Distributed balancing of the power grid

Results from the eFleks pilot in the mFRR-market 2019/2020

Preface

This report is the evaluation of the pilot project called eFleks, which tested 1 MW bid size and automated value chains in the mFRR market.

Statnett was the project owner, and the pilot partners were Tibber and Entelios. Enfo and Siemens were sub-contractors of Entelios. The respective team members can be seen in the list under.

The report is written with collaborative efforts from Statnett, Tibber, Entelios, Enfo and Siemens. Chapter 1 to 4 provide the reader with a background of why and how Statnett commissioned the pilot and the requirements we set for participation. Chapter 5,6,7 are the pilot partners own descriptions of the preparations for the mFRR-participation, electronic bid ordering integration, prequalification, and tests results from the operational phase. Still taking the perspective of the market players, chapter 8 contains a discussion of key learnings from the pilot and chapter 9 provides some inputs to continued work. Chapter 10 contains Statnett's final comments. Summarized, this report gives a detailed insight in the pilot results and learnings, focusing on the participants experiences.

We hope this report and our results will inspire more market players to make use of novel technologies and contribute to the realization of the flexibility potential.

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Content

Definitions

AHU	Air handling units
BAS	Building Automation System
BRP	Balance Responsible Party
BSP	Balance Service Provider
Landssentralen	Statnett's National Control Centre
eBestill	Statnett's system for electronic bid ordering of mFRR (Elektronisk bestilling)
ECP	Energy Communication Platform (developed by ENTSO-E)
EDI	Electronic Data Interchange
EDIFACT	Electronic Data Interchange For Administration, Commerce and Transport
EDX	ENTSO-E Data Exchange
ENTSO-E	European Network of Transmission System Operators for Electricity
FiftyWeb	Statnett's web interface for bidding
mFRR	Manual Frequency Restoration Reserves. Market for balancing reserves.
MADES	MArket Data Exchange Standard
RTU	Remote Terminal Unit
HAN	Home Area Network (data interface smart meters)

Executive summary

This report is the evaluation of a pilot scheme testing 1 MW bid quantum in the mFRR market in price area NO1 in 2019/2020. The goal was to increase the access to flexible resources, while maturing providers, grid companies and Statnett's operation and IT-systems for bids down to 1 MW, as well as taking a step towards more automatic value chains. The pilot has demonstrated that flexibility down to end-consumer can be made available for the balancing markets. Lowering the minimum bid size was essential to mobilize these new balancing resources.

Pilot partners Tibber and Entelios, the latter in cooperation with Enfo and Siemens, provided solutions for automated response to electronic bid ordering from Statnett. Tibber provided 1 MW flexibility from panel heaters and electrical vehicles, whereas Entelios provided flexibility from a portfolio of 4 MW from industrial loads and 1.37 MW from commercial buildings. Tibber and Entelios were both BRPs for their respective portfolios of flexibility. Tibber and Entelios participated in the mFRR-market during two periods in May and October 2020.

The pilot was a breakthrough as it was to our knowledge the first-time demand was automatically activated in the mFRR-market in Norway. Innovation was prioritized over mFRR-volume in this pilot. Nevertheless, the pilot partners had a total of 12 MW activated in the mFRR market, and of which 7.95 MW were delivered as agreed. Since a provider is obliged to deliver the amount offered in the mFRR-market, and always in integers, the pilot was an opportunity to mature the value chain and eliminate future failures.

Aggregators must handle complex value chains with multiple stakeholders to provide flexibility from distributed resources. Every market player must provide a single point of contact, which is able to manage and activate the bid and respond to enquiries from Statnett while the bid is active. The aggregator's risk management and redundancy plan must involve all elements in the value chain, and consider both technical and non-technical challenges, some of them exemplified in this pilot. Automatization enables effortless and rapid response from complex value chains, yet the human factor must not be forgotten. Non-technical challenges, especially in commercial buildings, have proven to be harder to overcome than the technical ones.

The pilot shows that successful integration towards Statnett's electronic bid ordering requires practical testing at the flexibility providers end, especially connected to bidding and activation of bids. A concrete measure for the market players is to have a test environment where they can test their solutions and integration towards Statnett both before entering the market and while in the market.

Good data quality represents an advantage to the flexibility provider when predicting the resources potential and availability, forecasting, verifying and securing the delivery. One learning is that if the balancing reserves are novel or otherwise difficult to predict or manage, this must be reflected in the aggregator's reserve buffer to secure the delivery. Load behavior after activation is also of interest, and should be assessed, especially when scaling up.

The report finally identifies a selection of measures to drive further development. Firstly, while fully digitalized solutions provide an efficient market access to new flexibility sources, they also come with new challenges. Digital security will need to be built into the systems by design, as well as throughout the whole service delivery supply chain. Secondly, price signals to the end-user and smart appliances standards and investments can be used to tap the residential capacity. Thirdly, collaboration and knowledge sharing are needed across the value chain to commercialize the flexibility from larger buildings. This includes understandable and accessible information about the balancing markets and their processes from the system operator to new market players.

The mFRR-market is open to new market players also outside the pilot. At the present you need to be the BRP or cooperate with the BRP of the flexible resources to become a market player. The minimum bid size is currently 5 MW in price area NO1, and 10 MW in the rest of Norway. Statnett's current estimate is that 1 MW bid size will be allowed in the Norwegian mFRR-market at latest with the implementation of 15 minutes imbalance settlement period (Q2 2023). Due to both a growing potential and need for flexibility in the power system, Statnett hopes to welcome both new market players, technologies and volumes in the mFRR-market in the years to come. Increased flexibility can be sustainable and cost-effective both for the society and the flexibility providers.

1. Pilot background

According to Statnett's latest long-term market analysis (Statnett, 2020), Europe's power system is heading towards zero emissions in 2050. The basis scenario in the analysis is that the development towards 2050 will be driven by three factors:

- A massive electrification which is directly and indirectly doubling the power demand
- A tenfold increase in the renewable production from wind and solar
- A total phase out of fossil power plants by 2050 and much reduced by 2040

This development needs to be followed by an increase in flexibility from producers and consumers. Norwegian power generators and large-consumption customers are already good at delivering flexibility, but we will need even more flexibility in the years ahead.

There are several trends in both technology and market development that increases the potential for flexibility.

Demand response right down to end consumers can contribute to increased flexibility and be sustainable and cost-effective both for the society and the consumers. As technologies and services to consumers develop, so does their ability to contribute. Today, many electrical domestic products come with a smartness including abilities for demand management, or if not, many of them can be retrofitted with plug-ins. We also expect that 20% of all electrical transport in Europe, or 60 GW, will be charging in a flexible manner in 2050 (Statnett, 2020). Systems for demand management can be coupled with price signals from electricity price, power tariffs or local flexibility markets and balancing markets. Within industry and commercial buildings, smart demand control has been in place for a while, and the digitalization increases the options available. However, smart demand control in commercial buildings and industry has traditionally not been used and optimized for market participation, so realization of this potential implies programming and adjustment of installed equipment. Different assets have different complexity and readiness for smart demand management, as we will see in this report.

Another perspective is that digitalization and the adoption of digital technology, meaning the ability to adjust to the new digitalized world with its cybersecurity challenges and the increased mix between IT and Operational Technology (OT), will disrupt the market. Furthermore, it will introduce new providers and a change in service and delivery models. OT are traditional systems controlling the physical world, such as protection devices, while IT are fully digital systems built and designed to be digital systems, such as office computer and personal computing. Flexibility is by nature disruptive as a “product”, and the “product” delivery is digital involving both OT and IT technology, such as cloud services. Energy production is with flexibility extended beyond the traditional and security contained production constructs, such as a hydro power plant, to distributed and IP-enabled equipment and systems such as electric vehicles, panel heaters and ventilation systems. The service delivery might involve cloud services, in addition to small and distributed energy production facilities, and such a distributed setup needs to be protected (secured) from the inside-out, as it cannot be contained within a perimeter.

The flexibility market represents an opportunity for new providers to enter the energy market. To succeed in the market of distributed and small resources, one needs to be dynamic, market-aware, and be able to pivot as the market changes. This may be harder for larger and traditional providers than for new and “young” providers whose products and services are built to be fully digital from the get-go.

The larger and traditional providers are on the other hand currently dominating the balancing markets. Balancing market participation from end-consumption is currently low, either at a testing stage or in the beginning of market participation. However, several measures are being made that will enable new technologies and demand response to provide balancing resources. This includes introducing finer settlement periods, changing from 1 hour to 15 minutes, and lowering the minimum bid size. The change is driven by activities such as the implementation the EU network codes (ENTSO-E, 2020), the Clean Energy Package for all Europeans (European Commission, 2020) and the Nordic Balancing Model (Nordic Balancing Model, 2020). In the future, the ordering and regulation of bids will be done automatically, see the plan for the Nordic Balancing Model (Nordic Balancing Model, 2020). However, automatic regulation still requires monitoring and possibility for fail search and corrections.

Summarized, there is an increased need for flexibility in the years ahead, and the Nordic TSOs are working actively to meet these needs, including by enabling new providers of flexibility to enter the balancing markets (SvK, 2020), (Fingrid, 2020), (Energinet, 2020), (Statnett, 2020). The eFleks pilot described in this report is one of these activities.

2. Pilot objectives

The goal of the pilot was to test 1 MW bid quantum and electronic bid ordering in the manual frequency restoration reserve (mFRR) market, while increasing the access to flexible resources in price area NO1 in Norway. Statnett used to phone each of the major power producers and consumers to request grid balancing, but this process is now performed digitally through an electronic bid ordering system.

Subgoals in the project were to mature providers, grid companies and Statnett's operation and IT-systems for bids down to 1 MW, as well as taking a step towards more automatization of the value chain. Statnett will lower the bid size in the mFRR-market to 1 MW, as it is the common bid size in the European mFRR platform called MARI (Manually Activated Reserves Initiative) (ENTSO-E, 2020). A handful European countries will start the rollout of the platform from 2022. Statnett's current estimate is that 1 MW will be allowed in the Norwegian mFRR-market at latest with the implementation of 15 minutes imbalance settlement period (Q2 2023) (Nordic Balancing Model, 2020). Statnett will continue with a minimum bid volume of 10MW before this transition. Exceptions may apply in some bidding zones or for pilot projects.

NO1 and the need for more balancing resources
The pilot was geographically limited to the price area NO1. The reason for this is that it is an area with high demand and few conventional regulating resources, like large hydropower and industry. Figure 1 demonstrates an example of a winter day where the power flow runs into the area from all surrounding price areas. It is therefore a need to stimulate that more flexibility resources, also new types, can participate in the market and with that, improve the access to flexibility in the area. Furthermore, a diversified portfolio of flexibility providers in the mFRR market will, in the long run, contribute to reduced socio-economic costs for the system operation.

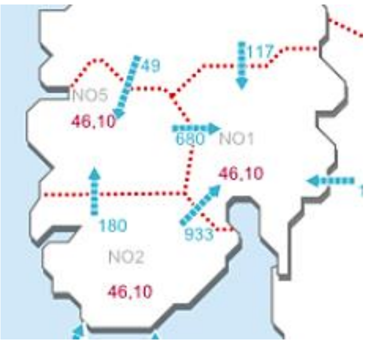

Figure 1 Power flow into NO1 a winter day.

It was expected that the pilot would enable more resources to enter the mFRR-market in NO1, and particularly in big-city areas with little other regulating resources. However, the volume of the new resources was a secondary target in the pilot, as innovation was prioritized over volume. Statnett's R&D requirements were used, and therefore one of the requirements for participating in the pilot was that there was an element of innovation, either in technologies used or in methods.

Bid size
mFRR is the transmission system operator (TSO) tool for handling larger imbalances and congestions in the power system, see the following figure which presents an overview of the balancing markets. Minimum bid size in the mFRR-market in Norway is currently 10 MW, except from NO1 where you can have one bid in the range of 5-9 MW per station group. A station group is the portfolio that is creating the basis for your bid.

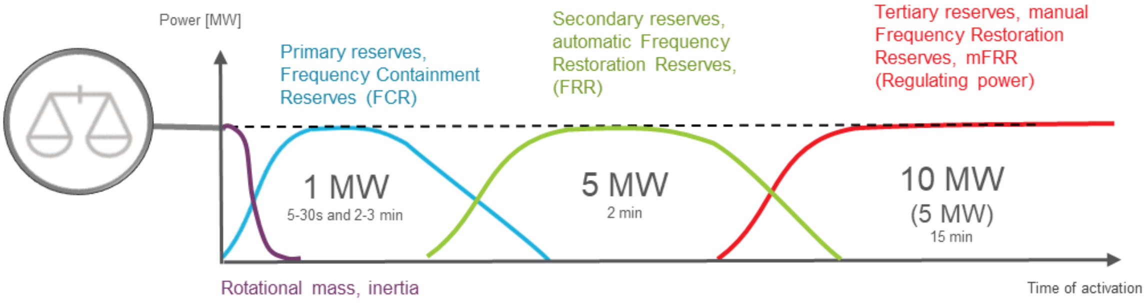

Figure 2 Balancing markets.

eBestill
eBestill is Statnett's system for electronic bid ordering. The pilot participants had to use this solution in order to participate in the pilot. It is currently not an mFRR-requirement to use electronic bid ordering, however it will be within July 2021. By this date, the market participants are required to have a solution for using electronic bid ordering (Statnett, 2020). In the future, the ordering and regulation of bids will be done automatically, see the plan for the Nordic Balancing Model (Nordic Balancing Model, 2020).

The market sequence when using electronic bid ordering is shown in the figure below.

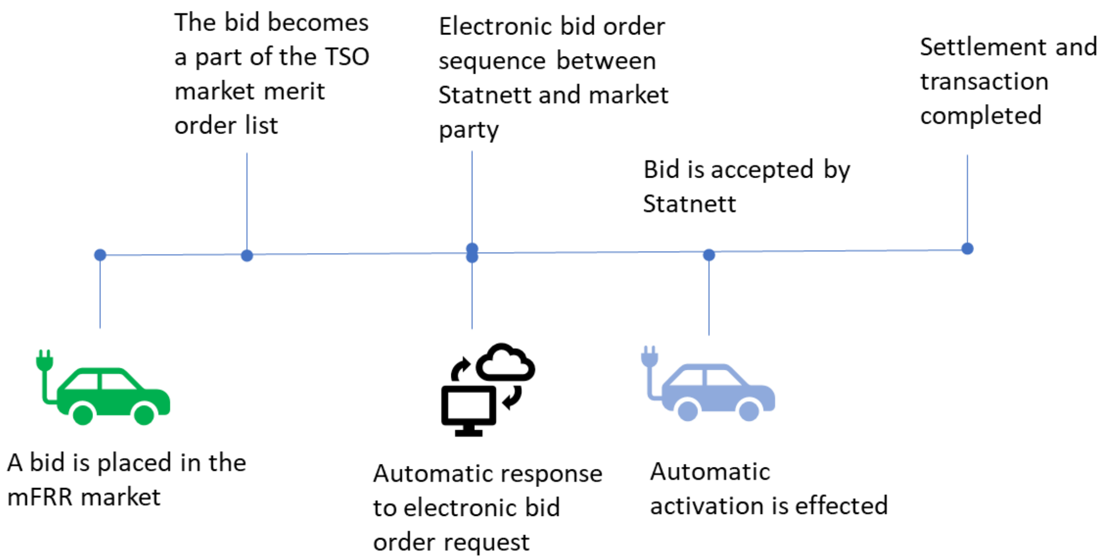

Figure 3 The market sequence, from placing a bid to settlement.

3. Pilot set-up

Timeline

The pilot was originally planned with a test phase in November, and operational phase from 2. December to 20. March. The operational phase was due to prolonged testing first extended to end in May 2020, and then further extended to October 2020.

Figure 4 The pilot timeline.

Selection of pilot partners

The project partners were selected through a procurement process. Before the process started, Statnett held a conference for all interested parties to discuss the project. The planned procurement process was presented and discussed with the attending parties. In order to reach as many interested parties as possible, Statnett announced the project in DOFFIN, the Norwegian procurement announcement database. All interested parties were invited to participate in the competition. The procurement process followed the rules for procurement below threshold.

Tibber and Entelios were selected pilot partners. Tibber and Entelios were the respective BRPs of the flexible resources offered to the market in the pilot. Enfo and Siemens were sub-contractors under Entelios. Tibber used technology from Easee and Mill to provide flexibility from their customers.

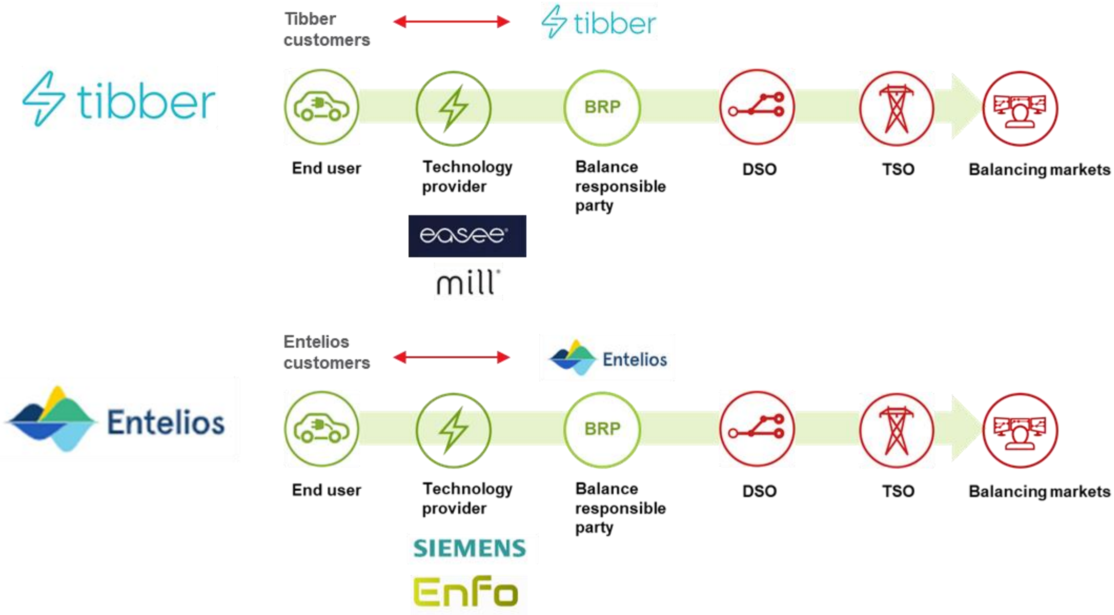

Figure 5 Project partners Tibber and Entelios with their respective partners.

Pilot activities
The pilot contained the following activities:

- Preparing the flexible resources for mFRR-participation
- Electronic bid ordering integration – preparatory work
- Prequalification – testing and verification. The provider must have passed the technical test and prequalification in order to participate in the pilot's operational phase.
- Operational phase
- Evaluation of the pilot and publishing results

The pilot partners' estimate of how the workload was divided on the different activities can be seen in the following table.

Table 1 Division of workload on the different project activities.

	% of total project work load			
Project activity (activity / subactivities**)**	**Tibber**	**Entelios**	**Enfo**	**Siemens**
Preparing the flexible resources for mFRR participation				
Project management		40 %		20 %
Onboarding customers		30 %		5 %
Installing new or updating hardware for demand control				40 %
Installing new or updating hardware for measurements				
Software development	30 %		30 %	5 %
Electronic bid ordering intergration - prepatory work				
Software development	25 %		40 %	
Prequalification - testing and verification	25 %	15 %	15 %	20 %
Operational phase	10 %	10 %	5 %	5 %
Evaluation	10 %	5 %	5 %	5 %

4. Pilot product requirements

In the pilot, the flexibility providers participated in the mFRR-market following the regular market requirements (Statnett, 2020). The only exception given was connected to the minimum bid size. Currently the minimum bid size in NO1 is 5 MW. In the pilot, the minimum bid size was 1 MW, and the pilot participants were allowed to deliver 1-2 bids of this size per hour in the pilot period. The pilot targeted up-regulation resources, meaning either reduction in demand or increase in production. The participants had to use Statnett's system for electronic bid ordering of mFRR, eBestill.

Apart from these conditions, the regular market requirements for mFRR-market had to be followed, and of which can be highlighted:

- In order to participate, the market party must be balance responsible party (BRP) or establish an agreement with the BRP of the resource owner. It is only possible with 1 BRP per bid, meaning load or generation in a bid must have the same BRP. The requirements and application to become a mFRR-provider can be found here (in Norwegian).
- Participation in the mFRR market and the pilot requires electronic bidding via EDI or Fiftyweb.
- Response time for full activation shall be less than15 minutes.
- A bid shall have a duration of at least 1 hour. When activated, the provider shall deliver constant power the whole hour.

- When bidding, the provider must inform the control centre if there are eventual restrictions regarding duration and rest time after activation. The provider has the responsibility for stopping the activation when a bid is no longer valid, or in the occasion of a deactivation from Statnett's National control centre (Landssentralen). eBestill currently does not hold functionality to handle bids with restrictions regarding duration- and resting time. This means that the provider must contact the control centre if the duration has reached its maximum time before a deactivation has been received from the control centre. Such contact must be made 15 minutes before the duration has reached its maximum limit, in order to make it possible for the control centre to deactivate the bid electronically and deactivate the bid according to rest time restrictions.
- There are requirements for delivery certainty, and the provider must demonstrate measures in order to ensure that agreed bid amount is delivered at activation. The provider must inform the control centre if a bid has become unavailable. According to the mFRR-requirements, the provider is obligated to deliver the amount of mFRR offered to the market. Bids based on aggregated portfolios must fulfil the requirements for delivery certainty at the same conditions as other providers.
- A contact person with the ability to regulate the reserves shall be available in the hours the bid is active.

In addition, these remarks were given in the announcement of the pilot:

- Simultaneous participation in the pilot and the option market for mFRR with the same resource is not possible.
- Demand that is part of the flexible power tariff scheme may participate in the pilot.
- Portfolios shall be aggregated within a regional grid operator's area. The pilot applicants can also offer portfolios that are distributed over a larger area, with the upper limit being NO1. In such cases, grid considerations will be made together with the local grid operators, and this may result in restrictions in geographical division of the portfolio.
- It is the aggregated delivery that is measured for portfolios. This means that even though singular units in the portfolio e.g cannot comply with the duration of 1 hour, the delivery can be secured by a rotation between the units. In this way the aggregated delivery can comply with the amount of MW and duration even if there should be issues for the singular units.
- The provider must be the BRP or cooperate with the BRP of the load or production which is offered to the mFRR market. The providers do not have to have recruited the resource owners for pilot participation at the time of submitting the pilot offer (September 2019). However, agreements with the resource owners must be in place at the latest to the start of the test period (November 2019). In such cases, the probability for a successful recruitment, and the plan for recruitment towards the test period must be described in the offer. It is only possible with 1 BRP per bid, and a bid must consist of either demand or production.

To see the requirements for measurements, data logging and reporting, see Attachment 1.

5. Preparing the flexible resources for mFRR-participation

This chapter provides an overview of the different technologies and methods the pilot participants have used for delivering mFRR.

5.1 Tibber

Tibber is a residential energy supplier as well as a provider of home automation and IoT services. Within Tibber's automation field, it controls devices to optimize energy consumption and comfort for the homeowner. This can range from charging an electric vehicle when the electricity price is lowest, to generating a heating scheduling that increases energy efficiency. The ability to control these devices enables Tibber to form pools of assets that can act in synchronism, expanding its capabilities to provide flexibility.

Value Chain
The value chain related to regulating reserves is outlined below in Figure 6 below, where the Easee charger has been used as an example. Commencing from the bottom right, the TSO procured flexibility from the aggregator Tibber, who in turn delivers the flexibility. Tibber has an official API agreement with Easee as the Original Equipment Manufacturer (OEM), together with a commercial agreement where Tibber acts as a reseller of the Easee wallboxes. Easee relays both commands and device statuses between Tibber and the individual units via the Easee cloud. Tibber has an energy retail contract with the end user, and in the case of Easee's with smart charging activated, guarantees a 20% discount on the cost of Easee charging compared to the cost of the rest of the household's consumption. The end user is the owner of the Easee wall box.

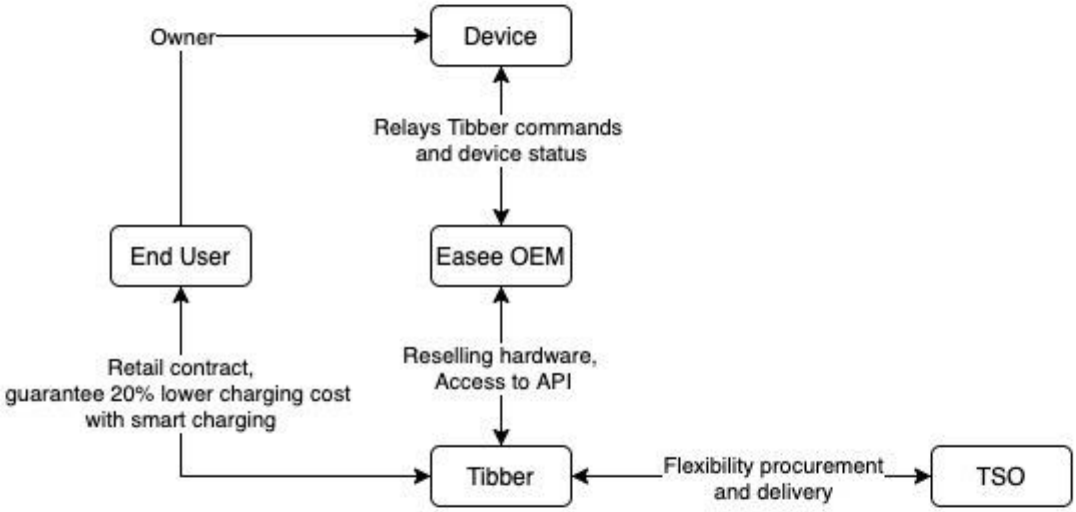

Figure 6 Value chain description Tibber.

Description of Devices
Focusing on mFRR activations for eFleks, the devices used by Tibber were EV chargers manufactured by Easee and electric heaters manufactured by Mill.

Easee Charger
Each Easee charger has a rated power of 22 kW, but the active charging power ranges mainly from 3 to 11 kW (limited by the home fuse size and the EV model). It can communicate through Wifi or 4G. When the EV is connected, it relays state data to Tibber on change. Tibber controls a fleet of thousands of charging units in NO1.

Chargers are only available to charge when an EV is connected, which generally ranges from 6 pm to 6 am. From this period, Tibber schedules charging when the price is the lowest, always meeting the constraint to be charged by the time the EV owner plans to use it. Usually, most charging is done from 11 pm to 5 am, making it the period with the highest capacity available to provide mFRR.
Thanks to the full control of the charging schedule from Tibber to each charger, the aggregated available capacity for mFRR activation can be known in advance of placing the order. To have enough margin of safety, the total capacity is not considered for the bid, but only a portion of it, the rest is defined as a reserve fleet.

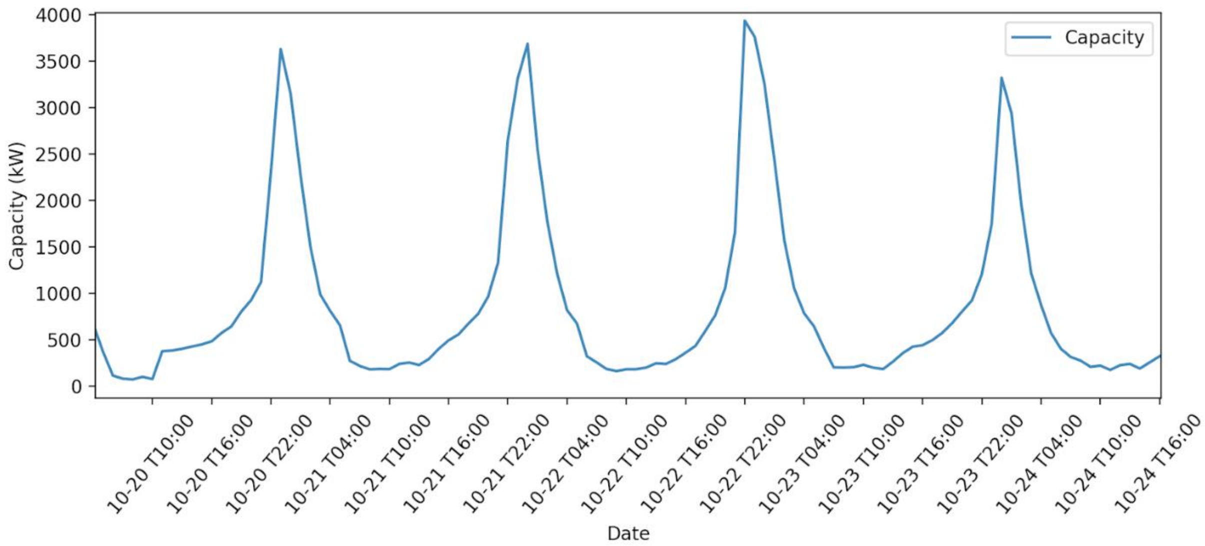

Figure 7 Load profile for EV chargers.

Electric Vehicle Battery storage

Tibber's residential electricity customers have the ability to pair their electric vehicles to the Tibber platform. Subsequently, Tibber can communicate with the electric vehicle OEM's API, thereby fetching vehicle state data such as State of Charge (SOC), battery capacity and GPS location. These parameters are input into Tibber's optimization model used to determine the available flexibility.

Mill heater

Mill Heaters used for the pilot have a rated power range from 0.5 to 2 kW. Tibbet fetches the status of each heater every 10 minutes through the manufacturer's API. The device communicates its status through Wifi. Currently, Tibber controls a fleet of 2500+ heaters in NO1. The reaction time after a command is broadcasted ranges between 0-2 seconds to turn on or off. Each device is equipped with temperature sensors.

Heaters are connected at all times to the electric supply, but heating is not necessary at all times. For an aggregated population of heaters, demand is usually characterized by two peaks and a constant base-load. There is a peak in the morning and a peak in the afternoon. Also, there is a strong correlation to the outdoor temperature. The max availability to provide up-regulation in mFRR would be during the peaks. However, with a large population of heaters, the base-lode can become interesting to provide flexibility.

Regarding seasonality, heaters are mainly needed during the cold season of the year. Another limitation is that heaters can be turned off as long as the indoor temperature doesn't decrease too much. For this reason, activations can only be maintained for a certain amount of time. If the heating population is large enough, this problem can be solved by rotating individual heaters. Another factor that increases flexibility is the home insulation, which at the same time decreases the need for heating.

As mentioned before, the predictability of demand is strongly correlated to the outdoor temperature. The lower the outdoor temperature, the higher the consumption will be, implying higher available capacity for activation. Although models were built to predict the available capacity, these models were built with data from last year's winter, where the number of heaters was smaller and the data available had a granularity of only 20 minutes. For these reasons, it was decided to be very cautious, and make the portion of heaters for bidding small enough to secure a successful activation. Moreover, a conservative margin of safety was achieved by having a reserve fleet.

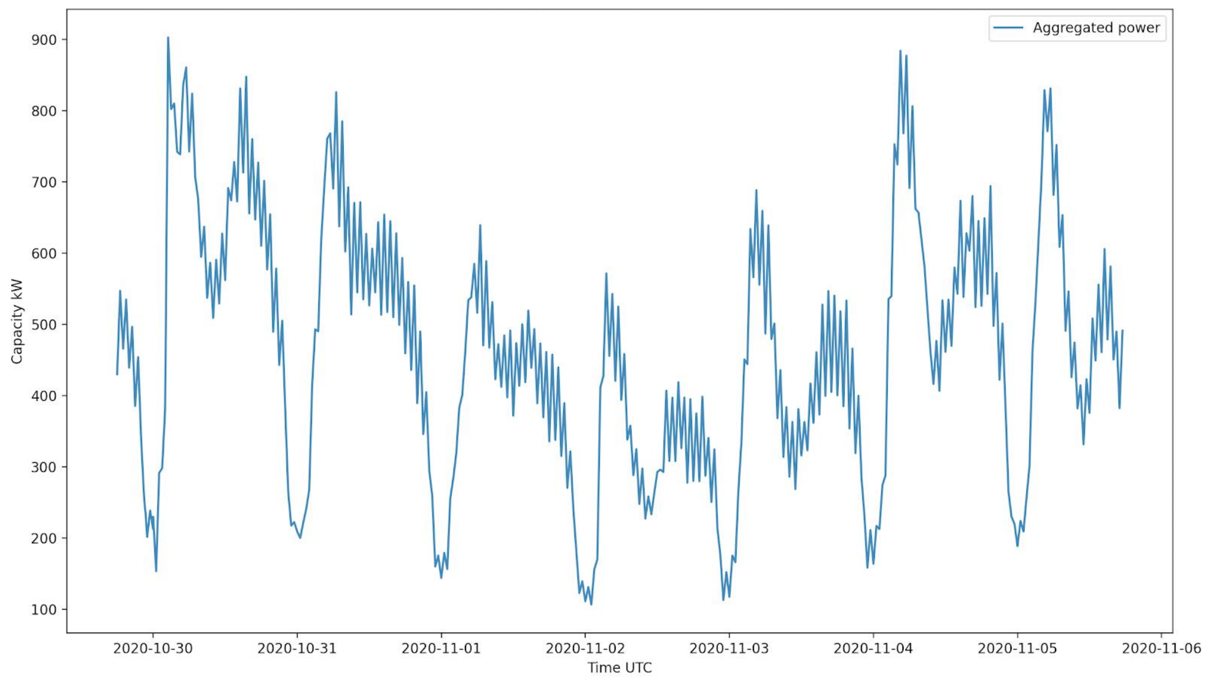

Figure 8 Load profile for heaters.

Preparatory work and delivery

Excluding the integration of eBestill (which is discussed in the next section), the development of the controller was one of the main tasks during the pilot project. The controller is the logic behind the activation and several tasks can be attributed to it.

The most basic and important one is to aggregate the active power consumption of each device and make sure it is following a certain reference power. To achieve this, the controller must process hundreds of incoming readings from each device and put them into an aggregated perspective. Moreover, the controller must comply with individual constraints for each device, such as time of departure for an EV or comfort temperature for a heater. If a device deviates from its constraints, the controller must replace the device with a reserve. In addition, the controller must ensure that both types of devices are combined to provide the service.

All measurements from the devices come from dedicated built-in metering. For EV chargers, most of the time it is not necessary to estimate the aggregated power, as Easee chargers transmit data on change, meaning that whenever there is a change in the status of a variable, Tibber gets a message. On the other hand, electric heaters currently do not support messages on change, so Tibber fetches the status of each device every 10 minutes. Although a change to automatic messaging would be an improvement to remain always within the temperature constraints, it is important to notice that heating behavior is slower, and temperature seldom varies several degrees within 10 minutes.

Regarding the security of delivery, several variables are taken into account when making a bid. For EV chargers, the scheduled start time for charging is known before an order is placed, therefore Tibber can determine when it will have the largest available capacity for regulation. For heaters, there is a baseload that secures a minimum bid (see previous sections for more details). Finally, a large margin of safety is considered at the activation time, defining the reserve pool of 100%. This means that for every device providing flexibility, there is one ready to replace it if necessary. The size of the reserve pool was initially established very high, but after testing it has been concluded that this number could be safely decreased.

5.2 Entelios

Entelios is an energy provider and trading company delivering services within portfolio management, sustainability, energy solutions, flexibility and trading. In 2008 Entelios started the Nordic region`s first market aggregator for demand flexibility. Flexibility services enables their customers to offer their flexible production or consumption to grid operators in order to generate new revenue streams.

Entelios background and competence within the power system, complimented with that of different technology providers such as Siemens and Enfo, who also were involved in the project as a technical aggregator, enables delivery of flexibility from heterogenous resources with varying technologies for connectivity and control.

Entelios together with Enfo operate a platform for aggregation, monitoring and market interfacing in order to enable the delivery of flexibility. Siemens in their turn were contracted in order to perform integration of commercial building loads to the platform, covering the full delivery from documentation and analysis to integration and testing.

Entelios has participated in the project with 14 different customer sites, five of these are industrial loads (approx. 4 MW) and nine building are commercial buildings (approx.1.37 MW). together with Siemens and Enfo.

5.2.1 Entelios value chain for delivering flexibility

The value chain for provision of building flexibility to ancillary markets involved several types of stakeholders during the project which all contributed to enabling flexibility. Some of the stakeholders were primarily involved during implementation of the project and others are necessary even for continuous operation of the solution. The primary stakeholders involved are firstly the flexibility providers, which were a mix of real estate companies and municipalities, all offering a flexible use of electricity from their assets to provide services to the other main stakeholder: the grid operator. Statnett, being the recipient for these services procures flexibility from an aggregator and balance responsible party, which in this case is Entelios. Entelios in their turn act as the main interface between the flexibility providers and the grid operators by aggregating the flexibility and providing this to Statnett.

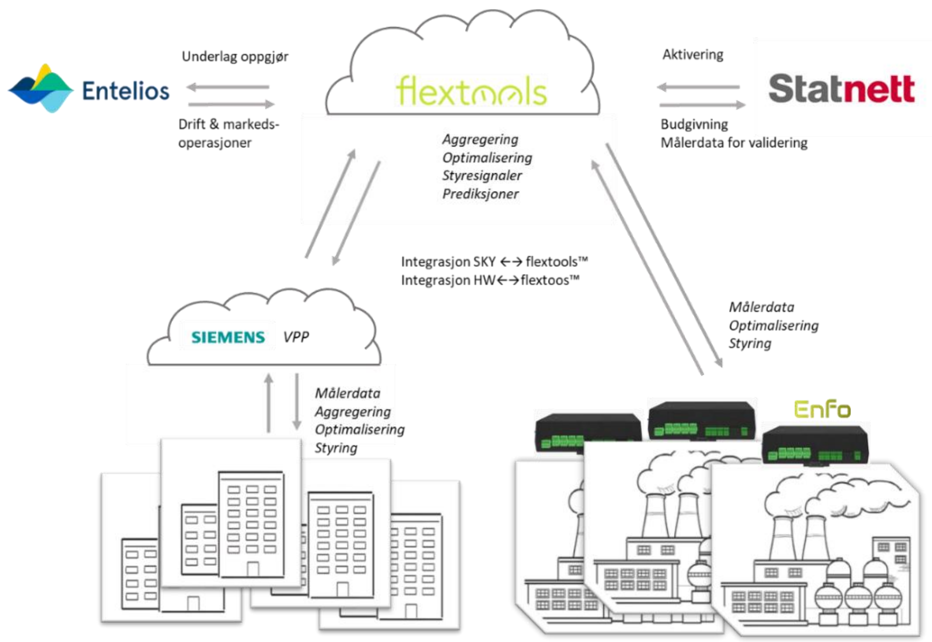

Figure 9 Value chain of flexibility.

In order to enable this, varying technology providers are involved in order to implement the technical solutions required to deliver flexibility. Firstly, having almost exclusive right through their in-depth knowledge of each building, is the automation company who has delivered each building's BAS. In this project, three different companies were involved who individually managed the aggregated buildings' BAS and configured them according to provided technical specifications. Secondly, in order to manage the implementation of the virtual power plant, Siemens had overall responsibility for building analysis and selectivity, providing technical specifications and coordinating integration work with automation companies, as well as being responsible for delivery and implementation of the cloud-platform to enable aggregation of the buildings. Lastly, in order to implement the market interface and to deliver any functionality to enable the necessary market actions, is the software company Enfo.

The value chain to enable building flexibility, looking at it in a holistic perspective, is complex as there are many stakeholders involved. To increase the complexity, it is also necessary to note the number of different competences and roles that need to be covered in order to cover the entire the value chain. Due to this, having holistic knowledge of flexibility, covering the entire value chain from asset to market, as well as having the required knowledge within project coordination and other administrative functions, is key in order to realise building flexibility at scale.

5.2.2 Siemens

Siemens is a global technology company specialized within driving digitalization, automation and electrification. In the context of flexibility, Siemens provides a holistic offering from services covering project management, analysis and integration, to technical solutions for aggregation and control of decentralized energy resources for flexibility provision.

5.2.2.1 Building selection and qualification

Entelios being a balance responsible party, has a customer data base providing potential objects for flexibility provision. A mapping of candidates from the data base was made where a total of 5 real estate companies and municipalities were chosen. These were all introduced to the project and the concept of flexibility and were then asked to provide recommendations of 5 buildings each from their portfolios, located within the NO1 electricity area and in the vicinity of Oslo. A total of 25 buildings were thus proposed and would create the basis for Siemens analysis.

The analysis was conducted by compiling contact information to site operators and other stakeholders knowledgeable of the proposed buildings and their systems. These were then interviewed and asked to provide information regarding each building's flexibility readiness, specifying information such as: number building assets, their corresponding rated power and average load as well as criteria to determine the building automation system (BAS) suitability. Also, an assessment of the overall maturity of the BAS was made to evaluate the complexity of implementing remote control signals. Through this compilation, an evaluation of the proposed buildings was made in order to determine the best approach for flexibility provision, with consideration of project- and market-specific requirements.

The documentation and analysis-phase presented several challenges to be overcome. Firstly, many buildings had neither sufficient documentation nor sufficiently knowledgeable stakeholders in order to perform a correct analysis, which is a general challenge for many commercial buildings. Due to this, several sites could simply be ruled out due to not having sufficient documentation. Secondly, the documentation that did exist was oftentimes scattered amongst the many stakeholders that are, and have been, involved in each building's operation and implementation. Due to this, in many cases it simply took too long time to compile the documentation that was necessary, meaning that yet another share of buildings was disqualified.

Lastly, once sufficient documentation was collected, many buildings were discarded due to not meeting the criteria defined in terms of:

- Types of assets – Some types such as air handling units (AHUs) are inherently more suited towards flexibility than other types of assets. Having the right type of asset is a key criterion for selecting buildings.

- Building tolerance – Depending on the type of assets, they supply different systems with individual requirements. AHUs for instance supply air flow to different zones of a building where a restaurant kitchen could be more sensitive to air flow changes than a high-ceiling shopping center corridor.

- Available flexibility – Of those assets which are flexible, they have to be able to theoretically provide sufficient amount of flexibility in order to motivate the required investment to unlock that flexibility.

- BAS suitability – In order to unlock the available flexibility, the BAS has to be able to support the necessary communication and control algorithms, in addition to any requirements related to integration with external control systems.

- Relations to service companies – In order to implement the necessary control algorithms and to collect the required power measurements in existing systems, it is necessary that the corresponding service companies are available, have the required competence, and in commercial projects, also are reasonably priced.

The framework of this analysis will not be presented in detail. However, it is to be noted that typically it is not how detailed the framework is, that determines the accuracy of the analysis, but rather the quality of the provided documentation. An example of this is when determining the amount of available flexibility. Without access to historical data of asset-specific load curves or, another historical data of a parameter closely correlating with the assets load, the best analysis that can be done is to make a theoretical approximation. This approximation can then only be based on similar but static values, such as the assets rated power combined with an estimated average operating point. Despite having algorithms to in a detailed manner determine the available flexibility with high resolution, it cannot simply be done due to poor documentation. Nonetheless, working with the best available documentation, the analysis resulted in nine out of 25 different buildings being selected, whose details are specified below. The assets were sorted into two respective pools based on their utility grid connection, respectively Hafslund/Elvia and Glitre.

Table 2: Overview of aggregated commercial buildings and their respective flexibility.

#	Building type	Utility grid connection	Asset types	Estimated flexibility*	Rated power
1	Office building	Hafslund/Elvia	AHU	73 kW	122 kW
2	Office building	Hafslund/Elvia	AHU	117 kW	195 kW
3	Shopping center	Hafslund/Elvia	AHU	170 kW	568 kW
4	Town hall	Glitre	Electric boiler	210 kW	350 kW
5	Nursing home	Glitre	Electric boiler	210 kW	350 kW
6	Health care	Glitre	Electric boiler	180 kW	300 kW
7	School	Glitre	Electric boiler	150 kW	250 kW
8	Sports center	Glitre	Electric boiler	90 kW	150 kW
9	Shopping center	Hafslund/Elvia	AHU	170 kW**	568 kW**
Total:				**1370 kW**	**2 789 kW**
* The flexibility is an estimation based on references from other projects and buildings. Note that is does not take into consideration any potential effects due to covid-19. **Both numbers are based on a similar building due to lacking documentation. In reality these would be larger but have been kept low to provide margin in the estimation.					

5.2.2.2 The potential for building flexibility

The potential of building flexibility is determined by several factors. The assets integrated in this project being air handling units and electric water boilers have dynamic loads which are dependent of the indoor climate. This in turn is affected by several factors such as number of occupants, the intensity of solar irradiation, thermal output from appliances and many more. However, in order to simplify the factors affecting the available flexibility of a building, they can be generalized to only the outdoor climate and the building's usage patterns.

With an aggregated rated power corresponding to more than 2 789 kW for the entire building portfolio, the expectation could be that at least half of this is available as flexibility. However, since assets rarely ever consume electricity at the rate of their power rating there is a large difference between the actual available flexibility of a building and the rated power of its assets. Since the buildings in addition do not have any existing power measurements isolating the load curve of single flexible assets, the amount of flexibility available has to be made based on a rule of thumb or based on a reference from other buildings. In this case, the number of buildings and their corresponding assets were chosen in order to meet the 1MW requirement based on this method and to provide some margin on top. This methodology was tested and verified with large accuracy through a dispatch of one building which provided in excess of 100 kW. However, what became evidently clear is that the method does not consider any unforeseeable events such as the spread of covid-19. This led to a significant decreasing in use of public spaces meaning that the aggregated buildings' usage patterns changed dramatically. With this, most buildings available flexibility plummeted as they were operating to reduce power consumption. In addition to this, delays in building documentation led to tests being performed later than initially expected. This implied that the outdoor temperature rose as the tests were now performed closer to summer than winter and with this the available flexibility from the electric boilers almost disappeared. Due to these changes, the minimum requirement of 1 MW could only be met with an additional supplement of flexibility being provided from assets in Entelios existing portfolio.

Despite having relatively predictable load curves and thus accurate flexibility forecasts, the challenge of forecasting dynamic loads which respond to completely stochastic events, will always remain. Despite this, building flexibility has shown potential for delivery of mFRR products, where it has met all requirements other than capacity. The results of this are summarized below. .

Availability
The availability of commercial building's flexibility is mainly determined by the buildings operating hours. Outside of these, the assets are typically operating in idle mode or to supply the minimum requirements in terms of air flow and indoor temperature. During these hours the available flexibility is almost negligible. For an office building the availability of flexibility from air handling units and electric water boilers could for instance be from 08:00 to 18:00, given a "9-5 job".

Endurance
The endurance of air handling units and electric boilers is largely dependent on the systems they serve. Air handling units' endurance are determined by the tolerance of the indoor climate where some zones are significantly more sensitive than others. Electric boilers' tolerance is in comparison determined by the thermal inertia of the heating system it feeds. The tolerance of the selected air handling units and electric boilers proved to be sufficient as an endurance of a one-hour dispatch was verified without noticeable effects on the indoor climate.

Responsiveness
The responsiveness of air handling units is largely determined by the performance of PID-regulators in existing BAS control systems. These are not typically trimmed to provide high responsiveness but do despite this respond quickly and well below the 15 min activation time. The electric boilers whose power are regulated through on/off control respond almost momentaneously. Both types of assets therefore are not significant contributors to the delay of activation. Since the assets are activated through cloud-based control of interlinked systems, the largest share of delay is instead introduced in communication interfaces between the varying systems. The three main contributors of delay in this sense are the cloud-connection between Siemens and Entelios platform, the dispatch cycle in Siemens platform, and the on-site connection between the gateway and the building's BAS.

The largest measured delay from dispatch to full activation of flexibility is seven minutes, well below the minimum requirement of 15 min.

Recovery

After ending a dispatch, the external control is nullified, and the normal control systems take back full control of the assets. The assets are thus, never forced back to normal operation but instead, return at the given rate that is determined by the normal control system. This rate varies depending on the individual control system and its configuration. The air handling units return quickly to their previous load before dispatch, as their set points momentaneously change back to nominal values, in effect simulating a step-response. The electric water boilers however, require longer times closer to 20 minutes, to return to normal operation, as their control occurs stepwise. Neither the indoor temperature of the buildings nor the supply water temperature from the electric boilers was measured in order to accurately assess the required recovery time after dispatch. However, a suitable assumption would be that flexibility provision during the entire next market settlement period, or more specifically the following hour, should be avoided in order to guarantee a negligible impact of building operations.

Capacity

The amount of flexibility or rather capacity of the asset is mainly determined the size of its load. The rated power of the assets does not correctly reflect this, but rather defines the upper boundary of the maximum available flexibility when delivering mFRR. Instead, the flexibility has to be determined by its operational data or more specifically, the historical load curve. Since this information was not available, a theoretical approximation had to be made. By using a rule of thumb based on previous project experience and other buildings as reference the estimated capacity was 1 600 kW. However, due to changed circumstances, this value was never confirmed.

5.2.2.3 Integration and control of building assets

Each building's assets are controlled through the existing BAS which is reconfigured to support the updated control algorithms required for flexibility provision. Since there are two types of assets, there are also two types of control algorithms which were implemented. In order to regulate the load of an AHU the speed of the motors driving the supply- and exhaust air fans has to be regulated. Since many AHUs and their automation does not support this control method, an alternative more widely accepted method had to be chosen which instead indirectly affects the fan speed. In most ventilation systems the most suitable approach would be to regulate the duct pressure or the volume flow through the fan. Pressure- and flow-regulation were thus selected and applied as control algorithms for each AHU depending on the supported functionality in the corresponding BAS. In many cases, the control algorithm had to be adjusted in order for each BAS to accommodate the new control method. One building for instance, utilizing an advanced pressure difference optimization software to increase energy efficiency, required a custom implementation to bypass the software and to deliver flexibility when required.

Despite the BAS in general having several factors introducing delay to the implemented control methods, the building flexibility's responsiveness is well within the requirements of 15-minute activation time, responding to changes instead in the scale of a few minutes.

Electric boilers are typically simpler in construction and control than AHUs, meaning that simpler methods of control can be applied. In order to regulate the load of the boilers, breakers were activated through each buildings BAS, effectively regulating the load with an on/off-control method. In comparison to AHUs there is no physical inertia introducing delay in the load regulation. Additionally, by disconnecting the load directly through a breaker, the responsiveness of electric boiler control is even faster than that of the AHU.

In order to control the distributed buildings and their assets, a gateway was integrated with each building's BAS. The gateway is delivered by Siemens and interfaces the BAS to Siemens cloud-based platform for virtual power plants. This enables a cloud-based delivery of a control signal from the platform, down through each building's BAS which then distributes and translates the control signal into a set-point for the control of the individual flexible assets.

This control signal is activated through dispatch from Entelios which performs market actions such as bidding, automatic dispatch, and settlement. Other flexibility-related operations such as pooling, aggregation and real-time control is handled by Siemens platform.

A feedback of power measurements from the site to the cloud-platform is established by connecting each building's main or sub-meters to the BAS and forwarding the measurements through the gateway to the cloud-platform. Using main meters implies that the total load of the building is measured, and the flexible and controlled asset is estimated from the total. This was chosen for those buildings where no other meters existed. An alternative to this would be to use sub-meters, located within the building and only measuring a share of the building's entire load. This alternative was chosen for any buildings where a sub-meter was available as it better isolates the flexible asset's load from other loads.

Whilst sounding simple, the implementation of power measurement proved to be a hassle since it in some cases involved upgrading to smart meters, cabling of large distances or both electrical- and extra documentation work. Nonetheless, the smart meters used for power measurements and the associated infrastructure were able to meet the requirements for power measurements, meeting the requirements for minute resolution, delay, and sampling rate. An overarching measurement and control topology of the technical solution is presented in the illustration below.

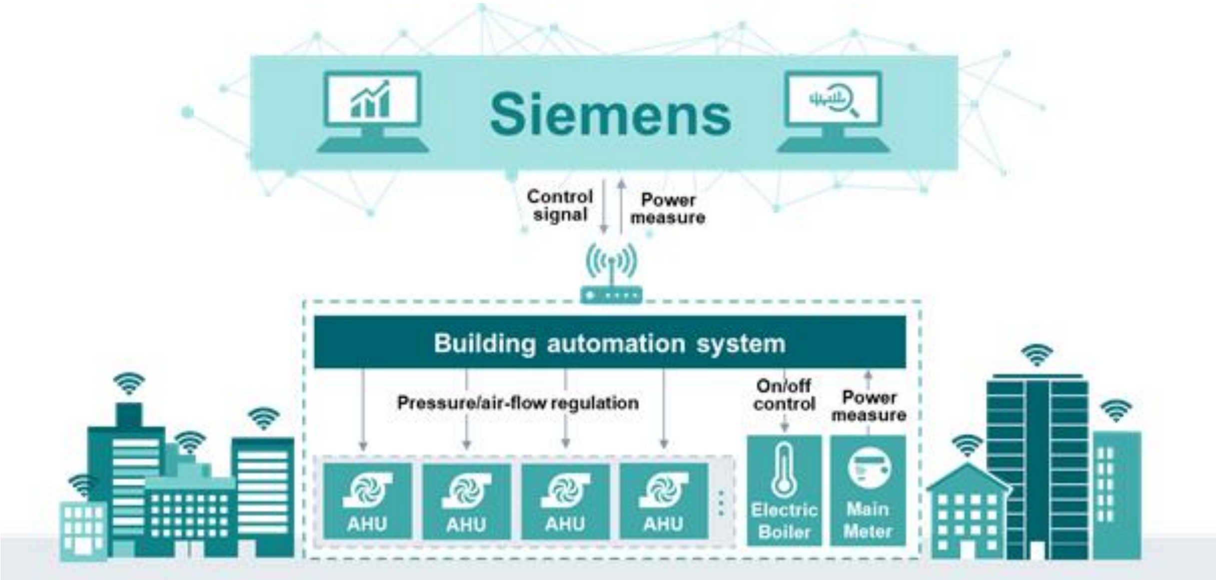

Figure 10: Measurement and control topology of commercial buildings flexibility solution provided by Siemens.

5.2.3 Enfo

Enfo's main role is to provide a flexibility platform for Entelios to operate. The platform makes sure that the consumer loads are connected to Statnett's mFRR market. The platform sends Entelios' flexibility bids to the Ediel platform and relays electronic activations from Statnett (eBestill) to the loads. The loads could be controlled by Enfo hardware (HW) or Siemens control system.

5.2.3.1 Industrial load selection and qualifications

Entelios surveys their customer base in the search for consumer side flexibility. The first level of assessment is done by looking at the consumer profiles and with basic knowledge of the main loads. When Entelios identify potential candidates for flexibility they often do a site inspection (physical or digital meeting) together with the end customer. At this stage Enfo is also brought in to evaluate the case together with Entelios.

During this evaluation we look at several factors to understand whether a customer is suitable for delivering flexibility or not:

- **Type of process**: What is the type of industry and how sensible are they for disturbance. Do the end customers have any restrictions to flexibility durations, rest time, time of day, day of week, etc.
- **Type of loads**. What are the main sources of flexibility here, examples are heat pumps, boilers, cooling compressors, HVAC systems, heaters, melters etc.
- **Load characteristics**: We also need to understand peak consumption, and most importantly what is the typical consumption. Variation during the hour and day. What is the expected response time for an activation?
- **Consequences:** What are the alternative energy sources if interrupted and and are there any potential side effects. In some market we need to know if the alternative is clean or if it contains burning fossil fuel for example.
- **Ease of integration and installation**: How ease is it to do integration with local control system? Can we do a cloud to cloud (ala Siemens integration) or do we need to install our own control unit? How many main meters will be involved? Can we connect to them all or do we need to gather meter data from a third party? How is the equipment placed? Is much cabling needed etc.
- **Cost considerations**: End customers will be affected by the flexibility being taken out. This might have consequences and that comes with a cost. So, we need to know that the alternative cost for the end customer is the correct range, or else it is not necessary to move on. How costly will the installation be?

This evaluation ends up in an installation order that is handles by Enfo. Enfo cooperates with installers that installs HW and cabling towards the existing control system. As a last step of the installation. We perform a site acceptance test (SAT) to test that our initial findings are still valid and that the expected flexibility volume is available.

After such process a lot of parameters are stored in the flexibility platform. These parameters are used "behind the scenes" in the bidding process. Since the system know the maximum duration of the flexibility, necessary rest time between activations, ramp up and ramp down times, expected flexibility etc, it can help both operator and the market in making sure the loads are not used in a way that violates the capabilities or agreement with the asset owners. The assets were sorted into two respective pools based on their utility grid connection, respectively Hafslund/Elvia and Glitre.

Table 3 Overview of aggregated boilers and their respective flexibility.

#	Industry	Utility grid connection	Asset types	Expected flex*)	Rated power**)
1	Process industry	Glitre	Electric boiler	1.5-2 MW	8 MW
2	Shopping centre	Elvia/Hafslund	Electric boiler	150 kW	730 kW
3	Nursing home	Elvia/Hafslund	Electric boiler	300 kW	635 kW
4	Educational facility	Elvia/Hafslund	Electric boiler	300 kW	1 MW
5	Food processing	Elvia/Hafslund	Electric boiler	1-1.7 MW	2.95 MW
Total:				3.25-4.45 MW	13,315 kW

*) Values based on experience from the project. Not all the rated power is available for dispatch, hence expected flex is lower than rated power. The expected flex from some of the loads was also affected by the covid-19 shutdown, due to lower consumption than normal (shopping centre, educational facility). Other sites were affected more indirectly by reduced physical access and lower tolerance for disturbances (nursing home, food processing).
**) Values based on peak power consumption during project

5.2.3.2 The potential for industrial flexibility

The total potential for industrial flexibility is very large. Norway has a lot of industrial buildings and energy intensive industry. These can play a part in the future power system. Many industry stakeholders are very skeptical to having their power controlled by 3. party. They seek a stable and reliable power connection. But most modern control system can receive commands to reduce or shift the power usage, not necessarily dispatch all. Instead of thinking “all or nothing”, we should focus on utilizing capacity from many different sources. In this way many can participate and help to operate the grid, increase overall availability and reduce operational cost, hence their own grid tariffs. New technology makes this more feasible and more economically sane.

Availability
Availability for industrial loads varies, but unlike the office buildings, there is normally some available flexibility 24/7. Some processes run at full speed even at night. We have cases where customers have connected the loads in such way that the flexibility is only available if consumption is above a certain limit. In other cases, flexibility is total, and the factory will do alternative tasks if the main production line is dispatched.

Endurance
Endurance, interpreted as maximum dispatch duration is an asset parameter we need to identify for all assets. For industrial loads this duration will vary, but many assets are quite flexible, and the asset owner often have a backup or alternative that need to run for certain time. The maximum duration parameter is used during bidding. The most flexible loads have possibility to dispatch 4+ hours. These are also identified as “high quality loads” by Statnett and they are associated with higher price (and higher fines if not delivered). Another parameter that is also important and related is the “rest time”, that is the minimum rest time an asset needs before being dispatched again. Typically, this can be 0-4 hours and varies a lot. Both duration and rest time is parameters we send as part of the bid and that must be respected to avoid problems during dispatch.

Responsiveness
In this project all of the industrial loads is equipped with a dedicated RTU/gateway unit. Enfo and Entelios uses a device named Enformer. This unit is running part of the flexibility platform software and is responding within seconds to commands. Depending on the control logic and delay in reporting we see response times vary between a few seconds to a few minutes. At some installations the load dispatches at an instance and in other locations they follow a startup/cool down process that reduces/increases the load at a graceful pace. In the project most of the loads are quite fast. We see that the loads can comply with bith mFRR but also faster markets such aFRR.

Recovery
We have the possibility to use the dedicated RTU or the local control system to do controlled ramp ups. For the assets in this test, there were no active control from the flexibility platform to control the ramp up. We know from previous testing that this might lead to peaks in power usage directly after reconnection. This is typical for assets that do not have sufficient backup and need to regain a certain setpoint. However, it is our experience that these peaks are quite short lived, and as the test reveals, for most assets the hourly consumption after a dispatch is only slightly increased compared to the hours before.

Capacity
The assets from both buildings and industry where placed in two portfolios; one for the Elvia pool and one for the Glitre pool. The industrial loads in this project, during market operations, had a peak of approx. 2.7MW divided between Elvia and Glitre grids.

5.2.3.3 Integration and control of industrial assets

Enfo control industrial/commercial loads by cloud to cloud integration toward a control system provider (like Siemens), or by installing a dedicated hardware (HW) unit called Former. The Enformer functions as a programmable remote terminal unit (RTU) and is developed by Enfo and is installed at the site.

The integration with the industrial assets is mainly being done in one of two ways: Most typically we connect to a local control system that in turn is controlling the flexible asset. The alternative is to control individual assets directly, utilizing the Enformer's 8 digital outputs. This could be a dedicated controller for a large boiler, or it can be control contactors directly. In either case we need to gather meter data in near "real time" and for this we most commonly use HAN-interface at the main meter. The main meter reports hourly values to the DSO, but we collect data from the HAN as soon as it is updating its output, every 2-30 second is typical. When possible, we use 4G mobile connection to connect the site to the flextools platform.

A benefit of having one single interface towards the local control system is the cost efficiency it provides, especially with regards to installation, as little cabling is necessary. But it can also add some complexity, because the end customer must be aware of not making changes in the control logic that intervenes with the control from Enfo.

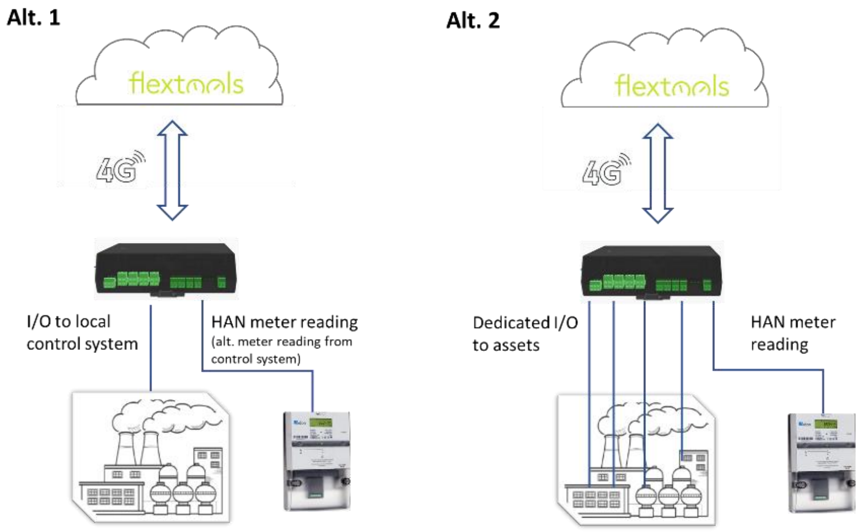

Figure 11 Different options for integration. Control via existing control systems or direct control of assets.

6. Electronic bid ordering integration and prequalification

This chapter explains the test protocol used, how Tibber and Entelios integrated their solutions towards its interface, and finally the result from the testing. This phase lasted from November 2019 to April 2020. The majority of the work was linked to preparation for testing, the actual testing towards eBestill lasted typically 1-2 hours.

There were two phases in the prequalification:

- Testing of the solution in the test environment
- Verification of the solution in the market system

After the parties had passed these steps, they could participate in the mFRR market in the pilot period.

6.1 Test protocol electronic bid ordering - eBestill

In the following we describe the test protocol used in the pilot for testing eBestill.

Ordering activation of bids through eBestill

- The provider must be able to receive activations through eBestill, Statnett's solution for electronic bid ordering of mFRR. There are multiple ways to integrate a provider's operational system with eBestill, either through (1) a self-developed solution (one for each participant, or pilot participants go together to develop a common solution), (2) providers already have eBestill, or co-operate with a BRP which has eBestill or (3) the provider buys a solution handling eBestill from a third-party.

- The solution/soft are should have functionality to electronically receive, approve and return answers on order requests from Statnett. In addition, the providers must install software for communication with Statnett (MADES/ECP/EDX). For more information about the interface for machine to machine messages, see the Ediel portal (Ediel, 2020), under "1. Norwegian balance regulation markedet" where you can find:
    - Nr. 45: Guide for mFRR-bids
    - Nr. 44: Guide for electronic bid ordering of activation of mFRR-bids

- Functionality in eBestill shall be tested before start of the mFRR-participation and is a part of the prequalification. The final approval test multiple scenarios for message exchange, and the test will last approximately 2 hours.

Test of ability to respond: Trial activation

Response time is equal or less than 15 minutes. We will perform 1-2 test activations with duration up to one hour.

The provider must provide a curve for activation (eventual ramping). Offered amount must be fully regulated within 15 minutes.

Deactivation of bids through eBestill

When bidding, the provider must inform about the duration of the bid and eventual resting time after activation. The provider carries the responsibility for stopping the activation when a bid is no longer valid, or if deactivated by Statnett's control centre. The provider must contact the control centre 15 minutes before the duration ends, if the bid has reached its maximum duration before a deactivation has been received. The control centre will then deactivate the bid electronically, as well as eventual following bids should the rest time require it.

6.2 Tibber – prepatory work eBestill

Generally, there was a good level of documentation for the eBestil process and Tibber was pleased with having a direct channel to Statnett's software vendor. Tibber uses a specific container platform for the development and delivery of the microservices within the Tibber architecture. There had been no previous experience within Statnett for running the eBestill services under such a container platform and hence there was some degree of caution to begin with.

A number of changes were carried out in order to handle edge cases. For example, Statnett did not at the time have support in eBestill for "rest periods". In order to handle the automatic recurring activations that did not account for the required rest period; Tibber implemented internal checks to ensure the rest time was respected and would reject any start orders that failed to do so.

6.2.1 Test results and prequalification Tibber

As part of the testing phase for prequalification, Tibber carried out a number of end-to-end live tests. This phase was critical for identifying any false assumptions and working through edge cases that would not have been identified otherwise.

Test eBestill start orders were sent by Statnett and activated on by Tibber. The number of electric vehicle chargers controlled in this phase was limited. In Test 2 portrayed below a total of 11 chargers were controlled.

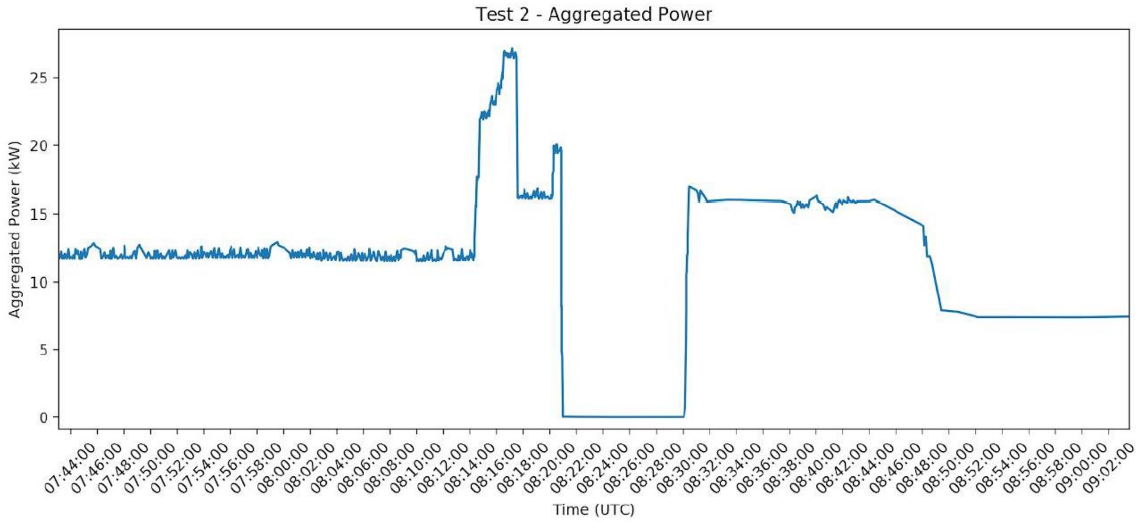

Figure 12 Aggregated power of 11 chargers in Test 2.

Tibber also carried out an internal test of 1MW to confirm the performance of the Tibber controller. The figure below portrays the satisfactory results from that test.

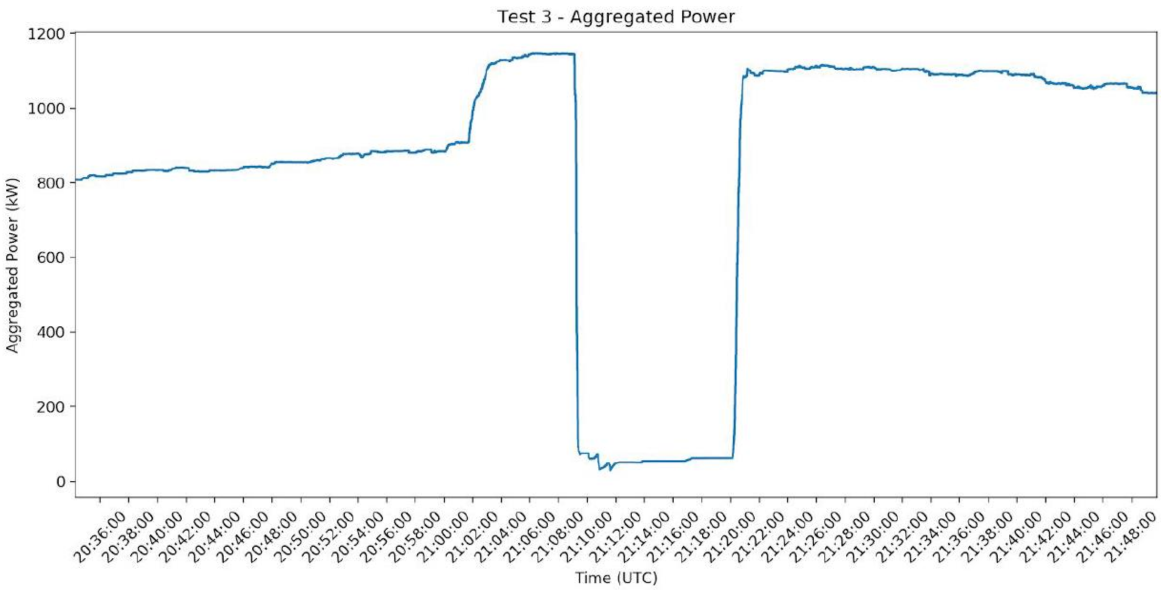

Figure 13 Aggregated power of 1 MW in internal test.

6.3 Entelios – prepatory work eBestill

Accessability and fit of information on how to develop an integration
Entelios uses flextools as their main platform for flexibility operations. Flextools, is delivered by Enfo, and is a complete solution for aggregators, including functionality for bidding and activations. The first main task of this project was to implement and test mFRR bidding. The second task was to implement and test eBestill for electronic bid ordering, including electronic activation of assets on the consumer side. In general, the documentation from Statnett is thorough, but building a good understanding of this complex process is not easy. Enfo spent some time in the beginning, waiting for clarifications, but as soon as we established connection with the correct responsible at Statnett, we received great support that was very helpful. Summarized, this was IT-development with a need for competence within market and operation, and hence an involvement both from Statnett IT and market and operation was needed in order to solve the issues and give clarifications.

For the mFRR bidding, there was a lot of information on the EDIEL portal. But it took some time to get a good grip around what was needed. Enfo, being a 3. party supplier for Entelios, also adds to the complexity because there are also other systems at the Entelios side that collect messages from Statnett. SMTP is being used to mail messages and we needed share endpoints between applications. This means that Enfo needed to filter messages related to mFRR, from the rest of the messages to Entelios.

The ECP implementation itself, information was given through eRooms. The documentation was detailed, and we received great support from Statnett personnel. Questions and clarifications were promptly given.

Alterations done in order to comply with the requirements
We already had in place a system to dispatch loads at command. The new part for the flexibility platform in this case was to handle the bidding directly (without fiftyweb) and to implement a completely electronic value chain from Statnett's control centre to the load. Before the project we already used the same components in the traditional mFRR market and in local flexibility markets (NODESMarket). The main task was then to implement a system than applies to the rules of the market and the described functionality of the eBestill.

The functionality for handling activations and corner cases was described in a separate document from Statnett. We used this to build up functionality to meet these requirements. We implemented a rule engine to make sure bidding and activation followed the rules of the market. Bid requirements are respected by the tool, meaning that activity violating the rules wil be rejected and not sent to Statnett.

In addition, we needed to make sure the asset properties such as rest time and maximum activation lengths is not exceeded. Activations request by Statnett that violates these constraints will be refused. This includes activation requests for extending an existing activation, that in turn will violate the constraints. To achieve this, we implemented logic to merge connected activations into one activation.

The activation request contains timestamps for both start and stop time. These time stamps dictated what will happen if an activation is sent within the last 15 minutes of the hour. If the starting point backwards in time, it will be translated as “activated as soon as possible”, otherwise the time stamp dictates when to start the dispatch, e.g. the next hour.

6.3.1 Test results and prequalification Entelios

Entelios participated in the operational phase of the pilot in May (Enfo/Entelios) and October (Enfo/Siemens/Entelios) 2020. Loads from both commercial buildings and industrial loads has participated in the pilot.

6.3.1.1 Data and documentation of tests – visualizations building loads

In the table below the overall procedure for the dispatch is presented, divided between the two aggregated pools in Hafslund/Elvia and Glitre grid area. Each pool was activated manually in Enfo's interface at the specified timestamps. Due to the dispatch-cycle in Siemens systems, the Hafslund pool was dispatched first since its command was received first.

Table 4 Testing procedure.

Hafslund/Elvia pool		**Glitre pool**	
Time (AM)	**Description**	**Time (AM)**	**Description**
11:13	Dispatch command sent from Enfo to Siemens	11:13	Dispatch command sent from Enfo to Siemens
11:15	Verification of dispatch command from Siemens	11:18	Verification of dispatch command from Siemens
11:16	Dispatch signal sent from Siemens to sites	11:19	Dispatch signal sent from Siemens to sites
11:45	End dispatch command sent from Enfo to Siemens	11:48	End dispatch command sent from Enfo to Siemens
11:47	Verification of end dispatch command from Siemens	11:50	Verification of end dispatch command from Siemens

In Figure 14 the overall dispatch from an asset-viewpoint is presented for both pools respectively. Following the Hafslund/Elvia measurements it is apparent that the full activation time of the dispatch, starting at 11:13 AM and ending at 11:20 AM, equals 7 minutes. After activation large fluctuations of other non-controllable loads connected behind the same meter as the controllable loads, decreases the overall flexibility achieved in the dispatch. The peak load during dispatch occurs at 11:20 with a value of 1 091 kW, which compared to the load just before dispatch 11:16 of 1 142 kW results in an overall dispatch of flexibility corresponding to 51 kW. For Glitre pool, the activation time was 6 minutes and achieved a dispatch of 20 kW, although by forcing the asset to activate just before the test to provide a dispatchable load.

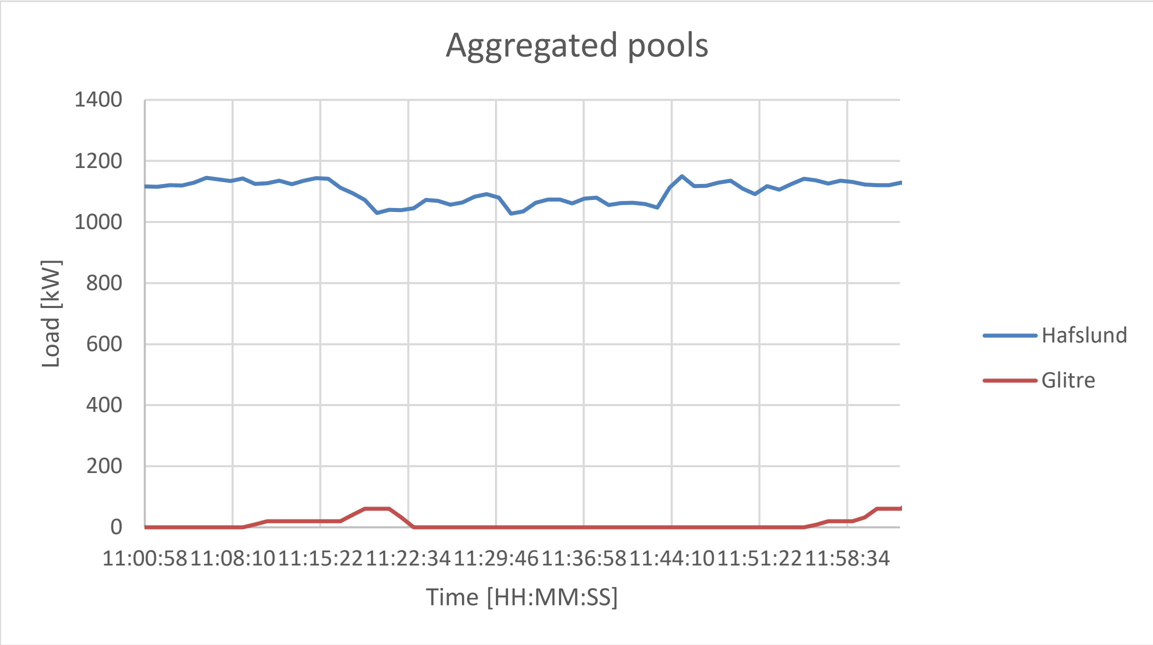

Figure 14 : Dispatch of Hafslund and Glitre pools as logged by Siemens.

In Figure 15 the specific power measurement for each site is presented. Site 5 with the largest load does not present a significant power reduction since variations of other non-controllable loads are larger than the available flexibility. Site 2 provides the majority of the flexibility despite also having large variations in non-controllable loads. Site 1 and 3 both have defined power reductions similar to site 2 but are limited in terms of available flexibility. Site 4 which constitutes the Glitre pool is inactive before the test since there is no heating demand for any of the buildings. By forcing the water heater to activate at one site just before the test a power reduction of 20 kW was performed. This forced activation of the water heater also results in the power peak of site 4 after the dispatch was ended.

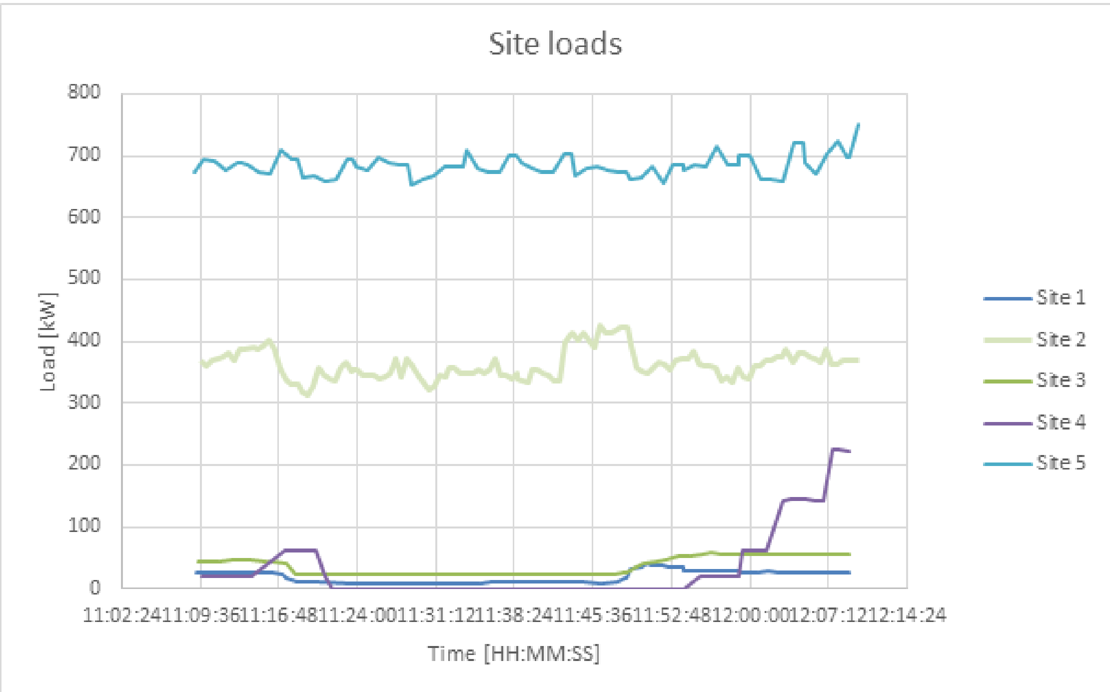

Figure 15 : Dispatch of all commercial buildings where site 4 is an aggregation of buildings 4-8.

In summary, a defined power reduction has been performed for all sites during a dispatch of approximately 30 min including the activation time of 6-7 minutes. Power measurement has also been confirmed meeting the requirement of one sample per minute.

6.3.1.2 Data and documentation of tests – visualizations building/industrial loads

Several tests were performed during the prequalification and preparation. The first major test was in February 2020. This test showed that the Enfo loads were able to provide approx. 1.8MW of flexibility in the Glitre pool and 1.3 MW in the Hafslund/Elvia pool.

Prequal test of the Glitre pool:

- Activation received in flextools at 06.02.2020 at 10.05 AM
- Start dispatach signal to load sent to the loads at 06.02.2020 at 10:09 AM
- Abort dispatch sent unit the 06.02.2020 at 10:19 AM
- Response time cloud to local control (Enformer RTU), less than one second

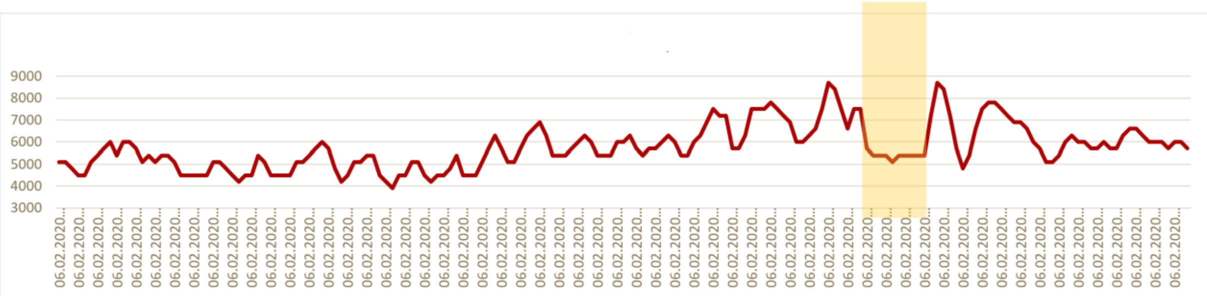

Figure 16 Dispatch of one of the loads (electric boiler) of the Glitre pool, approx. 1.8MW step down.

Prequal test of the Hafslund/Elvia pool:

- Activation received in flextools at 06.02.2020 at 10.27 AM
- Start dispatch signal to load sent to the loads at 06.02.2020 at 10:32 AM
- Abort dispatch sent unit the 06.02.2020 at 10:43 AM
- Response time cloud to local control (Enformer RTU), less than one second

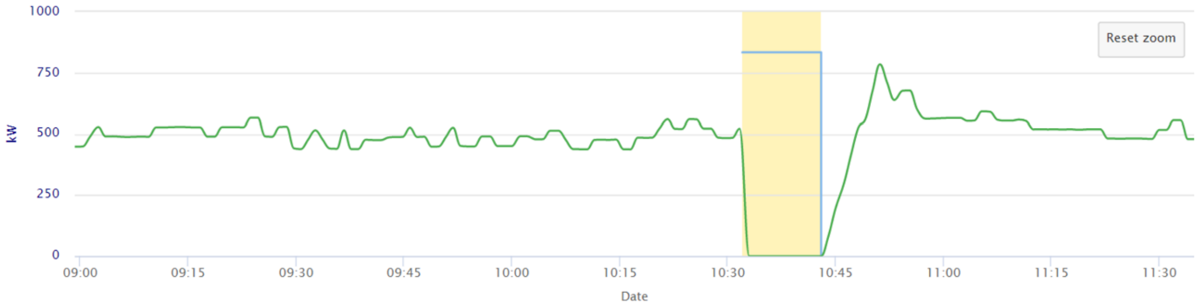

Figure 17 Dispatch of one of the loads (electric boiler) of the Hafslund pool, approx. 0.5 MW step down.

6.3.1.3 Findings in the test environment

To test efficiently we established a local test system, internal to Enfo, where we could simulate Statnett response to bids and simulate Statnett eBestill activations. Then we tested towards Statnett. Some of the testing required some manual operations from Statnett, but overall we could test all aspects.

During testing we discovered that Statnett wants to have the option to activate parts of bids, however our loads are mainly all or nothing. If an activation of for example half the volume is asked for, the activation will not be accepted.

Another finding during testing in the test environment, was that we saw a need for merging of connected dispatches. If Statnett extends the activation period or make a new activation to an already ongoing activation, this is handled on the Enfo side with a "merge"/extension of the ongoing activation. This also helps to avoid violating assets maximum duration.

7. Test results - Operational phase

The operational phase was divided into two periods; May 2020 and October 2020.

7.1 Activations Tibber

Tibber participated in the operational phase of the pilot in May and October 2020. During the full test, Tibber made the following bids available to the TSO, each bid containing 1 MW of demand reduction:

- 5 different days with 3 hours duration each for phase 1
- 7 different days with 3 hours duration each for phase 2

However, only 1 hour could be made available on each day if the bid was accepted, rejecting the activation for the other two hours. This means that in practice 12 MWh was offered to the market.

The results from the operational phase can be summarised as follows:

- On the 29th of May Tibber was activated and successfully delivered 1MW of mFRR with a fleet comprising purely Easee chargers.
- On the 20th and 30th of October, Tibber was activated and successfully delivered 1MW with a fleet comprising both EV chargers and mill heaters.
- On the 27th of October Tibber failed to deliver due to an error.
- On the 23rd of October Tibber was activated and delivered 0.95MW due to insufficient capacity from heating devices.
- The vast majority of devices physically react within 60 seconds to commands sent by Tibber. Reserve devices are activated, or additional commands are sent in the case of unresponsive devices.
- Tibber offers smart EV charging to its end-users where charging is scheduled at optimal spot price hours. Figure 17 below depicts the ramp up of the fleet at 01:00 according to the smart-charging schedules before the mFRR activation was received from Statnett. The ramp up from smart charging occurs on the change of hour and with full ramp typically reached within 5-15 minutes.

The figure below depicts a successful activation and delivery of 1MW by the Tibber fleet.

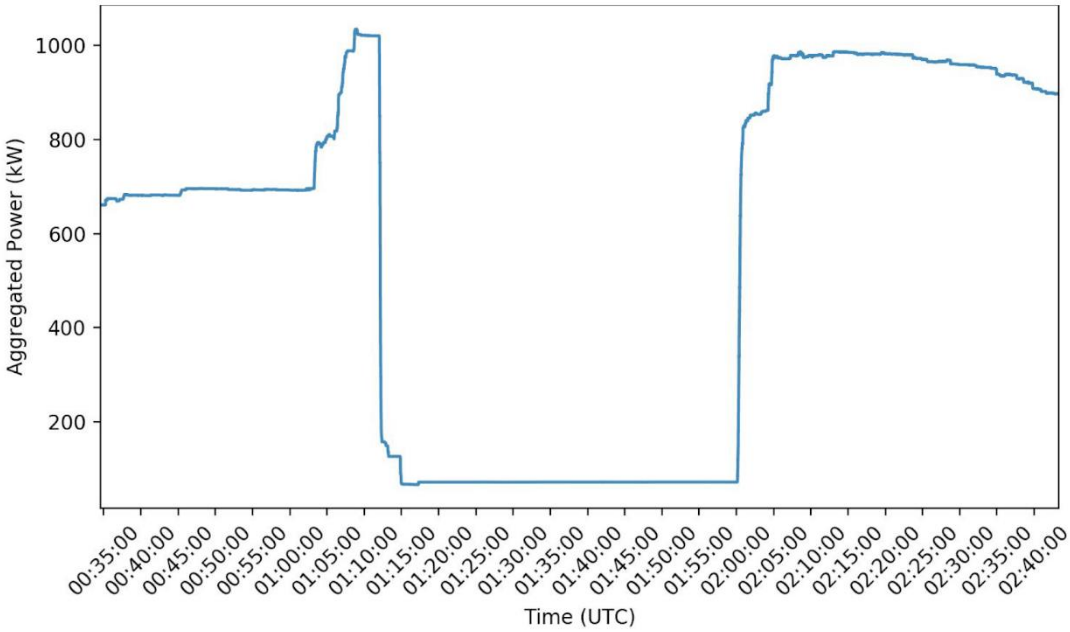

Figure 18 Activation and delivery of 1 MW.

7.2 Activations Entelios

Entelios participated in the operational phase of the pilot in May (Enfo/Entelios) and October (Enfo/Siemens/Entelios) 2020. During the testing, 7 bids of 1 MW/1 hour were made available to the TSO:

- 3 different days with 2 different bids of 1 hour / 1 MW
- 1 day with 1 bid of 1 hour / 1 MW

The results from the operational phase can be summarised as follows:

- On the 26th of May Entelios was activated and delivered 1.75MW flex in the Hafslund/Elvia pool
- On the 26th of May Entelios offered 1 MW flex in the Glitre pool but canceled the bid due to low usage at the main flex providers.
- On the 19th of October Entelios offered 1 MW and activated 2.2 MW flex in the Glitre pool
- On the 19th of October Entelios offered 1 MW and activated 0.8 MW flex in Hafslund/Elvia pool
- On the 20th of October Entelios offered 1 MW and activated 0.2 MW flex in the Glitre pool
- On the 20th of October Entelios offered 1 MW and activated 1.7 MW flex in the Hafslund/Elvia pool
- On the 23rd of October Entelios offered 1 MW flex and delivered 0 MW in the Glitre pool

Some deliveries were lower than the requirement of 1 MW. In general, covid19 led to very low usage in the buildings. We also saw high variation in the industrial consumption in addition to some end customers requesting not to participate, this made it hard to perform good prediction of the flexibility. For more learnings points, see later chapters.

Figure 19 One test dispatch from the Hafslund/Elvia pool – combined portfolio of both industrial and commercial (building) loads. Tested in May 2020. Approx 1.75MW of flex (Screenshot by Enfo).

Example cases
Here are some of the screenshots that demonstrates some of the challenges and complexity that a tool like flextools need to address.

Figure 20 Example of a load (electric boiler) with a good response and small/short overshoot. (Screenshot by Enfo).

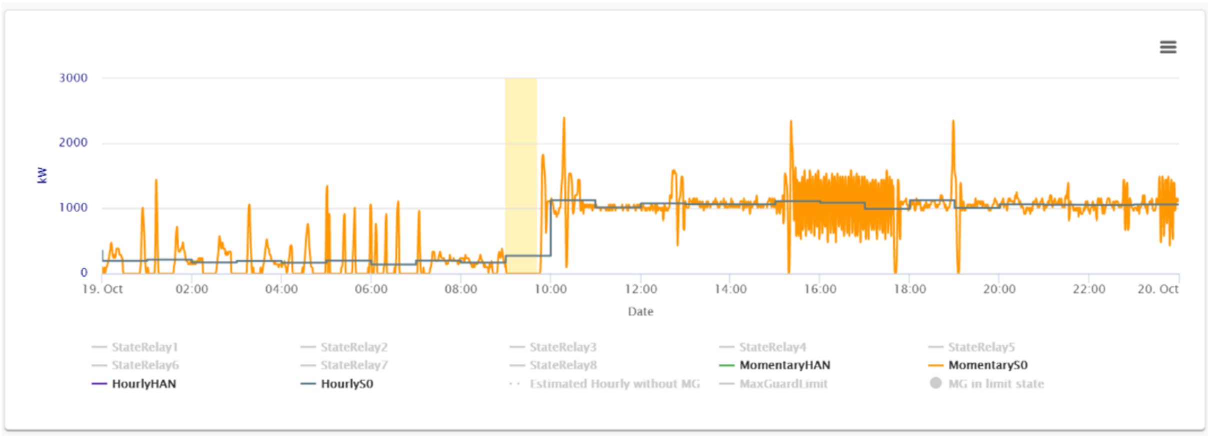

Figure 21 – Example of a load (steam boiler) at an industrial site. Very low demand at the point of dispatch and high demand directly after. Approx 160kW of flex. (Screenshot by Enfo).

8. Pilot learnings

This chapter contains a discussion based on the key learnings we saw in the project. The chapter is structured as comments from the different partners in the project. We are commenting on the following topics:

- the effect of a bid size of 1 MW
- the complex value chains aggregators must handle and be the single-point contact of
- how successful eBestill-integration requires practical testing at the flexibility providers end
- how measurements, forecast and buffers can help secure the flexibility delivery
- load behavior after activation increase in importance when scaling up

8.1 Lowering the minimum bid size to 1 MW enables more flexibility

Statnett comments

Lowering the minimum bid size in the mFRR-market in NO1 in the pilot scheme, from 5 MW to 1 MW, was essential in order to mobilize these new balancing resources. Due to the large volumes, the control centre at Statnett must be able to regulate fast and in large blocks at the time. Hence, aggregators play a role in aggregating lower flexibility volumes to minimum 1 MW for the mFRR market. The resolution of bids is not foreseen to be any lower than 1 MW, this means that a bid needs to be a multiple of 1 MW.

Statnett has a requirement to have access to around 1700 MW for balancing in the mFRR-market. 1200 MW of these are to cover a dimensioning incident, e.g. a trip of a large power plant or consumer, and additional 500 MW are for other imbalances. If Statnett is not certain that the mFRR-market can provide these volumes, we use the option market for mFRR to secure reserves.

Siemens & Entelios comments

Enabling new demand-side resources to participate in the ancillary markets can partly be done by adapting and changing these resources to meet the existing market requirements. However, this approach should be complimentary to identify, and lower barriers imposed by the existing requirements. However, in order to do this, it is important to first identify the barriers. Reducing the minimum bid size is a known enabler for new market participants.

The minimum bid size requirement for mFRR was decreased from 5 MW to 1 MW in this project, meaning that the overall entry barrier for flexibility was decreased since the resources or aggregated portfolios with a total flexibility less than 5 MW now could participate in the market. However, the resolution of bids of 1 MW was not changed. This means that in the pilot only bids with a capacity being a multiple of 1 MW and with a bid size equal to or larger than 1 MW could be placed. In order to illustrate the challenge that this presents, assume an aggregator having a portfolio where the forecasted flexibility one hour is 1.9 MW. This capacity according to the mFRR requirements would need to be rounded down to 1 MW, meaning that a total of 900 kW would not generate any revenue. When comparing the 1 MW-resolution to the available capacity of demand-side flexibility resources, which typically provide a flexibility much smaller than 1 MW, it is obvious that there is a significant number of resources not generating any revenue but still bearing the costs required to enable flexibility. This problem creates a barrier for aggregators with smaller portfolios of flexibility. Since they cannot effectively spread the cost of the redundant flexibility over their portfolio, they will either become less competitive or will have to only admit new customers that provide flexibility close to but just above the quantified requirements for capacity. Considering the rather small flexibility of individual resources, the bid granularity of this requirement could be increased to improve the effective flexibility. By for instance, accepting bids measured in multiples of 100 kW, this would lower the entry-barrier for aggregators and smaller flexibility resources and thus generate revenue without requiring extra capacity in reserve.

8.2 The aggregator must manage complex value chains

Statnett comments
The following figure depicts a typical set-up for a value chain for delivering flexibility to the ancillary markets.

Figure 22 The value chain of flexibility – multiple parties and technologies on the flexibility delivery side.

However, this value chain is currently developing. There are three elements that will drive the number of stakeholders for delivering flexibility:

- Already happening:
    - A possibility for the BRP to outsource tasks connected to electronic bid ordering and eBestill to another BRP.
    - Aggregators using multiple technologies and technical providers to deliver their services

- In the next years:
    - Splitting of the current BRP tasks and responsibilities into two roles; balance service provider, BSP, and a new BRP role (Statnett, 2018).

Swift action is key if failure occurs during operation. When the value chain for delivering flexibility develops into including multiple stakeholders, it has several consequences. One is that search for failure and fixing may potentially become more time consuming. As a first measure, it is advisable that the flexibility provider has a redundancy plan for each part of the value chain, both external and internal parts. Secondly, more complex value chains set stricter requirements to communication and coordination amongst the stakeholders.

The mFRR-requirements states that all market players need to be available for regulation in the hours a bid is placed. This includes being able to adjust bids or activations as well as being avaliable for eventual enquiries from Statnett's control centre. Statnett's control centre has and will maintain a requirement of single point of contact per market player, even for value chains with multiple stakeholders. The market player representing a value chain must in other words be able to adjust the bid, manually activate and deactivate and respond to enquiries from Statnett regardless of the mix of technology and number of units and stakeholders used to provide the flexibility.

It is the BRP which currently is the counterpart for Statnett and our single point of contact. The BRP must have an overview over the resources available for activation and be able to follow up in case the activation should fail. In the pilot, Tibber and Entelios were the BRPs of the flexible resources participating. This meant that they when a bid was ordered and activated, they had to be able to answer to enquiries regarding all the different technologies used for balancing. Tibber on their hand with their portfolio of EV-chargers and panel heaters, and Entelios on their hand with building management systems and electric boilers. For the aggregators to be the single point of contact to Statnett, they need a deep integration between themselves and the consumers with an automated system for updates of load and generation.

Siemens & Entelios comments
It is not only the subcontracted technology providers who increase complexity in a portfolio management point of view, but also the inherently random operation of the assets that are connected.

In an ideal case, the characteristics of the connected assets would respond to external parameters in a dynamic but predictable way. For instance, a building increasing the use of ventilation and cooling due to increased outdoor temperatures can be predicted through forecasts based on weather data. This can also be used to determine the buildings performance in regard to flexibility provision, which in the end will provide transparency to the BRP. However, since operation of these types of assets, such as buildings and industries, also includes a human touch through their operators, this will introduce randomness. For instance, this could be an industry where its available flexibility changes as its production schedule is updated for the day, or the process is stopped due to maintenance. The effects of this will be a flexibility potential that is harder to determine, as well as, decreased transparency to the BRP. In the end this challenge will only be solved through increased integration between the asset's operation and the flexibility it provides. But so far, the main solution for this is through educational and contractual measures.

Tibber comments
Service level agreements should be made with 3rd party service providers. A mix of technology resources providing reserves improves a service providers robustness. For example; by being less vulnerable to a single point of failure from a 3rd party provider.

8.3 New solutions need practical testing for successful eBestill-integration

Statnett comments
One of Statnett's main take-aways from the pilot is what we can expect and must plan for when new market players integrate their solutions towards ours, and especially connected to bidding and activation through the eletronical bid ordering process, eBestill.

The integration of the pilot partners system towards Statnett's solution for electronic bid ordering (eBestill) went well but was more work intensive than planned. Tibber used approximately 25% of their project time on the integration, whereas Enfo, providing the solution for Entelios and Siemens, used 40% of their time on this work. In addition, Enfo integrated a solution for sending the bids to Statnett through the EDIFACT format, whereas Tibber used Statnett's API for bidding called FiftyWeb.

One learning is that when a market party integrates a new solution towards eBestill, there is a need for a separate test environment at their end in order to test changes without affecting availability to system environments in production (production mode of the applications). Furthermore, both the standard procedure for testing eBestill, and requirements during operation should be more clearly communicated to new market parties.

Tibber comments
It was not until the prequalification phase that many operational nuances were understood. Having Statnett step through reasons behind many of the technical requirements and operational practices, from the perspective of the control room, clarified many misunderstandings and false assumptions. (For example; the 15-minute reaction time is taken from the time a start order is created and not from the order start time).

The testing and pre-qualification phase was also necessary to identify and fix human errors in the form of code mistakes and incorrect configurations.

Regarding the eBestill solution; the primary issue Tibber identified was the lack of sufficient support for the database system Postgres which Tibber uses. Postgres is one of the most widely used, object-relational database systems. This lack of support has contributed to stability issues in Tibber's development database. Additionally, eBestill uses a large number of database connections, most of which are idle. This inefficiency is unavoidable with the current arrangement of eBestill. Finally, being in the language java, it uses a large amount of memory which does not fit well with Tibber microservice architecture.

Enfo & Entelios comments prequalification
Even though the testing in Statnett's side was a bit cumbersome, as detailed in the next section, we were able to test most parts before moving to production.

In addition, we created test facilities that had capability of simulating all types of messages and events from Statnett. The transition from the test to the production environment was therefore quite smooth.

When testing electronic bidding to EDIEL, we had to send our test bids to a personal email. This made it difficult to test automatic sending of bids and made it more difficult to test bid acknowledgments. It seemed to be necessary with some manual labor on Statnett side. Ideally, we could have had a test system for the whole EDIEL bidding process.

For eBestill itself, there was a functional test system on both Statnett and Enfos side. This worked perfectly. However, it was a separate system from the test system for EDIEL bidding. Ideally, we could have saved time it there were a complete test setup, from EDIEL bidding to eBestill activation. The lack of a complete test chain, led to some unexpected findings and small hiccups, as mentioned below.

One important finding that we had after moving to the production environment, was that Ediel use the same SMTP address for all its communication. This makes it necessary to filter all incoming messages and route them based on information found in the message itself. When this issue was resolved the systems worked fine.

A second important finding is that Statnett has implemented ECP with one endpoint per actor. This means that Entelios (the BRP) must run all its services over this endpoint. For now, they only have eBestill, but for BRPs having several services, for example a BRP with both production related services and consumer flexibility, this needs to be taken into consideration.

8.4 Securing the delivery through measurements, forecasts and buffers

The pilot was a breakthrough as it was to our knowledge the first-time demand was automatically activated in the mFRR-market in Norway. However, automated activation also needs monitoring. In the pilot, we had lack of delivery or reduced delivery due to failure in forecast, control, communication and activation at the providers end.

The mFRR- requirements (Statnett, 2020) is Statnett's tool for ensuring that providers deliver. According to the requirements, the provider is obliged to deliver the amount offered in the mFRR-market. Providers that offer mFRR made available by a third party are responsible for that the third party also comply with this obligation. New bids or correction of earlier placed bids must be sent to Statnett at the latest 45 minutes before each operational hour. If the provider has failed to deliver multiple times, Statnett has the right to exclude the provider from the mFRR market.

In the pilot, the failed volumes were small. However, a failure in delivery will increase in importance with MW size and how much the TSO and DSO rely on it. In a future case where flexibility has become an important tool for both the DSO and TSO and where both short-term grid operation and long-term development rely on it, non-delivery of flexibility would have a larger impact than it did in the pilot.

The following table provides a summary of both successful deliveries and incidents during our two pilot phases of operation in the mFRR market respectively in May and October 2020.

Table 5 Activations during the pilot periods in May and October 2020.

Date	Original bid (MW)	Delivered (MW)	% delivery versus bid (0-100%)	Reason
26-05-2020	1	1.75	+75%	Min steps of 1 MW and we wanted to test all assets
26-05-2020	1	0	100%	Bid canceled due to low consumption.
29-05-2020	1	1	0%	
19-10-2020	1	2.2	+120%	Variation in consumption makes it more difficult to predict
19-10-2020	1	0.80	-20%	Lower consumption than expected
20-10-2020	1	1	0%	
20-10-2020	1	0.2	-80%	Lower consumption than expected
20-10-2020	1	1.7	+70%	Min steps of 1 MW. Higher consumption than expected.
23-10-2020	1	0.95	-5%	Incorrect allocation of capacity between resources
23-10-2020	1	0	-100%	Bid canceled due to low consumption.
27-10-2020	1	0	-100%	Failure in fetching prices
30-10-2020	1	1	0%	

12 bids were activated. 6 times the delivery was as planned or overshooting the agreed amount, 3 times reduced quantities was delivered, and 3 times the resources failed to deliver. Summarized, a total of 12 MW in demand reduction was ordered from Statnett, of which 7.95 MW was delivered as agreed, not counting the overshoot.

As mentioned, the provider is obliged to deliver the amount offered in the mFRR-market, hence the pilot testing was an opportunity to mature the value chain and eliminate future failures.

In the following we discuss three measures for ensuring the delivery certainty; measurements, forecasts and buffer.

Statnett comments
Access to unit data is crucial both for assessing flexibility potential, and for operation, where precise forecasts are key both to secure delivery and avoid imbalances in the power market.

Today mFRR is settled on agreed volume, yet measurements will play a larger role in the future, and it's both relevant for verification and control and settlement volumes. It is important to Statnett, and will become increasingly important, to know that the activation has taken place. The settlement in the project was done through the imbalance settlement process, meaning that the market party was remunerated for the agreed mFRR activation. The aggregators measurements and forecast has not been used for settlement purposes in this project.

No matter how precisely an aggregator can predict the demand, he or she still needs to maintain a buffer of resources in order to be able to deliver the bid even with last-minute changes in load. This is in particularly valid for end-user consumption where consumption will vary more randomly than an industrial process. It is difficult to say any generic about how much buffer an aggregator should have, also due to the different properties of the different loads. Since the mFRR-requirements as mentioned above obliges the provider to deliver the offered amount, the buffer becomes an important tool for the aggregator to ensure delivery certainty.

Siemens & Entelios comments
The current generation of smart meters in buildings provide sufficient performance to meet the metering requirements.

This means that despite the complexity of identifying the correct meter amongst several main meters in larger buildings, the process of integrating a smart meter to provide the measurements necessary for reporting and settlement is not a considerable challenge. However, the flexibility of a building may be a rather small part of the overall load when utilizing a building's main meter(s), and any dispatched flexibility might be increasingly hard to measure. For instance, if a shopping center's total load corresponding to 2 MW was measured at the main meter and a dispatch of 100 kW was ordered, the reduced power consumption of 100 kW would largely be concealed by variations of other building loads which in comparison are equally as large. Even though the assets would have reduced their power consumption by 100 kW, variations in other loads, independent of the controlled assets could hinder the power reduction from being identified at the main meter. Normally though, the power reduction would not be completely be hidden by variations of other loads; say that the variations before dispatch correspond to 1.9 – 2.1 MW where 2 MW is the average, then the load after dispatch typically would be 1.8 – 2.0 MW where 1.9 MW is the average. The point where requirements can help to enable flexibility is to acknowledge that the resources which provide flexibility are dynamic and change according to their utilization. An example of a requirement that could improve this settlement is to calculate the activated energy volume based on a power measurement which is averaged during the activated period. This way, many of the variations can be reduced whilst still delivering the same amount of flexibility but improving the prerequisites for building flexibility by utilizing the main meter.

An alternative to utilizing the main meter would be to apply sub-metering where each flexibility asset would be isolated and individually measured by a metering device installed in the switchboard feeding the asset. However, nearly all buildings do not have available power meters for assets like air handling units, meaning that in order to provide the capability of sub-metering, new meters would be needed to be installed. Considering the potential revenue from flexibility, the installation of 10s of meters in a building would be too costly and thus not feasible going forwards.

Today, Entelios would have around 20-30% reserve capacity for a bid of 1 MW. For smaller resources, a higher percentage of reserve capacity could be relevant. During the pilot we experienced large variations in the consumption. Some loads are only flexible above a given consumption.
In a pilot we can monitor the usage manually (operator/trader), but to cope with this complexity at scale, we need the help of computers. Using machine learning and rule engines to support the operators will be important moving forward. We must further improve forecasting to help the operators and traders. We also see the need for implementing even smarter and more automated functions. One example is that we implemented automatic cancellation of bids after experiencing this need in the pilot. This adds up to the functionality we have in place for making automated bidding in local flexibility markets. We also see that an increased portfolio size would improve the situation and not making us that vulnerable and dependent on all units.

In general, the need for reserve capacity should be minimized in order to improve the overall business case for flexibility providers and thus, to increase the number of players in the market. The requirement of reserve capacity can be viewed as a direct loss of revenue, which creates the risk of only some flexibility providers, which can unlock their flexibility more cost-efficiently, to become financially feasible. Nonetheless, it is always important to consider the accountability of a flexibility provider, where reserve capacity does play a role as it contributes with redundancy. In this sense, the required amount of reserve greatly depends on the type of asset, how it is operated, and the algorithm to forecast and calculate the available flexibility for the bidding procedure. With this, it is hard to generalize the required reserve in terms of percent of the provided flexibility on an asset-level, and consequently has to be done on a portfolio-level where the assets are typically more heterogenous. Irrespectively, the prerequisites for ensuring delivery of flexibility has to be considered on an asset level. Here, actions can be taken to improve the selection of assets which are more predictable, establish agreements with flexibility providers for operation during flexibility provision, improving the forecast and calculation of flexibility, and more. Ultimately, certainty of supply and the required reserve will be another factor to take into consideration when evaluating flexible assets and their respective business case.

Tibber comments
Forecasting capability will continue to develop as the volume of data and operational experience increases. In order to provide redundancy for user unexpected behavior, Tibber will continue to use a conservative buffer size of up to 50%.

8.5 Load behavior after activation should be considered when scaling up

Statnett comments
In an optimal situation, smart energy demand management is smart both for the consumer and for the grid. A rebound is an increase in demand after the reduction in demand, i.e. activation in the mFRR-market. It is a phenomenon particularly seen in connection with thermal loads, as demonstrated in the figure below. It may not be optimal neither for the grid nor the customer if the flexibility source has a rebound right after delivery. In the pilot, the mFRR-volumes were small. However, load behavior after activation should be assessed, especially when scaling up.

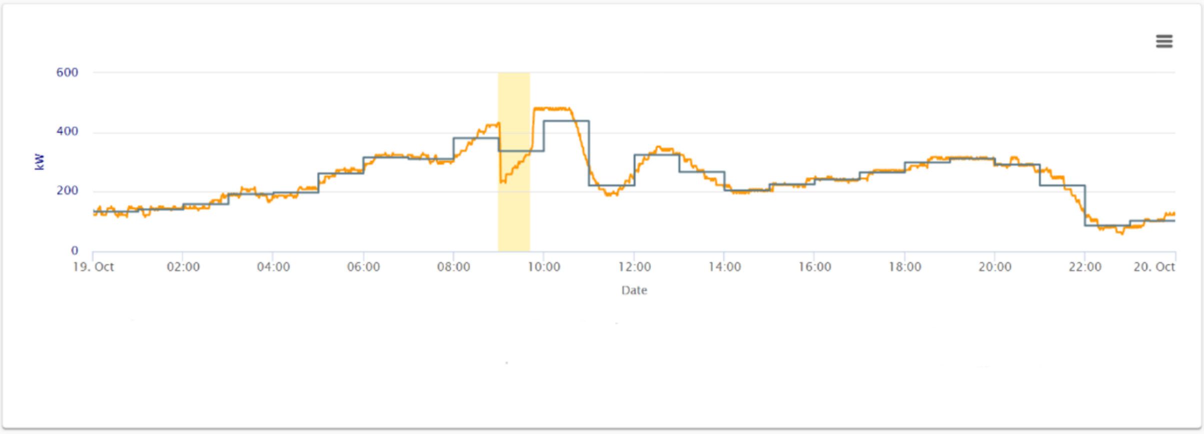

Figure 23 Example of a load (electric boiler) experiencing a side effect/with short duration, in addition to rebound. (Screenshot by Enfo).

Tibber comments
Tibber provides flexibility with residential loads. When a device is activated, its energy consumption is shifted from its initial schedule. This means that sooner or later EV batteries will be charged and homes will be heated. From an aggregator's perspective, there is no incentive or regulation that mandates a certain load behavior after the activation is over. Tibber currently has implemented a short ramp up time when the time of activation ends, but in practice all heaters and chargers could be started up immediately and at the same time. This might not be an issue today, but in the long term may bring problems in different levels of the grid.

Another important element related to the rebound effect is that of a BRPs imbalance settlement. During the activation time, the imbalance is settled through eSett, considering the activated capacity. However, any subsequent rebound energy is not considered, creating an imbalance for the BRP. This could be solved through a transaction in the intraday market for the shifted amount. However, this solution would increase the risk for aggregators, thereby increasing the price of offered flexibility.

Enfo & Entelios comment
There are two levels of seeing the rebound problem. The grid level: Will the rebound give issues? The local level: Will the rebound increase cost for the asset owner? If we look at the latter, the cost of a rebound will normally be quite low, given that you operate within recommendations from the producer. Most grid tariffs are based on hourly consumption, and the highest hourly peak consumption within a given time period, e.g. a month. If the rebound defines a new peak hour it comes with a cost. The asset owner then has an incentive to handle this. Using local control logic, it is possible to perform more controlled ramp ups. We know that the mFRR product in near future will dictate requirements for ramp up/down periods. This will also incentivize the BRP, that might get imbalance costs when these periods are not followed. Therefore, it is likely that stricter requirements to ramp up/down periods will help on this situation.

If this is a problem at the grid level, e.g. a lot of loads have short-lived high demand directly after an activation, Statnett also have possibility to implement simple algorithms to spread the reconnections over some time, 30 minutes for example. This is also a question about compensation. It is hard to motivate an end user to put more constraints on his facility, if there is no compensation for such efforts.

9. How do we drive further development?

In the following sub-chapters, we discuss some potential measures for further development. We discuss how security should be built into digital solutions by design, how we can tap into the existing residential capacity by using price signals and smart appliances standards and investment, and finally how we can commercialize larger buildings flexibility through collaboration and knowledge sharing.

9.1 Security should be built into digital solutions by design

We see that fully digitalized solutions provide an efficient market access to new flexibility sources, but they also come with new challenges. One of them is digital security. Cybersecurity and establishment of trust will be a driver in the flexibility market, and security will need to be built into the systems by design, as well as throughout the whole service delivery supply chain. ENTSO-Es work on the Network Codes implies the need for a structured approach to cybersecurity, and perhaps also certification when it comes to establishing trust in the providers and their products. It could end up with a situation where trust is built from certification and hence becomes a requirement. In practice, this means that organisations offering products and services to the flexibility market will need to be ISO 27001 certified or equivalent, or at least be required to document and provide proof of a well-established Information Security Management System (ISMS). Furthermore, it might also be the case that the certification requirement will cover the products themselves as well, not merely the organisation. Such a product certification schema would most likely either follow ISO/IEC 15408 Common Criteria or IEC 62443 Security for Industrial Automation and Control Systems (IACS).

Security by design is a principle that should be applied, and this includes, but are not limited to:

- Protection of information across all system components, including communication.
- Authentication and authorisation measures tailored for and across all system components.
- Integrity protection measures tailored for and across all system components.
- Availability measures tailored for and across all system components.
- Secure logging and audit measures.
- Incident response and recovery measures.
- Non-repudiation measures and assurance.
- Secure service delivery measures and assurance.

In cases where cloud services are used, it is important to note that this does not mean that cybersecurity is handled by the cloud provider. The product and service provider are still responsible for the security of their products and services, the customer information, as well as logging, audit, security events reporting to customers, and incident response and recovery. The cloud provider might be involved in many of these activities, but this is nevertheless still the responsibility of the actual provider.

Furthermore, when offering products and service using cloud services, it is important to understand the build-up of the offering and its associated supply chain. Cloud services could be based on infrastructure as a service (IaaS), platform as a service (PaaS), or software as a service (SaaS), and depending on which service level one adopts it is important to configure the cloud portion correctly so that security is maintained throughout the complete supply chain, including hardware, software, communication, users and data. It is also important to understand that the various could providers, such as Microsoft, Google, Amazon, etc. and their cloud platforms have slightly different offerings og configuration alternatives regarding cybersecurity, including which encryption key schemes that they support. When it comes to the encryption keys it is also important to understand the pros and cons of the various alternatives, such as who is the generator and holder of the encryption keys, what alternatives there are for data revocation, and the cost and trade-off related to these. For example, if each customer manages their own encryption keys, this will have an additional cost compared to the standard encryption schema offered by the cloud provider, but the customer will in this case be able to perform data revocation and have full control over their data. However, such a regime might be cumbersome to maintain and operate.

More details are given in Attachment 2 Statnett's requirements to cloud services.

9.2 Price signals, smart appliances standards and investments to tap the residential capacity

This project demonstrated the potential aggregated residential units have to provide flexibility to the power system. However, there is still a large potential in the residential side that has not been used or simply doesn't have the IoT capabilities to be used. A wider adoption could be achieved by upgrading the existing equipment, instead of its replacement.

The problem for the final user is the lack of incentives to make these upgrades. Nowadays aggregators can mainly do energy arbitrage to achieve a return on investment from smart appliances. Smart hardware may be supplied by an aggregator as a part of a deal with the consumer, or it may be purchased and installed by the consumer itself. In most cases users will not be willing to make the upgrade considering the initial capital required and uncertainty of benefits.

Several paths may be used to tap into the existing residential capacity. Economical, technical and regulatory barriers to smart demand management in households should be identified and actively built down.

Firstly, price signals to the end-consumer is key for realising residential demand response. Most aggregators offer means for the consumer to check real-time power consumption and daily energy use and come with suggestion for load shifting and possible energy savings. Large scale consumer tests show a significant potential in such real time solutions. VaasaETT estimated in 2014 that Norwegian households could save around 7 TWh within two years if effective feedback were applied following the roll out of smart meters that took place in Norway by 1 th of January 2019 ((NVE, 2014) . Further reports look into higher savings when making use of home automation systems in addition to real time feedback, not at least peak reductions, which are estimated at 23% (NVE, 2017).

Push or pull mechanisms in the market may be considered as economic measures to increase the pace of investment in smart hardware and home automation systems. There are several options for this. One example is to subsidize household investments through governmental schemes such as Enova. Another option are market schemas aimed at rewarding residential or disaggregated flexibility, similar to how the CO2 price or a Feed in Tariff stimulate renewable generation. Seen from an aggregator's perspective, measures such as the mentioned above, would drive innovation from aggregators, flexibility for TSOs and DSOs, financial benefits for final consumers, ease the introduction of more renewables and increase the energy efficiency.

Secondly, smart demand management should ideally include options for smart management also for the power grid and the society. TSOs, DSOs, aggregators, electricity suppliers, manufacturers of appliances, interest organizations and public institutions can all play a part in supporting such a development. A common agreement to smart appliances standards may be one way forward, as there is currently a gap in the regulation for ecodesign regulated products which consider both the needs of the grid and the consumer. The Ecodesign directive of 2009 set energy efficiency standards for a wide range of electrical appliances, however, the directive does not have a focus on active market participation from end-consumers. There is a project on smart appliances features for ecodesign products, however there is still much work to be done before this is force. In the following we'll briefly summarize current relevant regulation which supports smart demand management to illustrate this.

In 2015, the European Commission put forward a new vision for a retail market that intended to better serve energy consumers. In "Delivering a New Deal for Energy Consumers" the Commission stated: *" By taking advantage of new technology, new and innovative energy service companies should enable all consumers to fully participate in the energy transition, managing their consumption to deliver energy efficient solutions which save them money and contribute to the overall reduction of energy consumption."* (European Commission, 2015). The Electricity Directive in the Clean Energy Package is one of the places where these ambitions have been materialized, including by addressing how end users can participate in the electricity markets with the aid of aggregators (European Commission, 2019).

A preparatory study on Smart Appliances requirements to eco-design products was initiated in June 2015 and finalized in September 2018 (Rode, 2020) (European Commission, 2020). It recognises the demand for fast flexibility reserves.

Demand management, especially turning off demand, has the advantage that it can respond very fast to signals, from 2 seconds and less. This make demand resources especially fit for fast balancing reserves, such as the Fast Frequency Reserve (FFR) (Statnett, 2020). In the Smart Appliances preparatory study there are recommendations, they have however led to few tangible fixed requirements in present eco-design product regulations, such as heating devices or water heating devices. In lieu of these, some organisations have made their own “Smart-Ready” indicator (Rode, 2020) (Bundesverband Wärmepumpe, 2020). This indicator is however not supporting the fast reserves.

The eco design product group Building Automation and Control System (BACS) also has recommendations in their preparatory study initiated in 2017 and present in finalization (Rode, 2020). It also covers part of the flexibility issues for the grid, however mostly relatively slow flexibility most suited for DSO’s or consumers behind the fuse.

Finally, the Energy Performance of Building Directive revised in 2018 also includes a proposal for Smart Readiness Indicator, SRI (Rode, 2020). It has a comprehensive matrix of many parameters that may contribute to smartness, both fast aggregated responses, diurnal flexibility and more short, medium and long term (seasonal) flexibility.

9.3 Commercializing larger buildings flexibility through collaboration and knowledge sharing

One learning from this project is that building flexibility is a viable technical solution. It is a novel solution and thus potentially it needs improvement work. However, the key development work is related to non-technical challenges such as developing smart business models, effective processes for project delivery, improved frameworks for flexibility assessments, and more. Nonetheless, a prerequisite for success in commercializing building flexibility is to consider the challenges that do exist and to take measures accordingly.

Collaboration has been identified as a significant enabler for the market for flexibility. It has been made clear that non-typical players and resources, the ones capable of providing new flexibility sources, are not familiar with the prerequisites for flexibility. Typically, they do not have a sufficient understanding of ancillary services or other topics related to energy markets such as balance responsibility. Simplified, the two ends of the value chain for flexibility, the one end being flexibility providers such as real estate companies and the other being grid operators, have completely different backgrounds which creates a large gap to be overcome in terms of reaching a common understanding. Technology providers and aggregators can fill a part of that gap. However, in order to truly enable flexibility from these segments, more collaboration between all parties in the value chain is needed.

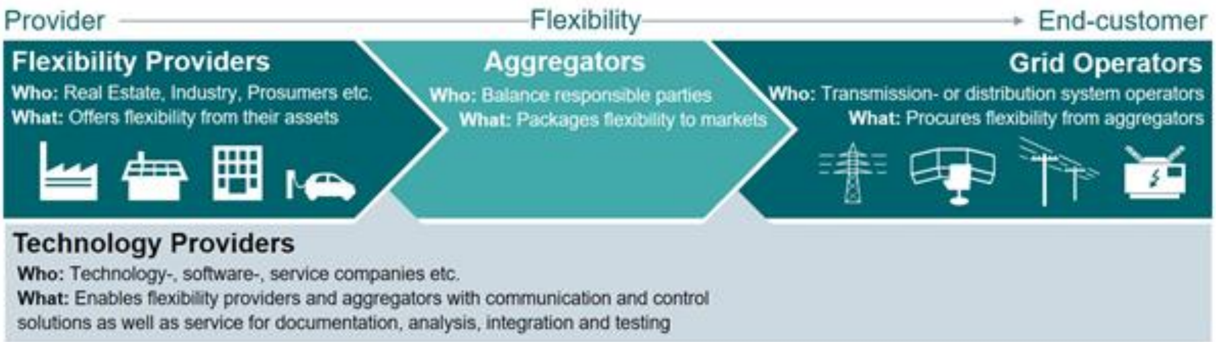

Figure 24: Value chain for flexibility illustrating the need for technology providers along the entire chain.

A first challenge is the large amount of knowledge required in order to understand the prerequisites for flexibility. To evaluate the potential and the risks for becoming a flexibility provider, one must also understand relatively complex concepts such as grid balancing, security of supply, ancillary services, and market requirements. The complexity of these technical and commercial concepts represents a barrier to new players, as establishing a sufficient understanding requires significant amounts of research.

The information required to understand the potential and the risks for investing in flexibility, must become more accessible and easier to understand for all new players. On the other hand, an aggregator or technology provider assessing a building's or building portfolio's potential for flexibility, will initially never have the same knowledge or understanding of the parameters that determine the potential for flexibility as the building operator does. This, combined with the fact that flexibility is a novel concept and is not well-known within the real estate business, it entails that the party performing the assessment is completely reliant on the available documentation describing the building or the knowledge available from the building operators. Considering the documentation that normally is available for buildings for the real estate business, this introduces significant challenges as the documentation typically does not provide a sufficient basis to perform an assessment. The problems encountered could for instance be no available documentation, outdated documentation, documentation scattered between different stakeholders or, readily available and updated documentation but one that does provide the required parameters or information.

In an ideal world the necessary information would simply be collected from a building information model providing a correct representation of a building's systems and operation and thus, an accurate basis for a flexibility assessment. However, since this is far from the actual status of building documentation, workarounds must be made in order to make the best of the situation.
A first and simple measure to improve the assessment is to utilize the knowledge available of site operators and other stakeholders in building operation. Despite potentially not possessing the understanding of flexibility they do provide a good understanding of typical building topics which can be translated into information useful for the assessment. A second measure is to create detailed and intuitive audit surveys which can be utilized by building operators to document the necessary information that does not already exist. A third measure is that the aggregator or technology provider perform a site audit by themselves and in this way collect the missing information. However, depending on the actual size of the building there might not be enough amounts of flexibility to generate enough revenue to motivate the business case to perform the audit. Irrespectively, of what work around are done and how the assessment framework is made, well-documented buildings have a clear advantage for providing flexibility.

A second challenge to be considered at the flexibility providers end, is the modernity of each building's Building Automation Systems (BAS). The BAS is the infrastructure in which low-level control of assets is performed and power measurements and control signals are communicated. Due to this, in order to enable building flexibility where control and communication is critical, since the buildings practically must emulate a traditional power plant, the prerequisites the BAS provides are also critical.

Today, many buildings have poor prerequisites for flexibility due to their BAS. This could be caused by several factors such as limited bandwidth for communicating new control signals, missing necessary signals describing asset operation, outdated firmware not allowing reconfiguration of control algorithms, isolated systems without external access for other parties than the OEM or, simply a BAS which is so outdated it requires significant upgrade investments in order to provide the necessary performance. Establishing a list of criteria defining the requirements for buildings' automation systems would be exhaustive. However, many of the criteria identified can largely be generalized as the modernity of a BAS; if it is more modern it also typically has better prerequisites. Doing this generalization does largely limit the set of buildings able to provide flexibility but does nonetheless provide a good assessment criterion. As for having a well-documented building portfolio, it is equally as important to have modern BAS as they provide the infrastructure for digitalized and flexible buildings.

New market players need accessible and understandable market information, such as clear and transparent historical data of bids, prices, and dispatch data. Sustainability is a common argument for flexibility investments. Yet, new players will often determine whether to invest in becoming a flexibility provider or not depending on the business case. New players can assess and reduce risk by having the access to transparent data of the potential revenue that can be gained by providing historical pricing as well as historical dispatch. A second example is to simplify and ease the process for prequalification of new resources. Something that is clear when working with flexibility is that most resources providing ancillary services are and will continue to be novel solutions for a period to come. Due to the required in-depth knowledge, new players cannot evaluate the feasibility of a novel solution or whether it will be approved in a prequalification process.

They have to choose between taking the risk of investing in the solution without any guarantee of being approved in the qualification process or to not invest at all. Even though flexibility solutions become more standardized, flexibility will continue to be novel to new providers and the associated risks will continue to exist. Grid operators providing support to new players through co-creation workshops, facilitating knowledge-sharing sessions or by providing guidelines is one way to provide feedback to new players, to decrease their uncertainties and ultimately, to reduce their risks for investing in flexibility.

10. Statnett's closing remarks

New sources of flexibility provide us with new value chains and stakeholders, and the pilot have given us new knowledge about both. We have seen that flexibility down to the end consumer can be made available for the balancing markets. Lowering the minimum bid size in the mFRR-market in NO1 in the pilot scheme, from 5 MW to 1 MW, was essential in order to mobilize these new balancing resources. Innovation was prioritized over mFRR-volume in this pilot. Nevertheless, the pilot partners had a total of 12 MW activated in the mFRR market, and of which 7.95 MW were delivered as agreed

Aggregators must handle complex value chains with multiple stakeholders to provide flexibility from distributed resources. Every market player must provide a single point of contact which is able to adjust the bid, manually activate and deactivate and respond to enquiries from Statnett regardless of the mix of technology and number of units and stakeholders used to provide the flexibility. The aggregator's risk management and redundancy plan must involve all elements in the value chain, and consider both technical and non-technical challenges, some of them exemplified in this pilot. We have seen that the way and amount of effort put down to enable market participation varies with the different technologies. It's a difference beween enabling a smart panel heater and a large building ventilation unit without documentation and metering. Automatization enables effortless and rapid response from complex value chains, yet the human factor must not be forgotten. Non-technical challenges, especially in commercial buildings, have proven to be harder to overcome than the technical ones.

The pilot shows that successful integration towards Statnett's electronic bid ordering requires practical testing at the flexibility providers end, especially connected to bidding and activation of bids. A concrete measure for the market players is to have a test environment where they can test their solutions and integration towards Statnett both before entering the market and while in the market.

Good data quality represents an advantage to the flexibility provider when predicting the resources potential and availability, forecasting, verifying and securing the delivery. One learning is that if the balancing reserves are novel or otherwise difficult to predict or manage, this must be reflected in the aggregator's reserve buffer to secure the delivery. Load behavior after activation is also of interest, and should be assessed, especially when scaling up.

The report finally identifies a selection of measures to drive further development. Firstly, while fully digitalized solutions provide an efficient market access to new flexibility sources, they also come with new challenges. Digital security will need to be built into the systems by design, as well as throughout the whole service delivery supply chain. Secondly, price signals to the end-user and smart appliances standards and investments can be used to tap the residential capacity. Thirdly, collaboration and knowledge sharing are needed across the value chain to commercialize the flexibility from larger buildings. This includes understandable and accessible information about the balancing markets and their processes from the system operator to new market players.

The mFRR-market is open to new market players also outside the pilot. To become a market player in the mFRR-market, you currently need to be the BRP or cooperate with the BRP of the flexible resources. The requirements and application to become a mFRR-provider can be found here (in Norwegian). Currently, 5 MW is the minimum bid size in price area NO1, and 10 MW in the other price areas in Norway. Statnett's current estimate is that 1 MW bid size will be allowed in the Norwegian mFRR-market at latest with the implementation of 15 minutes imbalance settlement period (Q2 2023) (Nordic Balancing Model, 2020). Due to both a growing potential and need for flexibility in the power system, Statnett hopes to welcome both new market players, technologies and volumes in the mFRR-market in the years to come. Increased flexibility can be sustainable and cost-effective both for the society and the flexibility providers.

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Attachment 1 Pilot requirements for measurements, data logging and reporting

Requirements for measurements and data logging

We set the following requirements for measurements and data logging

- Measurement and logging/presentation of active power (demand or production)
- Granularity measurement data: 1 minute or finer resolution
- Measurement equipment used must be described, and different technical solutions are accepted. The intention behind the measurement is to verify response and delivery.

Reporting requirements

We set reporting requirements for the 1) test phase, 2) operational phase and 3) evaluation report.

Test phase

The technical test consists of two elements:

- Deliver a plan for consumption or production with an hourly resolution. Verify the consistency between plan and actual delivery
- Perform up to 2 trial activations. Verification of activation with minute values when trial activation.

Registration and reporting of the following data:

- Time of order (received order from eBestill)
- Time of activation
- Activated volume (volume and grid location)
- Time of deactivation (received order from eBestill)
- Time of deactivation
- Measurement values for activated demand, 15 minutes before activation and 30 minutes after terminated activation.

Figures with an appropriate resolution (visual control of result) should be attached.

Operational phase

Activation in the operational phase shall be verified with minute values. In practice this demands a continously logging of minute values of the flexibility resource (demand or production).

In case of an activation we require that the providers log and later report to us:

- Time of ordering (received order from eBestill)
- Time of activation
- Activated volume (volume and grid location)
- If Statnett's National Control centre (Landssentralen) orders a deactivation before the duration has reached its end, the time for order for deactivation (received message from eBestill)
- Time for order of deactivation (received message from eBestill) also in cases where the duration has reached its end before the provider has received an order for deactivation from the control centre, and the provider has contacted the control centre 15 minutes before the duration expires so that the control centre can order the deactivation electronically.
- Time of deactivation and overview over power produced/used in the time after deactivation.

Figures with an appropriate resolution (visual control of result) should be attached.

Attachment 2 Statnett's requirements to cloud services

Statnett maintains a policy for the use of cloud services. The core principles in this policy are the following:

- Information shall be protected while at rest (encryption at-rest).
- Information shall be protected while in transit (encryption in-transit).
- Users shall be uniquely identified, and authorization shall be restricted to authorized use by uniquely identifyable users (which could be services).
- All activities, especially user activities, shall be logged and all logs shall be analysed to identify potential unauthorised activities. Such activity shall be reported to Statnett using a pre-agreed process.
- All user, system and configuration information shall be protected during transit and at rest. This includes, but are not restricted to passwords, API-keys, etc.

The policy includes a separate annex defining requirements to providers using cloud services in their products or services. Some of these requirements are:

Xa: It is required by law for Statnett as data owner to have full control of our data in your solution. This includes data in-transit and at rest. (i) Describe the full solution for handling of Statnett's own encryption keys (BYOK) and (ii) which encryption algorithms are used when, where and how in your solution. If not able to comply with (i), Xb and Xc becomes Must demands.

Xb: To be able to ensure secure use and operations of your solution, it is important that your solution and its whole infrastructure log and store relevant security events. Describe (i) which security events you are storing for your solution and the complete infrastructure, (ii) how you store them (i.e. in a SIEM solution), (iii) how your security events are analyzed and nominated to security incidents and (iv) how security incidents are handled internally and together with Statnett. If not able to comply with Statnett BYOK in Xa, please describe (v) how you will integrate and send all these security event logs in real-time to Statnett Security Operations Centre for Statnett analysis.

Xc: It is required by law for Statnett as data owner to have full control of our data in your solution. This includes who has access to our data. (i) List who has access, (ii) how access controls have been implemented within your solution and its infrastructure, (iii) how Statnett can use your access controls to view access and operations and (iv) how Statnett can restrict access to Statnett data. Showcase (v) how your access control can be connected to existing Statnett access control systems for authentication and single sign-on.

Xd: Describe how Statnett data handled by your solution (i) retain its integrity. Describe how your solution (ii) checks, verifies and maintains the data integrity when (iii) adding new data, (iv) operate on existing data and (v) deliver data from your solution to other parties.

Xe: Describe how you will check/verify and transfer data from Statnett to your solution, making sure that only (i) agreed upon data is transferred with its (ii) integrity intact.

Xf: Describe how you will make sure that storage, transfer, operation and management of Statnett data is only done within EU/EEA countries.

Xg: Describe how your solution is modelled to comply with GDPR's requirement to privacy by design and default, including but not limited to functionalities supporting the requirements to data minimization, deletion of personal data when the purpose of processing has expired and functionalities securing integrity, confidentiality and availability of personal data.

Xh: Describe how personal data is identified in the solution and how the solution supports the requirement to provide a data subject with information about his/her personal data processed in the solution (GDPR).

Xi: Describe how the solution supports fulfillment of data subjects rights pursuant to GDPR, such as the right to (i) access, (ii) rectification, (iii) erasure, (iv) restriction of, and (v) objection to personal data,

(iv) data portability and (v) rights concerning automatic decisions, including profiling that can have a legal effect or similarly significantly affects for the data subject in question.

Xj: Draw and describe the full security architecture in use for your solution. I.e. how the solution offered to Statnett is segregated from other customers, added security measures, arrows showing traffic initiators between components and within the systems, type of traffic, how backup solutions has been secured, user access, operator access etc.

Xk: As a responsible software developer, you have in place a procedure for secure software development lifecycle (SSDLC) for your solution. (i) Describe or add your SSDLC as an addendum to the contract and (ii) describe how you adhere to your SSDLC.

Xl: Statnett requires that you have in place an information security management (ISMS) system like ISO/IEC 27001:2017 or similar. (i) Describe which ISMS you have in place and how you (ii) manage and (iii) audit the associated controls.

Xm: As a subcontractor to Statnett you must conform with laws and regulations that Statnett must follow (i.e. Kraftberedskapsforskriften; KBF). (i) Describe your processes and procedures to be continuously informed on laws and regulations that Statnett is required to follow and (ii) how your offerings (products and services) conform with all laws and regulations that Statnett must follow. I.e. inform and report about organizational changes, and/or changes of subcontractors etc.

Xn: To ensure safe operations of your solution, usage of a control set like CIS or similar is highly recommended. (i) Describe which control sets you are using for safe operations of your solution, the (ii) responses to each control set item and (iii) how often you audit the controls in the control sets. In case you have not established a control set, we require (iv) a set of routines for vulnerability assessments and improvements. (v) Describe these routines and (vi) showcase the results.

Xo: To be able to showcase the maturity of your security measures, (i) provide Statnett with the results of security audits done by a third party.

Xp: In case of a breach of contract either (i) between you and Statnett or (ii) you and your subcontractors, describe in detail how you will (iii) ensure and verify revocation of Statnett data from your solution and (iv) subsequent return of Statnett data to Statnett.

Xq: Statnett requires that you have in place procedures to screen and qualify personnel and subcontractors and their subcontractors. (i) Describe your procedure for this practice and (ii) how you continuously verify that personnel and your subcontractors and their subcontractors are in accordance with your requirements.

Xr: Statnett requires you to have crisis- and contingency plans that are aligned with Statnett's own plans. (i) Describe your crisis- and contingency plans and (ii) how you will make sure that they are aligned with Statnett's plans. Statnett (iii) also requires you to participate in joint crisis- and contingency exercises.