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Unlocking distributed flexibility – electricity market actor roles for value realisation

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Anette Ryhänen

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Author Anette Ryhänen	
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Thesis supervisor Prof. Sanna Syri	
Thesis advisor(s) M.Sc. (Tech.) Jukka Rinta-Luoma	
Collaborative partner Fingrid Oyj	
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Abstract

The power system is shifting towards a renewable energy based decentralised and bidirectional system with multiple modern actor roles. This transition is a result of the increasing adoption of renewable and distributed energy resources. This change presents new challenges for the power system and consequently the demand for consumption side flexibility has increased. Demand side flexibility can support the changing power system by enabling consumers to become active market members. Unlocking the full potential of distributed demand side flexibility requires the participation and cooperation of multiple market actors. This thesis examines the roles and cooperation of market actors and the required measures to promote demand side flexibility development from a market-based approach.

This thesis consists of a literature analysis and an empirical study conducted through interview-based consultations. Based on the literature analysis, a concept of the value chain of end-user DSF is formed. The literature analysis also provides support for the empirical study and together they form the basis for the recommended measures presented in this thesis.

The importance of DSF was commonly recognised by the interviewees and they also presented a largely uniform view on the current challenges. The importance of cooperation was highlighted by all interviewees.

The identified challenges and development needs form the three key themes of DSF development: awareness and comprehension, technological advancement, and economic feasibility. Based on the literature analysis and the empirical study, recommended measures are presented. Firstly, the awareness of all market actors and cooperation within the value chain should be promoted. Secondly, more incentives and obligations for DSF development should be implemented. Finally, DSF should be supported by creating favourable market conditions for development.

Keywords Demand side flexibility, distributed energy resources, flexibility value chain, market actor roles

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Tiivistelmä

Sähköjärjestelmä on siirtymässä kohti uusiutuvaan energiaan pohjautuvaa hajautettua kaksisuuntaista järjestelmää, jossa on useita uusia toimijarooleja. Tämä muutos on seurausta uusiutuvien ja hajautettujen energiaresurssien kasvaneesta käyttöönotosta. Muutos aiheuttaa uusia vaatimuksia sähköjärjestelmälle ja sen myötä kysyntä kulutuspuolen joustolle on kasvanut. Kysyntäjousto voi tukea muuttuvaa järjestelmää antamalla loppukuluttajille mahdollisuuden ryhtyä aktiivisiksi markkinaosapuoliksi. Hajautetun kysyntäjouston potentiaalin hyödyntäminen edellyttää useiden markkinatoimijoiden yhteistyötä. Tässä diplomityössä tarkastellaan markkinatoimijoiden rooleja ja niiden välistä yhteistyötä sekä tarvittavia toimenpiteitä kysyntäjouston kehityksen edistämiseksi markkinaehtoisesta näkökulmasta.

Tämä diplomityö koostuu kirjallisuuskatsauksesta ja empiirisestä tutkimuksesta, joka toteutettiin haastattelututkimuksena. Kirjallisuuskatsauksen perusteella on muodostettu mahdollinen loppukuluttajan kysyntäjouston arvoketju. Kirjallisuuskatsaus tukee myös empiiristä tutkimusta ja yhdessä ne muodostavat perustan työssä esiteltäville toimenpidesuosituksille.

Haastateltavat tunnistivat kysyntäjouston merkityksen ja esittivät myös pitkälti yhdenmukaisen näkemyksen nykyisistä haasteista. Kaikki haastateltavat korostivat yhteistyön merkitystä.

Tunnistetut haasteet ja kehitystarpeet muodostavat kysyntäjouston kehityksen kolme keskeistä teemaa: tietoisuus ja ymmärrys, teknologinen kehitys ja taloudellinen kannattavuus. Kirjallisuuskatsauksen ja empiirisen tutkimuksen perusteella muodostettiin työn toimenpidesuositukset. Ensinnäkin kaikkien markkinatoimijoiden tietoisuutta ja yhteistyötä tulisi edistää. Toiseksi on luotava lisää kannustimia ja velvoitteita kysyntäjouston kehittämiselle. Lisäksi kysyntäjoustoa tulisi tukea luomalla kannustavat markkinaolosuhteet kehitykselle.

Avainsanat Kysyntäjousto, hajautetut energiaresurssit, jouston arvoketju, toimijaroolit

Contents

Preface

I want to express my gratitude to my advisor Jukka Rinta-Luoma and the whole market innovations team at Fingrid for their guidance and support. I also want to express my gratitude to Professor Sanna Syri from Aalto University for the supervision of my thesis and for guiding me through this process. Finally, I want to thank all the market actor representatives for their expertise and contribution to the research of this thesis.

Helsinki, 28 August 2023
Anette Ryhänen

Abbreviations

ACER	Agency for the Cooperation of Energy
aFRR	Automatic Frequency Restoration Reserve
BMS	Battery Management System
BRP	Balance Responsible Party
BSP	Balance Service Provider
DER	Distributed Energy Resources
DSF	Demand Side Flexibility
DSO	Distribution System Operator
EC	European Commission
EED	Energy Efficiency Directive
ENTSO-E	European Network of Transmission System Operators
EPBD	Energy Performance of Buildings Directive
ESCo	Energy Service Company
EV	Electric Vehicle
FCR	Frequency Containment Reserve
FCR-D	Frequency Containment Reserve for disturbances
FCR-N	Frequency Containment Reserve for normal operation
FFR	Fast Frequency Reserve
FRP	Flexibility Requesting Party
FRR	Frequency Restoration Reserve
IA	Independent Aggregator
MARI	Manually Activated Reserves Initiative
mFRR	Manual Frequency Restoration Reserve
NRA	National Regulatory Agency
OEM	Original Equipment Manufacturer
OTC	Over-the-counter
PICASSO	Platform for the International Coordination of Automated Frequency Restoration and Stable System Operation
PPA	Power Purchase Agreement
PV	Photovoltaic
SO	System Operator
SRI	Smart Readiness Indicator
ToU	Time-of-use
TSO	Transmission System Operator
V2G	Vehicle to Grid
VPP	Virtual Power Plant

1 Introduction

1.1 Background

The advancing climate policy and modern cost-effective solutions have resulted in the Nordic power system facing significant changes. The electricity generation mix has an increasing share of intermittent generation and distributed small-scale resources. Furthermore, rapid electrification and modern technologies are affecting the demand profile of consumers. Electrification is one of the key factors in reaching climate-neutrality. In accordance with the European Green Deal, Finland has recognised the importance of affordable and carbon free generation and consequently, the Finnish energy system is becoming increasingly dependent on electricity (EC 2023a, EC 2023b).

Wind power has become a significant part of the Finnish electricity generation mix and solar power is also showing promising potential. According to Fingrid´s (2023a) estimations, the share of wind power generation is going to increase significantly, rising to almost 30 percent by 2025 and to over 50 percent by 2030 (Figure 1). In 2022, the share of wind power in the electricity generation mix was 14.1 percent (Finnish Energy 2023).

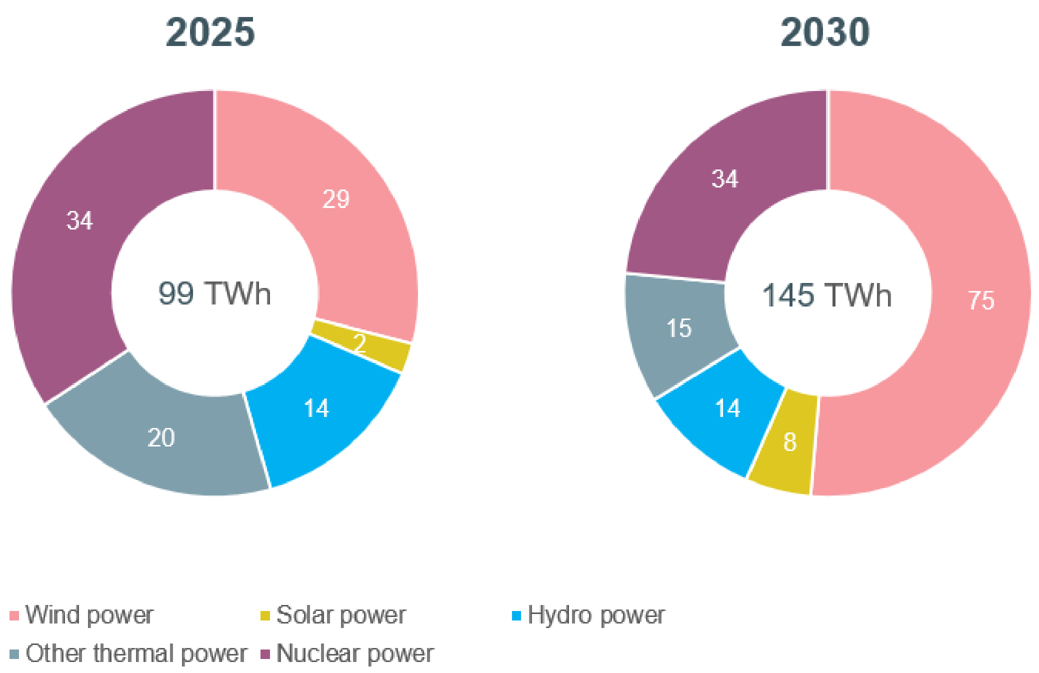


Figure 1. Electricity generation in 2025 and 2030 (Fingrid 2023a).

Figure 2 shows the estimated installed capacity and generation volume development of wind and solar power in Finland by 2030. Both figures present a rapid growth of these technologies.

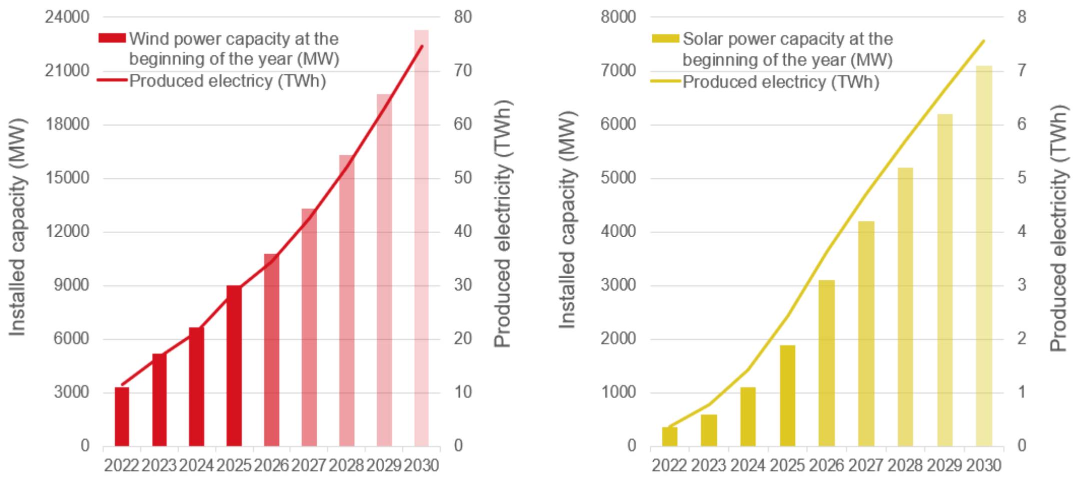


Figure 2. Wind and solar power capacity and electricity generation 2022-2030 (Fingrid 2023a).

The power system is shifting from a fossil fuel based centralised system with few market actors, to a renewable energy based decentralised and bidirectional system with multiple modern actor roles. The decentralised and bidirectional nature of the power system is a result of the increasing adoption of distributed energy resources (DER) (López González & Rendon 2022). The increasing share of renewable energy and the decentralisation of electricity generation present new challenges for the power system, such as maintaining power balance. However, this becomes more complicated as conventional flexible generation is phased out. Traditionally, generation has been adjusted to match the consumption profile. This change creates demand for flexibility also on the consumption side. Demand side flexibility can help mitigate these challenges by enabling consumers to become active members in the power system (IEA 2022).

To reach the full potential of flexibility, a mix of resources must be explored. While electrification causes a challenge due to the growing electricity consumption and peak loads, it also creates new distributed sources for flexibility, such as electric vehicles, solar systems, and electrical heat pumps. Based on Fingrid´s (2023a) estimation, peak demand side flexibility potential will increase significantly by 2030. The integration of DER flexibility into the power system creates the need for new market structures, regulatory frameworks, and technological solutions.

1.2 Objective and structure

Distributed flexibility is a key component in the ongoing transformation towards a more sustainable and decentralised energy system. Unlocking the full potential of distributed flexibility requires the participation and cooperation of multiple market actors, including modern actor roles, such as aggregators and prosumers. Currently, the lack of clarity in market actor roles and the underdeveloped cooperation between them is hindering the development and deployment of distributed flexibility. In order to increase flexibility in the system, value must be able to be collected from multiple sources. The 2022-2023 energy crisis has created a heightened interest in demand side flexibility participation and increased awareness among market participants regarding the functioning of the power system. During the period between September 2022 and February 2023, the electricity consumption of Finland fell by approximately seven per cent compared with the previous year (Fingrid 2023j). Moving forward, this enhanced knowledge should be sustained, which this thesis aims to support.

In this thesis, distributed flexibility refers to the flexibility provided by distributed energy resources (DER). The IEA (2022) defines DERs as smaller scale energy resources typically located near electricity use. These resources include controllable loads, small-scale generation, and energy storages. In this document, distributed flexibility providers are considered households and smaller scale buildings, such as commercial properties, both of which have DERs. The thesis focuses on developing flexibility in the Finnish electricity market with particular emphasis on distributed demand side flexibility (DSF).

To address the challenges posed by the changing energy system, European legislation encourages market-based approaches that rely on market prices to guide the development of flexibility, rather than predefined rules and tariffs. This approach promotes increased efficiency and innovation by allowing market actors to respond to price signals and adjust their operations accordingly. The Recital 22 of the Electricity regulation (EU) 2019/943 states that:

> *"Core market principles should set out that electricity prices are to be determined through demand and supply. Those prices should indicate when electricity is needed, thereby providing market-based incentives for investments into flexibility sources such as flexible generation, interconnection, demand response or energy storage."*

In accordance with EU policy, this thesis focuses on implementing distributed flexibility on market terms. A market-based approach creates a more dynamic and competitive energy market that can respond to changing circumstances and challenges and lead to a greater flexibility potential.

The objective of this thesis is to explore the roles and cooperation of market actors in unlocking distributed flexibility in the Finnish power system. The thesis examines the market actor roles related to distributed flexibility and the possibilities and barriers to their cooperation. The thesis also aims to map out the current state of development of DSF services and to define the framework for technological solutions enabling distributed flexibility. Finally, actionable proposals are presented to remove barriers hindering the development of DSF services.

The thesis aims to find an answer to the main research question:

- How can the value of distributed flexibility be unlocked and what are the necessary market actor roles and chains?

The main research question is further supported by the sub-question:

- What technological solutions enable the use of flexibility to match the needs of different market actors?

The findings of this thesis provide insight into the necessary market actor roles and cooperation for unlocking distributed flexibility. The findings can inform policy making and market design. Ultimately, this thesis aims to contribute to the development of a more sustainable and efficient power system.

The research is based on a qualitative case study approach, which involves interviews with various relevant market actors. Additionally, to support the empirical study, an analysis of relevant literature is included. The structure of the thesis consists of a literature review and an empirical part. Chapters 2-4 form the literature review and chapters 5-6 the empirical part of the thesis. In the empirical part of the thesis, the flexibility value chain is formed and market actor interviews are presented.

The thesis begins with an introduction to the background and objectives of the research. The second chapter presents the principle of the operation of the Nordic electricity system and the current electricity markets and market actors. The third chapter introduces the definition of flexibility and demand side flexibility. It also highlights the importance of DSF to the power system. In the fourth chapter, the various flexibility services and their deployment in Finland are presented. This chapter also presents the traditional and modern market actor roles related to DSF. Furthermore, the current challenges and development needs identified based on the literature analysis are discussed.

In Chapter 5 a concept of the value chain of end-user DSF is formed. Chapter 6 first presents the interview framework and then summarises the results of the interview study. The key findings from market actor interviews are presented and discussed. Finally, Chapter 7 proposes recommendations for measures that support the development of DSF. The recommendations have been formed based on the findings from the literature analysis and the interview study. The final chapter summarises the main conclusions of the thesis.

2 The Nordic electricity market

Finland is a part of the Nordic electricity system and the European wholesale electricity market. The Finnish electricity system is part of a dynamic power market, which allows for power to be sold or bought across countries and areas. Electricity prices are determined according to supply and demand and the lack of generation can be identified from the market price. The Nordic power markets were deregulated in the early 1990s and merged into a common free competition-based Nordic power market, which was later joined also by the Baltic countries. A free competition model and the ability to exchange power between countries increases social welfare, power system efficiency, and security of supply. Currently the shared power market reaches a large part of Europe, as transmission connections have been established between the Nordics, the European continent, and the Baltic countries (Nord Pool 2023a).

Electricity is traded on various market places, which are presented in figure 3. Liberalised market places include the financial markets and the wholesale markets where market parties trade with each other. In regulated market places, such as the balancing markets, market parties trade with a monopoly party, such as the Transmission System Operator (TSO) (Spodniak et al. 2019). In the Nordic electricity market power exchanges are responsible for physical market deliveries in the day-ahead and intraday markets. In the Nordics, Nord Pool is the largest trading platform for day-ahead and intraday markets, but EPEX SPOT also joined the market in 2020 (EPEX SPOT 2020). Both of them offer market clearing and pricing as well as transaction declaration and settlement (Cui et al. 2021). The Nordic power derivatives exchange is organised and operated by Nasdaq OMX (Spodniak et al. 2019). Transmission system operators are responsible for grid planning and operation. TSOs are members of the European Network of Transmission System Operators for Electricity (ENTSO-E). ENTSO-E coordinates grid planning and energy exchange in Europe (Cui et al. 2021).

2.1 Market structure

Electricity is traded on various market places. These markets are presented in Figure 3.

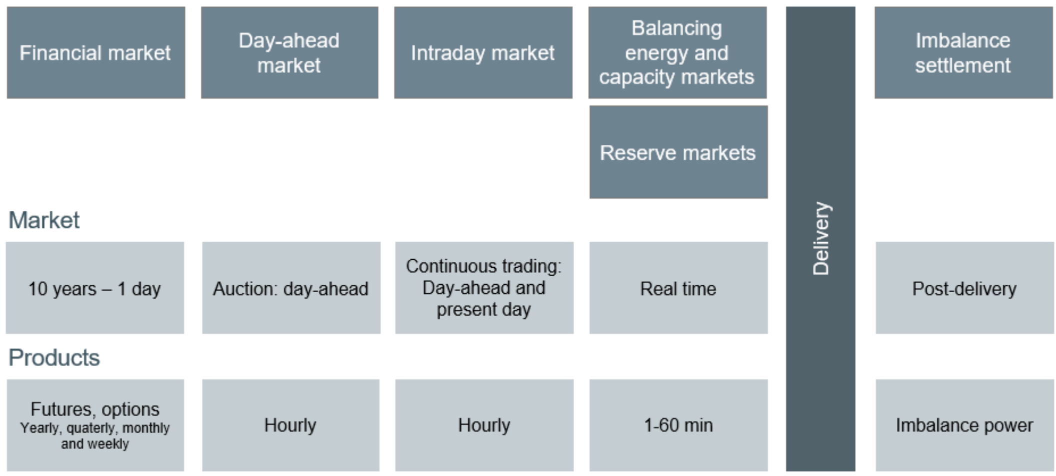


Figure 3. Electricity market structure (Fingrid 2023b).

Financial markets

In the financial market derivative electricity price related products, such as futures and options, are traded. In the Nordic power derivatives exchange, market actors can clear and settle their over-the-counter (OTC) and traded contracts. The financial market can also include long term contracts, such as power purchase agreements (PPA). Market actors use the financial market for risk management against electricity price fluctuations. Hedging can be done by a producer to protect themselves against exceptionally low market prices or by a supplier to protect against high market prices, since customer contracts might be fixed price. The financial markets do not include physical trading of electricity (Spodniak et al. 2019).

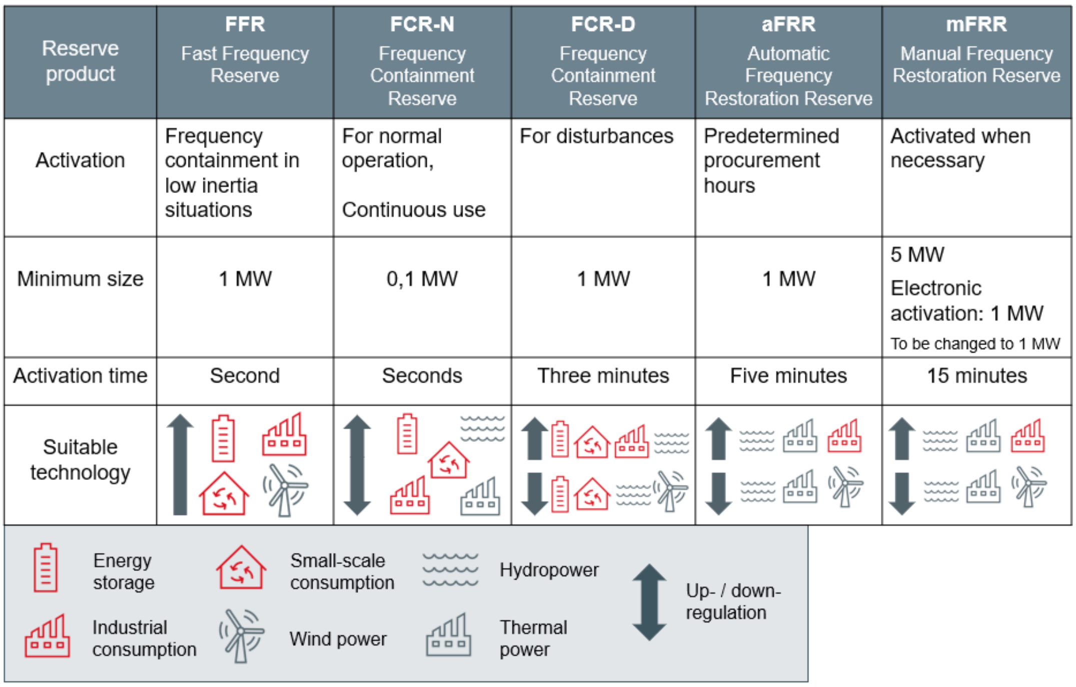
Day-ahead and intraday markets

Physical deliveries of electricity are traded in the day-ahead and intraday markets. In the day-ahead market electricity is traded on an hourly basis for the upcoming day. Market participants typically include suppliers, producers, end-users, and traders. In Finland, the majority of annual electricity demand is bought from the day-ahead market. Market participants evaluate the market situation for the next day and submit their final bids for the auction to a trading platform, such as Nord Pool. Hourly clearing prices are determined by the buy and sell bids at the point where they meet, taking into account constraints between bidding zones. The equilibrium price for the entire Nordic market is the system price, which is a reference price for a congestion-free grid (Faria & Fleten 2009). The day-ahead market is split into predefined price areas, where the price deviation from the system price is determined by the cross-border transmission capacity, which is also auctioned in the market. The difference in area prices reflects transmission scarcity in the transmission grid and helps to identify bottlenecks (Spodniak et al. 2019).

As physical delivery approaches, changes in consumption and generation may occur due to weather conditions or unexpected faults. These variations make actual consumption and generation deviate from the estimate. These deviations create a need for trading to maintain power balance. Market participants can adjust their balance in the intraday market. The intraday market allows market participants to alter consumption and generation plans closer to the time of delivery. Trading on the intraday market starts after the day-ahead market closes and lasts until the time of delivery (Cui et al. 2021).

Balancing and reserve markets

The balance of the power system is indicated by frequency level, which has a nominal value of 50 Hz. Even though market participants plan and balance their generation and consumption in advance, hourly deviations often occur. In order to balance these deviations, TSOs procure balancing services from the markets. The different balancing products, their activation times and technical requirements are presented in Figure 4 (Spodniak et al. 2019). Power system balancing is carried out in the balancing and reserve markets. In the reserve market, the TSO procures reserves to maintain power balance. Reserves can be power plants, consumption resources and power storages that adjust their profile according to power system needs. These actors, who provide balancing services to the markets, are called Balance Service Providers (BSP). Reserve products include Frequency Containment Reserves (FCR), Frequency Restoration Reserves (FRR), Fast Frequency Reserve (FFR) and Replacement Reserve (RR). Replacement reserves are not used in the Nordic power market (Khodadadi et al. 2020).



Reserve product	FFR Fast Frequency Reserve	FCR-N Frequency Containment Reserve	FCR-D Frequency Containment Reserve	aFRR Automatic Frequency Restoration Reserve	mFRR Manual Frequency Restoration Reserve
Activation	Frequency containment in low inertia situations	For normal operation, Continuous use	For disturbances	Predetermined procurement hours	Activated when necessary
Minimum size	1 MW	0,1 MW	1 MW	1 MW	5 MW Electronic activation: 1 MW To be changed to 1 MW
Activation time	Second	Seconds	Three minutes	Five minutes	15 minutes
Suitable technology					

Figure 4. Reserve products and suitable technology (Fingrid 2023c).

FCRs include the Frequency Containment Reserve for normal operation (FCR-N) and for disturbances (FCR-D). They are both active power reserves for capacity procurement and are automatically controlled based on frequency signals. The purpose of FCR-N is to maintain the frequency level in the standard range between 49,9-50,1 Hz. FCR-D limits frequency from deviating lower than 49,5 Hz or higher than 50,5 Hz in disturbance situations (Khodadadi et al. 2020). For FCR-N the minimum bid size is 0,1 MW with a full activation time in 3 minutes after a frequency step change of ± 0,1 Hz. For both upwards and downwards FCR-D the minimum bid size is 1 MW with full activation time of 5 seconds for 50% and 30 seconds for 100% after a stepwise frequency change from 49,9 Hz to 49,5 Hz or 50,1 Hz to 50,5 Hz (Fingrid 2022).

FRRs are used to return system frequency level to the normal range between 49,9-50,1 Hz and release FCRs back into operation. FRRs include the Automatic Frequency Restoration Reserve (aFRR) and the Manual Frequency Restoration Reserve (mFRR). The purpose of the Automatic Frequency Restoration Reserve is to return frequency level to the standard value of 50 Hz. It is a centralized automatic reserve, and it is activated based on an activation signal from the TSO. aFRR reserves are procured from both the reserve market and via inter-TSO trades with other Nordic countries. aFRR is procured for predetermined hours. In order to participate as a reserve to the aFRR market a minimum regulation capacity of 1 MW is needed with a full activation time of 5 minutes maximum. Balance service providers receive a capacity payment, the size of which is determined based on the price of the most expensive accepted bid (Khodadadi et al. 2020).

The mFRR market is divided into mFRR capacity and mFRR energy markets, and they are maintained by the Nordic TSOs. A BSP whose capacity bid is accepted on the mFRR capacity market is obliged to give up regulating energy bids to the mFRR energy market in exchange for a financial compensation (Khodadadi et al. 2020). Balancing energy bids have a minimum size of 5 MW or 1 MW if electronic activation is used. The maximum activation time is 15 minutes (Fingrid 2023c).

European market platforms MARI (Manually Activated Reserves Initiative) and PICASSO (Platform for the International Coordination of Automated Frequency Restoration and Stable System Operation) were launched for mFRR and aFRR in December 2022. These market platforms were created to increase liquidity in the FRR markets and to ensure harmonised European balancing markets (ENTSO-E 2022). The markets are already in operation, but the Nordic countries have not joined them yet. The future participation of the Nordic countries in the European balancing market is promoted by first creating a common Nordic market. The Nordic aFRR capacity market was launched in December 2022 (NBM 2022). A Nordic balancing energy and balancing capacity market will be introduced later (NBM 2023).

FFR has been used in the Nordics since 2020 for frequency control in operating situations with low inertia together with FCR. The purpose of FFR is to prevent the frequency level from falling below 49,0 Hz. A very fast activation time aids in preventing frequency level from falling. The reserve is procured from a national market (Khodadadi et al. 2020). The minimum bid size for FFR is 1 MW and the maximum activation time ranges between 1,3 and 0,7 seconds depending on the activation frequency (Fingrid 2021a).

Imbalance settlement

TSOs are responsible for maintaining continuous power balance in the power system and therefore all electricity market participants must maintain their power balance, i.e., the balance between the generation, procurement, consumption, and sale of electricity. To ensure power balance, market participants have an open supplier, which takes care of the final balancing. These participants, whose open supplier is the TSO, are called Balance Responsible Parties (BRP).

After the physical delivery of power, the difference between the offered and realised generation and consumption, i.e., the balance, of the BRP is checked. If the BRP´s plans do not match actual generation and consumption levels, adjustments in the power system need to be made. The imbalance leads to the need to restore the system balance in the reserve markets, which causes an imbalance cost. In the imbalance settlement process, the balance deviation is calculated for each balance settlement period. The costs of balancing actions are divided between the parties that have caused the imbalance. Market parties with a balance deviation either pay or receive payment according to the magnitude, direction, and price of balancing energy (eSett 2022). The Nordic imbalance settlement is handled by the TSO owned balance settlement company eSett (Spodniak et al. 2019).

As the share of variable renewable energy is rising and the amount of conventional adjustable generation is decreasing, the electricity market model needs to be adjusted. The market needs to be compatible with the growing share of renewables so that system balancing works reliably guided by the market price level (Fingrid 2023e). To support this transition, Finland and Europe are shifting to a shorter imbalance settlement period and towards a more real-time power market. The change is based on the Commission Regulation on establishing a guideline on electricity balancing (EU) 2017/2195, which obligates EU members to shift to the 15-minute imbalance settlement period. In Finland, the new imbalance settlement period was implemented on May 22, 2023 (Fingrid 2023f). The transition also applied to energy measurements and datahub, which is the centralised information exchange system on the electricity retail market (Fingrid 2023g). The cost of imbalance remains at an hourly level until the price of balancing power is determined on a 15-minute basis and intraday cross-border trading shifts to a 15-minute resolution. Shortening the imbalance settlement period increases the market-based balancing of the power system and enables for a more accurate sharing of the costs caused by balance deviations between market actors. The more accurate appearance of deviations and cost allocation acts as an incentive for market actors to manage their balance more precisely. Flexibility is rewarded and price signals provide more earning opportunities for adjustable generation and consumption (Fingrid 2023e).

2.2 Electricity market actors

The Nordic power market is an advanced system with many actors involved. For the objective of this thesis, the most relevant actors have been defined. These DSF related electricity market actors are introduced in this chapter.

Supplier and producer

An electricity supplier purchases electricity either through power exchanges or directly from the producer and then resells the bought electricity to end-users. End-users choose their preferred supplier and make a contract for electricity supply with them. There are more than 370 companies producing and 380 companies supplying energy in the Nordics and Baltics (Nord Pool 2023b).

Transmission system operator (TSO)

The transmission system operator (TSO) is responsible for operating and controlling the high-voltage transmission grid. This includes controlling and monitoring grid topology and grid voltage levels. The TSO is also responsible for the development on the electricity market, power system balancing, constraint management and grid planning. TSOs analyse power system balance and congestion based on trading and load forecasting information and based on the analysis, adjust their operation (Cui et al. 2021). Additionally, TSOs organise reserve capacity to ensure security of supply and are responsible for the imbalance settlement being carried out in accordance with national legislation (eSett 2022).

Distribution system operator (DSO)

A distribution system operator (DSO) owns the local distribution grid and is responsible for the distribution of electricity between producers and end-users. DSOs measure the consumption, generation and exchange in the grid and report the data to market stakeholders, such as datahub (eSett 2022).

Balance responsible party (BRP)

A Balance Responsible Party (BRP) is a company with a valid Imbalance Settlement Agreement with eSett and a balance agreement with a TSO. The BRP also manages its balance obligation on its own behalf or on the behalf of other parties. Balance obligation means the responsibility to plan and maintain balance between the supplied and consumed electricity of produces, consumers, or suppliers and to prepare the financial settlement of possible imbalances from these parties. The TSO defines and governs balance obligation requirements (eSett 2022).

End-user

An end-user of electricity is a market actor who consumes the energy generated by the producers and sold by the suppliers. The generated electricity is transferred and distributed to the end-user by the transmission and distribution system operators. End-users include all electricity consumers, such as households, companies, and industry. As the electricity system has advanced, the role of the end-user has developed as well. Traditionally, the end-user acted as a passive member of the system by only consuming energy. The possibility of having on-site generation or flexible consumption has made it possible for customers to become active members of the power system and have an increasingly meaningful role in the energy transition (Gržanić et al. 2022).

In addition to the consumption of electricity, many end-users have other flexible assets, such as small-scale generation and even energy storage, i.e., distributed energy resources (DER). Therefore, electrical storages can also be considered a type of end-user with flexibility potential. Electrical storages can efficiently participate in demand side flexibility by allowing for example surplus renewable generation to be stored increasing the utilisation rate of generation. The stored electricity can then be used to cover for hours when generation is less profitable. Electrical storages are slowly becoming more and more popular amongst households, especially in the form of electric vehicles (Woittiez 2016). Small-scale generation can be equated with demand side flexibility (DSF), if it reacts to the market situation and reduces the amount of electricity taken from the grid. In addition to small-scale renewable generation, this also refers to back-up power generators in buildings (Zhang & Grossmann 2016).

End-users that both consume and produce energy can be referred to as prosumers. In the electricity domain, a prosumer can refer to an end-user that, as well as consuming and producing energy, is also capable of operating flexibly. Therefore, in this document, prosumer refers to all flexible end-users. Prosumers can offer their flexibility to the aggregator, who pools this flexibility and sells it to a Flexibility Requesting Party (FRP). The more prosumers connected to the aggregator, the more flexibility is available (Kubli et al. 2018). It has been estimated that by 2050 around half of EU citizens would become prosumers. As the number of active consumers keeps increasing, more and more flexibility potential is added to the system (Saviuc et al. 2022).

(Independent) aggregator

As mentioned previously, flexibility can be provided by several technologies from different generation, consumption, and storage sites. However, only participants with large enough loads, such as industrial customers, can participate in the market on their own. Smaller loads from residential and commercial customers face barriers accessing these markets, because of the current capacity requirements. In order to reach full potential on flexibility resources and include smaller loads in the markets, an intermediary participant, the aggregator, is needed to combine the individual flexibility loads into a larger resource (Schittekatte et al. 2021b, Eid et al. 2015). The aggregator acts as a flexibility retailer between the prosumer and the FRP, i.e., the TSO, DSO and BRP. The aggregated portfolio is used to create services based on the accumulated flexibility and offered to various markets. The aggregator receives compensation for providing flexibility services and shares these compensations with the prosumers (Van der Veen et al. 2018). The aggregator and the FRP agree on terms and conditions for the procurement and management of flexibility (Sáez Armenteros et al 2021). The role of an aggregator can be taken by a supplier or BRP or by an independent participant outside the conventional power delivery chain. An independent aggregator (IA) is a market participant that aggregates flexible resources but is not affiliated with the supplier of the customer or the balance responsible party (Schittekatte et al. 2021b)

The independent aggregator role was introduced to improve the efficiency of the power system by facilitating demand side flexibility and energy efficiency. The independent aggregator can create services that help to reduce peak demand, increase consumption when the price level is low, provide balance to the system and increase security of supply. In addition, the independent aggregator has a crucial role in increasing the offering of DSF services, which will in turn increase competition on the market. Competition creates more interest in developing DSF related technology and services and increases the amount of market actors taking part in flexibility. Over time, cost efficiency increases, technology develops, and services become more advanced (Pöyry 2018). The independent aggregator has an important role in activating the full range of customers by providing a suitable technical and economic execution. While the independent aggregator model develops, it is important to ensure equal and fair treatment of all stakeholders in the value chain. When an independent aggregator procures flexibility, it might, for example, impact the energy and balance position of the supplier. Common rules and guidelines and transparency of information are needed to create a sufficient model (De Heer 2015).

3 Power system flexibility

Flexibility in the power system can here be defined according to the IEA and 21CPP (2018) as "the ability of a power system to reliably and cost-effectively manage the variability and uncertainty of demand and supply across all relevant timescales, from ensuring instantaneous stability of the power system to supporting long-term security of supply."

Flexibility is becoming increasingly valuable as there are higher levels of variable renewable energy connected to the grid. The increase in intermittent generation has raised the demand for flexibility on the consumption side. When both generation and consumption are able to modify their behaviour patterns in response to variability the security of supply can be maintained. Flexibility is characterised by several parameters, such as the magnitude of adjustable power, the rate of change, duration, response time and location. Based on these parameters, flexibility services can be defined and provided for corresponding needs. Power system flexibility can be further divided into two areas presented in Figure 5. The technical flexibility area refers to the capability of the system to manage current network issues, while users' behaviour area refers to the ability of grid users to modify their load and generation profiles according to system needs. These areas represent flexibility from the perspective of the power system. Flexibility from the user´s perspective refers to demand side flexibility (EC 2022). Demand side flexibility is presented in the next chapter.

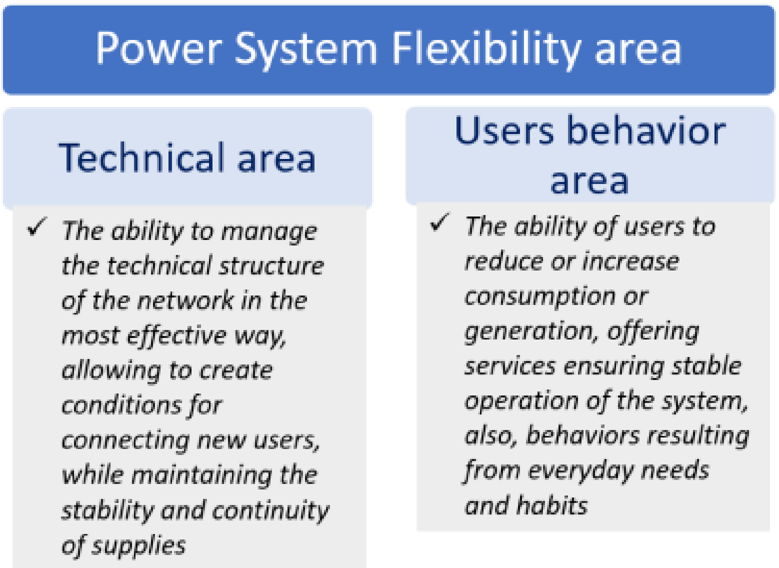


Figure 5. Power system flexibility area (EC 2022).

3.1 Demand side flexibility

Demand side flexibility (DSF) refers to reducing, increasing, or shifting load from the typical pattern in response to an incentive. DSF includes all intentional shifting of end-user consumption patterns that are intended to modify the timing and level of demand or the total consumption of electricity. Demand side flexibility promotes the integration of variable renewable energy by reshaping load profiles according to the generation of variable renewable energy and reduces the cost of electricity generation by shifting consumption from high priced periods to periods with a lower price level. DSF also reduces system peak load and seasonality, making power system balancing easier (IRENA 2019). It also allows for demand to become an active participator in grid operations, which improves the efficiency, safety, and reliability of the power system (D'Ettorre et al. 2022).

Several market actors can benefit from DSF. For the TSO, DSF acts as a tool for managing power system balance and securing security of supply. DSF can also be utilised by the system operators for constraint management services, including congestion management. For the supplier and the BRP, DSF creates an opportunity to manage their power balance, plan electricity procurement and to create new products for business development (Van der Veen et al. 2018). For the prosumer, the incentive for participating in DSF can be related to minimising the cost of electricity or to gaining profit from compensations. The two forms of DSF are called implicit and explicit flexibility (Figure D) (Albadi 2007).

3.1.1 Implicit demand side flexibility

Implicit demand side flexibility refers to consumers voluntarily adjusting their consumption based on e.g., external price signals. This can mean for example optimising prosumer load profile based on hourly electricity prices in order to minimise their electricity bill. Implicit demand side flexibility is also referred to as price-based flexibility. Implicit DSF mechanisms are based on time-varying energy prices or network tariffs. The varying price increases consumer awareness on the impact of their consumption profile on electricity prices and enables them to reduce their own electricity bill by shifting consumption to lower priced hours (EC 2022). The prosumer can participate in implicit DSF by utilising home automation or with a service provider. The entry barriers to implicit demand side flexibility are notably smaller than for explicit DSF, since there is no need for aggregation. Implicit flexibility can provide financial benefits for the prosumer, but it can also benefit the power system by increasing the cost-efficient balancing of the power system (Baltputnis et al. 2019).

3.1.2 Explicit demand side flexibility

Explicit demand side flexibility refers to committed and dispatchable flexibility. Explicit demand side flexibility can be traded on various electricity markets, such as the wholesale market and the balancing and reserve markets. Explicit demand side flexibility is also referred to as incentive-driven flexibility. Here consumers increase or decrease their load or distributed generation based on power system needs and receive compensation (Freire-Barceló et al. 2022). With distributed flexibility resources, explicit demand side flexibility is typically managed and facilitated by an aggregator. An aggregator is needed to combine distributed flexible resources into larger entities that can be utilised for the needs of the power system. The role of an aggregator can be taken by a BRP, supplier, or an independent service provider. The aggregator role is presented in chapter 2. Both implicit and explicit demand side flexibility complement each other and can coexist in the power system. By using both flexibility types, full system benefits can be reached (EC 2022).

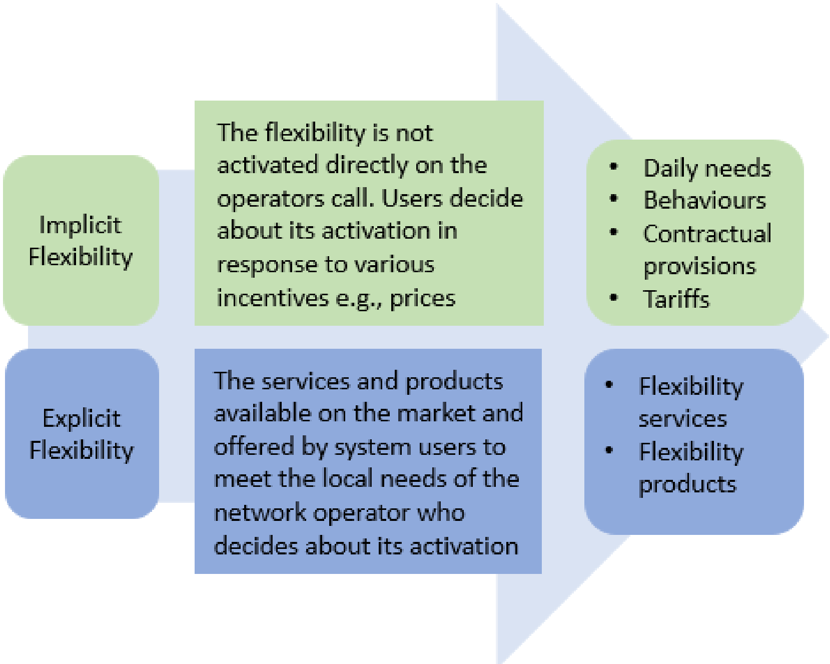


Figure 6. Implicit and explicit demand side flexibility (EC 2022).

3.2 Distributed Energy Resources

Large and industrial end-users with loads higher than 1 MW make up for the largest share of explicit DSF participation in Finland with the total available capacity from these resources being estimated to be around 300 MW. With the development of aggregation and independent aggregation, smaller loads below 1 MW are also able to participate in explicit DSF. The constantly developing building automation technology and electrical heating solutions are bringing even smaller distributed flexibility resources to the mix with the help of aggregation (Saviuc et al. 2022).

Distributed flexibility refers to the flexibility provided by distributed energy resources (DER). The IEA (2022) defines DERs as smaller scale energy resources typically located near electricity use. They can be situated behind the customer meter or be directly connected to the distribution grid. These resources include controllable loads, small-scale generation, and energy storages. DERs are increasingly widespread and are already transforming the power system. DERs can benefit both the end-user that owns them as well as the power system.

According to López Gonzáles and Rendon (2022) the incorporation of DERs promotes demand side participation, contributing to the objectives of energy security, decarbonisation, and market price efficiency. Allowing end-users to become more proactive prompts new actors, such as aggregators, to enter the electricity markets. The generation and trading of electricity is no longer limited to large, centralised entities and the flow of electricity has become bidirectional. Burger et al. (2019) states that DERs can provide the same electricity services as centralised resources with the added benefit of higher locational value. DERs have the ability to locate closer to the point of consumption and access locations inaccessible to larger resources. The close proximity to consumption can mitigate network losses and congestion. DERs contribute to decarbonisation especially by supporting fuel switching. For the prosumer, DERs, such as PV systems, can provide affordable electricity and shield from outages when paired with a storage system. DERs enable the optimisation of generation and consumption according to the prosumer´s needs (IEA 2022).

3.2.1 Flexible resources

Mature DSF technologies include power-to-heat solutions, such as electric heating systems. This type of sector integration has further increased energy flexibility in the power system. Alongside the mature DSF technologies, new solutions are arising (D'Ettorre et al. 2022). DERs include a variety of modern technologies, five of which the IEA (2022) has categorised as particularly promising. These technologies and solutions include battery storages, EVs, electrical water storages and space heaters, grid-interactive buildings, and virtual power plants.

Battery storage systems can provide a variety of flexibility services to the grid. Most importantly, they can support RES implementation by storing electricity during overgeneration periods and discharging during peak consumption periods. At the moment, their limitations are related to the relatively high costs and lack of sustainability. Electric vehicles (EV) are a rapidly increasing mobile battery technology that can in principle be used as stationary batteries. EV smart charging allows for them to provide grid balancing services as well as back-up energy for end-users. If equipped with sufficiently low-cost control devices, electrical water storage and space heaters offer great flexibility potential. Larger buildings, such as public properties, can act as grid-interactive efficient buildings, optimising their generation and consumption while accommodating the power system needs (IEA 2022). Finally, virtual power plants (VPPs), i.e., virtual networks combining storage systems, distributed generation, and flexible demand, can optimise the integration of DER flexibility over large are-as. VPPs utilise advanced data analytics to create a smart network for optimisation (Naval & Yusta 2021). Other flexible resources include wind power, PV systems, which are well suited for households, and quite modern solutions, such as hydrogen technologies (D'Ettorre et al. 2022).

3.2.2 Distributed flexibility potential

The flexibility potential of electrical systems varies on a seasonal, daily, and even hourly level. During the heating season, the highest load control potential exists in electrical heating and domestic water heating. On a daily scale, the highest load control potential is typically in the mornings and afternoons. In addition to heating systems, larger buildings have flexibility potential in ventilation, cooling, and lighting. The energy use of buildings covers about 40% of all energy consumption, with heating being the largest source. Modern technologies, such as electrical storages and electrical vehicles, also present a growing flexibility potential (Söder et al. 2018).

Heating and cooling systems present the highest DSF potential for small end-users, but various other dispatchable loads, including home appliances, can provide flexibility as well (Saviuc et al. 2022). For the power system, household heating systems have perhaps the most significant unutilised flexibility potential. The amount that can be shifted is limited by the level of living comfort, but even cutting one or two peak hours with a few hundred MW can have a significant effect on the power system and market prices. The peak consumption during the coldest winter days in Finland is around 15000 MW, of which the share of households is around 25-30 % (Mäntylä 2022).

A study carried out by Tampere University of Technology in 2015 assessed the technical potential of flexible loads. The loads with the most technical control potential were determined (Järventausta et al. 2015):

- Direct electric heating: 1 800 MW
- Hot water boilers: 1 200 MW
- Electric heating with storage: 1 300 MW
- Building ventilation: 400 MW
- Greenhouses: 300 MW

The growing share of electric vehicles also presents potential for DSF. EV smart charging is estimated to have a flexibility potential of 0.2 GW by 2030 (Fingrid 2023i). Rauma et al. (2021) found that residential and office charging sites offered the greatest load reduction potential with the minimum effect on customers. The 2030 flexibility potential estimate for household electric heating is 1.4 GW. According to Olkkonen et al. (2018) the estimated temporal availability of DSF could vary between 80-5600 MW in 2030.

Unlocking the flexibility potential of distributed energy resources requires the cooperation of market actors, the development of technologies and assets and the support from institutions and practises. The challenges related to distributed DSF, and possible measures are presented in Chapter 4.4.

3.3 Legislative advancements

Regulation can influence, guide and control electricity consumer behaviour in the power market. Through regulation, it is possible to influence the development and use of demand side flexibility both directly and indirectly. Regulation can include not only laws that directly obligate an activity, but also administrative guidance and incentives, such as taxation, recommendations, and subsidies. Regulation also includes the production and sharing of information. Regulation and governmental oversight can influence the prerequisites for power market formation and function, while letting the actual market activity be determined by market conditions (Järventausta et al. 2015). To solve the issues regarding the rising share of intermittent renewable energy in the system, the European legislation favours market-based approaches. This means that prices, not pre-defined rules, and tariffs, should guide flexibility deployment.

3.3.1 European Union legislation

The need for flexibility in the power system is recognised in the European Union (EU) energy policy and in 2019 EU legislation paved the way for DSF deployment. Guiding principles have been introduced through the Clean Energy Package and the Green Deal (EC 2023a, EC 2023e). The liberalisation of the European power market and the development of a smarter electricity grid has encouraged end-users to become active market members. Consequently, at the centre of the EU regulatory frameworks and policies is the customer, which is defined as the flexibility resource provider. Demand side flexibility has a crucial role in facilitating the efficient integration of renewables and modern DERs, such as electric vehicles, electrical heating, and power-to-X technologies. Customers´ willingness to shift their consumption ensures that the grid can cope with upcoming challenges and contributes to a climate neutral power system (Saviuc et al. 2022).

The Clean Energy Package, adopted in 2019, introduces amending directives and regulation that together define a comprehensive framework for DSF promotion. The amending directives introduced measures to promote dynamic pricing schemes and support DSF market access by defining the role of the aggregator and energy communities and by incentivising the use of DSF for congestion management and efficiency improvement on the distribution system level (EC 2023a).

In 2012 the Energy Efficiency Directive (EED) 2012/27/EU defined the contractual and technical actions to support DSF and included provisions for enabling DSF participation in the balancing and wholesale markets. The Electricity (Recast) Directive 2019/944/EU, introduced in the Clean Energy

Package, amends the 2012 EED and addresses the aggregation of DSF in Article 17:

> *§1 Member States shall allow and foster participation of demand response through aggregation. Member States shall allow final customers, including those offering demand response through aggregation, to participate alongside producers in a non-discriminatory manner in all electricity markets.*

Also, the independent aggregator role is recognised:

> *§3(a) Member States shall ensure that their relevant regulatory framework contains the right for each market participant engaged in aggregation, including independent aggregators, to enter electricity markets without the consent of other market participants.*

The directive foresees that the independent aggregator is enabled to access the market without needing permission from the supplier and the BRP of the customer. This supports market competition where the customer is allowed to have multiple contracts with different market actors. The aim of the Electricity Directive is to adapt electricity trade policies towards low-carbon power markets and decentralised generation using renewable sources. The aim is to also integrate renewable energy producers, service providers, energy storages and DSF into the market. The directive has included provisions to incentivise and enable DSOs to procure market based DSF services provided by DERs to efficiently operate the distribution grid and limit costly investments and expansions.

The 2012 EED was also amended by the 2018/2002/EU Directive on Energy Efficiency, which states that energy efficiency and DSF should be able to compete on equal terms with generation. The directive is further amended in the upcoming EED recast in September 2023. The amending directive places a strong emphasis on energy efficiency and the suggested measures to support its implementation are in line with the development of demand response (EC 2023d). DSF is also implemented into the Energy Performance of Buildings Directive (EPBD) 2018/844/EU. The directive states that the flexibility of a building´s electricity demand, both implicit and explicit, is one of the key functionalities in rating the smart readiness of buildings, which is determined by the smart readiness indicator (SRI).

The European Commission (EC) has identified demand side flexibility alongside cybersecurity as the key areas in developing network codes and guidelines. The two have been defined as key factors to meet the opportunities and challenges of the developing power system in line with Article 59(3) of the

Electricity Regulation (EU) 2019/943. The network code for demand side flexibility is being developed. In June 2022 the European Commission requested the EU Agency for the Cooperation of Energy Regulators (ACER) to develop a framework for the development of a DSF network code. The network code will strive to enable market access to DSF, including consumption, storage, and distributed generation. The code will also aim to facilitate the market-based procurement of services for the DSOs and TSOs. The DSF network code is applicable to all EU member states (ACER 2022).

Several parts of DSF related legislation are under development. The Renewable Energy Directive 2018/2001/EU was introduced as part of the Clean Energy Package and is now being revised to better match the EU Fit for 55 package, which strives for a 55% emission reduction by 2030. The revised renewable energy directive is going to increase the EU 2030 target for renewable energy and further promote DSF deployment by addressing the need for specific requirements for removing remaining barriers and obstacles to distributed storage solutions, such as household batteries and electric vehicles (EC 2023b). A revision of the Energy Performance of Buildings directive (COM(2021) 802 final) has also been introduced. In terms of DSF, the revision states that member states may adopt minimum requirements on the demand response capacity of buildings. The Electricity Directive is also facing amendments. The energy crisis and volatile prices highlighted the lack of flexibility in the European power market, both on the supply and demand side. In March 2023, the European Commission proposed a reform to the EU power market. The proposed reform further increases support for demand response and storage as a competitor to natural gas (EC 2023c).

3.3.2 National legislation

The Finnish electricity market legislation already covers many of the requirements for flexibility deployment. The deregulated power market, balancing responsibility and dynamic tariff supply all support DSF engagement. The previous Electricity Market Act already enabled the deployment of DSF but not to its full potential. Until the recent regulatory amendments, the independent aggregator role was not specified in the Finnish legislation (Electricity Market Act 588/2013).

The Electricity Directive 2019/944/EU was recently implemented into national legislation. In December 2022 the Finnish Government presented the proposal to the Parliament on amending the Electricity Market Act and related legislation. The proposal was accepted by the Parliament on the 23 of March 2023 and the new Electricity Market Act 588/2013 was entered into force on June 1, 2023.

The main goal of the proposal was to implement the changes required by the EU in the 2019 Electricity Directive to the national legislation on electricity markets. Another goal was the implementation of the actions proposed by the Ministry of Economic Affairs and Employment´s Smart Grid Working Group for a smart electricity system in 2018. The new electricity market legislation will further promote the possibility for customers to participate actively in the electricity markets. Additionally, measures to prevent inappropriate contractual and marketing practices are implemented. The revised Electricity Market Act introduces the independent aggregator as a recognised actor role in the electricity market. The independent aggregator is allowed to access the market without the consent of other market participants and the customer is allowed without extra cost to freely choose and change its independent aggregator. The possible imbalance caused by the independent aggregator must be compensated to the open supplier of the customer or its BRP. The Act also states that the operator of a market place may not impose market access conditions that would unjustifiably discriminate against demand side flexibility. Transparency requirements concerning flexibility and consumption are increased. Information on smart meter measured data and flexibility activations has to be available for the flexibility service provider (Electricity Market Act 588/2013).

The Finnish legislation further supports DSF deployment through developing building energy efficiency targets. The Energy Efficiency Directive 2012/27/EU was implemented into the Finnish legislation by the Energy Efficiency Act 1429/2014, which entered into force on January 1, 2015. The new Act on Public Procurement and Concession Contracts 1397/2016 gave the public sector increased opportunities for promoting innovative energy efficiency and DSF solutions. Also, the Land Use and Building Act 132/1999 was implemented in accordance with the EPBD, with increasing requirements for the energy efficiency of buildings and the use of renewable energy sources, which supports the utilisation of flexibility. On March 1, 2023, a new Building Act was accepted by the Parliament. The new act implements climate change mitigation comprehensively into the building legislation. The new act promotes circular economy, energy efficiency and digitalisation, increasing the importance of smart technological solutions. The Building Act will enter into force on January 1, 2025 (Ministry of the Environment 2023).

In accordance with the EPBD and the European Commission's implementing regulation (EU) 2020/2156, Finland has started the testing phase of the smart readiness indicator at the end of the year 2022. Based on the testing phase, the necessary decisions on SRI introduction are made. A high SRI means that the building´s energy use is flexible and can be adjusted according to supply (Ketomäki 2022, Motiva 2023b).

Smart meters play a significant role in enabling DSF flexibility services. Finland was one of the first countries to introduce smart meters and almost all Finnish electricity consumption points have them. The obligation for hourly metering was introduced in the decree of the Finnish Government on electricity supply settlement and measurements (66/2009) and the majority of first-generation smart meters were installed by 2013 (Pöyry 2017). The second generation of smart meters has now arrived and are being installed over the next few years. The second-generation smart meters are implemented in accordance with the most recent version of the decree of the Finnish Government on electricity supply settlement and measurements (767/2021). Second-generation smart meters provide an increased amount and quality of data and allow for consumption to be measured in a 15-minute period. They also provide almost real-time information. In 2018 the national Smart Grid Working Group in Finland suggested opening the control of smart meters to the markets and allow commercial parties to participate in DSF control through them. According to the Smart Grid Working Group, the estimated controllable load through smart meters was around 1800 MW (Pahkala et al 2018). The decree of the Finnish Government on electricity supply settlement and measurements (767/2021) states that the control of smart meters is to be opened for other market actors on January 1, 2026. The decree requires further refinements in order to successfully open smart meter load control to the markets.

While the new legislation specifies the conditions and requirements for flexibility, there remains lack of standardisation. The independent aggregator role has been introduced and market access barriers have been reduced, but for example specific compensation schemes need to be defined. Also, prequalification requirements, defining baselines and technical modalities require further development across the member states. Notably, the framework for aggregation has limited harmonisation and standardisation at EU level. Without mutually compatible requirements across the member states, the cost for the cross-border participation of aggregators could become a barrier. To remove this barrier, guidelines should be expanded to ensure a harmonised aggregation framework (EC 2020). The harmonization of the DSF framework is promoted through the upcoming network code for DSF (ACER 2022).

4 Flexibility Value Chain

Prosumer level demand and supply, such as flexible loads and local generation and storage units, can provide flexibility by allowing for the load or generation profiles to be modified from the planned or usual pattern. This demand side flexibility from DERs can create value to different market actors. Value can be created through both implicit and explicit demand side flexibility. The value created by DSF that flows through the different market actors forms the flexibility value chain (Van der Veen et al. 2018). The value is created with services, that can be procured and provided by different actors. These services are presented in this chapter, as well as the deployment of these service in Finland. Additionally, the market actor roles related to DSF are introduced, both traditional and modern, and the barriers and required measures identified from the literature analysis.

4.1 Flexibility services

The prosumer can use flexibility to optimise their consumption profile. Optimisation can be done to for example match consumption with a dynamic price power supply contract or to maximise the use of self-generated energy. For the balance responsible party flexibility can act as an additional tool in optimising its portfolio. BRPs aim to avoid imbalance fees, maximise revenue of generation, and limit the cost of sourcing power. Distribution System Operators can use flexibility to increase the efficiency and performance of their operation. Flexibility can be used to improve congestion management and thus help to delay or potentially even avoid reinforcing the grid. The same applies for Transmission System Operators, who can utilise flexibility for constraint management as well as for ancillary and adequacy services (Van der Veen et al. 2018). Flexibility services can be divided into explicit and implicit demand side flexibility services.

4.1.1 Implicit demand side flexibility services

Implicit flexibility services can be provided to a prosumer by a flexibility service company, an (independent) aggregator or a supplier. Prosumers can also implement implicit flexibility by themselves by following electricity market prices or by using automated equipment that follows price signals (EC 2022). Implicit flexibility services can be divided into four categories based on their purpose: Time-of-use (ToU) optimisation, in-home balancing, maximum load control and emergency power supply.

Time-of-use optimisation is the most common form of implicit demand side flexibility and it means the shifting of consumption based on market price signals. When the market price reaches a certain threshold defined by the prosumer, they can shift their consumption to another time point when the price level has dropped. The flexible load can be for example an electric vehicle or electrical heating. Time-of-use optimisation can also refer to the prosumer increasing the use of their own generation or using previously stored energy during high priced hours. In order to successfully optimise load based on price signals, market prices need to be known in advance, which is available for end-users in Finland. The goal of time-of-use optimisation is the reduction of the customer´s overall electricity cost (Bilbiloska et al. 2022).

In-home balancing means the optimisation of buying, producing, storing, and selling energy. Prosumers can use their own surplus generation in electrical heating or store it, for example, in batteries. Surplus generation refers to the energy that would not be consumed with the typical load profile of the consumer. By shifting flexible consumption, such as electrical heating, to match the generation profile, surplus energy can be utilised (SmartEn 2022). Smart meters have enabled end-users to receive detailed information about their consumption, which makes optimisation possible (Paiho et al. 2018). Surplus energy can also be sold to the market, but the profitability of selling depends on the market price level. Self-consumption is usually preferred due to costs from taxes and grid tariffs present in grid consumption that are not accounted for in feeding surplus generation into the grid.

Maximum load control means reducing the maximum load of the prosumer. In addition to the distribution fee, which is based on the consumed energy, the distribution cost includes a basic fee, the size of which is tied to the connection capacity. By utilising DSF, the maximum load of the end-user can be reduced possibly allowing for a smaller connection capacity. Some customers also have a grid tariff component in their contract that is based on the maximum load and/or the connection capacity. If the maximum load is decreased, it can lower the grid tariff costs for the prosumer (Huuki et al. 2018).

Finally, demand side flexibility can be used as part of emergency power supply during outages. Flexibility can be utilised for islanding with emergency power supply. During an outage a backup power supply, such as energy storage, may only cover a part of the typical electricity consumption. When available power is limited, loads require to be shifted to minimise damage and costs caused by the outage and keeping the most important equipment running (Van der Veen et al. 2018).

4.1.2 Explicit demand side flexibility services

Explicit demand side flexibility services can be divided into four categories based on their purpose. These services are mainly provided by an aggregator, but large enough prosumers with high flexibility capacity can provide the services by themselves. The four categories include wholesale services, constraint management services, balancing services, and generation adequacy services.

Wholesale services

Wholesale services are provided for the balance responsible party to decrease the costs of purchasing electricity on the day-ahead and intraday markets as well as through the balancing mechanisms. By utilising flexibility, the BRP can increase the value of their portfolio. These services can also be provided for the supplier. Since all market participants need a BRP, services for the supplier can be considered indirect services to the BRP. Wholesale services can be further divided into four subcategories: day-ahead optimisation, intraday optimisation, self-balancing and passive balancing, and generation optimisation.

The aim of day-ahead optimisation is to shift loads from high-priced periods to low-priced periods on a day-ahead basis or on a longer timescale. Using flexibility to optimise day-ahead loads reduces the overall costs of electricity purchase for the BRP or supplier. Demand side flexibility can be traded by establishing a bilateral agreement or via day-ahead market exchange (Van der Veen et al. 2018).

Intraday optimisation has the same principle but with a shorter timeframe. Intraday optimisation can be carried out only after the day-ahead market has closed. This gives opportunity for a more detailed optimisation. BRPs and suppliers can use intraday optimisation to adjust and repair forecast errors remaining after the day-ahead market.

Self-balancing means the reduction of portfolio imbalance to avoid imbalance fees. A BRP can use demand side flexibility to optimise its portfolio position and therefore lower expected imbalance costs. In some markets, such as in the Netherlands, TSOs give compensation to BRPs that deviate their portfolio balance position towards the right direction, reducing the total system imbalance. This is called passive balancing and the TSO provides the BRP with real-time information to support imbalance prediction. Passive balancing includes the risk of making the total imbalance and thus the final imbalance fees less predictable (Van der Veen et al. 2018).

Generation optimisation refers to the optimisation of generation units as they are preparing for the next generation hour. Because conventional generation units have limited control speeds, they start to ramp generation up or down minutes before each hour. In order to avoid imbalance, generation units must have some over or undershoot, which can reduce the lifetime and increase the fuel consumption of the unit. Demand side flexibility can be used to avoid this over or undershooting of power output. (Van der Veen et al. 2018).

In some countries, such as France, BRPs are obliged to take care of security of supply or to hedge its risk and can therefore benefit from using flexibility for adequacy services. In the Nordic markets adequacy services are provided by the TSOs (Van der Veen et al. 2018).

Other explicit demand side flexibility services are provided for the TSO and DSO. These include constraint management services, balancing services, and adequacy services.

Constraint management services

Constraint management services support transmission and distribution system operators in optimising grid planning and operation during both physical and market constraints. Demand side flexibility for constraint management can be divided into four categories: voltage control, grid capacity management, congestion management and controlled islanding (Van der Veen et al. 2018).

With the increase in renewable energy in the power system, overgeneration may occur increasing the grid voltage level. This can lead to voltage problems in the grid. Increasing load or decreasing generation can help to lower the voltage level of the grid and thus prevents voltage level from exceeding limits. By using demand side flexibility for voltage control additional investments in for example automatic tap changers and generation curtailment can be avoided (Forero-Quintero et al. 2022).

Grid capacity management refers to system operators using flexibility to increase their operational efficiency. Grid capacity management is carried out on a voluntary basis. The aim of grid capacity management services is to delay grid reinforcements, optimise component operational performance, reduce grid losses, and increase reliability during planned outages. By adding demand side flexibility to the system peak loads can be reduced deferring the need for reinforcements. Reducing grid peak loads also reduces the load on grid components and their lifetime can be extended. Reducing peak loads also affects grid losses. Transmission energy losses are proportional to the square of transmitted energy and thus lowering peak load also reduces losses. Grid reliability can be increased during maintenance when consumption is reduced on a voluntary basis when needed (Nordic Council of Ministers 2017).

Like capacity management, congestion management is also used for avoiding system overload and failures by reducing peak loads, but it can be carried out non-voluntarily. The need for congestion management services occurs when overload has not been anticipated in the grid planning process. Unlike grid capacity management, congestion management mechanisms affect the freedom to dispatch, trade and connect power in the grid (Nouicer 2023).

Controlled islanding refers to the prevention of interruptions in grid sections that are affected by a fault in a feeding grid section. Demand side flexibility is used to balance local supply and demand when the grid section is disconnected from the faulted one (Van der Veen et al. 2018).

Balancing services

Balancing services refer to the TSO utilising demand side flexibility in the balancing and reserve markets. In balancing services, demand side flexibility is used in the reserve markets to support maintaining the system frequency at 50 Hz. Demand side flexibility can be used in all reserve products. The aggregator or flexibility service provider can receive remuneration based on the available flexibility capacity or on activated energy (Forero-Quintero et al. 2022).

Generation adequacy services

Adequacy services are used to increase security of supply by maintaining an adequate amount of long-term generation capacity in the system. The requirement for this capacity can be reduced by introducing demand side flexibility as a service. Adequacy services can be divided into four service categories: capacity markets, capacity payments, strategic reserves, and hedging (Van der Veen et al. 2018).

Capacity markets are used to secure generation capacity for long-term demand. Increasing security of supply by a market-based service ensures that the resources with the lowest costs are built or remain in operation. Capacity markets can be further divided into centralized and decentralized. In centralized markets the transmission system operator estimated the capacity needs and procures capacity. Contracts are made with production assets that are approved below the clearing price. Some countries (e.g., France) have a decentralized capacity market where the BRP/supplier has an obligation to provide capacity. Demand side flexibility can be used to help the BRP/supplier to reduce its capacity requirements. Demand side flexibility can also be used as an asset to the capacity market (Van der Veen et al. 2018).

Capacity payments are used to achieve enough liquidity in the market. The TSO pays the capacity provider to deliver capacity to the market. Demand side flexibility can be used as a capacity asset here as well.

Strategic reserves are managed and activated by the TSO. The reserves are kept out of the market and can be activated based on a price signal or a technical signal. Demand side flexibility can be utilized as a strategic reserve (Van der Veen et al. 2018).

With hedging, the BRP can mitigate price risks associated with fluctuating electricity supply and demand. Since high price levels usually occur during times of scarce production, hedging can be considered a mechanism for adequacy. Hedging is typically carried out with over-the-counter contracts or with futures exchanges. DSF can be utilized as an instrument in hedging products or traded as a hedging product by itself. For example, the aggregator could offer the FRP the opportunity to activate DSF at a certain price level (Van der Veen et al. 2018).

4.1.3 Flexibility remuneration

The flexibility requesting party (FRP) requests flexibility from the flexibility service provider in exchange for a compensation. Compensations can be given based on energy volume, power performance, availability, or compliance with delivery requirements. Energy volume compensation is based on the requested volume or the activated volume of flexibility. Power performance compensation depends on the delivered power in kW. Availability compensation means receiving a fixed price based on the availability of capacity in kW/h. Finally, the compensation can be affected by how well the flexibility service provider meets delivery requirements, such as response time, duration, and ramp rate. If the requirements are not met, the flexibility service provider can receive penalties or disqualification. In addition to these compensation methods, FRP can request prequalification assessments and availability assessments outside activation (Van der Veen et al. 2018). As declared in the European legislation, the acquisition of flexibility should be market-based. This implies that the principle of flexibility price formation on all markets is to be non-discriminatory, transparent and ensure competitiveness (Electricity Regulation (EU) 2019/943).

4.2 Flexibility deployment

The Nordics already have a relatively favourable market platform for flexibility deployment compared with many other European countries. The preconditions for market participation are relatively favourable, the retail markets are notably competitive, there are multiple competing suppliers that end-users can choose from freely, all suppliers provide a dynamic tariff contract and there is a nearly full roll out of smart meters. The recent legislative changes further improve the conditions for DSF deployment in Finland (Electricity Market Act 588/2013). The participation of new actors, such as the independent aggregator, is supported by removing the favouring of traditional supply compared to flexibility (Bergaentzlé et al. 2021). This chapter first introduces on which markets and services are open to DSF and independent aggregation in Finland. The second sub-chapter discusses the current state of flexibility service deployment for small-scale prosumers.

4.2.1 Independent aggregation and DSF

In this chapter, the markets and services that are open to DSF and independent aggregation are presented.

Reserve markets

All reserve products in Finland are open to demand side flexibility when the preconditions are met. Independent aggregation was first introduced in the FCR-D market in 2017 and a year later also in the FCR-N market (D'Ettorre et al. 2022). FFR was opened to independent aggregation in 2020. aFRR capacity markets were opened for independent aggregation in May 2023 with a temporary model, which will be further developed after the implementation of the aFRR energy market (Fingrid 2023h). Independent aggregation was also piloted in the mFRR energy market in 2018-2021. The aggregation pilots were carried out by the Finnish TSO and the pilot partners in 2018, 2019, and 2020-2021. The gained experience from the pilots remained narrow. During the 2019 pilot, activations of regulating bids by the independent aggregators were made six times. In 2020, the corresponding number was five. No activations were made during the pilots in 2018 and 2021. Despite the few activations, the pilot allowed for the development and testing of operating models for independent aggregation in the Finnish electricity system. A model for independent aggregation is going to be developed in the future (Fingrid 2021b).

Generation adequacy

Finland has a strategic reserve for peak load capacity, which secures the security of supply in situations where electricity procurement does not cover the anticipated consumption. The strategic reserve, operated by the TSO and procured by the National Regulatory Agency (NRA), allows demand side flexibility but not independent aggregation (Sáez Armenteros et al 2021). For the period 1.11.2022-31.10.2023 a strategic reserve was not procured because the

Finnish Energy Authority did not receive offers that met the strategic reserve conditions (Energy Authority 2022a). The energy authority has also proposed not to acquire strategic reserve for the following period 1.11.2023-31.10.2024. An opportunity for stakeholders to comment on the Energy Authority´s draft decision has been reserved. The proposal is based on a resource adequacy assessment for the period 2023-2033 carried out by AFRY Management Consulting and the Energy Authority concludes that a strategic reserve is not needed to reach the national reliability standard (Energy Authority 2023).

Congestion management

In the transmission network, aggregated DSF is allowed for congestion management, but the participation of an independent aggregator is not (Sáez Armenteros et al 2021). In addition to power system balancing, the mFRR market is used for congestion management in Finland. The TSO can procure regulating power for special regulation, which refers to the procuring of regulating power from the balancing markets to other uses than balancing. To be ordered for special regulation, the reserve may include more detailed location information. Traditionally, location information on the north-south level has been sufficient, but recently the need for more detailed information has arisen (Fingrid 2023c). At the distribution level demand side flexibility has been piloted in various trials. However, the Finnish distribution grid has been dimensioned to withstand high electricity consumption and therefore there has not been a significant need for congestion management so far, which has hampered the deployment of flexibility for these services (Sáez Armenteros et al 2021).

In the long term, however, the need for congestion management on the distribution level may arise as the grid load increases (Nordic Electricity Market Group 2022). The European legislation is also promoting the use of flexibility on the distribution level. Article 32 of the Electricity (Recast) Directive 2019/944/EU requires the DSO to procure market-based services, such as flexibility, when such a service is cheaper than grid reinforcements.

Wholesale

Wholesale services are open to demand side flexibility in Finland, but they are limited to the BRP portfolio, i.e., an independent aggregator cannot provide the service (D’Ettorre et al. 2022).

4.2.2 Flexibility services

Consumer interest in dynamic supply tariffs has been relatively low. In 2018, around 9% of Finnish electricity consumers had opted for a dynamic pricing contract (Energy Authority 2019). The 2022 energy crisis in Europe caused energy prices to hit an all-time high and the uncertainty of the electricity market increased significantly. Consequently, most electricity suppliers stopped offering customers new fixed-term and fixed-price electricity contracts and most available contracts were dynamic priced. The kilowatt-hour price of new fixed-term contracts rose from 10 to up to 40 cents between January and September 2022 (Energy Authority 2022b). By January 2023, the share of dynamic supply contracts had risen to 14%. Customers with fixed priced contracts were also encouraged to decrease their overall consumption level and shift it to lower priced hours. Pilots were launched by Finnish suppliers where fixed price customers received compensation if they participated in demand side flexibility. These flexible contracts are still available and have gained customer interest (Haapala 2023).

At the beginning of 2023, the uncertainty of the power market decreased, and price levels started to fall back towards the level of January 2022 (Haapala 2023). While price levels are decreasing, the awareness gained remains. The high price levels and limited contracts available significantly increased the interest in smart electricity systems and demand side flexibility. Automated market price following smart home systems have gained interest as they can result in savings of up to tens of percent. These services were available already ten years ago, but they have not received much attention before due to the major share of fixed-price electricity contracts. The minority of customers with dynamic pricing tariffs were not ready to invest in expensive systems with a long payback period. With the increasing interest in these systems, the investment costs have also gone down, from thousands of euros to a few hundred and shortened the payback time to down to even a few months. For some energy service competitors, the wait was too long and had to shut down their operation before the shift in the market conditions. Even though price levels have gone down, they are likely to stay volatile as the share of intermittent renewable energy increases in the system. This maintains the incentive for customers to keep participating in demand side flexibility (Mäntylä 2022).

Energy service companies, such as OptiWatti, offer implicit DSF services to customers, both households and businesses. The services include automated smart home systems that control space heating, solar power and EV charging based on the customer´s behaviour. When combined with a dynamic supply tariff, the system reacts to market price signals bringing cost savings up to 40% (OptiWatti 2023).

There are around 20 aggregators, both independent and suppliers, active in Finland. They bring together generation and flexible loads and compensate their flexible resources for the provided service (Saviuc et al. 2022). Both independent and supplier aggregators provide explicit flexibility services for companies and larger buildings in Finland. For example, the service provided by the supplier Väre requires a minimum load of 50 kW from participants (Väre 2023).

The participation of households in aggregation services has been piloted in Finland, but currently, to the author´s knowledge, there are no services available. The suitability of household flexibility for power system balancing was piloted for the first time by the electricity supplier Helen in 2014. The pilot was conducted in cooperation with Fingrid and There Corporation (Helen 2014). In 2017 Helen launched a DSF service for companies and household customers. With the service, they were able to participate in power system balancing while maintaining their desired level of living comfort. To access the service, the household had to have a smart home management system provided by an energy service company (Helen 2017). Fortum also introduced an explicit DSF service for households but stopped accepting new customers in 2020 (Fortum 2023).

On the distribution level DSOs offer peak/off-peak tariffs with different price levels during e.g., different seasons. Customers are also offered night grid tariffs with lower prices during night-time. In addition to time bound tariffs, some DSOs offer tariffs based on peak capacity. For congestion management, electrical load control through smart meters is used. According to Saviuc et al. (2022) the implementation of smart meters has been one of the most significant technical preconditions for participating in DSF. The arrival of the second-generation smart meters provides even more opportunities as they allow a 15-minute measurement resolution, compared with the current level of 1 hour time frames.

4.3 Flexibility actor roles

While the economic and technological factors have a significant role in DSF deployment, the social, behavioural, and political aspects also need to be considered. If the focus is kept only on the techno-economical aspect of DSF, it could delay the transition to more flexible demand side resources and increase the costs to market actors. In this regard, it is important to develop and define the markets and actor roles, while taking into consideration policies and regulations and the behaviour of consumers and companies.

Traditionally flexibility services were procured by the TSO from power plants and large consumers. In the flexibility markets, which include all markets where flexibility is traded, traditional market actor roles are accompanied by new roles and completely new actors. The rising share of market actors requires an even greater need for coordination and collaboration (Forouli et al. 2021). This chapter introduces the role of traditional market actors in DSF as well as the new roles that have arisen as a result of the deployment of new flexibility markets.

4.3.1 Traditional market actors

In the flexibility markets traditional power system market actors introduced in Chapter 2 are taking on new roles and responsibilities. This includes, for example, the changed perspective on end-users who are now becoming active members of the power system instead of just being passive consumers of energy. In the flexibility markets, end-users become prosumers who can act as DSF providers to grid operators for power system balancing. Moreover, prosumers can help to balance the grid from the supply side. As the need for flexibility grows in the system, unlocking DSF from smaller end-users, such as buildings and households, has become increasingly important. The issue with small loads is that the existing traditional market actors have no incentive to utilise them, hence the role of the aggregator was created. The aggregator pools the flexibility capacity from prosumers and offers it as a service to other market actors, such as the TSO, DSO or the BRP (Bergaentzlé et al. 2021).

Among Finnish market actors, the TSO has been a pioneer in DSF utilisation. Flexibility has been used for quite a long time for system balancing and the independent aggregator was allowed to join the first balancing market in 2017. From there, flexibility has become increasingly popular, and the independent aggregator role has developed and is finally recognised in the recently published legislative amendment (Electricity Market Act 588/2013). The successful utilisation of flexibility for power system balancing has created the basis and incentive for the deployment of DSF. The TSO keeps developing new market possibilities for flexibility by opening new reserve products for independent aggregation (Sáez Armenteros et al 2021).

The supplier and the BRP both have significant potential in utilising flexibility. They are well-positioned to collect, access and utilise customer DSF resources (Saviuc et al. 2022). Electricity suppliers have direct access to the consumer interface. They are also probably the best known out of all market actors since end-users have to choose their supplier by themselves. This gives the electricity supplier an enhanced possibility to reach customers with DSF services compared with for example independent aggregators. One of the challenges with flexibility deployment seems to be the lack of knowledge of these services amongst end-users. Suppliers could increase the awareness of customers by providing flexibility services. Suppliers and BRPs have a variety of possibilities when it comes to DSF services. They could provide both implicit and explicit DSF services, from which customers can choose their preferred model. These services and the flexibility systems can be provided by the supplier themselves or in cooperation with other market actors. Offering an implicit DSF service to customers widens the service selection of the supplier and creates new business opportunities with new products. This can increase customer attraction and loyalty. With explicit services the supplier or the BRP can take the role of an aggregator and either provide flexibility for the TSO reserve markets or use it to optimise the BRP balance portfolio (Bergaentzlé et al. 2021).

The traditional role of the DSO, which includes the planning, operation, and maintenance of the grid, is also evolving. As the power system keeps transforming, the DSO is becoming more active and could in the future have a market-facilitating role providing access to DSF services in a technology-neutral manner to ensure the utilisation of the most efficient resources. This could be implemented with a cost-reflective grid tariff structure and local market platforms. Regarding congestion management, the TSOs and DSOs must avoid the situation where the activation of flexibility solves national congestion issues for the TSO but causes local problems to the DSO. Overall, the cooperation of the DSO and TSO is crucial when bringing DSF to the distribution level as well (Bergaentzlé et al. 2021).

4.3.2 Modern actor roles

In addition to the traditional market actors, new roles have been introduced to the markets. This chapter introduces the most relevant roles identified. One market actor can take on many roles and one role can be shared by several actors.

Independent aggregator

The independent aggregator has a key role in unlocking distributed DSF. The role of the independent aggregator was presented in more detail in Chapter 2. The independent aggregator role was introduced to improve the efficiency of the power system by facilitating demand side flexibility, energy efficiency and automation of consumption. The independent aggregator can make use of value stacking and offer multiple services, such as flexibility from storages, based on the aggregated resources (Saviuc et al. 2022).

Energy community

An energy community can be seen as a new and wider role of the prosumer. Energy communities are associations of different actors that utilise their joint electricity generation, storage, and flexibility. An energy community can be set up by anyone, such as a housing association. An energy community can aggregate the distributed resources of the participants creating a higher flexibility potential. An energy community can also form a virtual power plant and aggregate loads that are not located near each other. Through energy communities, it can be easier to make investments in energy generation or storage, and to share risks and responsibilities. A smaller energy community can be further aggregated by an aggregator or if the total flexibility potential is high enough it can participate straight to the market (Bergaentzlé et al. 2021).

Energy service provider

Energy service providers are companies that provide various types of energy management services. These companies include Energy Service Companies (ESCo) and other providers of smart energy management systems and services. These services implement measures and investments to increase energy efficiency and reduce overall consumption (Motiva 2023a).

Many service providers have implemented implicit DSF into their systems. These services provide the end-user with a smart system that helps to minimise costs and optimise energy usage based on the customer´s needs. In addition to following market price signals, the smart system may allow the end-user to determine desired room temperatures. The system can also analyse outside temperature and weather forecasts to react in advance to temperature changes (OptiWatti 2023). In Finland heating and cooling make up for a major share of final energy consumption (Motiva 2023c). Consequently, they have the highest potential for cost savings. When coupled with a dynamic supply tariff, the greatest benefits are achieved. In addition to the implicit DSF, energy service companies would have the potential to offer explicit DSF services with the help of market actor cooperation (Van der Veen et al. 2018).

Possible controllable appliances include various cooling and heating systems such as electrical radiators, underfloor heating systems, air-source heat pumps, boilers, trace heating and car heating. Additionally, these services can include the control of electric vehicle charging and PV systems. For the PV system the generation, consumption and storing of solar power can be optimised. The system can strive to use as much of the PV generation as possible by shifting consumption to sunny hours or, if the market price is high enough, the system can direct the excess to be sold to the grid (Van der Veen et al. 2018).

Modern energy service systems are cloud-based services and require no major renovations. They are typically controlled though the consumer´s computer, tablet or smartphone and can be controlled from any location. Also, the implementation costs are going down as the popularity of these services increases (Mäntylä 2022).

Original Equipment Manufacturer (OEM)

The flexible resources, such as electrical heating systems and solar panels, are provided by the original equipment manufacturer. The OEM defines the level of automation the appliances have integrated to them. Some appliances might have the possibility for reacting to price signals already integrated into them, but a separate control system is still needed if all flexible resources want to be controlled together.

Supporting actors

Unlocking demand side flexibility also requires the participation of other supporting entities, such as the retailers of flexible resources. Retailers sell for example PV systems from the OEM to the end-user while providing customer service and possible maintenance services. Other supporting entities include R&D institutions, regulators, and market operators. Regarding institutions and regulators, the effect of policies and regulations on enabling DSF need to be considered. Also, the informal norms, rules and attitudes that are affecting the behaviour of actors need to be considered. Market operators, such as Nord Pool, also have an important role in allowing flexibility to be traded in different wholesale markets (Bergaentzlé et al. 2021). These supporting roles are less relevant to the scope of this thesis and are thus not discussed in more detail.

4.4 Barriers and measures for DSF deployment

Efforts are being made on the regulatory level to promote the development and deployment of DSF. However, the development and expanding of DSF services is hampered by the lack of market products accessible to small end-users. Moreover, although smaller scale end-users could have access to the markets through aggregators, the roles and responsibilities of traditional and modern market actors remain somewhat unclear (D’Ettorre et al. 2022).

According to Schittekatte et al. (2021) one of the key challenges with DER participation is that the value of direct interaction with the electricity markets is considered too low compared with the costs incurred and the knowledge needed. Aggregators help to mitigate this challenge by acting as intermediaries between the end-user and the market actor. On the end-user side, the aggregator offers the ability to understand, adapt and react to the market and correspondingly on the wholesale market side the aggregator takes care of pooling small heterogeneous resources (Schittekatte et al. 2021a). The costs of DER flexibility can be reduced by further increasing competition and energy efficiency. This requires establishing the role and responsibilities for independent aggregators, which have been presented in the recently amended Electricity Market Act 588/2013. Additionally, the independent aggregator could be allowed to access all markets in order to reach full potential. This is currently not possible in Finland, but new markets are being piloted and opened for independent aggregators. DERs can also participate in explicit DSF through a supplier or a BRP.

Schittekatte et al. (2021a) also identified challenges related to the participation of the independent aggregator. The interaction between the independent aggregator, the BRP, the supplier and its contracted customers was found to present a considerable challenge in the EU. Suppliers procure electricity based on consumers´ expected load and BRPs are responsible for maintaining power balance. An independent aggregator sells a reduction or increase in consumption compared with the baseline, which can cause an imbalance to the supplier and BRP portfolio. Even though the portfolio value of the supplier or BRP can be increased through flexibility, it can also expose the portfolio to more risks (Schittekatte et al. 2021a). This issue is addressed in the Article 17 of Directive 2019/944/EU and has been implemented into the Finnish legislation through the amended Electricity Market Act 588/2013. The suitable compensation models must be defined for new DSF services in accordance with the legislation. Implicit DSF can also complicate the suppliers' and BRPs´ operations when customers deviate from the predicted consumption profile. Additionally, the uncertain nature of flexibility presents a challenge for the (independent) aggregator. Unforeseen changes in end-user consumption can occur, the need for flexibility can be predicted incorrectly and the automated systems can malfunction (Woittiez 2016).

Small resources, such as household heat pumps, typically lack control and monitoring capability. These qualities must be added on separately, which increases costs. Compared with larger resources, where one installation provides a large amount of flexibility, smaller resources require multiple installations in order to achieve the same level of flexibility (Burger et al. 2019). This challenge is especially prevalent in behind-the-meter resources, as stated by the IEA (2022). Smart meters could provide a solution for managing behind-the-meter loads without requiring additional installations (Pahkala et al. 2018). These resources are also affected by the consumer´s interests, which may not align with the needs of the power system. Therefore, effective incentives are needed to attract and maintain consumer interest. Another challenge recognised by the IEA (2022) is the difficult estimation of consumption and flexibility potential due to the increasingly variable weather patterns and consumer behaviour. Rapid and more intense weather changes, the prevalence of dynamic supply tariffs and new technologies, such as EVs, make power flows in the low voltage networks less predictable, which causes uncertainty.

Another challenge is related to measuring power delivery i.e., how much consumption or generation was actually shifted. Baselines should be defined and introduced because DERs do not typically have formal schedules for their generation or consumption. System operators and DERs should agree on a baseline, which is used to verify flexibility activations by comparing the realised load to the baseline. It was found by Ziras et al. (2021) that baseline methodologies may be too simple, lack transparency and might lead to inefficient utilisation of DERs. Schittekatte et al. (2021a) argue that there is currently no consensus on an adequate way for defining baselines. Prequalification requirements can also create a challenge for aggregators. If a formal prequalification process has to be performed for each small flexibility unit, the costs can become too high compared with the gained revenue. Allowing the aggregator to manage their own pool and take responsibility for them reduces barriers for entry (Schittekatte et al. 2021a).

A significant issue in flexibility deployment has been the lack of consumer awareness on flexibility. Until last year and the record high electricity prices, most customers had not experienced problems with electricity supply and pricing, which has hampered the growth of interest on the matter. A study carried out in the BCDC Energy (2017) research project showed that only around 10% of the survey respondents had even heard the term demand side flexibility. However, the study also showed that consumers´ interest in the subject increased when they received information about flexibility.
According to Woittiez (2016) the key to unlocking market-based flexibility is to offer a compelling proposition to prosumers. The aggregator or flexibility service provider needs a compelling service model. The proposition should be easy to understand and highlight the incentives for flexibility, such as cost savings, environmental benefits, and enhancing power system reliability. Also, convenience is a key factor in developing flexibility services. The majority of consumers do not want to invest much time and effort on implementing flexibility, and therefore, automated solutions have significant potential. Finally, it is important that the service provider is a reliable party who offers

expertise, transparency, and the protection of the participants´ privacy (Woittiez 2016).

The end-user’s willingness to participate in a flexibility service is highly dependent on the economic potential that can be gained from the system. The achieved savings should be high enough in relation to the capital costs of the home automation systems (D’Ettorre et al. 2022). However, the importance of cost savings is dependent on other aspects. The study carried out in the BCDC Energy (2017) research project revealed that some consumers were willing to decrease their cost savings if they achieved environmental benefits from flexibility. It can be concluded that consumers are not only interested in the financial gains of flexibility, but they also value the environmental aspects (Ruokamo et al. 2018).

D’Ettorre et al. (2022) argue that because of the more straightforward nature of implicit DSF, it could be considered a gateway to unlocking the potential of DSF. Implicit DSF services are easier to develop and implement because they do not require pre-qualification tests, fast activation times and detailed measurements. Furthermore, implicit DSF services are already available to small-scale prosumers.

The IEA (2022) highlights the importance of digitalisation and technological development in unlocking distributed flexibility. Technological development can be promoted by updating grid codes to ensure that DERs have the capability to participate in flexibility services. With the right incentives, digitalisation can transform DERs into valuable grid assets. Also, the cooperation and information transparency between market actors is crucial. An idea proposed by the IEA is to develop a common flexibility resource register to all market actors (IEA 2022).

Based on the findings from the literature analysis, the deployment of distributed flexibility includes three key aspects: the cooperation of market actors, the development of technologies and assets and the support from institutions and practices. The key aspects of DSF deployment are presented in Figure 7.

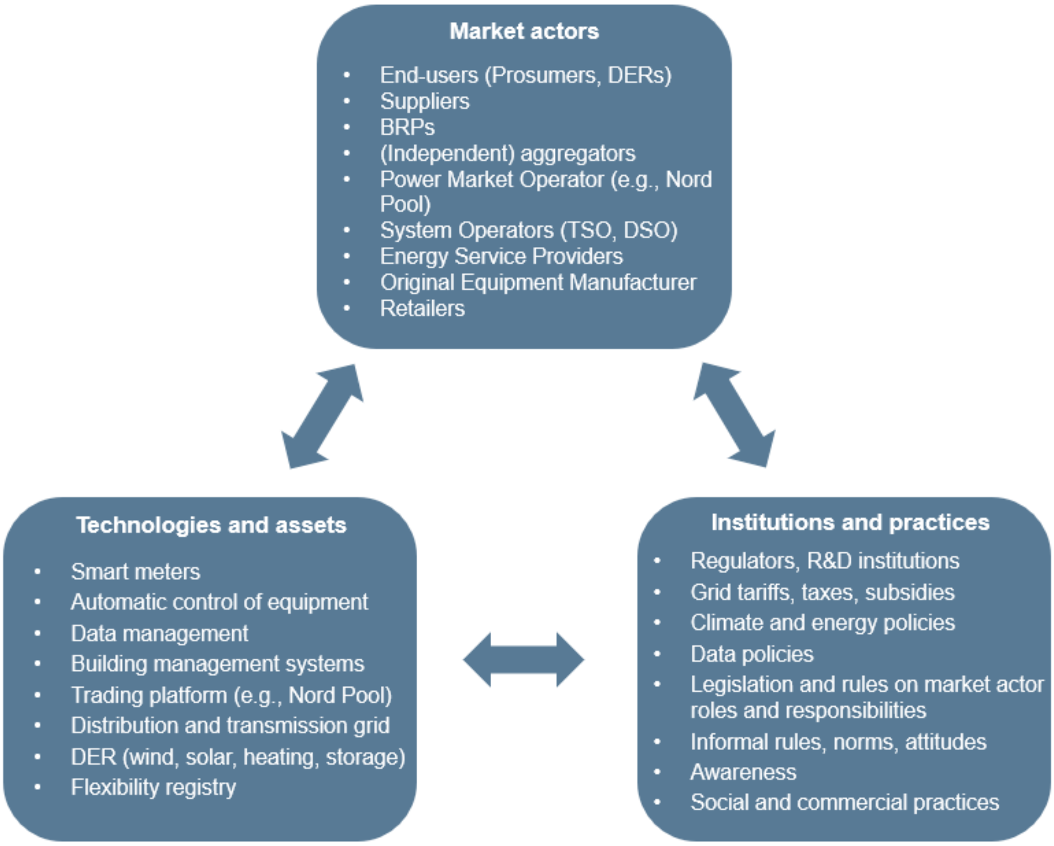


Figure 7. The key aspects of DSF deployment (Bergaentzlé et al. 2021).

5 Value chain of end-user DSF

Once the DSF services and different market actor roles have been defined, the value chain can be formed. The flexibility value chain represents the co-operation of the market actors, which is a necessity for unlocking flexibility. The market-based value chain of end-user DSF in the Finnish flexibility market is presented in Figure 8. The different role opportunities for market actors can be obtained from the value chain. The different roles can be taken on by multiple actor types and one actor can represent more than one role.

A building management system (BMS) is a system that manages and monitors all systems in the building, including storage, generation, and electrical consumption. The BMS provides the necessary ICT solutions that enable the control of flexible resources. Some type of BMS solution is necessary for an automated DSF system. With implicit DSF the prosumer can also control their consumption manually by following market prices themselves. The BMS can be provided by the OEM, the Energy Service Company, the aggregator, or the retailer. It is also possible that the BMS solution comes from an external party (Eini et al. 2021).

The aggregator role can be taken on by the supplier, the BRP or by an external actor. The supplier can act as an aggregator, but it can also provide DSF services without aggregation, such as implicit flexibility services. In addition to providing the BMS, the supplier and BRP can act as an Energy Service Company, or they can work together with one to create the service. This cooperation of actors has already been implemented in Finland (Helen 2017).

The value of flexibility can move through the market actors in different patterns. The TSO receives flexibility from the aggregated resources either through the supplier and the BRP or from an independent market actor. The balance responsible party can procure flexibility straight from its own portfolio or through the wholesale market, where flexibility can be traded. The (independent) aggregator receives remuneration for the flexibility they have provided and compensates its potential partners and the flexibility resource, i.e., the prosumer. The end-user can also participate in implicit DSF and save on electricity costs on both the supply and distribution level. These various possibilities of flexibility are presented in Figure 8.

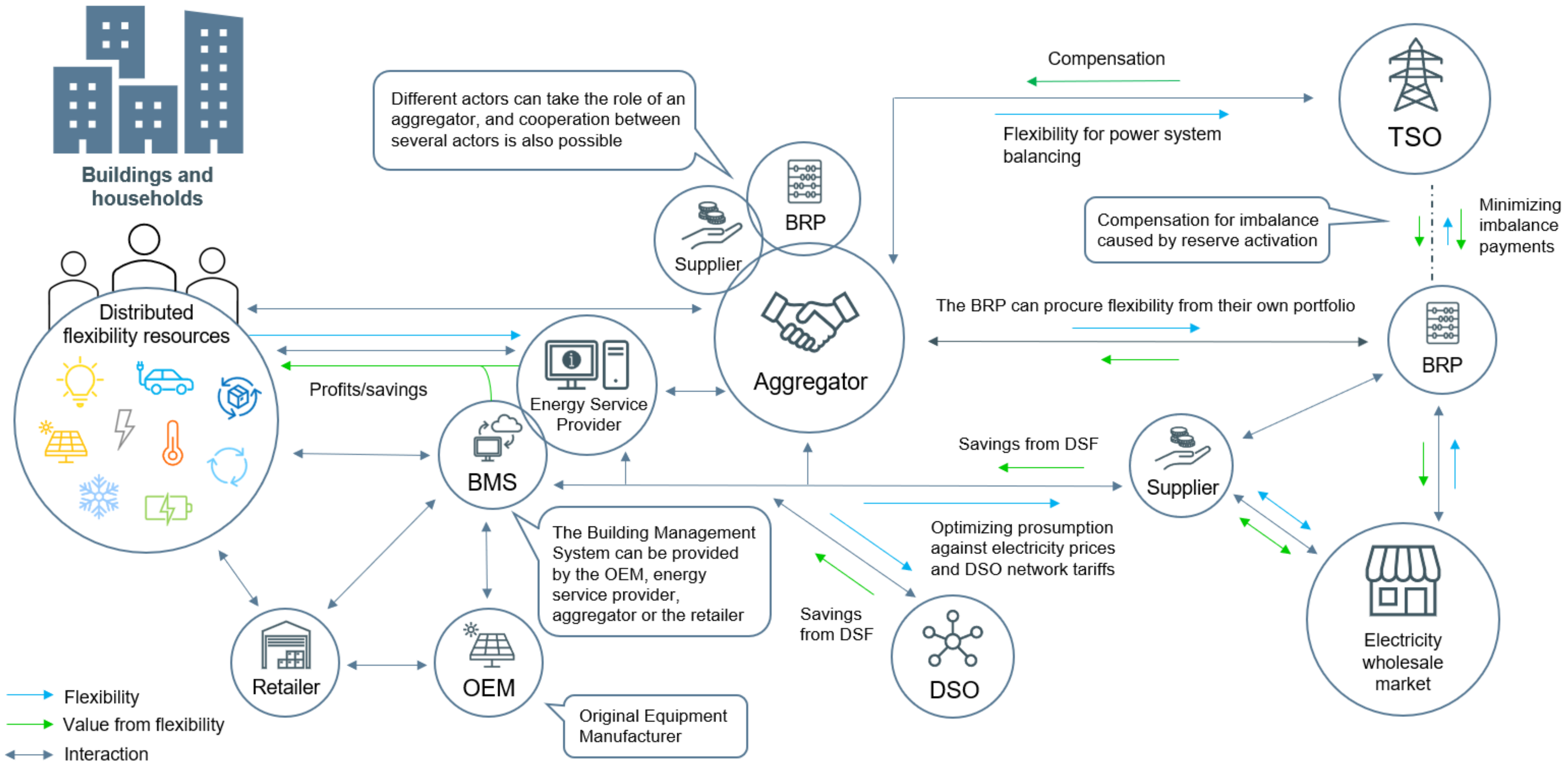


Figure 8. Value chain of end-user DSF

6 Market actor views on unlocking flexibility

This chapter presents the results of the empirical study of the thesis. The study was conducted through interview-based consultations with DSF related market actors. The market actors interviewed were chosen based on the actor roles identified in chapter 4.3. Due to the limited time frame, the roles identified as the most relevant were selected for the study. Suitable industry experts were chosen to represent each role. All interviewees operate in Finland. The case study consists of 15 interviews held in the spring of 2023. The chosen actor roles and the number of representative actors is presented in Table 1.

Table 1. Interviewed actor roles and number of representative actors

Market actor role	Number of representative actors
Supplier	3
Consumer	3
OEM	3
Energy service provider	2
DSO	2
Independent aggregator	2

In addition to the pre-assigned roles, most of the interviewees represented other roles related to DSF. The connection and overlapping of different roles are presented in Figure 9 in Chapter 6.3. The findings from the interviews have been summarised keeping specific companies and interviewees anonymous.

In addition to the interviews, a separate questionnaire was conducted for electricity suppliers. The questionnaire was carried out on the basis of an online workshop held in February 2023. The workshop was organised together with the Finnish Clean Energy Association and was attended by 25 representatives from different market actor roles. The workshop provided background information for the thesis and highlighted the relevant actor roles (Finnish Clean Energy Association 2023). Based on the lack of supplier/BRP representation in the workshop and their significant role in unlocking flexibility, it was beneficial to expand the research beyond interviews. This allowed for a more comprehensive view on the perspective of the supplier/BRP. The questionnaire was sent to 11 suppliers, eight of whom responded. The majority of respondents also acted as BRPs. Questions for the survey are presented in Appendix B.

The aim of the interview study was to explore the actor roles related to DSF, the potential and barriers for their cooperation and to assess the current state of DSF service development. The objective was to gain insight into the current challenges regarding DSF development and the solutions and measures required to address them. This included discussing the interviewees thoughts on their and other actors´ role in DSF development, the challenges they have recognised and their views on cooperation and measures to support DSF deployment. The chosen interview method combined the features of an unstructured and semi-structured interview (Hirsjärvi & Hurme 2015). Interviewees representing a specific role were asked the same questions, but between different roles the questions varied. The predetermined questions were followed, but free discussion and follow-up questions were also asked if needed to achieve better understanding on the subject. The interview framework consisted of common questions, which were presented to all participants except consumers, and actor-specific questions. The common questions provided a comprehensive view on the current market situation and market actor cooperation regarding DSF. To gain better insight on specific actor roles, more in depth actor-specific questions were included. The interview framework and questions are presented in Appendix A.

6.1 Possibilities and barriers

All interview participants recognised the importance of developing DSF in the changing power system. Many participants mentioned the promotion of social goals, such as reaching carbon neutrality and sustainable development, as the key objectives for DSF. Also, supporting the operation of the Finnish electrical system and preventing electricity shortages were mentioned. From the market actor perspective, different advantages were brought up.

For the electricity supplier, DSF brings new business opportunities. Suppliers can create services, both implicit and explicit, to customers and create new revenue streams. By aggregating explicit DSF the supplier/BRP can gain compensation from e.g., the reserve markets. The development of new services can also increase customer interest and loyalty. The suppliers also mentioned that DSF could and probably will be utilised for managing portfolio balance in the future.

DSF creates new business to other market actors as well. Independent aggregators, energy service providers and OEMs can increase their profits by developing DSF. The business model of independent aggregators is based on explicit DSF, but they can also take on the role of an energy service provider and create implicit DSF services to expand their business. Energy service providers can add implicit DSF services to their business and increase the benefits customers can gain from acquiring their services. The energy service provider can also take on the role of an (independent) aggregator and aggregate the flexible loads in their system. For the OEMs, integrating smart readiness into their appliances increases their competitiveness. A couple of the interviewees also mentioned that DSF brings secondary use to devices that already exist, which means that existing equipment can be used more efficiently and sustainably. One of the energy service providers mentioned that DSF and smart readiness can raise the value of a building, improve the image of a brand, and help to receive environmental certificates. The DSOs can gain similar benefits from DSF as the TSOs, including improving power quality, increasing security of supply and congestion management.

All interviewees mentioned the benefits that end-users can gain from DSF. The end-user has a significant role in the value chain as the source of flexibility. The end-user can lower their electricity bill and gain compensation from participating in DSF. They also benefit from lower market price levels. Customers can also gain better awareness of their overall electricity use, making optimisation easier. Some customers appreciate the societal benefits gained by participating in DSF, such as lowering emissions. During the energy crisis many end-users took part in lowering and shifting their consumption to support the power system. It should be noted that the benefit gained from DSF depends on many factors. End-users with very little consumption, such as people living in apartment buildings with district heating and no sauna or electric vehicles, do not gain much financial savings from these services. On the other hand, an electrically heated detached house can achieve significant savings.

Despite the significant possible benefits, there are still many challenges associated with the development of DSF. The interviewees had a largely uniform view of the challenges regarding DSF development and most challenges were recognised by all parties. More detailed actor-related challenges varied between market actors. The results from the interviews indicated that the participants had a comprehensive view on current issues.

For the consumer, the most significant barrier to participating in DSF is the lack of awareness and understanding about the subject. Especially until last year few consumers knew what was meant by DSF. According to the consumer representatives, the energy crisis and high price levels clearly sparked an interest to learn about one's energy use and the effect it can have on both their own electricity costs and the society. Still, most questions arising from consumers were related to how they can lower their energy costs, not how they can participate specifically in DSF. This further emphasises the lack of knowledge on DSF. Energy advisory services became increasingly popular last year but now that the price levels have dropped the interest level has gone back to its usual level. Last year's exceptional situation prompted several consumers to take part in DSF and some acquired automated building management systems. Although this was a development in the right direction, these active end-users still cover only a small percentage of possible participants. Many end-users still find the concept of DSF complicated and participating in it too difficult. An additional challenge is whether the end-users think that they can gain enough from DSF. The relation between the effort of participating in DSF and cost savings gained from it needs to be attractive enough. This is highly dependent on the end-user's electricity use, contract type, market price fluctuations and standard of living. If the market price level is too low or the consumer has a fixed-price supply contract, the cost savings from DSF do not act as an incentive. According to all interviewees, there must be enough financial benefit to gain and maintain consumer interest. The possible cost savings are also dependent on how much the end-user is willing to flex. The flexibility potential of a consumer can be limited by the lack of suitable technology but also by the lack of willingness to change their consumption habits. For example, the more indoor temperature is allowed to fluctuate, the more flexibility potential is reached.

Even though there are some existing DSF services, the market is still limited, especially to households and smaller commercial properties. The lack of service options, high costs and the risks of a novel business model have limited the interest in participating. Also, end-users might find it difficult to understand how these services work and whether they are trustworthy.

Another factor hindering the deployment of DSF is the poor compatibility of the current building stock with smart systems, causing more work and costs for all service providers. This may not be a barrier to DSF acquisition but complicates implementation, since the electrical system does not support a BMS. Electrical equipment in buildings is often not grouped in a way that allows for the easy implementation of a BMS. The same applies to most individual equipment, which do not have smart readiness integrated into them. This issue was mentioned by both the suppliers and the independent aggregators. According to the OEM interviewees, the smart readiness of appliances is still lacking. Currently, EVs were seen as the most advanced flexible technology. The majority of heat pumps, on the other hand, do not have any controllability implemented into them or it is limited to an on/off control. One of the OEMs had, however, already developed heat pumps with stepless control for commercial use many years ago. While most interviewees mentioned the lack of smart readiness as a challenge, one energy service provider had created a system that can relatively easily be installed in all types of equipment regardless of their smart readiness.

For the suppliers, who were currently not developing DSF services, the key issues were related to per unit costs, choosing which market to participate in, defining a baseline and the lack of properties in smart meters. Because the current technology and buildings lack integrated homogenous smart readiness, an electrician is typically needed to make necessary installations. This takes work hours and causes costs. Costs also arise from the development and manufacturing of smart systems and from tailoring them to each building. The existing building stock is very heterogeneous and therefore BMS must be somewhat tailored to fit the electrical system of each building. Considering these factors, the cost of the system can become significantly high relative to its cost-saving potential. This varies by the type of end-user, but generally, the per unit cost can be expensive. This also applies to explicit DSF, where only a small amount of flexibility is acquired with one installation. From the cost perspective, the suppliers stated that the most significant issue is requiring the electrician for installations. These concerns were also stated by the independent aggregators.

Choosing the market where to focus development has also been a challenge for the suppliers and one of the independent aggregators. All markets have their unique requirements, such as requirements for measuring and activation capability, which affect the decision making on investments. The suppliers stated that the predictability and persistence of market terms and requirements could be improved. However, they also recognised the need for development in the changing electricity system. Also, the lack of visibility to the future profit potential was mentioned as a hindering factor. One of the suppliers also stated that some of the requirements, such as the measurement accuracy and authentication of flexibility activations, could be defined in more detail for distributed flexibility. The potential of smart meter load control was recognised, but the lack of a common interface and the insufficient resolution and activation times of currently used meters were mentioned as an issue. Due to these limitations, a separate meter must be installed for explicit DSF, which further raises the costs of creating these services. This issue was pointed out by the independent aggregators as well. One of the suppliers had developed an EV control service and they were also currently developing a smart home system for households, with the plan of aggregating the loads in the future. In addition to the challenges already mentioned, developing an explicit DSF service has presented the challenge of deciding on profit distribution, i.e., what incentives are required for customers to become interested in participating. This supplier argued that market prices might not always align with power system needs, which is why the lost savings from deviating from market price optimisation must be compensated.

All suppliers had recognised the impact that implicit DSF can have on their operations. However, this was not seen as a concern that could not be managed. The effects are being minimised by maintaining and developing the forecasts for demand and supply. Detecting and forecasting flexibility activations from data is being developed and researched. One supplier thought that this could cause a temporary challenge but forecast models will develop and adapt to the market accordingly. The other suppliers thought that this could create more of a challenge in the future, but they were optimistic about resolving it. The suppliers´ view on the independent aggregator was positive, however, one possible challenge was pointed out by one of the suppliers and energy service providers. Ultimately, the independent aggregator´s effect on BRP portfolio could potentially influence customer prices within the supplier portfolio, unless effective compensation measures are implemented. The supplier also pointed out that the amended Electricity Market Act is taking development in the right direction.

The OEMs also highlighted the lack of consumer interest and the costs as key challenges. If there is no demand for smart appliances, it will not promote supply. One of the OEMs offers heating equipment integrated with the possibility for implicit DSF, but customer interest for this service has been minimal, especially before last winter. After the increase in price levels the interest in smart equipment has also risen. However, most consumers still do not require these features. The OEM also mentioned that in smaller properties, such as detached houses, the energy use of heat pumps is so low that significant cost savings cannot be achieved. Regarding explicit DSF, creating a large enough pool of flexible resources can be challenging. The interest of a large number of customers has to be first attracted and then maintained to gather enough flexibility potential. Another OEM has piloted a smart heating system before but are currently not providing them for smaller end-users. This OEM stated that the market has not been evolved enough to create a business model for DSF. Creating the technology is not simple and thus development should have a high enough incentive. Currently, they were exploring the idea again as the interest in DSF, especially on the end-user side, has increased.

The third OEM, which is a manufacturer of EV charging equipment, stated that currently the biggest barrier is the absence of vehicle to grid (V2G) technology. Most of the current vehicles and chargers do not support V2G, but they are already becoming more popular. The current vehicles need a system update to be suitable for V2G and new chargers are currently being developed. Implicit DSF, however, is possible with the current technology and this OEM already provides smart charging to customers. One of the OEMs expressed their own lack of understanding and knowledge regarding flexibility and the electricity markets. They expressed the desire to receive more education, alongside consumers. This OEM also argued that the sharing of

information should go both ways and that market participants should learn more about the technological perspective.
From the independent aggregator perspective, the current per unit costs of DER flexibility are too high to create a profitable business case. One independent aggregator emphasised that having to do thousands of installations to reach the flexibility potential gained from one large industrial resource is the largest barrier at the moment. The heterogeneous nature of smaller end-users requires additional work to adapt the installations to each destination. The independent aggregators also pointed out the inflexible nature of smaller end-users. The flexibility potential of smaller buildings, such as commercial properties and households, is affected quite significantly by comfort and safety requirements. The temperature requirements for healthy and comfortable living conditions and each end-user's personal preferences make developing a DSF system more complex. For example, a consumer might require that their EV is always on full charge and ready to go, even during the night. The third issue recognised by the independent aggregator is the uncertainty of legislative advancements. With such a modern business model, the future of legislation is unpredictable, which causes uncertainty in making investment decisions. The role of the independent aggregator was only recently officially recognised in the Finnish legislation.

The uncertainty of legislative advancements was also recognised by one of DSOs and they were hoping for a longer-term perspective regarding DSO level flexibility. From the DSO perspective, the market-based procurement of distributed DSF is possible but not in the current state of development. Using DSF to support the distribution grid is more complicated because of the locational requirements. The DSO level also includes more requirements for the availability of flexible capacity. If a grid reinforcement is deferred with flexibility, this flexibility must be available as long as the reinforcement is deferred.

One of the energy service providers, who was going to take on the role of an independent aggregator, had identified some challenges with taking on another role. This energy service provider was aggregating flexibility mainly from heat pumps, which causes two issues. The first issue is related to the technical limits of heat pump control i.e., most of the individual pumps only having the ability for on/off control while some of the electricity markets have linear control signals. The second issue was related to the absence of controllable loads outside the heating season. In order to create enough flexibility potential not only is a large amount of flexible equipment required but also a variety of technologies. The energy service providers emphasised the influence of the market price level. Before the energy crisis, consumer interest in DSF has been very low due to the low price level and prevalence of fixed-term electricity contracts. During the spring of 2023 market prices started to fall and dropped even below negative on some days. This might give consumers the impression that participating in DSF is no longer worthwhile, just like before the energy crisis. One of the energy service providers also brought up the issue of the smart meter control access being opened to market participants. The interviewee stated that this goes against the market-based approach of DSF development, and that regulation should not intervene the commercial market by being more favourable to certain types of flexibility control technologies.

Defining a baseline for DSF was mentioned as an important issue by a few interviewees. Providing explicit DSF services requires information on how much flexibility has actually been activated. This has proven to be difficult with distributed resources, especially households and other entities with unpredictable load profiles.

6.2 Solutions and measures

This chapter presents the solutions and measures required to solve the previously presented challenges, as identified by the interviewed market actors. The solutions and measures implemented by the interviewees themselves are presented as well as more general thoughts on developmental needs.

One of the most relevant measures that all interviewees highlighted was to continue to educate end-users and other stakeholders about DSF. The consumer representatives pointed out that the informative campaigns arranged last year achieved great results, but in order to maintain and further increase this gained knowledge and interest, more campaigns should be organised. Also, continuous communication on the subject should be continued. Otherwise, the interest in this issue might fall as the risk of electricity shortages has subsided and the market price level has dropped. An important aspect of communication is to provide customers with concrete real-life examples. Sharing customer experiences from a variety of different end-user types gives a better understanding of how they can profit from participating in DSF. The information provided should also be easily understandable and accessible, meaning that also non-electronical material should be available. The Down a Degree campaign was mentioned as an exemplary measure to involve customers in DSF. The Down a degree campaign, organized by the state administration, aims to lower energy consumption, and reduce electricity consumption peaks by providing information to end-users (Down a Degree 2023).

Most of the interviewed market actors have shared information about DSF with their customers and stakeholders. One of the interviewed suppliers offered customers with fixed-term and fixed-price contracts the opportunity to lower their electricity bill by participating in DSF during the energy crisis. This increased the share of customers participating in DSF and provided hedging against the predicted energy prices.

While educating end-users is an important aspect of DSF deployment, other market participants should be involved as well. One important target for information sharing, as mentioned by a consumer representative, are building developers. If building developers were to recognise a competitive advantage from implementing smart controls to the buildings, it would promote the deployment of DSF. As one of the OEMs stated, more discussions and education should be arranged between market participants and OEMs.

Making DSF attractive to end-users was another factor emphasised by most of the interviewees. This includes developing smart home systems and automation to make the services as easy to use as possible. Most consumers are not willing to put a lot of effort into participating in DSF, especially if the cost savings achieved are not significant. DSF services should provide consumers with detailed information of their electricity use and how the service has functioned. One OEM pointed out that providing customers with information on their electricity use can motivate them to modify their consumption habits. More invested consumers should be able to monitor and optimise the system, but it should also function fully automatically to suite those who want a low-effort service. An optimal service pools all the controllable appliances of the end-users and optimises their energy use as one cohesive system. Also, as stated by a consumer representative, if the customer is provided with implicit and explicit services, they should be optimised together to allow for the best result for the customer. The consumer representative and an energy service provider also argued that in order to increase competition in the market, services should not be limited in such a way that only one service provider is allowed to control the end-user's equipment. The end-user should be able to purchase an appliance and choose between available service providers to procure the flexibility service.

While the automatization of DSF is important from the system perspective, one of the energy service providers pointed out that we should also remember to utilise simpler means to complement automation. This can refer to for example using media outlets to ask consumers to lower their consumption, as was done during 2022 when the risk of electricity shortages was present. They also mentioned day/night tariffs as a great way to easily involve customers in DSF with already existing systems. Many households and buildings do not have advanced equipment or electrical systems that would support a BMS, hence they should be involved through other measures. Also, some end-users can find automation too complicated as a concept or be worried about safety and would prefer to participate by manually modifying their consumption. This way the highest flexibility potential can be reached.

The consumer representatives also emphasised that the prerequisite for acquiring a DSF service is openness and transparency. It must be ensured that consumers understand how these services work and what has been agreed on. Especially explicit DSF services must convince the consumer that their living comfort and safety are not going to be affected. It must be ensured that consumers do not get a false impression that they might run out of warm water or experience uncomfortably low indoor temperatures. Otherwise, selling the concept can become significantly challenging. Ensuring a good and reliable reputation is a condition for success. Thus, the flexibility service provider needs to have a comprehensive understanding of how their controls affect the building. A clear set of guidelines and rules should be defined for explicit services, which would address how and to what extent customer loads can be controlled and how safety, both electrical and cyber, can be ensured.

The consumer representatives stated that to further increase the flexibility potential of smaller end-users, they should be encouraged to acquire distributed generation and storage. Thus, they should both be tax free and free of distribution charges. This applies to household energy storages as well as EV batteries when V2G is implemented.

Legislation could provide requirements and incentives to support DSF development. The interviewees´ had varying views on how much impact legislation should have. Some argued that stricter requirements are necessary, while others thought that legislation should create incentives and then follow and adapt to DSF development. One OEM stated that as long as the market price level stays too low and stable, it is very difficult to attract consumers without making DSF compatibility mandatory by the legislation. Another OEM stated that if new equipment were required to be more DSF compliant, it would solve the uncertainty on whether it is a viable business case of not. The OEMs and some other interviewees, such as the consumer representatives and suppliers, thought that an important measure would be to impose stricter demands for new equipment and buildings. One of the energy service providers stated that even though they have done a lot of development and succeeded in making data measurement more cost effective and accurate, installing additional meters, and connecting them to the cloud would become easier if equipment had integrated smart readiness. For equipment development, one independent aggregator stated that the goal should be to create more than just on/off controllability. Implementing linear controllability into equipment increases their flexibility potential, which allows participation to technically more demanding flexibility services.

Legislation has been developing in the right direction and for example the SRI requirements for buildings have become stricter. This, however, only applies to large buildings. Many interviewees argued that these requirements should be gradually extended to smaller buildings as well. The aim should be to require that the electrical system of new buildings should be planned from the beginning to support DSF integration. Increasing the DSF compliance of equipment and buildings could eliminate the need for complicated electrical installations and make it easier to implement additional metering. Also, these standards and requirements should create more uniform solutions, which would make the building and equipment stock more homogeneous. This would result in making it easier to implement one DSF system to multiple resources without having to do major customisations.

For smaller scale properties, such as households, the interviewees stated that more incentives should be created. These incentives could be for example tax or subsidy related. An energy service provider and the consumer representatives stated that the tax credit for household expenses should be extended to include equipment expenses rather than just the installation costs. One supplier argued that a subsidy for end-users acquiring for example energy storage could be beneficial. One OEM suggested that DSF compliant smart households and other smaller properties could receive a certificate that could possibly raise the value of the building in the future. Properties with enough smart readiness could be given the title of a smart home. One of the independent aggregators and DSOs expressed a desire for better visibility on legislative developments to confirm that investments are worth making. The independent aggregator mentioned that the smart readiness indicator has been a valuable sign and has alleviated the uncertainty in developing DSF services.

One of the OEMs had already taken part in V2G deployment and they were currently developing charging devices that support two-way charging. They were also developing the integration of batteries to work together with the smart charging stations to increase flexibility potential. To solve the issue of lacking market knowledge, the OEM has plans to cooperate with an aggregator in the future to provide explicit DSF. To ease the development of both implicit and explicit charging services, a standardised interface between all European countries would be beneficial. Unlike other DSF suitable technologies, as pointed out by the suppliers, consumer representatives and OEMs, EV chargers are already integrated into a cloud through which their output can be controlled. Therefore, there is no need for expensive and complicated retrofits.

Another OEM was already advanced in their stage of development. Most of their equipment are already DSF compliant and accessed through an API interface. Their older equipment can also be updated to include smart readiness. A stepless linear control can be achieved with inverted-controlled compressors and the power is adjusted by changing the compressor rpm. While this capability does add some complexity and slows down the control speed, it enables precise adjustments.

The development of common interfaces was promoted by the suppliers, DSOs, and energy service providers, but they had differing opinions on their implementation. One of the energy service providers had the vision of providing their flexibility pool for electricity suppliers, preferably through a common interface. An interface would allow cooperating with multiple suppliers and not having to create individual systems for each partner. This energy service provider and one of the suppliers were going to take part in a development project where the cloud-based interface between suppliers and flexibility service providers is developed.

One of the DSOs and suppliers pointed out that in order to successfully open smart meter load control to the market, a common interface should be developed. This DSO thought that it would be best to first develop the interface for the suppliers and then extend it to other market actors as well. Suppliers already have a customer relationship with end-users and their electricity use points, which makes creating an interface easier. The right to smart meter control could be tied to each electricity use point. To speed up the development process of DSF, the DSO had plans to offer an implicit DSF service for their customers with the next generation smart meters. This service would allow customers to choose how many hours of consumption they would like to schedule for the cheapest hours. The DSO pointed out that there is great flexibility potential behind smart meters, and it should be unlocked.

Smart meters have limitations compared with modern building management systems. They can manage a limited amount of technology, typically electrical heating or water heaters and are only capable of on/off control. However, smart meters also have their advantages. Building management systems are less accessible and do not provide enough benefit for many end-users with little flexibility potential. Smart meters can be found in nearly all electricity consumption points and therefore a major share of flexible resources can be accessed through them. They are going to be installed in any case, so they do not cause extra costs for consumers and are thus a great way to implement more flexibility to the system. The DSO emphasised that these technologies, smart meters and BMS, can work side by side and buildings with more automation potential should utilise BMS. This way flexibility is maximised. Most interviewees, with whom the topic was discussed, had a neutral or positive attitude towards smart meter load control. One energy service provider, however, stated that opening smart meter control to the market interferes with the market and hampers their business and investment decisions. They emphasised that legislation should not affect the market. Legislation should rather let the market operate on its own as it has done thus far and support DSF development by setting incentives, requirements and guidelines that do not interfere with competition.

One of the independent aggregators mentioned that making smart meters compatible with explicit DSF would contribute to its advancement. Smart meters should include information on the device status and the activation times and measurement accuracy should align with market requirements.

The energy service providers, suppliers and independent aggregators mentioned that, in order to procure explicit flexibility successfully, the prequalification process needs to be modified. The testing process should not be required to be carried out for each individual property and appliance. The process of testing tens of thousands of appliances creates too much work to make explicit DSF profitable. For the baseline issue, one of the DSOs suggested that common rules are to be defined for baseline calculations. It must be ensured that market participants are not able to manipulate the controls to maximise their own benefit.

It was commonly recognised that dynamic supply tariffs are a key factor in DSF deployment. Even though dynamic contracts became more popular during the 2022 energy crisis, it must be recognised that this was mainly due to the fact that only record expensive fixed-term and fixed-price were available. The interviewees argued that if consumers recognise the benefits of DSF and the market price level remains fluctuating, an interest in dynamic supply contracts can be maintained. In addition to dynamic supply tariffs, one of the OEMs and one of the consumer representatives argued that peak tariffs on the distribution grid could be implemented to all end-users. This has already been discussed for a long time and was supported by the Smart Grid Working Group (Pahkala et al. 2018). Peak tariffs for end-users would incentivise the acquiring of implicit DSF services and automation. Additionally, it would help to lower the peak load of the system. One consumer representative also pointed out that if DSOs started to acquire market-based flexibility or showed interest in it, it would create another FRP that consumers could gain compensation from.

Datahub was mentioned as a potential interface by a few interviewees. One DSO mentioned that it could be utilised with smart meter control, since it already has the information on DSOs, suppliers, and their customers. Datahub was also mentioned by a consumer representative as a possible platform for acquiring flexibility from electric vehicles and V2G. Each charging point could become its own electricity consumption point. Datahub could be utilised to collect information and data on flexible resources, such as which smart meters are participating in DSF and who has access to their control.

Finally, all interviewees emphasised that more active discussion and cooperation is to be had between market participants. This measure is presented in more detail in the next chapter.

6.3 Roles and cooperation

All interviewees highlighted the importance of cooperation between market actors in the successful deployment of DSF. All interviewees emphasised that the most important thing at the moment would be to form an active discussion between market actors. Otherwise, the opinions of the interviewees about the quality and quantity of further cooperation varied. The connection and overlapping of different roles are presented in Figure 9. Figure 9 illustrates the six main actor roles chosen for the interviews and the additional roles they each represent. The arrow indicates overlapping between the roles, showing how one role can represent or plan to represent another role.

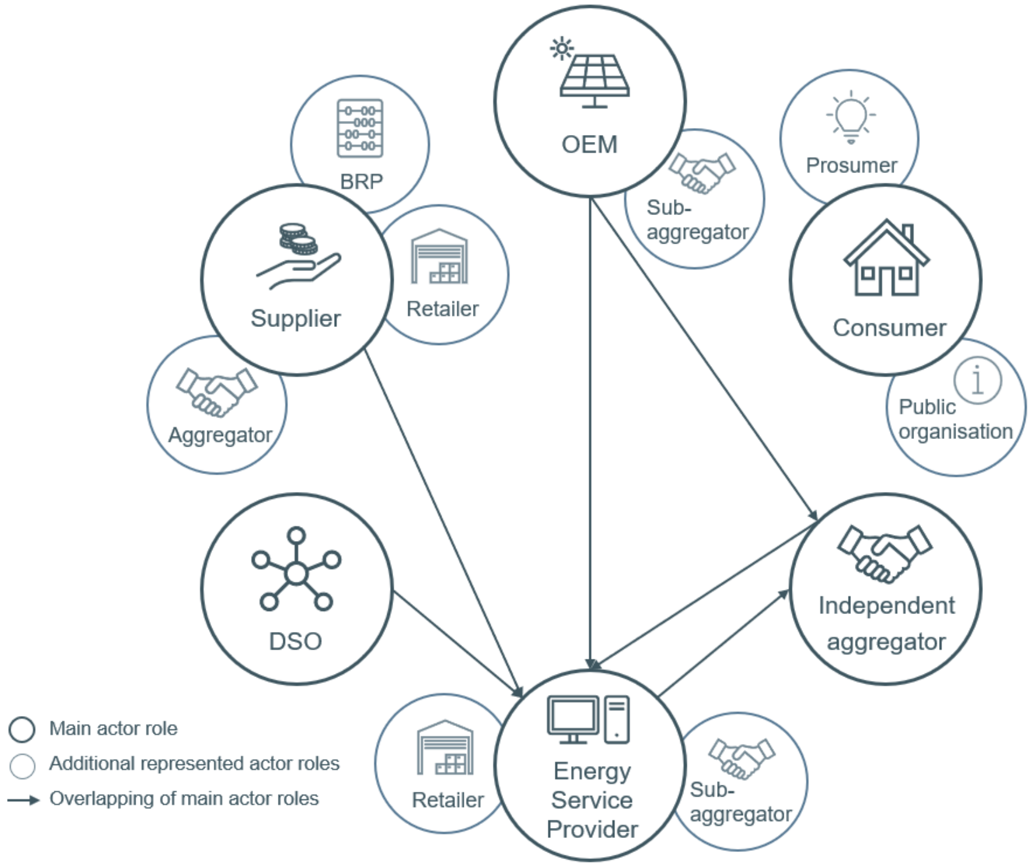


Figure 9. The connection and overlapping of interviewed actor roles

Some of the actors were more willing to keep their role more specific and collaborate with multiple other roles, while others wanted to take on a bigger role in the value chain. For example, one OEM had interest in taking on the role of an energy service provider and an independent aggregator and provide DSF services, both implicit and explicit, to consumers and the market operators. This was motivated by past cooperation, where the involvement of multiple actors in the development of DSF services was found complex. The other two OEMs were interested in collaborating with an external aggregator to participate in the electricity markets. These actors found it more profitable to focus on their own expertise and acquire market expertise through an external participant. One OEM emphasised that OEMs and market actors, such as suppliers and aggregators, should gain better understanding about each other's operations. To make the OEM role function in the value chain, they too need to understand the market. All OEMs recognised their important role in developing technology to support flexibility deployment and were already developing solutions at least to some extent. At the moment, the OEMs found that customer interest in these attributes was minimal and an increase in interest would encourage faster development as demand creates supply. The operations of independent aggregators, suppliers/BRPs and energy service providers have a significant impact on OEMs as they are providing flexibility services through appliances manufactured by the OEM. The OEM can integrate the necessary smart readiness into the equipment and provide third parties access to it or keep it to themselves.

The difference in views was also observed with energy service providers. One interviewee was already developing their role as an independent aggregator while one was interested in collaborating with a supplier/BRP for explicit DSF. Similar to the OEMs, one actor wanted to focus on their role as the implicit DSF service provider while the other actor recognised a business opportunity in also taking the independent aggregator role. That said, they also highlighted the importance of close communication with BRPs about their planned flexibility actions. Energy service provers have an important role in productising DSF to match consumer needs and increasing competition, especially regarding implicit DSF. They are already providing smaller customers, such as households, these services. The energy service providers´ wishes for other market actors differed. One energy service provider wished that OEMs would allow access to their smart systems to third parties, who could then compete in providing the best BMS for the owner of the property. The other interviewee was planning on cooperating with suppliers/BRPs to create an explicit DSF service. This actor was also going to take part in a collaborative project where the interface between suppliers and flexibility service providers, such as energy service providers, is developed. The energy service provider mentioned that their flexibility resources and systems can be used for explicit DSF and only the aggregator interface is missing. Both interviewees mentioned that OEMs developing increasingly smart ready appliances makes it easier to integrate them into the BMS.

Two out of the three supplier interviewees also acted as BRPs. The supplier representatives had quite varying positions with DSF development. One supplier had already taken on the role of an energy service provider and developed an implicit DSF service for electric vehicles. They were also in the process of extending the service to households. Furthermore, they were exploring the possibility of aggregating the resources from their service interface. The other two suppliers had piloted DSF services before but did not have any development plans at the moment. These suppliers stated that if they were going to participate in DSF services, they would take on a more market-based approach and not develop the technical side of the service. They also stated that they were open to aggregating smaller distributed loads to the reserve markets and for their own portfolio balance, but at the moment it did not seem profitable. One supplier had piloted a smart home implicit DSF service in the past but at the time, before the energy crisis, the value obtained was not high enough to continue with the service. They are however exploring the possibility of developing services in the current market situation and are very active in supporting DSF development through other measures, such as participating in R&D projects. This supplier had a positive outlook on utilising distributed flexibility for portfolio balancing. They stated that they could and would like to use distributed flexibility for this purpose in the future.

The role of the independent aggregator was viewed positively by all supplier representatives. Independent aggregators are developing DSF-based business and increasing competition on the market, which benefits other market actors as well. The independent aggregator was also seen as a possible collaborator by one supplier. The impact of the independent aggregator on portfolio balance was recognised. This did not cause concern at the moment as the balance deviations are corrected, but the future remains uncertain. One of the suppliers pointed out that often the balance deviations caused by the independent aggregator happen in the right direction, supporting the power system balance. According to this supplier, the best scenario would regardless be that the supplier and the independent aggregator cooperate and the supplier and BRP are informed of upcoming flexibility activations.

All suppliers stated that they would not take on the role of an OEM and would rather work together with one to produce DSF services. Consumer interest plays a big role in choosing the services to be developed. Such as the OEMs, the suppliers mentioned the effectiveness of demand creating supply.

The independent aggregators did not have a very optimistic outlook on smaller scale DSF services in the current market situation and neither had current plans to extend their services to small consumers due to the high per-unit costs. However, they both expressed interest in future development when the smart readiness of smaller properties would be more advanced. One of the independent aggregators had also taken on the role of an energy service provider to their existing customers and was interested in collaborating with other energy service providers by aggregating their flexibility load to the markets. The other independent aggregator has worked together with suppliers and even procured customers through them. This provides the supplier and BRP access to information on flexibility activations. The independent aggregators described their role as the developers of DSF-based business and as educators of the subject.

DSOs highlighted the importance of making DSF activations compatible with the distribution and transmission grids. This requires communication and cooperation between all market actors. When the flexibility markets are being developed, it must be ensured that it does not have a negative effect on the power system. Regarding the smart meter control being shifted to other market actors, the DSOs emphasised that common rules and objectives should be defined to create a functioning model. Both DSOs were supportive of this transition, but one would have preferred to provide DSF services themselves in the future. The DSO who was already planning to provide a smart meter implicit DSF service to their customers wanted to take on the role of an energy service provider to accelerate the development of DSF and provide customers with the opportunity to utilise the new smart meters. One of the DSOs stated that the best solution would be to allow meter load control first to the suppliers, who already have contracts with customers. It was also pointed out that even though there is no critical need for DSF in the distribution grid, developing DSF will ensure that the best practises for Finland are created. If we are not proactive, the EU could offer a ready model that is not the best fit for the Finnish power system.

From the consumer viewpoint, it was seen important that they have a variety of optional service providers who provide competitive options. The consumer representatives found it unlikely that consumers would have a single market actor role through whom they would like to purchase the service. Some customers find it convenient to purchase the service through their own supplier, while others prefer a separate service provider. Whether the provider is a supplier, energy service provider or distribution company, the procurement decision is mostly affected by the price, quality, and reliability of the service.

All interviewees emphasised the importance of wider discussion between market participants. The Finnish TSO was mentioned as a suitable neutral actor to spark discussion. Based on the interviews, it seemed that quite a few actors were still waiting for the market to develop and for proactivity from other market actors, especially consumers. Most interviewees emphasised the importance of establishing practices and objectives that would benefit all participants and aligning the development of DSF accordingly. It was also suggested that a steering group could be formed with representatives from all actor roles.

6.4 Questionnaire for suppliers

The views of electricity suppliers were more widely examined through a survey. Eight suppliers answered, three of whom were also interviewed. Six out of the eight suppliers were also acting as BRPs and seven had developed or were currently developing DSF services.

The one supplier who was not developing DSF services had no current plans of developing them in the future either. The supplier stated that they were developing heat related DSF, but they would rather leave the development of electricity related DSF to larger actors. They mentioned that it would be too difficult and expensive to integrate the large variety of consumer appliances to a system.

The rest of the suppliers were interested in or were already developing services to various end-users. Some had already piloted services while others were currently developing various types of DSF services. Some were developing the monitoring of more specific technologies, such as water heaters and small-scale production. Others had focused on a more general service, that can include various loads. Some of the suppliers also pointed out they have offered or are currently offering supply contracts that combine the features of a fixed-price and dynamic-price contract where the customer can lower their electricity bill by modifying their consumption based on market price levels.

The suppliers who were interested in or developing DSF services aimed to offer them to all the end-user segments presented. The suppliers stated that it is important to acquire flexibility from all end-user types to gain as much flexibility potential as possible. One supplier stated that households present great potential in terms of quantity that can be used for their own portfolio balance management. Larger customers, such as companies were interesting due to their larger loads. The suppliers also pointed out that it is important to create customised services for each end-user type to match their operations and needs. One supplier mentioned that at the moment they are waiting for the technology of households to develop for it to be profitable to create these services. They were planning on first implementing batteries that can be connected to solar systems.

Even though all the suppliers recognised the importance of DSF development, they had identified many challenges related to the development of these services. As stated by the interviewees, the financial side of development was seen as a key issue by most. The complex and difficult integration of management systems and the large variety of customer appliances were pointed out. Creating user-friendly automated services is a condition for successful development, but it makes the development process more challenging. Other issues brough up by the suppliers included the uncertainty of the market price level, whether it is profitable to participate in explicit DSF, and the lacking information on baseline and prequalification requirements.

Certain suppliers had already implemented measures to address these concerns by developing data-analytics, cooperating with other market participants, and conducting pilots. Others, on the other hand, had not implemented measures themselves and some perceived that the current challenges are predominantly technological and outside their operational scope. On the contrary, some stated that there is great progression with technological advancements, while the commercial aspect is still in the early stages of development. Other important measures pointed out were engaging the customer in the service design process, creating a baseline standard, and creating standardised interfaces. One supplier also highlighted the importance of maintaining and developing the current market-based electricity market model, as it creates the foundation for DSF.

7 Key findings

This chapter presents the key findings from the interview study and literature analysis, focusing on the main aspects of flexibility development. Three themes were identified: awareness and comprehension, technological advancement, and economic feasibility. The key challenges and development needs related to each theme are presented. Recommended measures for promoting the unlocking of distributed flexibility are presented in the next chapter. Figure 10 shows the identified themes.

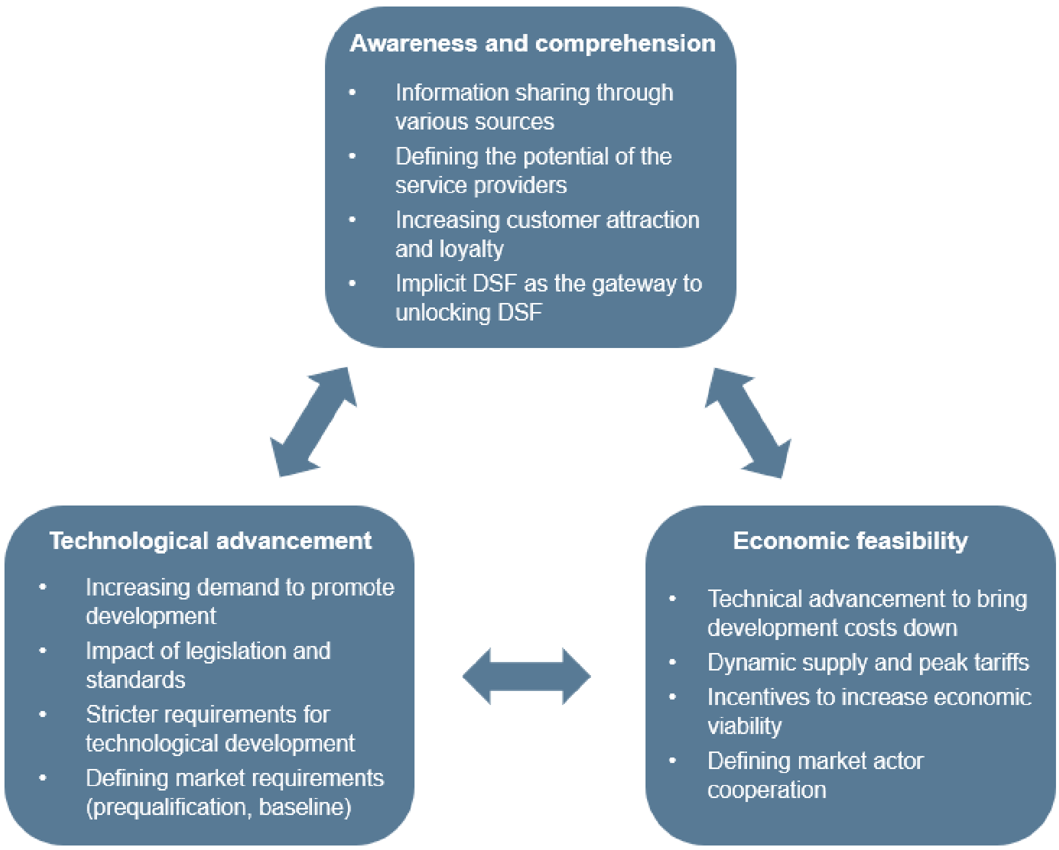


Figure 10. The three themes of DSF development

Awareness and comprehension

Increasing awareness and comprehension among end-users and other market participants is required for the successful deployment of DSF. It is the first crucial step in unlocking distributed flexibility. Enhancing awareness will result in end-users making more informed decisions about their energy usage. When end-users understand the concept of DSF, they can take on a more active role in the power system and participate in DSF services. Effective measures, such as organising campaigns and sharing information through various sources, have proven to be successful in increasing awareness and comprehension. All interviewed consumer representatives recognised that consumer interest grew significantly during the energy crisis, due to successful information sharing. Other market actors had noticed this effect as well, as the interest in smart technologies and home systems increased significantly. Maintaining and further promoting this interest was recognised as a prerequisite for DSF deployment.

Attracting the interest of end-users requires the sharing of real-life experiences from DSF participants. Providing information and examples about various end-user types helps consumers to understand how they can benefit from these services. The information should be accessible and understandable, highlighting the effect and benefits of DSF participation. Openness, transparency and ensuring cybersecurity and electrical safety are prerequisites for acquiring DSF services. Creating and maintaining the reputation of a reliable and functional service is crucial for the development of such a modern concept. Encouraging consumers to acquire a DSF service requires advanced automation to create services that the effortless optimisation of electricity use based on individual preferences. The service should provide end-users with real-time information on their consumption and service performance.

To maximise flexibility potential, all levels of flexibility should be considered. While advanced automation is the most crucial development need for efficiently supporting the power system, simpler measures should also be implemented. End-users with a limited possibility or desire for automation can still participate by manually adjusting their consumption.

Increasing awareness is to be extended to other market participants as well. Cooperation and the sharing of information among market participants allows for a better understanding about the current state of development and goals of DSF. To unlock the potential of DSF, the value chain needs to function cohesively, with close collaboration between the technological and market expertise.

From the actor roles, the potential of the supplier was recognised. Suppliers have existing customer relationships with end-users through their supply contracts. The existing relationship facilitates the sharing of information and promotion of new services. An already existing customer relationship may also lower the participation threshold for end-users. By creating DSF services, suppliers can create new revenue streams and increase customer loyalty and attraction. The supplier can also gain insight into flexibility activations and take this into consideration with managing their portfolio balance. Energy service providers and independent aggregators also have their advantage in creating DSF services. Their business model is based on developing these services, enabling them to allocate a larger share of resources to the development of DSF. Both actors have already created advanced services for their customers.

Implicit DSF services can be considered a gateway to unlocking DSF. These services are easier to implement compared to explicit DSF services, as they do not have the requirement of advanced measurements and activations and performing prequalification tests and verifications. They are also easier to comprehend by the end-user, making them a likely starting point for DSF participation.

Technological advancement

The level of technological advancement is a key factor in the effective controlling and optimisation of end-users´ equipment and consumption. Technology enables the collection and analysis of large amounts of data on consumption behaviour. Data analysis helps to better understand the needs and preferences of end-users, enabling the development of tailored and efficient DSF services. Additionally, technology allows for the implementation of intelligent automated systems that can provide services to both the end-user and the power system. Smart home systems can optimise energy consumption based on the end-users needs and market price signals while communicating with the electricity grid.

Legislation, standards and the behaviour of end-users and other market participants have a significant impact on technological advancement. The current lack of DSF compatibility in buildings and equipment leads to complex integration processes, increasing development costs. The heterogeneous nature and lack of smart readiness in buildings and equipment hampers the economic viability of creating services.

Technological development is heading in the right direction and significant progress has been made. However, these advanced features have not been implemented on a larger scale. The new smart meters offer better potential for flexibility and equipment development has advanced to include linear stepless control alongside on/off control. EV chargers also present immense potential, as they are connected to the cloud during manufacturing. If a viable business case for V2G arises, vehicle manufacturers will update their vehicles and charger manufacturers will produce two-way chargers.

Despite the technological advancement, there has been lack of demand for smart readiness from both end-users and other market actors. This creates uncertainty for the development of smart readiness. Legislation is also not providing sufficient support or requirements for developing the controllability of smaller resources. Without incentives, there will not be much progress in development or implementation.

Technological barriers also arise from the current market requirements or lack thereof. Smart meters can be utilised for implicit DSF, but their measurement accuracy and activation times are not suitable for explicit DSF. In addition, smart meters do not provide information about the state of individual devices, making it challenging to determine the activated flexibility. Common rules should be defined for baseline calculations. Defining a baseline has proven to be difficult with distributed resources, especially households and other entities with unpredictable load profiles. The prequalification requirements for distributed resources should also be defined and they should have less strict demands for the testing and verification process.

Economic feasibility

In order to successfully develop DSF services, it is important to ensure financial viability for both consumers and service providers. However, the lack of consumer interest and technological development often results in the created value being too low in comparison with the costs incurred. Creating a business model becomes challenging when developing the service requires significant effort and there is a lack of customer interest.

Technological advancement has a major impact on the cost of developing DSF services. When the building and equipment stock are very heterogeneous and not DSF compliant, complex and expensive integrations are required. The heterogeneous nature of resources created the need for customised systems for each resource. The lack of development also causes the need for installations done by an electrician in most properties. The deficiencies of smart meters create the need for additional metering, further increasing costs. Developing a system that requires complex installations is challenging, and therefore incentives are necessary to create better conditions for service development.

Increasing awareness and comprehension among end-users creates more demand for DSF services, but legislative support is also needed. The procurement of DSF services can be encouraged by providing tax or subsidy related incentives to end-users. These incentives could include extending the tax credit for household expenses to include equipment expenses rather than just the installation costs and creating a certificate for smart properties to bring up their value. Additionally, stricter legislative requirements for the DSF compliance of new buildings and equipment would further incentive the development of DSF services.

From an economic perspective, the end-users´ supply contract type, and the market price levels have a significant impact. Customers with fixed-price contracts lack the motivation to acquire DSF services. Although dynamic supply tariffs are ideal for promoting DSF, many customers prefer the sense of security provided by fixed-price contracts. During the energy crisis, suppliers started offering contracts that combine the features of both a dynamic supply contract and a fixed-price contract. These contracts allow the consumer to lower their electricity bill by modifying their consumption according to the market price. To further promote flexibility participation, peak tariffs could be introduced more broadly by the distribution companies, incentivising DSF participation in both the market and the distribution level.

The roles and cooperation of actors have a significant impact on creating a business model. When developing a service, it is important to determine the desired number of collaborating participants and what expertise they can bring to the service. The combination of several actors allows focusing on one´s own expertise and brings more resources for service development. On the other hand, the cooperation of multiple actors can complicate operations contractually. Additionally, when creating a service with several participants, revenue sharing and financial feasibility must be considered. As was identified from the interviews, this varies between different actors. Nevertheless, cooperation plays a significant role in the successful development of DSF although the specific format of cooperation might differ for each actor.

8 Recommendations

Legislation plays a significant role in supporting DSF development. Legislative initiatives, such as the Clean Energy Package, the Fit for 55 package and the upcoming DSF network code aim to promote and enable the implementation of demand side flexibility into the power system. These initiatives include guidelines and provisions for DSF development and encourage end-users to actively participate in flexibility. The legislative advancement has helped to create a more favourable environment for DSF in the Finnish electricity market. However, based on the findings of this thesis, more measures are needed to successfully unlock distributed DSF.

In this chapter, three key recommendations for unlocking demand side flexibility are presented. These recommendations have been formed based on the findings from the interview study and the literature analysis. Firstly, the importance of increasing awareness and promoting cooperation among stakeholders is emphasised. Secondly, the significance of incentives and obligations is presented. Finally, the development of supporting market structures and mechanisms is discussed. The aim of the presented recommendations is to maximise the potential of DSF and contribute to its value realisation.

Increasing awareness and promoting cooperation

To attract and maintain consumer awareness and comprehension regarding DSF, the active sharing of information should be continued. The Down a Degree campaign successfully engaged end-users in DSF participation and in the reduction of overall energy consumption. Now that the immediate concern for electrical shortages has subsided, a more long-term outlook should be adopted. The exceptional circumstance experienced last winter created a strong incentive to take action. However, the need for flexibility is constantly increasing as the power system becomes more decentralised. To support this transition, various forms of communication should be continued. Recommended measures are to organise another national campaign solely focused on DSF and to continue information sharing through various sources. Market participants, such as retailers, and the media can utilise their platforms to effectively share information. A reliable public organization that has expertise on promoting energy efficiency could take on the role of organizing the campaign.

To effectively communicate the benefits of DSF participation, real-life examples of various end-user types should be provided. By showcasing the savings achieved from the service and the impact it has had on living comfort, all end-user types can gain a better understanding of how they could profit from acquiring a service. Electricity suppliers have a unique opportunity to share information to end-users due to their established customer relationships. Information sharing should also involve providing information about existing flexibility services, as is to be mandated by the recast Energy Efficiency Directive. Member states are obligated to provide an up-to-date list of qualified service providers. This information should be included in public communications to ensure better accessibility.

Communication and collaboration among stakeholders should also be promoted. Market experts, such as suppliers, and technology developers should engage in active discussions to gain a deeper understanding about each other's operations. Various information briefings and workshops among stakeholders serve as excellent measures to promote communication. Furthermore, active participation in development projects and pilots is encouraged for all market participants. As demonstrated in this thesis, DSF offers benefits to all the presented market actors, making its promotion a positive endeavour for the whole electricity market.

Creating incentives and obligations

Incentives and obligations can effectively promote DSF development. While the current legislation has already established these measures, they should be further enhanced and extended to include smaller resources. Gradually extending energy efficiency requirements to smaller buildings would be beneficial, while providing subsidies and incentives is more suitable for small resources, such as residential properties.

To encourage the participation of smaller scale properties in DSF, it would be beneficial to introduce incentives, such as subsidies or tax related benefits. For instance, the tax credit for households could be extended to cover not only the installation cost of a DSF service but also the installed equipment. Additionally, a subsidy could be provided for the adoption of technologies increasing energy efficiency and automation. The incentive for DSF participation could also be increased through certificates or titles earned from the property or appliance being DSF compatible. For instance, a separate certificate could be created for smart homes, which could enhance their future value. Implementing a smart readiness indicator score for small properties could also encourage the implementation of smart readiness.

Alongside incentives, it would be beneficial to introduce stricter requirements for the DSF compatibility of new buildings and equipment. The possibility of DSF should be considered already during the construction phase to help avoid costly retrofits. Additionally, efforts should be made to develop requirements towards a more standardised building and equipment stock in terms of electrical systems, simplifying the installations of controllability without excessive customisation. The combined impact of subsidies and obligations would create a stronger incentive to adopt more advanced technologies into equipment and buildings.

Before implementing subsidies and other incentives, a comprehensive assessment should be conducted to determine the most effective measures to support DSF. Before conducting the assessment, the objectives for incentives should be defined. Based on a national assessment the best measures can be identified and implemented. Based on the findings from this thesis, expanding the tax credits for measures supporting energy efficiency and creating a certification/SRI for smaller properties is encouraged.

To incentivise participation in DSF from the market side, it is important to promote dynamic pricing. As mentioned earlier, dynamic supply contracts are ideal for supporting flexibility. However, to enhance accessibility and attractiveness, sellers should also offer options that combine the features of dynamic and fixed-price contracts, providing consumers with the desired sense of security while incentivising them to adjust their consumption according to market prices. Additionally, peak tariffs at the distribution network level could be a viable addition to further incentivise flexibility.

Developing supporting market structures

To support DSF deployment, it is crucial to not only promote awareness, cooperation, and development, but also create the necessary market conditions for flexibility. Since the aim is to specifically promote market-based flexibility, it is essential that the electricity market provides a favourable environment that encourages DSF development.

Developing market-based flexibility requires establishing suitable interfaces between different stakeholders. These interfaces eliminate the need for separate cloud-based systems having to be developed for each market participant. Similarly, the development of a common flexibility register promotes DSF. By developing interfaces and a flexibility register, the operations of newer market actors are also facilitated. For instance, in the case of an independent aggregator, it is not enough to only enable its operation. The independent aggregator should be supported by creating suitable conditions for aggregation.

Additionally, various conditions for distributed flexibility should be developed and clarified. According to the findings of this thesis, there is currently a need to develop the determination of baseline and prequalification requirements. Given the variable nature of distributed flexibility, implementing a baseline model would be useful in ensuring fair and open competition. Establishing rules would help prevent the manipulation of flexibility activations. Additionally, reviewing and clarifying the prequalification requirements for distributed flexibility is recommended.

When considering the market-based approach to DSF development, it is important to recognise that implicit DSF can act as a gateway to explicit flexibility. Implicit flexibility does not require the same level of development and is not subject to the strict requirements concerning explicit DSF, such as measurement accuracy and activation times. Also, the next generation of smart meters are suitable for implicit DSF.

9 Conclusions

This thesis examines the roles and cooperation of market actors in unlocking distributed flexibility in the Finnish power system. The thesis maps out the current state of DSF service development and examines the barriers and possibilities related to it. Additionally, the framework for technological solutions enabling DSF is defined. The findings of this thesis provide insight into the necessary market actor roles and cooperation for unlocking distributed flexibility. The findings can inform policy making and market design. Ultimately, this thesis aims to contribute to the development of a more sustainable and efficient power system.

The research in this thesis was based on a qualitative case study approach, which involved interviews with relevant market actors. To gain better insight on the views of electricity suppliers, a separate survey was conducted. Additionally, to support the empirical study, an analysis of relevant literature was included. Based on literature analysis, a concept of the value chain of end-user DSF was formed and the most relevant actor roles for the scope of this thesis were identified. The findings from the literature analysis and the market actor interviews were cohesive and supported each other. Together the literature analysis and the empirical study formed the basis for the recommended measures presented in this thesis.

A common recognition of the importance of DSF development was observed within the interviewed market actors. The interviewees also had a largely uniform view of the challenges regarding DSF development and most challenges were recognised by all parties. More detailed actor-related challenges varied between market actors. The interviews indicated that the participants had a comprehensive view on current issues. The importance of cooperation was highlighted by all interviewees. However, the opinions of the interviewees about the quality and quantity of further cooperation varied.

The key findings from the literature analysis and the empirical study form the three themes of DSF development: awareness and comprehension, technological advancement, and economic feasibility. These three themes represent the main aspects of flexibility development and were recognized to be the most crucial development areas.

Considerable development has already been made to support DSF, particularly through legislative advancements. However, based on the findings of this thesis, additional measures are necessary. The recommendations of this thesis aim to support the successful unlocking of distributed DSF. The first recommendation is to increase the awareness of all market participants and to promote cooperation within the value chain. The active sharing of information has proven effective in promoting DSF participation and it should be sustained not only through official campaigns but also through continuous information sharing. The supplier was recognised to have noteworthy potential in reaching end-users through their existing consumer interface. The key in increasing awareness is to provide easily accessible and understandable information across various platforms. Promoting cooperation entails the organisation of information briefings, workshops and maintaining active discussion among market actors.

The second recommendation involves introducing more incentives and obligations to support DSF development through legislation and the market. The development of DSF services and compatible technologies can be promoted through various incentives and obligations. Subsidies or tax related benefits and certificates can encourage end-users to acquire smart systems. Furthermore, implementing more requirements and standardisation for technological development can further facilitate the advancement of DSF services. From a market perspective, dynamic pricing schemes should be promoted both on the supply and distribution level.

The final recommendation is to establish market structures that create favourable market conditions for DSF development. The market-based approach to DSF can be supported through developing suitable interfaces and a common flexibility register that facilitate the operations of modern actors. To create favourable conditions for distributed flexibility, the determination of baselines and prequalification requirements should be developed. Furthermore, when considering the market-based approach to DSF development, it is important to recognise that implicit DSF can act as a gateway to explicit flexibility.

To further support the findings of this thesis, the research should be continued with a broader and more long-term perspective. This would entail conducting interviews with a larger group of market actor representatives and actively following the state of development of DSF services. By staying informed about the ongoing development, supporting measures can be implemented effectively. Additionally, a quantitative study should be considered. By quantifying the potential value obtained from developing and acquiring DSF services from the perspective of end-users, other market actors and the society, a better understanding about its value can be gained. The findings from a financial analysis could be utilized to justify the implementation of various incentives mentioned in the recommendations. It would also be valuable to examine the state of DSF development in other countries, particularly in the Nordics and Europe. By examining practices outside Finland, new insights and ideas can be obtained and applied to the Finnish electricity system.

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Appendices

Appendix A. Interview framework and questions

Introduction

- Background
  - o The transition to a decentralised and bidirectional energy system
  - o Energy crisis and the growing need for flexibility
- Scope and objective of the thesis
  - o Unlocking the potential of distributed DSF
  - o Market-based approach
  - o Roles and cooperation, possibilities and barriers, solutions and measures, state of development
- Utilisation of results from the interviews
  - o Interviewee Anonymity
  - o Recording of the interviews

Common interview questions

Which actor role or roles related to demand side flexibility do you represent?

- Electricity consumer
- Electricity prosumer
- OEM
- Retailer
- Equipment installer
- Aggregator
  - o An aggregator combines smaller flexible resources into larger entities that can participate in the electricity market
  - o An independent aggregator is a market participant that aggregates flexible resources but is not affiliated with the supplier of the customer or the balance responsible party
- Electricity supplier
- BRP
- DSO
- Energy service provider
  - o An energy service provider offers a DSF/BMS service to the prosumer
- Public/nonprofit organisation
- Other?

What are the most significant benefits of DSF?

What challenges and obstacles have you identified in relation to the development of demand response services? (For example, from the perspective of legislation, technological solutions and productization)

What kind of development and solutions do the challenges and obstacles you identify require?

What practical measures do the solutions require? Have you introduced or planned to introduce measures?

What role do you play in the development of DSF services? How can other market actors contribute to the increase in DSF services and how will their actions affect your operations?

What kind of market actor cooperation is required to develop DSF?

Actor-specific interview questions

Supplier

Have you determined your customers' outlook on DSF? What have you observed and how has it affected your operations?

What is your view on utilising DSF for portfolio balance optimisation?

What is your view on the independent aggregator as a flexibility service provider? How does the impact of implicit DSF on consumption profiles affect your operations?

DSO

How much potential does DSF have for the distribution network in the future? Could there be a need for DSF, and could it be acquired on market terms?

What is your role in developing DSF services now and in the future? Could smart meters be utilised more widely for managing demand, similar to current peak/off-peak load control?

Energy service provider

Do you have the readiness to cooperate with suppliers by providing them aggregated flexibility? If yes, what kind of readiness?

Would you take on the role of and independent aggregator and provide flexibility directly to the market or would you rather cooperate with an aggregator? Could you justify your point of view?

Independent aggregator

What is your view on the participation of smaller distributed flexible resources, such as households and commercial buildings, in DSF services?

Have you planned to expand your operations to smaller end-users as well?

OEM

How smart ready and DSF compliant is existing technology and equipment?
What kind of technological changes are required for smart readiness?
What demands do consumers have regarding the smart readiness of their devices? How will the requirements develop in the future? Have you discussed the topic with energy service providers?

Consumer

Which actor role or roles related to demand side flexibility do you represent?

Due to the high price level and the prevalence of dynamic supply tariffs, consumers´ interest in DSF has increased and smart home systems have been adopted. Have you noticed this phenomenon within the association and what kind of observations have you made?

What benefits do consumers see from participating in DSF?

From a consumer perspective, what are the biggest barriers to participating in DSF?

What incentives and solutions are needed to increase consumer interest in DSF?

Are consumers more interested in managing their own devices in accordance with the price of electricity, or are automated smart home systems considered a more functional solution?

Are consumers also interested in participating in explicit DSF? If yes, on what terms?

Through which market actor would consumers preferably participate in DSF? (Supplier, DSO, or an energy service provider)

Appendix B. Questionnaire for suppliers

What company do you represent?

Do you also act as a BRP?

Are you developing or have you developed DSF services for consumers?

- Yes
    - What kind of DSF services are you developing or have developed?
- No
    - Are you interested in developing DSF services in the future?
        - Yes
            - What plans do you have for developing DSF?
        - No
            - Why are you not interested in developing DSF?

Which end-users are you interested in providing DSF services to?

- Households
- Condominiums
- Public and commercial buildings
- Industry and businesses
- We are not developing DSF services

Could you justify your choice?

What challenges and obstacles have you identified in relation to the development of demand response services? (For example, from the perspective of legislation, technological solutions and productization)

What kind of development and solutions do the challenges and obstacles you identify require?

What practical measures do the solutions require? Have you introduced or planned to introduce measures?

We would like to hear more about your thoughts on DSF. If you are interested in continuing the conversation in the form of an interview, please add your contact information below.