innovative solutions, improved information, and lower transaction costs that are undoubtedly important enablers for the development of liquid flexibility markets.

However, the necessary comprehensive set of EU rules and regulations for efficient utilisation of DSF in the IEM is (still) on the drawing board. When it comes to EU policy development, it is quite common that early provisions are quite general and subsequently tightened and followed up by more detailed provisions over time, as experience is gained and technologies, solutions, and methodologies are developed. It is also quite common that some regulations and rules apply at the EU level, while others still give the member states significant freedom when it comes to implementation nationally. Notably, the NC DR contains several national TCMs applying to, e.g., baselining methodologies and rules for TSO-DSO and DSO-DSO coordination. Sometimes, such national leeway is provided due to system differences that imply that uniform rules across the EU are not deemed efficient, and sometimes, in cases where new solutions are developed, one wants to stimulate continued innovation until the solutions are sufficiently mature to tighten the regulation and decide on uniform rules and standards. Such an approach is also in accordance with the development of regulation in contango with the CRI level described in section 4.3.

As noted on the website of the CoC initiative, "policy support for a wide-scale deployment of Energy Smart Appliances is a complex matter". One of the difficulties is the baselining issue that has haunted the flexibility discussion for years. Unable to find the perfect, or generally well-working, solution, the NC DR still leaves the question to national authorities, while requiring that the chosen solutions be reported to a common directory. Presumably, this directory will serve

as a basis for future assessments of the various models and, hopefully, for further common rules and regulations based on the best practices that emerge. A timeline for such developments has, however, to our knowledge, not been set.

Apart from an understandable impatience with a seemingly slow-working EU rule-making process, there is little evidence that the EU regulations directly hamper the development of flexibility markets for member states that wish to go further in their efforts. Based on the comparably advanced experience from numerous pilots and demos, the regulations leave room for the Nordic countries to continue to be front-runners in the development and utilisation of DSF in both market and system operation.

On the supply side, the development of regulations to ensure the smartness and interoperability of appliances is, however, less advanced. The lack of such industry standards and regulations does come with the risk of hampering the advancement of flexibility solutions and provision in the Nordic market, thus indirectly also hampering the DSOs' demand for DSF and the development of liquid flexibility markets.

The process towards future common "plug and play" standards and requirements for appliances is left open-ended, which is unfortunate. The EU's justification for *not* setting common standards for appliances is explicitly that setting common standards at an early development stage risks being counterproductive when it comes to developing optimal requirements for the smartness of electric appliances (cf. the CRI approach described in section 4.3). The CoC process and the application of its results in EU regulation are an important step towards ensuring "interoperability across the board", and its progress is vital. The CoC process should result in technical and commercial maturity of flexible and smart appliances and provide a basis for standardisation of product requirements and inclusion of corresponding minimum requirements integrated into the ESPR sustainability regulation, according to specified criteria and depending on available technology. However, to our knowledge, there is no set timeline for the CoC process, nor is there any plan for the inclusion of its findings in EU regulations. In addition, participation in the CoC process is voluntary for industry actors. In order to step up and speed up the process to remove this crucial barrier, it is necessary to develop a road map with an action plan, stricter timeline, and clearer milestones for the advancement of these crucial elements for the development of the supply side, i.e., standards for the flexibility of appliances and their interoperability. In this respect, the vital steps are to determine the flexibility criteria and set appropriate minimum requirements for the relevant appliances.

Policy Recommendations

The objective of this report is to inform regulatory approaches that can facilitate and promote the adoption of beneficial demand-side flexibility solutions in the Nordic power system. Increasing the provision of flexibility by engaging and enabling demand side flexibility requires investments by providers as well as users and includes the provision of explicit as well as implicit flexibility. Such investments will only happen if there is a positive "business case" for flexibility provision.

The profitability of investing in flexible solutions can be enhanced by reducing costs and increasing revenues. Regulations can promote cost reductions and increased revenues. On the cost side, making appliances smart and accessible via automatic signals is necessary to make it technically feasible, easier, and cheaper to react to market signals. Reducing the costs of flexibility provision should also, *ceteris paribus*, cater for increased interest and demand for DSF from TSOs and DSOs. Regulatory measures could also promote more efficient use and increased revenues from flexibility provision by strengthening the grid companies' incentives to use flexibility in grid operation and planning. This includes expanding the opportunities to supply flexibility across platforms and uses, i.e., removing unnecessary barriers to value stacking, taking into account that explicit TSO and DSO flexibility markets will not be the only revenue stream for flexibility providers. Other revenue sources include adapting to spot prices and grid tariffs.

Combining the insights from the 10 case studies with knowledge of how Nordic DSOs and TSOs are using demand side flexibility today, we discuss possible policy measures to address the barriers summarised in Table 27. We have organised the policy discussion on the basis of six overarching *messages* that may guide the Nordic regulators' further work on framework conditions in this field.

Six messages guiding the future regulation of DSF in the Nordics

The case studies reveal an array of both specific barriers and enablers for flexibility provision, thus providing an up-to-date knowledge basis for the continuation of regulatory efforts to enhance the provision and use of DSF in the Nordic markets. However, the mapping of pilots and initiatives shows that the knowledge base is fragmented, and a host of issues still need to be resolved. Our general assessment is that it is premature to recommend a specific set of measures that could be readily implemented. We do, however, think that the insights from the studies provide valuable guidance on the way ahead for the Nordic regulators.

The detailed case studies focus on the provision of DSF in explicit market contexts or pilots that are limited in scope, space, and time. Recommendations on policy frameworks need to take into account the larger picture, including market signals and grid tariffs incentivising the provision of implicit flexibility and the multiple uses of explicit and implicit flexibility. Notably, the lack of standardised requirements for flexibility and interoperability of smart appliances acts as a barrier for the provision and use of both explicit and implicit flexibility. Similarly, the possibility to earn revenues from the provision of flexibility depends on access to all procurement platforms where the flexibility bears value for the system (where the opportunity cost is – or may be – higher). Limiting access to products, platforms, and markets reduces the potential revenues for providers and increases the cost of using flexibility for DSOs and TSOs. Notably, such limitations also increase the uncertainty of investing in flexibility for both suppliers and grid companies.

In section 4.3.6, we provide recommendations that mainly regard the establishment of standards and requirements for the smartness and interoperability of appliances in the EU. Such standards and requirements should indeed be developed on an EU level, both because the appliances are traded in a European market and because the standards and requirements are integrated in other EU regulations that apply to the Nordic markets as well. Hence, we recommend that the Nordic regulators take initiatives to speed up the processes by developing a road map and work plan for the inclusion of such standards in EU regulation.

A similar comprehensive road map and work plan, covering the development of other elements that are necessary to advance the use and provision of flexibility, should be developed for the continued efforts to develop flexibility solutions for the Nordic market. Below, we present our recommendations for what such a road map should focus on and for the principles or factors that should guide the development of such a plan.

Message 1 – Using demand-side flexibility to solve grid issues represents a fundamental change in how DSOs operate their grids, increasing the importance of technology-neutral economic regulation of DSOs

Well-functioning markets where DSF can participate and be adequately remunerated require that the demand is there. Explicit demand for DSF depends on the demand for the relevant flexibility services from DSOs and TSOs. This demand depends heavily on the incentives embedded in the economic regulation of grid companies.

DSOs are responsible for providing grid capacity to all customers with satisfactory quality of supply according to current regulations. This objective may be achieved

through grid investments and operational measures. Until recently, access to adequate operational measures has been limited for DSOs. Technology development has changed this for the better. At the same time, operating the grid has become more complex. Along with the energy transition, we have seen an extraordinary increase in demand for grid capacity in addition to an ever-growing proportion of power production that is not continuously available. Transitioning from reliance on grid investments alone to also trusting market measures to deliver the necessary flexibility at the right time and place requires the right incentives for DSOs to adopt new solutions and change their "culture". This requires adaptation in the economic regulation of DSOs that was developed according to traditional grid operation.

The authorities should adapt the economic regulation of DSOs to make it technology-neutral in terms of how they choose to comply with their responsibilities, cf. the approach of E.ON Energidistribution. Changing the economic regulation of DSOs is a complex matter that needs to be well thought through to achieve the desired effects, and the details need to be analysed beyond the scope of this project.

This first message addresses one of the barriers described in Chapter 4.1., "*Counteractive incentives in the economic regulation of DSOs.* In both Norway and Sweden, we have identified through the case studies that the economic regulation of DSOs makes investments in physical grids more economically appealing than investing in flexibility measures. Making sure that the economic regulation is technology-neutral will remove such counteractive incentives, which may prevent DSOs from choosing the overall most economically efficient solutions when providing grid capacity.

Message 2 – When establishing a local DSF market, the DSO should commit to and invest in it, building market liquidity for the longer term

A barrier that is recurrently reported from the case studies is the lack of market liquidity, in particular in terms of the supply of flexibility sources. Linked to this challenge is low or lacking economic compensation, uncertainty of its future value, and a lack of information and knowledge among potential flexibility providers.

From the DSOs' standpoint, they need to trust that sufficient demand-side flexibility capacity can be delivered at the right time and place. However, demand-side flexibility providers will only deliver what the DSOs need if the investment and/or effort is worthwhile, i.e., expected to pay off. This chicken-and-egg dilemma needs to be resolved.

From the mapping of flexibility initiatives and case studies conducted in this project, we observe that most of the pilots are limited in both scope and time, and as such, likely to yield limited information about the full potential of DSF provision in a future, mature market. In general, the pilots test solutions, but to reveal the full scope of the demand and potential for provisions needs to be seen in a wider context and over a longer time period where both the demand and the supply side have time to mature. To bring about such necessary changes, regulatory action is likely to be necessary.

The only Nordic country with semi-permanent local DSF-markets is Sweden, where E.ON Energidistribution has established DSF markets in nine grid areas. This case study clearly shows what they do differently to make it work: After having established through thorough analyses for each grid area that a DSF market is the better solution, they invest in the market by ensuring that it will be operational for a set number of years and guarantee the providers a minimum reservation (availability) fee.

Correspondingly, regulators can enhance such behaviour by requiring that the DSOs integrate analyses of the long-term potentials and benefits of exploiting DSF in their long-term grid planning, and that, if the analyses show that the use of DSF is a promising avenue to take – in combination with other measures – that the DSOs take steps to develop the supply of flexibility in their grid area. Moreover, the regulator should provide guidance on how the DSOs can take action to reduce the uncertainty for potential providers in order to enhance market liquidity (provision). Building on the experience from the E.ON markets, reducing uncertainty by guaranteeing minimum compensation for a set time period and informing on how and when they are planning to use the market the most, based on which grid issues the market will be used to fix, and educating and informing their grid customers, are steps likely to increase flexibility provision.

Making the general DSO regulation technology-neutral in the choice between grid investments and operational measures (cf. message 1) would reinforce the attractiveness of increased use of DSF for DSOs and should thus increase the explicit demand for local DSF further.

Establishing a local flexibility market is, however, not always the right procurement method for DSOs who want to use demand side flexibility to solve grid issues. We discuss this in message 6.

This second message addresses four of the identified barriers. When grid companies ensure that the flexibility market will be operational for a set number of years and guarantee the providers a minimum reservation (availability) fee, this will both help increase the market liquidity and address issues of no or too low

economic compensation. It will furthermore reduce the uncertainty about future market conditions and reliability. Finally, an important finding from the use cases is that many potential flexibility providers are unaware of their own ability to participate in and profit from flexibility markets. Clear communication from the grid companies on how and when they are planning to use the market the most should help increase the knowledge of possible flexibility suppliers.

Message 3 – New initiatives should continue to build on experience from previous studies and address identified barriers, but focus on TSO-DSO and DSO-DSO coordination

Ongoing initiatives are developing solutions to identified barriers and building on experience from earlier pilots and initiatives. However, as the pilots are fragmented and often limited in scope, there is a clear need for a strengthening of the DSO-DSO and TSO-DSO coordination dimension to further leverage the learnings and increase the attractiveness of flexibility provision as an integral part of grid operation and planning. Lacking opportunities for value stacking or prohibitively high costs of participating in more than one market with the same loads are important barriers for the development of liquid markets for local flexibility. Related to this is the need for further technological development and standardisation of the appliances and their interoperability, which is necessary to make DSF attractive for DSOs and aggregators to bring down the cost for the provision of flexibility from smart appliances. While the conducted studies and pilots have increased the understanding of the issues and developed solutions to some of them, several barriers related to coordination and value stacking opportunities are yet to be solved, in addition to a lack of standardized communication protocols, including rebound effects causing voltage issues in the local grids, baselining issues, and different participation requirements and designs in local markets.

Examples of important barriers experienced in early pilots that are addressed in subsequent and ongoing flexibility initiatives are:

The development of a flexibility register in Euroflex. Flexibility registers will ease the ability to participate in multiple markets and thus achieve value stacking, which is stated as a barrier in many of the case studies.

Introduction of the new product, *MaxUsage*, introduced in the NODES platform. The new product eliminated baseline issues by only requiring a pool of loads to stay within a certain capacity level.

- Preventing rebound effects due to pure price optimisation, causing voltage issues by *"Grid-friendly activation",* may be solved through better

coordination. In Battflex, the issue of potential rebound effects was mitigated through implementing an automatic and autonomous voltage control algorithm in the smart control unit of each appliance. Combining this with price optimisation, grid-friendly activation was achieved, and rebound effects were prevented.

- Most initiatives only involve one or a few DSOs. Solutions and coordination necessary to enable participation in multiple markets should be developed through pilots where both TSOs and DSOs participate. The only case study where a marketplace for both a TSO and a DSO is established is Helen Electricity Network's and Fingrid's marketplace for congestion management. The goal of this pilot is to establish a common national marketplace. An important benefit of developing such a common marketplace is that it prevents different requirements and designs of local DSF markets.

This third message addresses five of the identified barriers. Baselining issues and value stacking are important barriers that are addressed in subsequent flexibility initiatives, showing a healthy innovation process. At the same time, the initiatives are not sufficiently focused on coordination between the actors. Strengthening the DSO-DSO and TSO-DSO coordination is crucial to enable value stacking. Enabling participation in more than one market with the same load will increase profitability and, by that, contribute to the development of liquid markets for local flexibility. We have also seen that coordination between actors is crucial for solutions to prevent voltage issues due to rebound effects. Coordination may also prevent different requirements and designs in the different local DSF markets, which can cause entry barriers and reduce economies of scale.

Message 4 – Verification requirements for smaller loads should be simplified, and the focus should be on incentivising the ability to react to market signals

The loads from smart appliances are generally small, and using them as flexibility resources can easily be dismissed as not being worth the hassle. Our estimates of the overall flexibility potentials of smart appliances show, however, that on an aggregated level, they can offer substantial amounts of flexibility to the power system. In view of the prospects for a growing need for flexible resources in the power system, their significance should not be dismissed. Being able to react to variations in spot prices (implicit flexibility) is currently the main motivation for demand-side investments in flexible solutions. This could be interpreted as implicit flexibility outcompeting explicit flexibility. In other words, it is more money to be made by simply following the spot price than participating in flexibility markets. While the latter might be true, it is not necessarily a problem. On the contrary,

without the profits one can gain by adjusting electricity consumption according to the spot price, it could very well be too costly for providers to make the investments or changes in behaviour necessary to be able to participate in (explicit) flexibility markets. Beyond what is required for implicit flexibility, additional requirements to enable explicit flexibility are related to the aggregation and verification of delivery. Simplifying requirements to offer explicit flexibility beyond what is necessary to react to spot prices will make the provision of explicit flexibility easier and more profitable for many loads.

As stated, the value of flexibility from each appliance is small. For smaller loads to deliver flexibility, the necessary investment must also be small. Thus, we cannot require the same accuracy of data and verification as for big industrial loads participating in TSO reserve markets. An important question is what the most important feature is – that they react exactly like what they are paid to do, or that they act according to what is beneficial for the power grid in the situation. The overarching goal is to ensure the availability of resources that are able to be flexible. Several examples show that implicit flexibility has solved prognosticated grid issues that would otherwise have had to be solved by explicit flexibility. For example, in Sthlmflex, projected grid issues did not occur to the expected extent due to increased electricity prices after the Russian invasion of Ukraine, in addition to reduced electricity demand due to a mild winter. Another example is the Swedish activation strategic reserve, which, according to Svenska Kraftnät, has not been used to support the Swedish power system for the last 10 years[112]. Earlier analyses show that actual loads have consistently been lower than expected during times of system stress, probably at least partly due to implicit flexibility provision [113].

For many small loads, like smart appliances often are, the most valuable approach might be to only incentivise the loads to be able to react to market signals. This could imply paying resources to be able to react to relevant activation signals, leaving verification and payment of activation out of the equation. One way to do this could be compensating all resources that are registered in the flexibility register, provided that they qualify according to a given set of requirements. Over time and with the employment of forecasting models, it will be easier to estimate the share of resources that are actually available for activation. Hence, DSOs and TSOs should consider simplifying verification requirements for smaller loads like smart appliances in buildings, where complex requirements related to baselining,

112. The strategic reserve was activated one time during the winter of 2021/2022, but this was related to offering help to Poland: https://www.svk.se/press-och-nyheter/nyheter/allmanna-nyheter/2023/om-inte-elen-racker-till-finns-effektreserven/

113. THEMA (2015): Capacity Adequacy in the Nordic Electricity Market. https://library.oapen.org/bitstream/handle/20.500.12657/32905/594223.pdf?sequence=1

individual measurement, and verification requirements would make participation in flexibility markets too costly.

This fourth message addresses three of the identified barriers. Simplifying verification requirements for smaller loads directly addresses the barrier regarding electricity consumption measurement and verification accuracy. Removing verification requirements for smaller loads will also remove the baselining issues for these loads. Finally, making provision of flexibility easier and more profitable for small loads can increase market liquidity.

Message 5 – We need to rethink risk in the power grid

Technology developments have enabled increased grid capacity utilisation without increasing the risk of outages. This is, for instance, achieved by relying on actual measurement of grid capacity, rather than on theoretical limits with substantial margins. At the same time, the cost of maintaining the delivery quality we are used to has increased. Operating the power grid has become more complex with a new generation mix. In many of the Nordic countries, long grid connection queues are waiting for grid investments, which also come with a high cost for society. When achieving the same level of outage risk (loss of load probability) becomes more costly, it should be considered whether a slight increase in the loss of load risk is acceptable. In the 2023 strategy of Norwegian TSO Statnett, one of the main points was that digitalisation would make it possible to increase the utilisation of today's power grid through grater calculated risk taking.

Taking calculated risks is enabled by digitalisation, which provides more and better data that can be used in grid operation and planning[114]. This is in line with our suggestion above, where simplifying verification requirements from smaller loads can increase market liquidity, thus making the market able to deliver what is needed to solve grid issues, and in the end achieve cheaper grid operation overall. Such an approach implies accepting that not all loads receiving an activation signal will respond, or that the response cannot always be explicitly verified. This would not introduce a novelty in the power markets. Every day, BRPs need to "guesstimate" how much electricity their household customers will use hour by hour. Because they must pay for deviations, they have incentives to make their guesstimates as accurate as possible and have become pretty good at doing so.

114. Statnett (2024): Økt utnyttelse av anlegg i det grønne skiftet - håndtering av risiko. Presentation at "NVEs kraftberedskapskonferanse", 16th of January 2024

This fifth message addresses calculated risk-taking in general and is illustrated by an example where the identified barriers of baselining issues and lacking harmonisation of electricity consumption measurement and verification accuracy are addressed.

Message 6 – Complex markets are not necessarily always the best way to utilise demand-side flexibility

As shown in Chapter 2, local flexibility markets are not the only way to make use of demand side flexibility to solve grid issues. Conditional connection, bilateral agreements, and grid tariffs are examples of other means that can also be used and are generally a lot easier to handle for both parties. These measures do not generally involve bidding and activation, eliminating many important barriers like baselining issues, non-standardised communication protocols, and verification. For instance, as we have previously discussed, it can be difficult to acquire sufficient market liquidity in local flexibility markets aimed at solving local bottlenecks. In Sthlmflex, they decided to discontinue the market mainly due to lower-than-expected demand for flexibility. The DSOs see the need for flexibility as present and growing, but in the near term, they see other flexibility measures, such as bilateral contracts or conditional connections, as more promising. In general, the benefits of more advanced and accurate measures should be weighed against the costs. This also underscores the importance of technology- or solution-neutral economic regulation of DSOs to incentivise their finding of the best combination of solutions to comply with their responsibilities.

This final message is a reminder that there are other efficient procurement methods of demand side flexibility that do not face many of the issues markets bring with them. This includes three of the identified barriers regarding lack of standardised communication protocols, lack of harmonisation of electricity consumption measurement and verification accuracy, and baselining issues.

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