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Understanding barriers to utilising flexibility in operation and planning of the electricity distribution system – Classification frameworks with applications to Norway

Hanne Sæle[a,*], Iver Bakken Sperstad[a], Kristian Wang Hoiem[b,2], Vivi Mathiesen[b,1]

[a] SINTEF Energy Research, P.O. Box 4761 Torgarden, NO-7465, Trondheim, Norway
[b] Energi Norge, P.O. Box 7184 Majorstuen, NO-0307, Oslo, Norway

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ABSTRACT

There is an increasing need for flexibility in power systems worldwide, giving rise to European policy documents outlining how Distribution System Operators (DSOs) should procure and include flexibility in the planning and operation of their electricity distribution grids. This implies a remarkable change from today's situation where DSOs rely on investments in grid assets that they have full control of, to a new regime where DSOs would rely on flexibility provided by third parties. The objective of this work is to gain a better understanding of the barriers to and opportunities for wide-spread utilisation of flexibility in planning and operation of electricity distribution grids. Building upon a previous literature review and taxonomy for classifying and characterising power system flexibility, we propose frameworks for i) classifying flexibility resources and flexibility enablers in grid operation and planning, and ii) classifying and understanding barriers to utilising them in terms of a flexibility value chain. These theoretical frameworks are tested against empirical data collected in semi-structured in-depth interviews with a representative selection of Norwegian DSOs. Mapping the findings to the frameworks gives a systematic overview of the flexibility situation in Norway and presents both country-specific and general insights about barriers to utilisation of flexibility.

1. Introduction

During the last decade there have been significant changes to the European energy system due to electrification, decarbonisation, digitalisation and increase in distributed generation based on intermittent energy sources (sun, wind). These changes have resulted in an increased need for flexibility in the power system (CEER Distribution Systems Working Group, 2018), (USEF, 2018). The power system is changing from the traditional power system where the electricity is produced in large power plants and exported via the power grid to the consumers, to the future power system where grid users[3] play a more active role in the operation of the system and where the power flows in both directions. This transition implies that we are changing from a power system where generation follows consumption, to a power system where consumption follows generation, and this also requires flexibility from the consumption side.

1.1. Literature review

The concept of power system flexibility has been comprehensibly reviewed from several perspectives in (Degefa et al., 2021) and multiple other review articles cited therein. Utilising flexibility in the power system can contribute to reduced or deferred investments, better system reliability or other system cost reductions. To achieve this, the Distribution System Operators (DSOs) need to include flexibility solutions both in the planning and operation of the electrical grid, but at present this has been done to a limited extent (Nordic Council of Ministers, 2017). Previous research has summarized the current practice and state of the industry for specific types of flexibility resources and for specific

* Corresponding author.
E-mail address: Hanne.Saele@sintef.no (H. Sæle).
1 Heimdall Power, St. Olavs Gate 28, NO-0166 Oslo, Norway (Present affiliation).
2 Statnett, Nydalen allé 33, NO-0484 Oslo, Norway (Present affiliation).
3 The term "grid users" is in this paper used to describe different types of customers connected to the grid, with the possibility to consume electricity from and/or feed electricity into the grid.

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List of abbreviation

BTM	Behind the meter
CAPEX	Capital Expenditures
CEER	Council of European Electricity Regulators
DCC	Demand Connection Code
DSO	Distribution System Operator
FFR	Fast Frequency reserves
FTM	In front of the meter
OPEX	Operating Expenses
TSO	Transmission System Operator

geographical regions. The situation for electrical vehicles and battery energy storage systems has previously been summarized in (Marinelli et al., 2020) and (Sperstad et al., 2020a), respectively, both focusing on demonstration projects in Europe. There are also several studies of motivations for and barriers to consumer engagement, focusing on residential customers (Darby, 2020) - (Parrish et al., 2020), and energy flexible buildings (Mlecnik et al., 2020). In Norway, the TSO has performed demonstration projects focusing on how flexibility resources can contribute as Fast Frequency reserves (FFR) (Statnett, 2018), and a commercial market for FFR was established in 2022 ('Fast Frequency reserves).

However, these works have not contributed significantly to understanding why flexibility to a limited extent has been utilised beyond demonstration projects by the DSOs both in Norway as well as internationally. Policy issues related to demand-side flexibility have been studied from different perspectives in several recent publications. For instance, (Brown and Chapman, 2021) investigated the barriers to the utilisation of demand-response in the state of Georgia in the U.S., (Stede et al., 2020) carried out a semi-structured interview study to understand the role of demand response aggregators in Germany, (Cappers et al., 2013) investigated market and policy barriers to the aggregation of demand response from smaller customers providing ancillary services, and (Leinauer et al., 2022) investigated barriers to industrial companies' contributing with flexibility services. Examples of identified barriers related to utilising flexibility are technical risks, insufficient revenue, reliability, complexity, effort, and the aggregation of several smaller flexibility resources.

None of the works reviewed above focus on the perspective of DSOs. However, through the Clean Energy Package European DSOs are given recommendations to use flexibility and optimise decisions for grid investments (Eurelectric, 2020).

Including flexibility solutions in the planning and operation of the electrical grid is a remarkable change from today's situation where the DSOs have full control of their grid assets, to a new regime where the DSOs would rely on flexibility services from third parties. The degree to which flexibility will be utilised in the power system, will, among other things, depend on the DSOs' confidence in and the credibility of different flexibility resources, depending on factors such as their availability and predictability, combined with proper incentives and framework conditions. According to (USEF, 2018), this requires a holistic approach that focuses on the complete flexibility value chain, and includes both availability of and needs for flexibility, business models, actors and regulatory conditions.

Based on the changes in the power system and the increased focus on flexibility, the Council of European Electricity Regulators (CEER) has published an overview of the most fundamental preconditions that need to be met before DSOs can procure flexibility and manage congestions in system operation (CEER Distribution Systems Working Group, 2020). This report outlines principles on a European level, and to successfully implementing these in individual countries requires an understanding of national circumstances and barriers to DSOs' utilisation of flexibility. To this aim, based on the CEER report, an in-depth interview study on the utilisation of flexibility in the operation and planning of the electricity distribution system has been performed, where seven Norwegian DSOs[4] were interviewed. The study was performed in a cooperation between the Norwegian research centre CINELDI[5] and Energy Norway.[6]

1.2. Contributions and structure

The main scientific contributions of this work can be summarized as follows:

1. An extended framework for classifying flexibility resources and flexibility enablers as solutions within the operation and planning of distribution grids.
2. A general framework for classifying and understanding barriers to utilising flexibility by relating them to the flexibility value chain, and
3. A demonstration of how empirical data on DSO's utilisation of flexibility for one specific country (Norway) can be mapped to these frameworks in order to present both country-specific and general insights into barriers to the utilisation of flexibility.

In contrast to the previous works reviewed above, this work takes a more holistic approach in the sense that it considers multiple types of flexibility resources and solutions and multiple actors across the flexibility value chain. The frameworks and its application to map the flexibility situation in Norway forms a template that can be used to map and understand the situation and prospects for utilisation of flexibility in other countries. The situation is expected to differ from country to country, but the frameworks are general and can be used both as a basis for i) structured comparisons between countries and ii) policy recommendations tailored to the regulatory framework of specific countries.

This paper starts by introducing conceptual frameworks for understanding what flexibility is and how it can be utilised in the power system in Section 2. These theoretical frameworks also include a classification of regulatory frameworks and other potential enablers for the successful utilisation of flexibility in the power system. Conceptual frameworks proposed in Section 2 were used as a basis for the design of the interview study, and the methodology for the study and data collection is presented in Section 3. Section 4 first gives an overview of the main findings from the study and discusses its limitations. The findings are then mapped to the theoretical frameworks introduced in Section 2. Conclusions, implications and policy recommendations based on the work are presented in Section 5.

2. How flexibility can be understood and utilised

This section introduces the term "flexibility", relevant enablers for the utilisation of flexibility, and how DSOs can utilise flexibility in both the planning and operation of the electrical grid, how flexibility can be achieved through the flexibility value chain and an overview of framework conditions as potential enablers for utilising flexibility.

[4] Strictly speaking, a Norwegian equivalent of the term "distribution system operator" is not used in Norwegian legislation. In this paper, we have nevertheless chosen to use "DSO" as a term to describe grid companies and owners/operators of distribution grids in a given area. This is the same choice of terms as in (Ekspertgruppen for organiseringen av driftskoordineringen i kraftsystemet, 2020). In EU legislation (European Commission, 2019a), the term "distribution system operator" is defined as a specific role with specific responsibilities.

[5] CINELDI (Centre for Intelligent Electricity Distribution) is a Norwegian Centre for Environmental-friendly Energy Research (FME), www.cineldi.no.

[6] Energy Norway is a non-profit industry association for the Norwegian electric energy industry, www.fornybarnorge.no.

2.1. Characterisation and classification of flexibility resources and their enablers

There is still no uniformly accepted definition of the term "flexibility" in power systems, and various definitions are being used by different stakeholders (Degefa et al., 2021). Based on the definition by (CEDEC EDSO for Smart Grids Eurelectric GEODE, 2018), FME CINELDI has proposed the following definition of flexibility (Kjølle et al., 2021), (VefsnmoTonje, 2020):

> Flexibility is the capability and willingness to modify production and/or consumption pattern, on an individual or aggregated level, often as a response to an external signal, to offer a service to the power system or contribute to stable grid operation.

Moreover, flexibility resources are understood to include flexible generation, flexible load demand, and energy storage. Digging further into the details, characteristics of flexibility resources give an overview of how resources can respond to service requests from the power system, and in (Degefa et al., 2021), a comprehensive overview and classification of important characteristics of flexibility resources has been proposed. The characteristics are divided into technical and economic characteristics, where technical characteristics are classified into quantitative, qualitative and control technical characteristics, and economic characteristics are classified into capital (investment) and operational economic characteristics (CAPEX and OPEX[7]). This classification is illustrated in Fig. 1 with some relevant examples of each group of characteristics. An overview of quantitative technical flexibility characteristics is presented in Fig. 2.

The characteristics described above, primarily characterise the flexibility resources. In addition to the flexibility resources, *enablers* for flexibility (for example, markets) are also required to have a viable *flexibility solution*. Different approaches and mechanisms for enabling grid companies (DSOs) access to flexibility are described in (CEER Distribution Systems Working Group, 2018), (CEER Distribution Systems Working Group, 2020). In Fig. 3 we propose a classification of flexibility solutions that encompasses both flexibility enablers and flexibility resources. This is based on the classification in (Degefa et al., 2021), but the classification of enablers is augmented to incorporate the regulatory frameworks as classified in (CEER Distribution Systems Working Group, 2018), (CEER Distribution Systems Working Group, 2020). This classification of enablers is introduced in more detail in Section 2.4. Moreover, the classification of flexibility resources from (Degefa et al., 2021) has, in Fig. 3, been adjusted to be consistent with the definition in (Kjølle et al., 2021), (VefsnmoTonje, 2020) introduced above.

In order to ascertain more details about actual flexible resources and their characteristics, this classification will further be used as part of a theoretical framework, to understand the flexibility value chain and interpret the findings of the in-depth interview study performed as a basis for this paper.

Additionally, from the DSO's point of view it is also relevant to use the terms Behind-the-meter (BTM) and in front-of-the-meter (FTM), where BTM typically includes flexibility assets on the grid user's premises in combination with other non-flexible assets (consumption, generation, and storage), and FTM typically includes assets directly connected to the distribution grid (grid connected batteries, controllable generation etc.) where the complete asset is controlled when flexibility is activated (Freeman).

2.2. Utilising flexibility in grid operation and grid planning

Since the scope of this research covers both grid planning and grid operation, we need to clarify the distinction and relationship between these groups of DSO activities. This distinction is becoming more challenging to make within the emerging paradigm of *active distribution grids* (CIGR É C6.19 Working Group, 2014), which requires closer integration of planning and operation activities by the DSO. Traditionally, measures considered in distribution grid planning have been "passive" measures such as grid reinforcement (grid investments). Active measures, on the other hand, are defined as measures in distribution grid planning that involve the active utilisation of resources in the operation of the distribution system. This is illustrated in Fig. 4, which is based on a framework for active distribution grid planning that treats active measures on equal footing with passive (traditional) measures (Sperstad et al., 2020b). In this framework, flexibility solutions are involved in a subset of active measures that involve the utilisation of flexibility resources in the operation of the distribution system. However, to be able to utilise flexibility in grid operation, the DSO must have already selected a flexibility measure to implement in the planning phase. In addition, to assess the technical feasibility and risk of a potential flexibility measure in the planning phase, the DSO must already consider how the distribution system will be operated. The assessment of risk should consider that a flexibility measure may imply operating the system with smaller security margins than if a passive measure is selected to increase the grid capacity. Smaller security margins may in turn imply a greater risk of power supply interruptions and voltage problems in the operational phase, and as consequences increased interruption costs (an economic risk to the DSO due to the Norwegian income cap regulation) and damaged public opinion.

As shown in Fig. 4, the starting point of the grid planning process according to this framework is identifying needs in the grid. This could be due to either an existing or future grid problem. It is useful to distinguish between two main groups of planning processes based on the needs that they are triggered by. The first main group includes processes triggered by requests for connecting new grid users to the grid or for increasing the demand of existing end-users. Planning studies for such use cases are typically limited in the considered scope and time horizon. In the other main group, one finds at the other extreme, long-term power system analyses that considers planning horizons of several decades into the future. In the case of Norway, such analyses are mandated by the Norwegian energy regulator (NVE)[8] and referred to as KSUs ("kraftsystemutredninger"/Power system studies). Long-term grid planning processes are nevertheless generally driven by some identified needs, due to present or expected future grid problems. These can be future needs identified in KSUs, or a combination of grid connection requests that need to be considered jointly.

2.3. Flexibility value chain

When DSOs use flexibility as active measures in planning and operation of the grid, this is a fundamental change from the traditional situation where the DSOs operate their own grid assets, to a new situation where they interact with third parties to procure flexibility. This extended scope in the planning and operation of the electrical grid – from complete and direct control to procuring flexibility will be explored in this paper.

Flexibility from different sources can be used for different purposes by different stakeholders. Additionally, flexibility can be traded through different markets. This requires a holistic approach, that focuses on the complete flexibility value chain, as introduced in (USEF, 2018).

We first need to establish an understanding of the terms "value" and "value chain". According to (Porter, 2008) "value" can be defined as "the amount buyers are willing to pay for what a firm provides them". Flexibility has no value in itself, unless it enables a realisation of

[7] CAPEX = Capital Expenditures, OPEX = Operating Expenses.

[8] Information available on the web site of the Norwegian energy regulator (NVE): https://www.nve.no/energi/energisystem/nett/kraftsystemutredninger/. The guidelines of NVE require that the potential for demand-side flexibility is considered as part of a KSU.

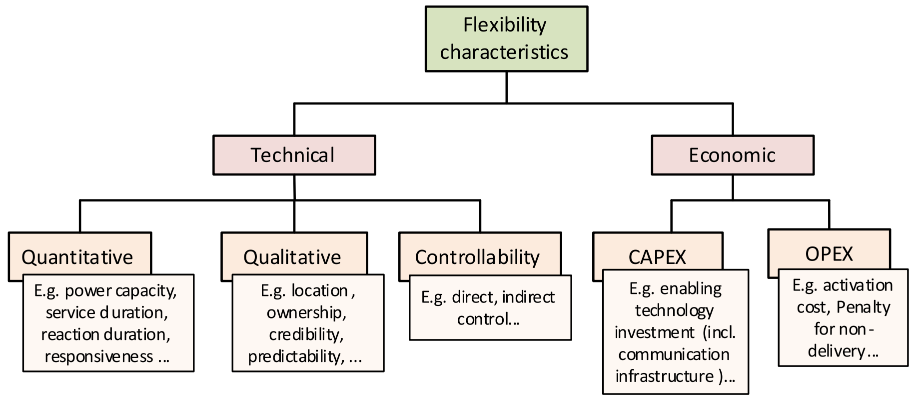

Fig. 1. Classification of flexibility characteristics, based on (Degefa et al., 2021).

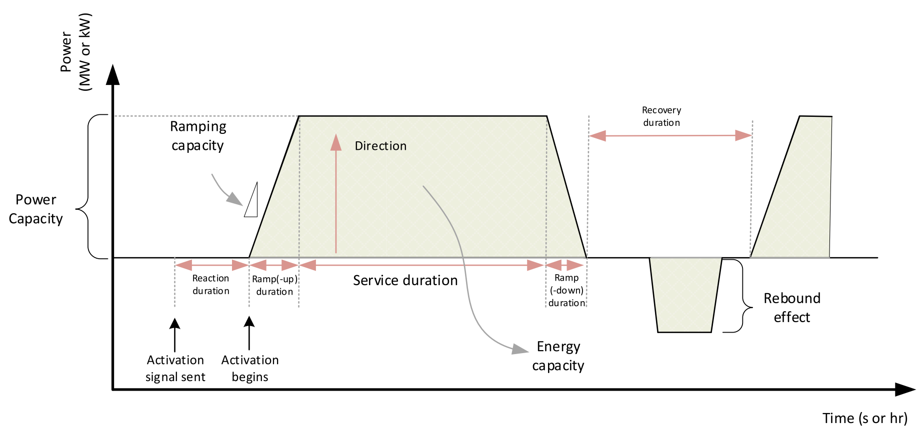

Fig. 2. Comprehensive illustration of important characteristics of flexibility resources (Degefa et al., 2021).

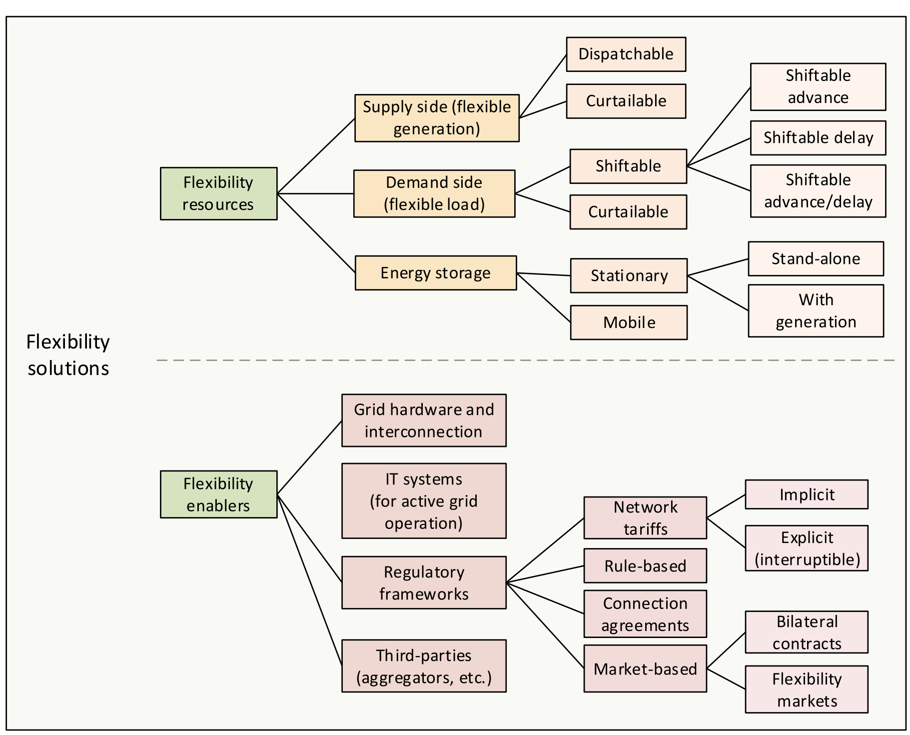

Fig. 3. Classification of flexibility resources and their enablers, based on classification proposed in (Degefa et al., 2021) and on coordination mechanisms (enablers) for accessing flexibility described in (CEER Distribution Systems Working Group, 2018), (CEER Distribution Systems Working Group, 2020).

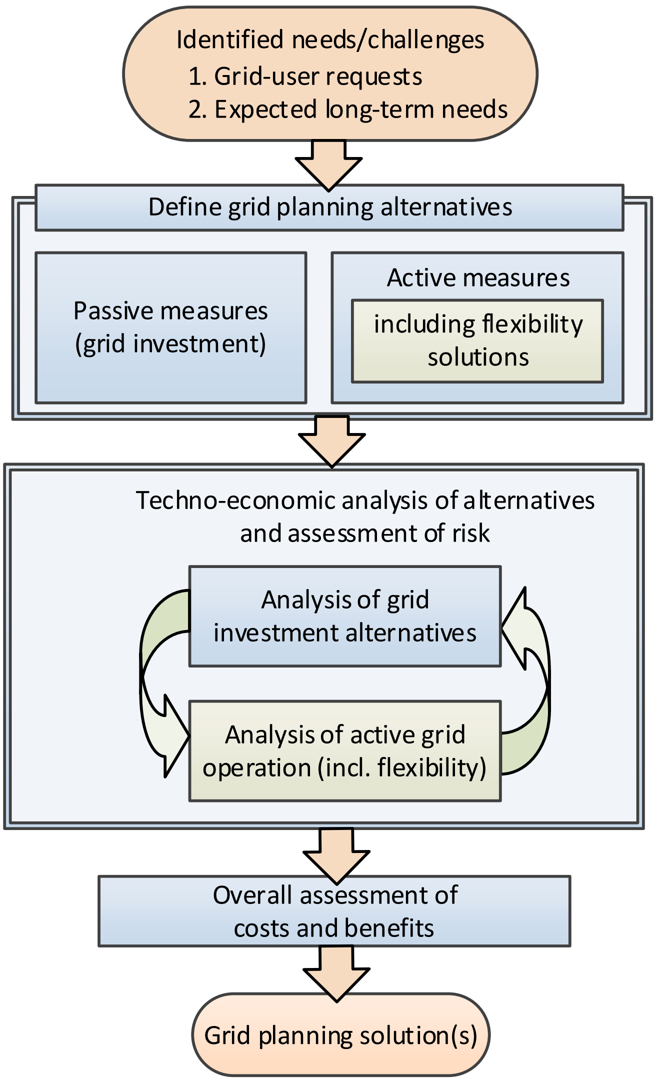

Fig. 4. Framework for active distribution grid planning (based on (Sperstad et al., 2020b)).

benefits, such as reducing DSOs' needs for grid investments (Nordic Council of Ministers, 2017). In (Porter, 2001) the term value chain is defined as "a representation of a firm's value-adding activities, based on its pricing strategy and cost structure". The general value chain is mainly developed for a firm offering a specific product that generates a value for a customer, but on equal terms a value chain can be developed for the process by utilising flexibility as a service in the power system, for the benefit of both involved stakeholders and for the complete power system.

An illustration of the flexibility value chain is presented in Fig. 5. This figure will be basis for the categorisation of barriers for utilising flexibility in the operation and planning of the electricity distribution system, based on the interviews with the DSOs. The flexibility value chain starts with the flexibility provider, which can be different flexibility resources from different types of grid users. The upper half of Fig. 3, which classifies the resources-part of a flexibility solution thus corresponds to the grid user side of the flexibility value chain in Fig. 5. The flexibility value chain ends with the procurer of flexibility, which has a need for activating flexibility and will benefit from the flexibility solution. For example, this can be the DSO or TSO[9] using flexibility for grid services. To complete the flexibility value chain and get a holistic overview, different business models/agreements, responsibilities and technological requirements for the realisation and activation of flexibility, have to be identified and developed. These are found in the lower half of Fig. 3, which classifies the flexibility enabler-part of a flexibility solution. The regulatory framework needs to support all stakeholders in the flexibility value chain, both monopoly actors such as DSOs and TSOs, and actors operating in the market such as grid user providing flexibility or third-party (aggregator) trading flexibility.

[9] TSO = Transmission System Operator.

2.4. Framework conditions as potential enablers for utilising flexibility

Through the Clean Energy Package, European DSOs have received recommendations to use flexibility and optimise decisions for grid investments (Eurelectric, 2020). In total, the package consists of eight new legislative acts, and these new rules are intended to benefit both grid users, the environment and the economy (European Commission, 2019b). According to Article 15 in Directive 2019/944 for internal market for electricity (IEM) Member States shall ensure that active customers[10] are entitled to participate in flexibility schemes and energy efficiency schemes (European Commission, 2019a).

Furthermore, Article 32 in the IEM Directive elaborates on the requirements for incentives for the use of flexibility in the distribution networks – especially paragraphs 1 and 2. Hence, **paragraph 1** will improve efficiencies in the operation and development of the distribution system through development of necessary regulatory framework to allow and provide incentives to DSOs to procure flexibility services, including congestion management in their areas. DSOs should be able to procure flexibility services where this is a cost-efficient alternative to upgrading or replace electricity capacity and support the efficient and secure operation of the distribution system. Further, flexibility services should be procured according to a transparent, non-discriminatory and market-based procedures unless the regulatory authorities have established that the procurement of such services is not economically efficient or that such procurement would lead to severe market distortions or to higher congestion. Further, **paragraph 2** specifies that the process for procurement of flexibility should be performed in a transparent and participatory way, where relevant stakeholders such as system users (i.e., grid users and market participants) and TSOs, are included.

Grid users can provide flexibility through different types of incentives. When flexibility is activated by a grid user as a response to a price signal, to optimise energy costs, this is known as *implicit flexibility* (USEF, 2018), (CEER Flexibility Task Force, 2016). With *explicit flexibility* the flexibility is sold as an explicit product (volume) in different market segments or as a grid service to system operators (CEER Flexibility Task Force, 2016). In this paper the main focus is on explicit flexibility.

In (CEER Distribution Systems Working Group, 2020) CEER gives an overview of the most fundamental preconditions needed before DSOs can procure flexibility and manage congestions in system operation, also including market-based approach following the principles: balances incentives, adequate neutrality, technical prerequisites and an overall framework for procurement. An overview of these categories, with examples of products and type of incentive is presented in Table 1 (Based on (CEER Distribution Systems Working Group, 2020)).

[10] In Article 2 part (8) 'active customer' is defined as *a final customer, or a group of jointly acting final customers, who consumes or stores electricity generated within its premises located within confined boundaries or, where permitted by a Member State, within other premises, or who sells self-generated electricity or participates in flexibility or energy efficiency schemes, provided that those activities do not constitute its primary commercial or professional activity* (European Commission, 2019a).

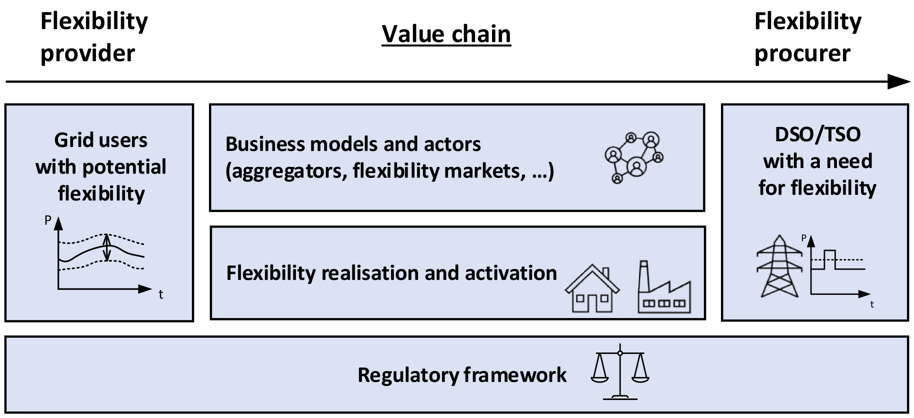

Fig. 5. Illustration of the flexibility value chain.

Table 1
Overview of categories for enabling DSOs' access to flexibility (Based on (CEER Distribution Systems Working Group, 2020), (Høiem et al., 2021)).

CEER Categories	Description (CEER Distribution Systems Working Group, 2020)	Type of incentive	Mechanisms
Rules-based approaches	Codes and rules imposing detailed flexibility requirements	Explicit	The Demand Connection Code (DCC) (European Commission, 2016) sets requirements for connecting large renewable energy production plants and demand response facilities. Organised by the system operator (TSO or DSO). The flexibility procurer can for example enter into an agreement with customers in a grid area with limited capacity.
Connection agreements	Agreements with network users for the provision of flexibility	Explicit	Allowing new connections without reinforcing the grid, in grid areas with limited hosting capacity.
Network tariffs	Tariff structures designed to encourage network users to alter their electricity consumption for a more efficient use of the distribution grid	Implicit	Tariffs focusing on peak capacity will give customers an incentive to reduce peak load, reducing the DSOs need for buying flexibility in peak load periods.
		Implicit	Dynamic tariffs with differentiation in time and location will give customers an incentive to reduce consumption in high price periods. The effectiveness of such tariff depends on available flexibility in the specific periods.
		Explicit	Tariff for interruptible loads gives the customers a rebate in the grid costs if the load can be disconnected based on the request from the DSO. Typically, loads are disconnected according to grid-related conditions (for congestion management, during grid outages, etc.).
Market-based procurement	DSOs can procure flexibility to be included in grid services from a market.	Explicit	Bilateral contracts procured in a market (via auctions), for example when buying flexibility to solve a specific grid challenge.
		Explicit	Flexibility procured in a marketplace, based on bids from both flexibility providers and procurers. (Daily/weekly/monthly clearing of the market)

3. Data and methodology

The interview study was designed as an explorative study, to map todays' experiences and expectations for the future (towards year 2030/2040) among Norwegian DSOs related to utilising flexibility in planning and operation of distribution grids. The objective was to identify whether there are practical, technical and framework conditions, or other barriers, that prevent DSOs from utilising flexibility in their planning and operation of the grid. To meet this objective, a qualitative research approach was chosen using in-depth interviews as a research method. Compared to quantitative methods such as surveys and statistical analysis, such an approach is better suited to understand complex issues (Krumsvik, 2013)– (Corrêa et al., 2022). DSOs were interviewed during spring 2021, and the results from these interviews were further verified at a workshop with other DSOs in November 2021.

3.1. About the survey (data)

The empirical material was collected through in-depth interviews performed with groups of 2–3 persons from each of the 7 DSOs. The informants represented different aspects of the grid enterprise, including grid operation, grid planning, R&D and innovation, and regulatory framework conditions. The DSOs were selected to have a representative sample of Norwegian DSOs, according to number of customers in their grid (small/medium/large), geographic location (North, North-West, West and East part of Norway), and voltage level (230 V-1 kV low-voltage distribution grid/1–22 kV high voltage distribution grid/up to 132 kV regional distribution grid). In total the DSOs represented 1.54 mill. end-use customers (approximately 50% of the total grid users) in Norway. See details in Table 2.

3.2. Methodology

The interviews were semi-structured which allowed the informants

Table 2
Number of grid users divided by grid level and type of consumption (NVE-RME, 2021).

Grid level	Type of consumption	Number of grid users (per 31.12.2019)		% share of grid users in Norway
		In total for the DSOs participating in the survey	In total for all Norwegian DSOs	
Distribution grid	Prioritised	1.54 mill.	3.1 mill.	50
	Flexible[a]	1712	2124	81
Regional distribution grid	Prioritised	88	172	51
	Flexible[a]	17	23	74

[a] Mainly related to tariff for interruptible loads.

to bring up various issues of concern (Krumsvik, 2013), (Winther et al., 2018), (Burghard et al., 2022), (Sahlberg et al., 2022). After introduction of the study within CINELDI, information about how data would be collected, stored, and used was provided. The informants accepted that the interviews were recorded.

An interview guide was developed and sent to the DSOs in advance of the interviews. The interview guide was based on the conceptual frameworks introduced in Section 2.1 and covered the following topics:

1) The status of available flexibility and what is triggering grid investment planning today.
2) Expectations towards 2030/2040 related to use of flexibility in grid planning and operation, and enablers for utilising flexibility.

The interview guide is available (in Norwegian) as an attachment to the full report from the study (Høiem et al., 2021). An English version of the interview guide is presented in appendix to this paper.

Four researchers conducted the interviews together, and the duration of each interview was 1.5 h. The interviews were performed in spring 2021. Everyone from the research group took notes in all interviews, in addition to the recordings. The analyses of the interviews were mainly based on the meeting notes, and the recordings were only used as back-up if it was necessary to check details.

The data collection (recordings) performed during the interviews was approved by NSD - Norwegian centre for research data.[11]

Even if a limited number of DSOs was interviewed, it has been possible to understand why flexibility has not been utilised to a larger degree by the different DSOs. Performing the study as semi-structured interviews is supporting organisational and personal factors rather than quantifying the use of flexibility. Recordings from interviews are considered personal data according to Norwegian law and had to be kept confidential. Therefore, raw data from the study cannot be disclosed.

To eliminate part of the uncertainty related to the small sample size (only 7 DSOs), the results from analysing the interviews were presented to and verified by other Norwegian DSOs and relevant stakeholders at a workshop in November 2021. In total 3 DSOs, 1 TSO, 1 national electricity association and 3 vendors were represented at this workshop. The verification was performed with use of slido polls, with 11 active participants. The participants were presented the preliminary list of barrier descriptions and relevant flexibility resources identified through the interviews, and were asked to rank these by relevance. The poll results were then discussed, using the participants as an informal focus group. This step of the methodology was included to test the interpretation of the data from the interviews, structure the findings, and assess which findings were most representative on a national level.

4. Main findings from the study

4.1. Status today

4.1.1. Utilising flexibility

According to the survey among the DSOs, limited use of flexibility for planning and operation of the grid was identified. Use of flexibility was mainly related to pilot projects and through direct contracts with grid users related to grid tariff for interruptible loads (See Table 1). Different alternatives of this agreement were already put into practice among the DSOs, with different requirements related to *reaction duration*[12] (response time varying from instantaneous disconnection of loads and up to giving the grid users time to start up alternative energy carriers), and *service duration* (for example limited to 4 h, or disconnection for an unlimited time – relevant for boilers with alternative energy carriers available). Additionally, some agreements included requirements related to limited number of days during a year for activating flexibility.

A limited number of DSOs indicated that in cases where flexibility was evaluated as an alternative to traditional grid investments, the flexibility potential was mainly investigated when new grid users should be connected to the grid, especially in grid areas with limited hosting capacity.

An overview of flexibility resources considered as relevant by the interviewed DSOs is presented in Table 3. The different flexibility resources are presented for transport, buildings, industry, and storage/generation/other, and sorted in time based on what is in use today, and which resources are considered relevant in a short-term (within a few years) and in a long-term (2030–2040) horizon. The flexibility resources can be utilised for different purposes, as for example voltage control, congestion management, balancing services (Degefa et al., 2021).

4.1.2. Triggering of grid planning and grid investments

With reference to the framework for active distribution grid planning in Section 2.2, the grid user-initiated planning processes were most common among the DSOs. The main triggers for considering grid investments were related to connection of new types of loads such as ferry charging, public charging stations, data centres, aquaculture industry, as well as increase in distributed generation from solar panels, etc. Principally, all DSOs answered that they in the grid planning process do not consider flexibility as an alternative to grid investments. The only exception was use of the grid tariff for interruptible loads, where some DSOs offered this as an agreement with new grid users or as an active measure to defer grid investments for a shorter period (months/few years). One DSO specified that the load with this tariff was regarded as potential flexibility in grid planning by not including this load in the dimensioning basis when planning future grid investments, but the flexibility was not included as part of a more active grid operation.

The main reasons for not including flexibility in grid planning were related to uncertainty about available flexibility volume from different grid users, and location of flexibility resources. Even if the DSO knows where the flexibility resource is located, it might be located where there are no grid problems to be solved.

Table 3
Overview of flexibility potential among different types of grid users - for different time horizons.

Time horizon Category	In use today	Relevant within a few years	Relevant in long term
Transport	Hybrid ship (Onshore power supply)	Electric ferry (Ferry charging) Passenger buss Heavy transport EV owners Public charging stations	n/a
Buildings	Municipality buildings (schools, sport centre, swimming pool, library, cinema, ventilation etc.) Housing cooperatives	Office buildings (shops, office, auto dealer, etc.) Airport	Nursing home Hospital
Industry	Aquaculture industry (fish farm, fish processing) Greenhouse Energy intensive industry Data centre	Agriculture	n/a
Storage/ Generation/ other	n/a	n/a	Owners of battery banks Small power plant Prosumers (PV panel combined with battery)

[11] https://www.nsd.no/en.
[12] Flexibility characteristics in italic are illustrated in Fig. 2.

4.2. Barriers and possibilities related to use of flexibility

All DSOs participating in the interviews were well aware of the potential from utilising flexibility. However, their answers revealed a wide range of evaluations about the possibilities and to which degree the barriers were interpreted as larger than the possibilities. Several barriers were identified through the interviews with the DSOs, and the main barriers remaining after the verification process described in Section 3.2 are presented in Table 4. The barriers are grouped into the categories: physical/geographical barriers, technical barriers, missing links in the value chain, grid company maturity, grid user maturity and regulatory barriers. These barriers are further mapped to the flexibility value chain introduced in Section 2.3, as presented in Fig. 6.

Table 4
Identified barriers related to utilising flexibility – based on interviews with DSOs.

Barriers	Related to	Description
Physical/ geographical barriers	Location of flexibility resources and grid related problems	• With a limited number of flexibility resources available today, the probability that these are located in the same place as grid problems to solve, is low.
Technical barriers	Software solutions	• Lack of connections between IT systems for grid operators and grid planners. • Lack of information about actual capacity in the grid (overview in real time).
Missing links in the value chain	Actors and business models	• The aggregator role is not sufficiently developed to utilise flexibility from smaller grid-users (for example household customers).
Grid company maturity	DSO competence	• Lack of competence and tools to estimate predictability and the necessary security margins related to the use of flexibility in long term grid planning. • Lack of competence and capacity to efficiently map potential flexibility and to know which resources to look for, for example, to see if the resources are available in the grid areas where flexibility is needed.
	Culture and work processes at DSOs	• Lack of culture for communication and cooperation between different parts of the DSO organisation (grid planning, operation, customer relations, R&D, contact with authorities, …) • Work processes and procedures are not developed to evaluate flexibility as an alternative (in other words, this is not included in the toolbox for grid planners).
Grid user maturity	Maturity on the customer side	• Grid users have limited knowledge about their own consumption, their consumption pattern, and what it means to act flexibly. • Lack of understanding of cost and benefits related to flexibility, for the grid user, the DSO and society.
Regulatory barriers	Regulation/framework conditions	• Incentives to realise implicit flexibility (demand response as a result of price response in electricity consumption) are not targeted enough. • Distribution of responsibility between TSO and DSO makes it more difficult for the DSOs to utilise flexibility as an alternative when handling bottlenecks in the regional distribution grid.

Differences among the DSOs in terms of utilising flexibility were related to both the confidence that persons working with grid operation and planning have in flexibility as an alternative to traditional grid measures, and how these persons evaluated risks in their work. The group interviews revealed that differences in how flexibility is viewed within each DSO can be more pronounced than differences between DSOs.

In grid operation the risk is related to low or insufficient response when flexibility resources are activated to solve grid problems; in other words, their responsiveness, reliability or availability characteristics (Degefa et al., 2021). Grid operators are more comfortable with having grid capacity with margins that suggest that the activation of flexibility will almost never be needed to solve any problems. However, if proper software solutions and flexibility have been made available for grid operation, use of flexibility was evaluated as a relevant measure for grid operation. Flexibility could be a useful addition to the "toolbox" of grid operators that does not require fundamental changes in work processes.

For grid planners, on the other hand, flexibility solutions were often thought of as being too unpredictable. If flexibility is to be included in grid planning, more fundamental changes and new work processes must be established, in addition to the development of software tools for grid planning. Most of the DSOs considered themselves as not being ready for evaluating flexibility in current grid planning, but there were differences related to how the different DSOs understood the term "flexibility" and what they considered when evaluating flexibility in grid planning. This finding is further elaborated in Section 4.4. Some DSOs even expressed that they did not plan for a more active operation of their grid where the grid is being operated with smaller security margins – in contrast to statements found in more academic literature (CIGR É C6.19 Working Group, 2014), (Moslehi and Kumar, 2010).

4.3. Expectations for 2030/2040

4.3.1. Utilising flexibility in grid planning and operation

In summary, the most relevant role for utilising flexibility is to increase the reserve capacity (redundancy) in the grid in case of outages. More specifically, the following alternatives were evaluated during the interviews:

- Disconnection of loads at grid users with access to alternative energy carrier in order to secure sufficient reserve capacity in the grid, for the long term duration of disconnections (most relevant for hybrid or electric ferries, data centre, electric boiler etc.)
- Reduced consumption at larger grid users (shopping centre, cold storages etc.) to level out the consumption and reduce peak load in the grid,
- Disconnecting loads to support the management of bottlenecks in a transmission grid (in cooperation with TSO),
- Deployment of electric batteries to handle voltage problems in rural parts of the distribution grid (long radials), and
- Electric water heaters at households as potential resources for solving local problems in low voltage distribution grid (pilot projects).

Several DSOs emphasised that it will not be expedient to allocate specific flexibility resources for specific purposes, because this can be a barrier to the further development of market-based solutions for flexibility (in other words, avoid locking in flexibility resources to specific flexibility products). Flexibility solutions can be utilised for different purposes in the grid independent of the actual type of flexibility resource.

4.3.2. Enablers for utilising flexibility

Based on the interviews it was clear that the DSOs had different

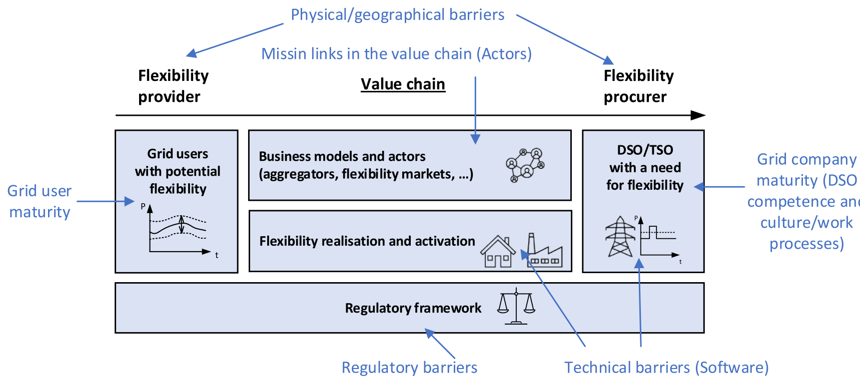

Fig. 6. Barriers mapped to the flexibility value chain.

experiences related to flexibility, which also was reflected in the discussion about enablers for utilising flexibility. The DSO with the most experiences related to grid tariff for interruptible loads, promoted this as the best tool, also towards 2030. Other DSOs thought that there would only be a limited number of grid users that could be disconnected for a longer period, so that the flexibility potential would be quite limited with this agreement.

Several DSOs were positive to the new regulation for connection agreements with conditions related to flexibility, especially due to the reduced risk for the DSOs when new loads are connected with such an agreement. For the grid users, the regulation gives them the possibility to be connected earlier and without grid reinforcements, and therefore to also avoid paying contribution fees for the DSO's grid investments. Therefore, the customer is given incentives to evaluate their need for grid capacity and to investigate if parts of their consumption can be flexible.

Tariffs for interruptible loads and connection agreements with conditions are mainly considered as tools to secure enough reserve capacity in the grid in case of outages, with the objective of deferring grid investments and/or connect new loads to the grid before grid investments are possible (for example due to time-consuming concessionary processes). With these agreements, the grid can be dimensioned with a

Table 5
Mapping of findings to the classification of flexibility resources and enablers (flexibility solutions).

Classification of flexibility resources and their enablers (From Fig. 3)			Main findings (related to flexibility enablers)	Main findings (related to flexibility resources)
Flexibility resources	Supply side (flexible generation)		Flexible generation received little attention[a].	n/a
	Demand side (flexible load)		Larger loads (cf. Table 3) were seen as the most promising flexibility resource in distribution grids.	n/a
	Energy storage		Grid-connected batteries are currently at the pilot stage but were seen to have long-term potential for certain applications.	n/a
Flexibility enablers –Regulatory frameworks	Network tariffs	Explicit flexibility	A tariff for interruptible loads is the only regulatory/market enabler that is currently implemented.	Larger loads were seen as an important flexibility resource at present only when combined with tariff for interruptible loads
		Implicit flexibility	Dynamic tariffs and capacity-based tariffs incentivise give grid users to change their consumption, but the flexibility is not available directly on request from the DSOs. Incentives must be supplemented by clear information to increase grid users' understanding (cf. Table 4).	Flexibility from smaller grid users such as individual households was seen to be most relevant to utilise as implicit flexibility
	Rule-based		Rule-based regulatory enablers have not been implemented and were not given attention.	
	Connection agreements		Conditional connection agreements were believed to have great potential in the short term to enable flexibility from new load demand.	In the future, it was believed that it would be important to enable flexibility from new larger loads from conditional connection agreements, particularly for grid users with alternative energy supply (e.g., hybrid ferries, datacentres, aquaculture industry, ...)
	Market-based	Bilateral contracts:	Bilateral contracts received little attention in the interviews.[b]	
		Flexibility markets	Flexibility markets are at the pilot stage, and full-scale implementation of market-based procurement of flexibility was expected to be more relevant in the long term.	
Flexibility enablers – others	Grid hardware and interconnection		It was pointed out that for utilisation by DSOs, the location of the potential flexibility resources (in the grid topology) was a key characteristic.	
	Third parties (aggregators, etc.)		Aggregators were seen as a crucial enabler for large-scale utilisation of local flexibility markets	In the long-term, flexibility from smaller grid users such as individual households was expected through aggregators
	IT-system (for active grid operation)		DSOs lack information (overview in real time) about actual capacity in the grid and the location of available flexibility resources. There is a lack of connections between IT systems for grid operators and grid planners.	

[a] The Norwegian power system is hydropower-dominated, and hydropower plants with reservoir is by far the most prominent flexibility resource on the transmission level. For local distribution grids, on the other hand, there is a limited potential for flexible power generation from hydropower plants.
[b] The use of bilateral contracts related to utilising flexibility is very limited, mainly related to emergency situations to avoid power supply interruptions.

lower capacity, not including the consumption with flexibility agreements in the load development scenarios that are used in grid planning studies.

The Norwegian energy regulator introduced the possibility of connection agreements with conditions for flexibility in spring 2021 (at the same time as the interviews were performed). This agreement triggers the need for evaluating flexibility, both for the DSOs and grid users. The interviews confirmed that this arrangement was considered as a catalyst for increasing the availability of flexibility in Norwegian distribution grids in the future.

Most of the DSOs evaluated bilateral agreements and local flexibility markets more relevant in the future, as a complement to connection agreements with conditions. This finding stands in contrast to the relatively high attention given to local flexibility markets in the academic literature (Bjarghov et al., 2021)– (Guerrero et al., 2020).

4.4. Mapping of main findings to flexibility classification framework

The flexibility classification framework presented in section 2.1 (Fig. 3) has been used to structure the findings from the study described in the preceding subsections. An overview of the main findings mapped to the classification framework is presented in Table 5. This gives a concise overview of the status and potential for utilising flexibility. According to the framework, a flexibility solution needs to have both the physical (flexible) resource and the flexibility enabler in place, and this is addressed in the two rightmost columns in Table 5. Although it is specific to the situation in Norway, we believe that a structured mapping according to this classification framework can be useful also for other countries and for comparing the situation across different countries.

It is interesting to note which flexibility resources were *not* given any attention by the DSOs. For instance, in the interview guide, the DSOs were informed about alternative components within each households, such as different appliances, based on the classification in (Degefa et al., 2021). However, only water heaters were discussed by the informants. The explanation can be that electric water heaters contribute to a large share of the electricity consumption in Norwegian households (typically 15% of total yearly electricity consumption), and through both pilot projects and simulations, they have been highlighted as a flexibility resource with high potential (Lakshmanan et al., 2021)– (Saele and Grande, 2011). The lack of any of the more exotic or unusual energy storage technologies (flow batteries, compressed air, etc.) as well as pumped-hydro storage was also conspicuous in the responses from the DSOs.

It is also interesting to note that several informants interpreted the concept of “flexibility” quite differently from the definition they were presented in the interview guide (cf. Section 2.1). Some seemed to restrict their definition to only include demand-side flexibility, despite being informed that the definition used in the study also included supply-side flexibility and energy storage. Others said that they considered flexibility in their grid planning studies in the sense that they estimated the coincidence factor of aggregated loads when they were dimensioning new grid investments, which they saw as an indirect expression of the flexibility of the underlying individual loads, but they did not clarify to which degree price-elasticity of the demand was included in the coincidence factor. This substantiates the findings from the literature review in (Degefa et al., 2021) that the understanding of “flexibility” varies widely between different stakeholders.

4.5. Limitations of the study

In this study, in-depth interviews have been performed with limited number of DSOs, following a qualitative and not a quantitative approach to the overall research question. This qualitative research method does not form a basis for statistical analysis but is instead an approach for better understanding complex issues related to barriers to the utilisation of flexibility.

Since only Norwegian DSOs were interviewed, the focus in the interview study was on Norwegian conditions. However, the selected DSOs were evaluated to be representative for Norway based on criteria such as number of customers in the grid, geographic location, and voltage level. The experiences from the Norwegian DSOs are relevant for other countries, since the need for flexibility in both the planning and operation of the electrical grid is valid for other countries (CEER Distribution Systems Working Group, 2018), (USEF, 2018), and also emphasised by European industry and authorities (Eurelectric, 2020), (European Commission, 2019a). Despite the Norwegian focus in the interviews, the framework for the classification of flexibility resources (Degefa et al., 2021) used for mapping the findings from the in-depth interviews, is based on an extended survey of the international literature and is therefore valid for other countries. The interview guide used in the study is enclosed, enabling barriers to be identified for a larger share of DSOs – both in Norway and in other countries.

That only DSOs were interviewed in the study is also a limitation, and the results predominantly reflect the DSO perspective. However, this was also identified as a gap in the literature review, despite recommendations on DSOs’ use of flexibility through for example EU’s Clean Energy Package. The same flexibility resources can provide benefits and create value for other actors in the flexibility value chain (e.g., TSOs) that may not be accounted for in the DSOs’ cost-benefit analyses. Moreover, flexibility can also have wider societal benefits beyond the boundaries of the power system and the flexibility value chain, such as accelerated development of generation from renewable energy sources (sun, wind) and grid connection of new, sustainable industries.

The focus in the interview study was to map current experiences and expectations for the future (2030/2040) among Norwegian DSOs, related to utilising flexibility in the planning and operation of distribution grids. The discussion in the interviews was based on the individuals’ expectations for the future, and not related to specific scenarios. A limitation related to this, is that the expectations for the future can be influenced by previous experiences related to utilising flexibility.

5. Conclusion and policy implications

Utilising flexibility in the planning and operation of the electrical grid is a remarkable change from today’s situation where the DSOs have full control of their grid assets, to a new regime where the DSOs should rely on flexibility services from third parties. In this new regime, secure grid operation will be dependent upon more actors, more ICT systems, and in general more links (direct and indirect interactions) between the grid operator and the grid users.

This requires a holistic approach, considering the complete flexibility value chain, and not solely limited to a subset of possible flexibility solutions as defined in section 2.1. Additionally, this change from traditional grid investments to an increased use of flexibility resources in both the planning and operation of the grid is immature and not fully deployed. Through directives and other policy documents, DSOs are motivated to utilise flexibility, but there are still many barriers to overcome. The DSOs have extensive experience with traditional grid investments as their default solution, but with flexibility as a relatively new concept, the DSOs lack familiarity with the different resources at different grid-users. There is also a barrier related to the necessary infrastructure for activating flexibility. Changing work processes and mindsets so that flexibility is considered more naturally in the planning phase could be accelerated by regulatory requirements (for example based on Article 32 in the IEM Directive (European Commission, 2019a)) but probably more importantly by cultural changes within DSOs with commitment from all levels of the organisation.

Most research focuses on the quantitative characteristics of flexibility resources and how these determine the flexibility procurer’s costs and benefits of flexibility utilisation in the planning and operation of the distribution grid. The informants of this study, on the other hand, were predominantly concerned with characteristics that are not easily quantifiable. Most prominent were characteristics related to the availability, reliability, predictability and controllability. The associated uncertainties related to more active grid operation lead to operational risks that are not present today when planning the grid with traditional measures such as grid reinforcement. Grid planners may be averse to accepting smaller security margins in operation or taking the risk that flexibility resources may not always be available and respond when called for during grid operation. One contributing factor to this risk averseness might be that planning with flexibility resources implies transferring a certain amount of risk from the grid planners to other stakeholders: It implies that the grid operators have to deal with new kinds of operational risks, and more generally that the DSOs need to rely on flexibility delivered by third parties. Some implications are that policies and regulatory frameworks should acknowledge i) qualitative as well as quantitative characteristics, ii) that the risk associated with utilising flexibility solutions should appear acceptable to the DSOs, and iii) that expected cost-effectiveness by itself may not be sufficient to convince DSOs to adopt flexibility solutions. Another recommendation is that regulation should allow for business models and contracts that give the DSOs the necessary security (predictability) that they can accept the risk and trust the flexibility solutions.

Planning with flexibility involves new ways of thinking for the grid planners: It involves more interactions with grid-users and with grid operation, and it changes the risk picture. This appears to be an important cultural barrier to fully utilising flexibility solutions. In addition, there is the competence element of the barrier, wherein many grid planners lack the mindset and toolbox to deal with uncertainty, probabilities and risk related to flexibility in long-term grid planning studies. One recommendation is to contribute to demounting such barriers through continued support for demonstration projects and piloting of flexibility solutions. Pilot projects are important to the realisation of full-scale solutions in the distribution system, such as an increased utilisation of flexibility (Sæle et al., 2021). This would build DSOs experience, reduce uncertainties of the operational flexibility characteristics, and thereby contribute to de-risking flexibility solutions.

Several informants expressed the view that enablers such as flexibility markets, were unlikely to be fully realised in the near term. At the same time, some saw a future where different flexibility enablers would have complementary roles and be useful for different purposes. Furthermore, since flexibility resources can contribute to different types of flexibility services, the alternative flexibility providers should also be treated as complementary providers of flexibility. This view is supported by the theoretical frameworks established in Section 2. One implication is that the regulatory framework should be designed to accommodate all enablers rather than favouring one or a few. Regulation should open for low-threshold enablers that can be seen as “stepping-stones” for solving the problem with lack of familiarity by building experience, and addressing cultural and competence barriers. Pilot projects that feature different flexibility resources contribute to this, for example, by building experience related to the remote control of electrical water heaters at a household level (Saele and Grande, 2011), and adaptive regulations that include regulatory sandboxes allowing time-limited derogations from existing regulation, can be tools for enabling such experiences (Council of European Energy Regulators, 2022).

The new regulation for connection agreements with conditions related to flexibility was by seen by the Norwegian DSOs as a key enabler for electrification and providing new sustainable industries faster access to the grid, with less delay due to grid investments. Furthermore, enablers in the categories of “Rules-based approaches” and “Connection agreements” are furthermore not dependent on as many actors in the flexibility value chain as flexibility markets, and can be adopted as the value chain and associated business models are mature. In the long-term, it is important that policies are developed with a holistic view of the flexibility value chain and contribute to supporting sustainable flexibility business models, put in place links that are currently missing, increase the DSOs’ trust in utilising flexibility in the planning and operation of the electrical distribution grid and build grid users’ maturity and awareness of their role in the flexibility value chain.

CRediT authorship contribution statement

Hanne Sæle: Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Project administration. **Iver Bakken Sperstad:** Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Writing – review & editing. **Kristian Wang Hoiem:** Conceptualization, Methodology, Formal analysis, Investigation, Writing – review & editing. **Vivi Mathiesen:** Conceptualization, Methodology, Formal analysis, Investigation, Writing – review & editing, Project administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.enpol.2023.113618.

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