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Final Report of the Swedish Demonstration: *Ten key abilities for DSO's to unlock flexibility*

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Executive summary

This report presents the main learnings and conclusions from the Swedish CoordiNet demonstration. In the Swedish business use case, the Distribution System Operator (DSO) utilises the flexibility service to lower peak demand in the grid during the winter season from November to March. The document presents the outcome from four Swedish marketplaces for congestion management operating during the three winters of 2019/2020, 2020/2021 and 2021/2022 and two peer to peer markets operating during maintenance periods. Figure 1 shows the locations, flexibility technologies, and services considered in the Swedish demonstration.

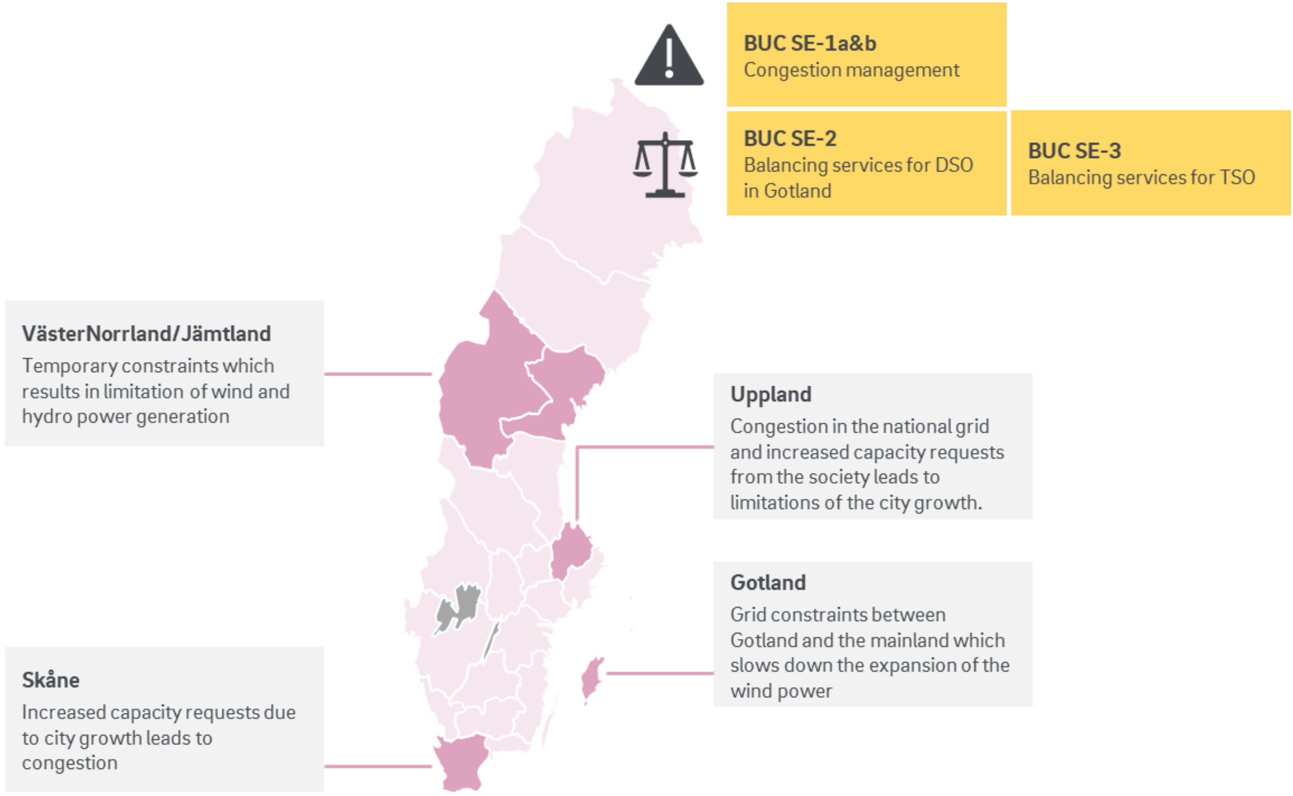


Figure 1: Swedish Demonstration Regions and Services

For each of the demonstration areas, flexibility resources have been engaged in an open, non-discriminatory and market-based way to participate in the demonstration. In winter 2019/20, 14 flexibility service providers participated in three congestion markets in Skåne, Gotland and Uppland. For the second winter of 2020/2021 the number of flexibility providers doubled in Skåne and Uppland to a total of 25 over the three markets. Participating flex capacity in the congestion management markets increased from 196 MW in the first winter to 397 MW in the second before reducing to 152 MW in the final winter.

In addition to the flexibility market for congestion management, two markets for peer-to-peer (P2P) trading were tested in Gotland as well as Västernorrland/Jämtland. These markets were operated during limited periods when maintenance was performed in the grid and are described in previous report D4.1 [1] and also supported the use of block-chain recording of trades as further described in D2.5 [2].

Total in all demonstration areas – congestion management and peer-to-peer 39 flexibility service providers participated.

The Swedish CoordiNet demonstrations aim was to handle congestion management with flexibility services. In the demonstrations two of the largest Swedish DSOs, Vattenfall and E.ON, together with the Transmission System Operator (TSO), Svenska kraftnät, took a broad approach and looked at the Swedish energy market not just from a technical and engineering perspective but also consider cultural, political and financial aspects. To operate the flexibility markets, a series of abilities were required to analyse, understand and develop routines, corporate culture and systems with regard to flexibility. These abilities are summarised in Figure 2. This report presents the ten required abilities to utilise flexibility in a systematic way, summarising the main lessons learned and conclusions for each of the ability in Figure 2.

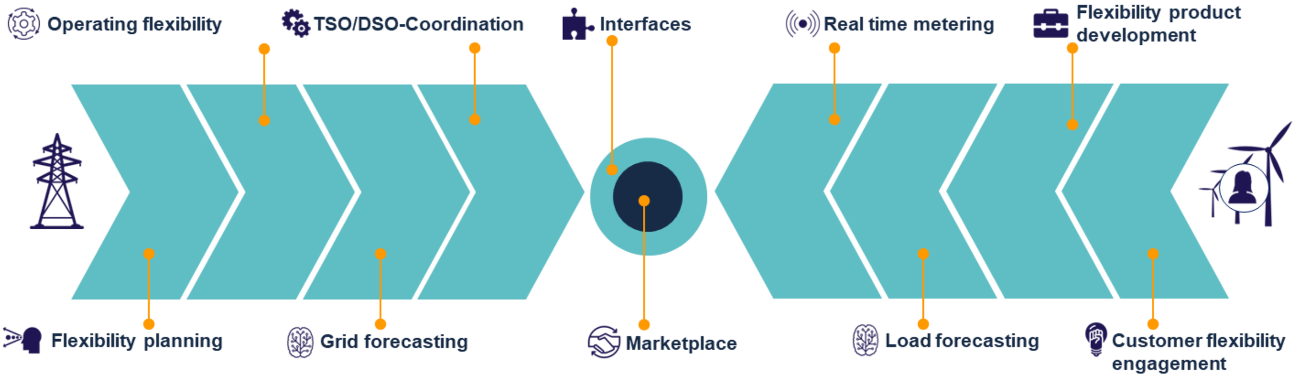


Figure 2 A holistic approach on transformation, multiple technologies and perspectives are needed to drive change in order to achieve a local flexibility market where TSO/DSO (left side) can meet with flexibility providers (right side). This approach consists of ten abilities outlined in this report.

Table of contents

Notations, abbreviations and acronyms

Table 1: Acronym's list

Acronym	Definition
API	Application Programming Interface
BRP	Balancing Responsible Party
BSP	Balancing Service Provider
BUC	Business Use Case
CHP	Combined Heat and Power
DER	Distributed Energy Resource
DNO	Distribution Network Operator (traditional role/acronym)
DSO	Distribution System Operator (new role/acronym)
ENTSO-E	European association for the cooperation of transmission system operators for electricity.
FCR-N	Frequency Containment Reserve for normal grid operation,
FCR-D	Frequency Containment Reserve for disturbed grid operation
FSP	Flexibility Service Provider
HVDC	High Voltage Direct Current
LV	Low Voltage
mFRR	Manual Frequency Restoration Reserves
MV	Medium Voltage
PTDF	Power Transfer Distribution Factor (Swedish: påverkansfaktor)
RES	Renewable Energy Source
RMSE	Root Mean Square Error
SGU	Significant Grid Users
sthlmflex	A flexibility market for congestion management in Stockholm inspired by CoordiNet and using same DSO flexibility tool
SCADA	Supervisory Control and Data Acquisition
TSO	Transmission system operator

1. Introduction

1.1. The CoordiNet project

The CoordiNet project is a response to the Horizon 2020 programme call LC-SC3-ES-5-2018-2020, entitled "*TSO – DSO – Consumer: Large-scale demonstrations of innovative grid services through demand response, storage and small-scale generation*". The project aims at demonstrating how Distribution System Operators (DSO) and Transmission System Operators (TSO) shall act in a coordinated manner to clear and activate grid services in the most reliable and efficient way through the implementation of three large-scale demonstrations. The CoordiNet project is centred around three key objectives:

- Demonstrate to which extent coordination between TSO/DSO will lead to a cheaper, more reliable and more environmentally friendly electricity supply to the consumers through the implementation of three demonstrations at large scale, in cooperation with market participants.
- Define and test a set of standardised products and the related key parameters for grid services, including the reservation, activation and settlement process for the assets.
- Specify and develop a TSO-DSO-Consumers cooperation platform starting with the necessary building blocks for the demonstration sites. These components are to pave the way for the interoperable development of a pan-European market that will allow all market participants to provide energy services and opens new revenue streams for consumers providing grid services.

In total, eight demonstration activities are carried out in three different countries, mainly Greece, Spain, and Sweden. In each demonstration activity, different products will be tested, in different time frames and relying on the provision of flexibility by different types of Distributed Energy Resources (DER). Figure 3 presents a preliminary set of product characteristics, periods for contracting the services, and types of DER in each demonstration activity. Grey boxes represent demonstration activities in Greece, pink boxes represent demonstration activities in Spain, and the yellow boxes represent demonstrations in Sweden.

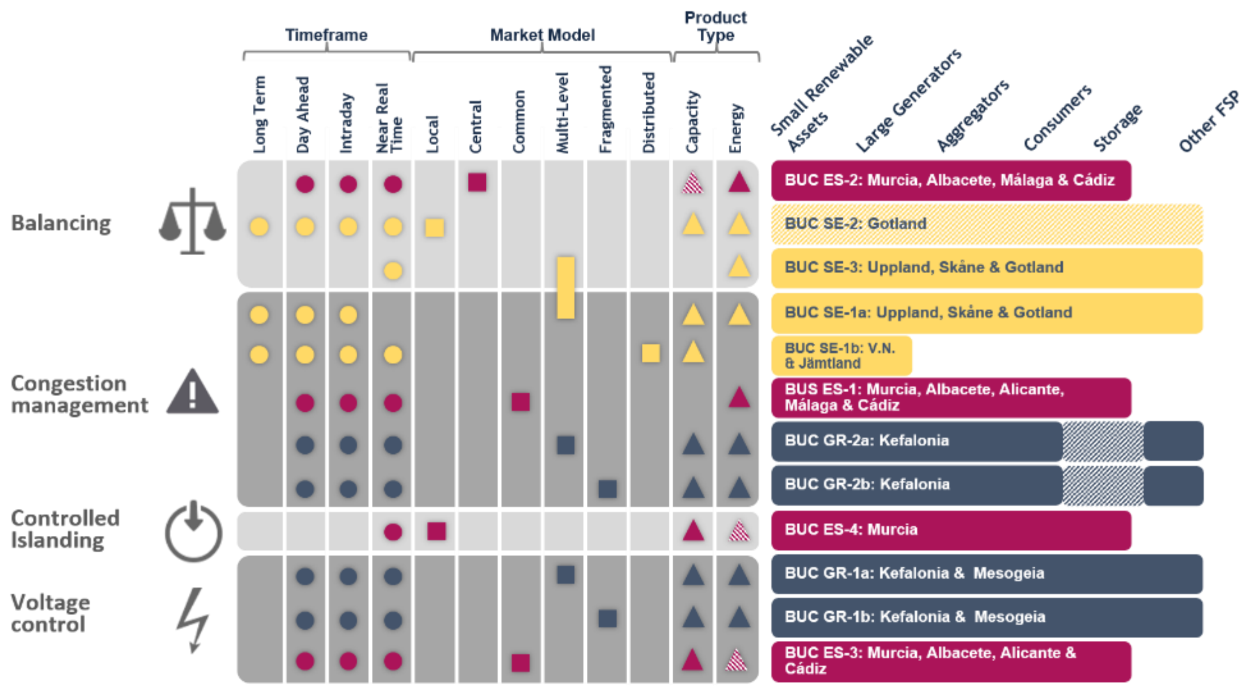


Figure 3: Characteristics of products to be tested in the demonstrations, in yellow the four Swedish demonstrations. (Light yellow shows a product which only has been investigated, not tested in demonstration)

The Swedish demonstration aims to bring the following benefits:

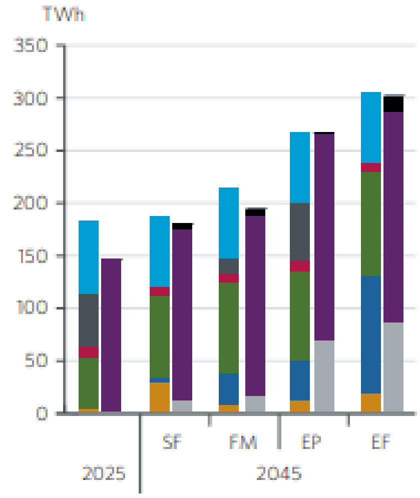
- Enable city and economic growth through a new way of using network capacity more flexibly over time.
- Establish flexibility markets on which flexibility providers can offer capacity and DSOs can clear this additional capacity, when needed.
- Flexibility products developed and incorporated into DSO operations and grid planning perspectives, as well as customer routines.
- Implementation of market design and coordination between TSO and DSOs.
- Digital market established, supported by real-time data and machine learning models to forecast customer and grid behaviour.
- New types of actors connected at local DSOs participating with flexibility.
- DER like energy storage and wind generators as well as small-scale customers through aggregation participating with flexibility supported by real-time data and forecasting for customer and grid behaviour.
- Contribution to national and local goals for climate and renewables as well as better economical utilisation of assets.
- Digital peer-to-peer market in place to enable trading, planning and economical transactions.
- A marketplace that provides a cost-efficient way for including local flexibility resources to provide ancillary services to DSO and TSO.

Three open, non-discriminatory, calls were made to recruit flexibility for the winters of 2019/2020, 2020/2021 and 2021/2022 and for three maintenance periods. For further information on the set-up and results of the Swedish CoordiNet demo each section provides references to further reading. Reports are available under tab 'WP4' at: https://coordinet-project.eu/publications/deliverables

1.2. The Swedish CoordiNet demonstration

The objective of the Swedish demonstration lies in relieving the existing and growing large scale network constraints in the regional DSO grid and DSO/TSO interfaces, allowing for the ongoing integration of RES and the ongoing urbanisation and industrialisation. In the Swedish business use case, the DSO utilises flexibility services to lower peak demand in the grid during the winter season November to March. This is achieved by establishing new and innovative local flexibility markets, next to the centralised market for ancillary services, also capable of providing additional contributions to the market for ancillary services. This will also be achieved by establishing new and innovative peer-to-peer markets. Prerequisites for these markets are improved cooperation between the DSO and the TSO, suitable coordination schemes for the different markets, necessary market tools and a thorough understanding of both customer and grid operator user conditions.

In Sweden, the decarbonisation of society is driven by electrification of the industry and transport sectors. The electricity mix is already today a fossil free mix of hydro, nuclear and to an increasing extent wind. A smaller contribution from industrial and district heating combined heat and power using biofuels is also present [3]. Heating is today free from gas with district heating and heat pumps (i.e., electricity) by far the most common source, with biofuels to a smaller degree. Thus, with a fossil free electricity mix already in place, the main challenge for further decarbonisation therefore becomes a challenge of connecting new customers for electric mobility, fossil-free steel, cement or fertiliser production. Likewise, more producers need to be connected to feed these new electricity users. The TSO counts on up to twice as much electricity consumption in its scenario for renewable and electrified energy system in 2045 with today's net export of electricity replaced by a export of low green-house emissions products such as steel, cement and fertilisers produced with hydrogen from electrolysation [4], see scenario 'EF' in Figure 4. Much of this new electricity demand is expected to be in the North of Sweden with its heavy industry and electricity price area with lower electricity costs.



Scenarios:

Electricity production and consumption in TWh

Scenario:	2021	SF	FM	EP	EF
Hydro	68	68	67	68	66
Nuclear	51	0	14	55	0
CHP	11	9	8	10	9
Wind, land	48	76	88	85	98
Wind, sea	1	6	29	39	113
Solar	3	28	8	11	18
Total production	**182**	**187**	**215**	**269**	**304**
Total consumption	-148	-174	-188	-266	-286
of which hydrogen	*-2*	*-11*	*-16*	*-69*	*-85*
Net export	34	6	21	2	2

SF: Small scale distributes production with considerable energy efficiency increases. No nuclear production.
FM: Scenario based on nati0nal plan for fossil free [5]. *Some nuclear.*
EP: High consumption scenario and nuclear.
EF: High consumption scenario in addition to heavy export of fossil free produced commodities. No nuclear

Figure 4 Estimate of future electricity production and consumption by TSO. Reproduced from [4].

There is an increasing need for flexibility for the TSO as forecasted by the Nordic TSO [6] [7] as well as the Swedish TSO, Svenska kraftnät, whose probabilistic simulations of the North European energy system in 2045 show that demand side flexibility is a necessity for a functioning power system [4]. On the local level, the DSOs have already today an urgent need for flexibility provided by customers, aggregators and generators, which is the background and reasoning for conducting the demonstration at four different sites, Skåne, Uppland, the island of Gotland and rural north of Sweden. In these regions, flexibility solutions presently are required to alleviate network congestions. Since there are much different conditions locally, each of the four sites require a separate solution and are described in separate sections below.

The marketplace of the Swedish demonstration is focused on a holistic approach to unlock flexibility. In the scope of the marketplaces, Vattenfall, E.ON and Svenska Kraftnät looked at the Swedish energy market, not just from a technical or engineering perspective but also consider cultural, political and financial aspects. As illustrated in Figure 5, the Swedish demonstration established new pathways between flexibility service providers such as DERs (both aggregated into VPPs and autonomously) and flexible demand. New abilities were developed to solve issues with congestion management and other distribution and transmission grid needs and create a functional blueprint for change management in the energy sector. Together the ten abilities developed in the Swedish CoordiNet projects have shown a more dynamic and digital way for DSOs to utilise flexibility for the operation of the electricity network.

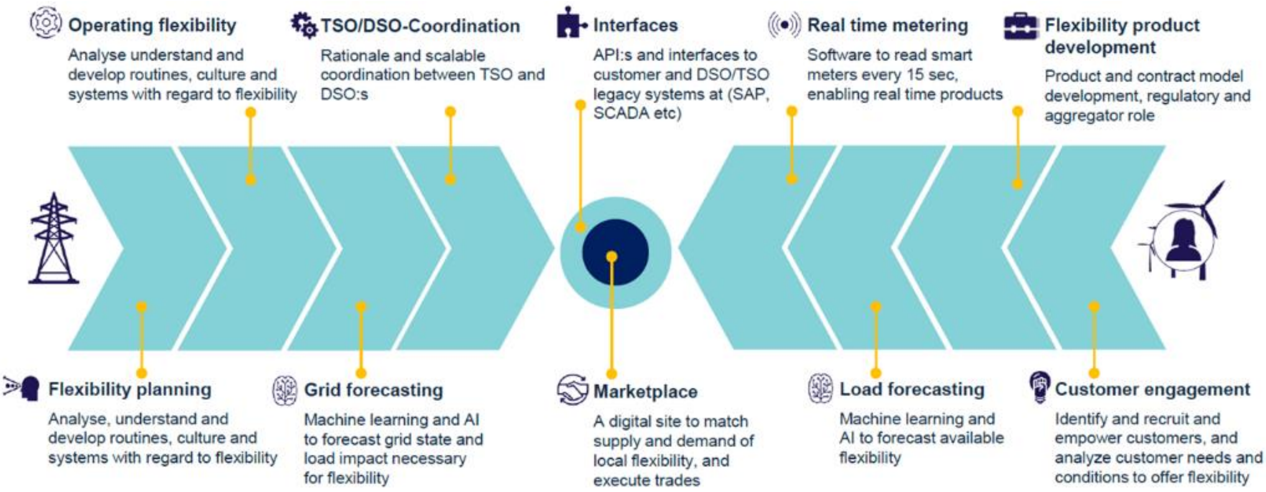


Figure 5: Ten key abilities constituting a holistic approach on transformation, technologies and perspectives to drive change in order to achieve a local flexibility market where TSO/DSO (left side) can meet with flexibility providers (right side).

1.3. Consortium members in the Swedish demonstration

The Consortium Members in the Swedish demonstration are: Two of the four regional DSOs in Sweden Vattenfall Eldistribution AB, E.ON Energidistribution AB, the national transmission system operator, Affärsverket Svenska kraftnät, Uppsala municipality, the research institute Energiforsk AB and a provider of commercial forecasts, Expektra AB.

Special thanks are sent to the Swedish Energy Markets Inspectorate and Swedish Energy Agency for active and constructive dialogue as well as to all flexibility providers who have invested time and effort to make their resources available for the market.

Figure 6: Members of the Swedish CoordiNet consortium in February 2019.

Figure 7:Flexibility providers, national regulator and members of the Swedish CoordiNet consortium at the final event in Brussels in June 2022

2. Background and demonstration areas

This section provides background to the Swedish electricity network and markets including the regulatory framework. The demonstration areas with their constraints and flexibility providers are presented.

2.1. Subscription between TSO and regional DSO, and regional DSO and local DSO

For the context of the Swedish CoordiNet demo it is important to understand the concept of a regional DSO that operates electrical networks (normally between 70 kV-130 kV) in between the TSO's 400 and 220 kV lines and local DSOs. The regional DSOs in Sweden have a contract with a subscription level towards the TSO, as shown in Figure 8.

The business use case of the Swedish demonstration is the congestion management resulting from the TSO denial of raise of the annual subscription level and/or denied temporary subscription.

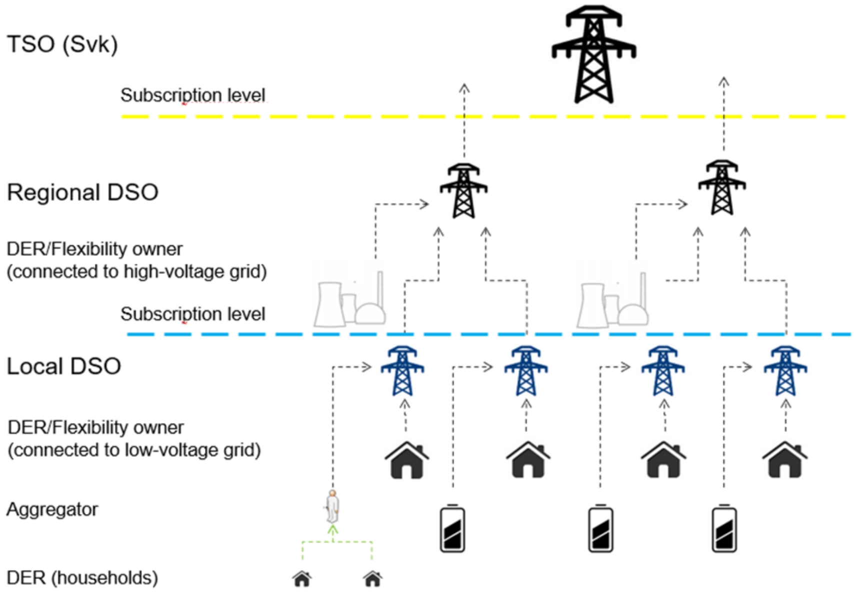


Figure 8: Principal levels in the Swedish transmission grid.

The subscription level, called the regular capacity plan by the TSO [8], is the annually contracted level of power that is allowed to be drawn by the regional grid from the TSO grid, without further agreement. Also, the local DSO will have a subscription level governing the amount of power with the regional DSO.

This subscription limit is not to be confused with the physical constraints of the networks passive components (or voltage and small signal stability) that are higher than the subscription limit. The subscription limit is instead a threshold for power that can be fed in without prior notification. It is possible to apply for a temporary subscription in addition to the annual subscription. (The TSO then needs to assess if the increased flow is possible with anticipated network flow and constraints). Temporary subscriptions refer to input or consumption in addition to the regular subscription and the raised level for outtake from TSO grid apply normally for the seven following days. However, the TSO reserves the right to cancel the temporary limit increase at any time, should the grid need change.

Historically, the regional DSOs have received either subscription raises or temporary subscriptions upon request from the TSO. Requests for temporary plans are submitted to Svenska kraftnät at least one hour before subscription start and cover the period up to 24:00 on the last day of the subscription week. The subscription can be retracted at anytime. The application is submitted to Svenska kraftnät´ s duty engineer and is granted subject to available network capacity [8]. However, in recent years the regional DSOs in both

Uppland and Skåne have the risk of being denied subscription raises while awaiting completion of TSO grid reinforcement. The denial of temporary subscription requests is especially problematic given the long planning time for higher voltage levels of the grid. Traditionally, the infrastructure of power distribution in Sweden involves long-term planning in 50-year cycles, which is not compatible with current trends of electrification of the transport and energy sector. Lead times to build new transmission grid infrastructure have risen to 5-7 years at the regional level and 10-15 years for the transmission grid. Also, the connection of larger loads often entails more complex grid analysis and the need for subscription raises, that in turn involves the grid on both the regional and TSO levels. During the last 20 years, DSOs have had fewer large customers to plan for, and those actors have been aware of the lead time needed for planning. In recent years requests for new types of large customers like data centres, production of electric fuel and electric vehicle fast chargers have appeared and these customers planning period has a shorter timescale than traditional grid planning processes allow for. These new customer types future demand capacityare also less predictable.

Finally, a few additional reasons for temporary subscriptions are to be stated. In the case of maintenance or different grid situations, the subscription level of regional networks may be reduced to uphold the security margins of the TSO. In addition, a temporary subscription could also be requested on behalf of reserved (long-term) bid providers. This allows the flexibility provider to pay for a TSO raised subscription, instead of being curtailed in accordance with the contractual agreement with the DSO. An example of this are district heating companies that have conditioned connections or beneficial network tariffs granting a DSO the right to curtail their electricity use.. In this case the district heating company can avoid switching their heat pump to a non –electricity-based heat source. Instead, they could pay the cost associated with the temporary subscriptions they have utilised.

The control room operators have instructions to clear flexibility bids at a cost lower than temporary subscription rates in Uppland, when temporary raise of subscription is granted (see Annex A). If a temporary subscription raise is not granted by the TSO, the operators in Uppland, Skåne and Gotland are instructed to buy more expensive flexibility.

2.2. Regulatory requirements, old and new sources of flexibility

The business use case for congestion management is in response needs of the DSO and TSO to market based purchase flexibility services following the EU Energy market directive. Requirements for DSO to handle network challenges through market based acquisition of flexible resources is outlined in the electricity market directive 2019/944/EU [9] and electricity market regulation 2019/943/EU [10] as well as in the EU's Clean Energy Package, (regulation 2018/1999/EU [11], 2018/2001/EU [12]). Together these directives and regulations imply that DSO should use market-based options when they are more cost efficient compared to network investment.

EU Energy Market Directive (2019/943) chapter II, article 13 states that non-market-based re-dispatching of generation, energy storage and demand response may only be used where: no market-based alternative is available; or liquidity of market is too low to "*ensure effective competition*"; or there is a risk of gaming from market participants.

The national regulator, Swedish Energy Market Inspectorate, sees different driving forces behind the need of flexibility in the different regions that have started congestion management markets(3eyond CoordiNet, such markets have been started for the two largest cities, Stockholm and Gothenburg). The capacity problems stem from either rapid regional growth and planned maintenance or the increasing need for frequency regulation. Both short term and long-term products have been developed [13].

Necessary steps for efficient and transparent markets includes, but is not limited to:

- Clarifying roles and responsibilities of market platform operators and independent aggregators
- Defining procedures for market monitoring and compliance
- Develop framework guidelines on demand side flexibility

To unlock flexibility the regulator stresses the role of network development plans where flexibility is considered. These will cover both demand and supply and the new regulation will be in place in Sweden from July 2022. The First Network Development Plans will be published 2024/2025.

Going forwards DSO incentives for procurement of flexibility will be important. These may include revenue cap regulation that promotes making an efficient choice between grid investments and the use of flexibility services. Network tariffs with a power component are believed to be possible to co-exists with flexibility markets. In order to make flexibility available to both TSO and DSO the regulator stresses the importance of coordination between them [13].

The idea of flexibility on the customer side is not new. Sweden has network customers with a long tradition of being flexible. The flexibility has mainly been from large scale hydro (providing the bulk of frequency regulation and reserve capacity) but also from centralised district heating plants, some gas turbines and industries. These customers provide flexibility resources either individually or via a virtual power plant, providing system services in the day-ahead or intraday timeframes. This flexibility has been provided in the electricity market meeting the TSO need for frequency regulation.

Also domestic households have historically provided considerable amounts of flexibility for the grid. In the mid-1990s, prior to the deregulation of the energy sector in Sweden, many Swedish DSOs had ripple control systems installed in substations. A kHz signal would be sent on top of the base 50 Hz sinusoidal frequency to change between low and high tariffs or turn on or off streetlamps and domestic water boilers in times of high grid congestion[1]. Typically the domestic for two hours per day or during 15 minutes out 60 during of a congested hour. The customers were incentivised to install such systems by a fixed monthly discount on the grid tariff. It was not unheard of that 10-20% of customers could each provide 1-3 kW of such flexibility giving the possibility to curtail up to 7-8% of peak load in a smaller DSO networks [14]. It is estimated that a few hundred MW of flexibility might have been available in Sweden at one point in time [15] [16]. However both cogeneration of electricity at some district heating plants and the domestic ripple control flexibility was quickly phased out in Sweden around the year 2000 with the absence of delivery responsibility in the no longer vertically integrated utilities [17]. This had little impact since electricity consumption was declining from 1990 to 2020 despite a 20% increase in the population of Sweden [18].

For the DSO sector specific tariffs have been in place for specific Significant Grid Users (SGU). Often the central district heating plant would account for 10-30% of the net load in a local DSO with some cogeneration installed meaning also electricity was produced at time of peak demand. Their tariff would entitle the DSO to request reduction in plant's consumption in times of congestion. Some DSO:s also had agreements with CHP:s that were called for during colder winter days. All forecasts and calls by the DSO until 2019 were made manually by looking at the weather forecasts and using the telephone.

With the growths of electricity sector for the first time in 30-years, anticipated in Figure 4, there is a need to reinvent flexibility. This time in a more digital and market-oriented way.

[1] In Swedish "rundstyrning" defined as "a system for time and tariff control in older mechanical meters, disconnection of loads during peak load as well as for control of streetlights. This ripple control signal is also used for remedial actions during electricity shortage" [40]. As an example Värnamo Elnät with 10 000 customers had 6 MW ripple control flexibility installed in 2008 [14]. Monthly discount on grid tariff of 19% or 45 EUR/month was still in place in 2021 for 16A customers with "disconnectable ripple control [41].

2.3. Demonstration areas

The Swedish CoordiNet demonstration of flexibility markets were operated for three winters. The peer-to-peer markets operated during maintenance periods. The demonstration was open to all flexibility providers that want to participate and open calls for participation are made before every season. The first winter operation of the flexibility markets for congestion management started in November 2019. The regional DSO challenges faced in the four Swedish CoordiNet demos differ as describes in the following sections 2.3.1 to 2.3.4.

In total, 34 flexibility providers were prequalified to participate in the Swedish demonstrations of flexibility markets and 8 in the peer-to-peer markets Flexibility forms a broad range of different resources was tested as can be seen from Table 2.

Table 2 Type of technology used for flexibility in the demonstration of flexibility market for congestion management (KPI38)

Type of technology	Uppland				Skåne				Gotland		
Winter	**19/20**	**20/21**	**21/22**		**19/20**	**20/21**	**21/22**		**19/20**	**20/21**	**21/22**
Renewables		Hydropower (60 MW) *									
Conv. Gen. to DSO	Gas turbine Waste combustion										
Conv. Gen. to TSO											
Aggregators		Residential heat pumps, Cooling ice rink and heating sports complex				Industrial processes	Res. heat pumps				
Consumers	Electric boiler, industry and residential heat pumps				Metallurgic smelter District heating				Electric boiler Heat pumps refrigeration system		
Storage		Battery storage				Battery storage					
Gensets		Reserve power			Reserve power					Gas and biodiesel (60 MW) **	
Electrical vehicles	EV chargers*					EV chargers					

** FSPs that signed up for providing flexibility but, after initial integration with platform and testing was found to not be able to participate in the market*
*** Included in the market platform for monitoring reasons, but not traded in the market*

2.3.1. Uppland

In Uppland there is an increase in power demand as cities are growing and as a result of increasing electrification of industry and society in general. Furthermore, the closing of local CHP production increases the need for withdrawal from the transmission grid. The TSO is not able to increase the subscription level for the local and regional DSOs without grid reinforcement. The first time the TSO denied the regional grid an increase in the subscription level for the local DSOs was in 2016. The necessary grid reinforcements will take up to 10 years to solve. Customers want to be connected before grid reinforcement is completed.

Uppsala is Sweden's fourth largest city with 170,000 inhabitants. It is situated 70 km north of the capital. In recent years multiple customers have been denied increased capacity or connection in time, hindering city growth and economic development in the region. Without coordination of flexibility between local grid, regional grid and national grid reserved capacity in some connection points leads to sub-optimisation in capacity utilisation during temporary grid constraints. Vattenfall Distribution has since 2018 responded to these challenges by manually steering flexible loads and by developing bilateral agreements for load and production steering between grid customers and regional DSO or local DSO to meet regional DSO grid need or local grid need. The bilateral agreements allow connection of new customers by enabling the subscription level to be kept by manually, steering down the consumption of specific flexibility resources when needed. These kind of bilateral firm-bid capacity agreements are manual and not possible to scale up further. The agreements are targeting only customers with high availability. With CoordiNet' s market-based approach, urban and economic growth can be enabled with less administrative over-head, through a more flexible way of accessing capacity. Furthermore, the goal is to encourage new types of actors to provide flexibility.

The main population centres and transmission network in the Uppland region is depicted in Figure 9. DSO grid needs (e.g., subscription level from TSO, physical limit in cable, transformer etc.) to participate in the demonstration were identified related to two different TSO substations with the sum of their power flow limited by the TSO subscription.

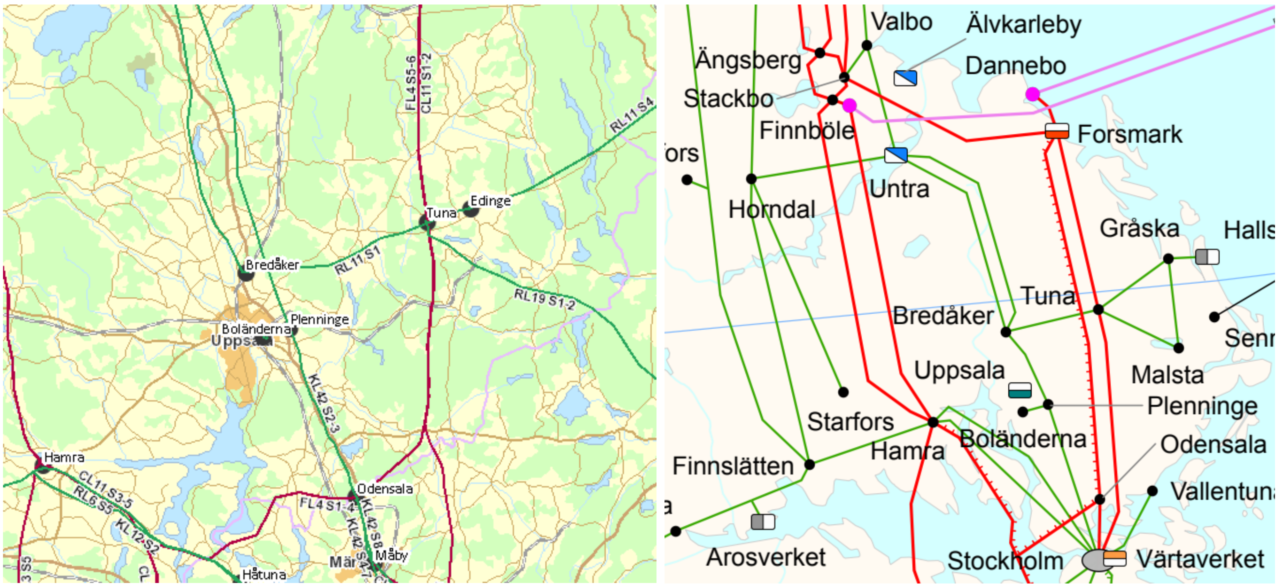


Figure 9: Population density and transmission network in Uppland region (right figure shows a grid map depicting international interconnections extracted from ENTSO-E).

Examples of flexibility resources in the CoordiNet Uppland demonstration is presented in Figure 10 with the full list of FSPs in Uppland is presented in Table 3.

Figure 10: Example of flexibility resources in the CoordiNet Uppland demonstration winter 21/22.

During the five years prior to the inauguration of the Uppland flexibility market for congestion management, the TSO subscription limit in both connection points combined was exceeded about 2 % of the time (and only in winter). In total, 112 days with violation of the subscription were registered totalling 802 hours. The subscription levels could be exceeded for as long as 16 h at a time. The congestion correlates to periods of low temperature and thus high demand, but the local nature of the local congestion was not historically manifested in the spot market price for the price region Uppsala is in.

Table 3 Flexibility service providers in the Uppland congestion management demonstration

Flexible Resource	Number resources	Flexibility volume (duration)
Participating from winter 19/20		
Upplands Energi* (Aggregator Ngenic) Heat pumps, single-family houses	300	0.5 – 2MW (1-4 hours daily)
Cytiva* Heat pump, industry	1	1 MW (1-24 hours daily)
Uppsala Hem* Heat pumps, multi-family housing	3	0.1 MW (1-4 Hours daily)
Vattenfall Värme* Electric boiler, heating company	1	59 MW, min 5 MW
Vattenfall Värme* Heat pumps, heating company	2	8 MW, min 4 MW (≥1 hours)
Vattenfall Värme* Gas turbine heating company, production	1	16 MW, min 5 MW (≥1 hours)
Vattenfall Värme* Waste incineration, heating company	1	10 MW, min 2 MW (≥6 hours)
Participating from winter 20/21		
Ngenic Heat pumps from single family houses	50	0.5 – 2MW (1-4 hours daily)
Vattenfall Elanläggningar Energy storage	1	0,5-5 MW, 20 MWh (1-4 hours)

Castellum (2 office buildings) Geothermal heat pump	2	0.187 MW, min 0.1 (2-5 hours per day)
Riksbyggen Heat pumps (aggregated multi- family houses)	2	0.22 MW, min 0.1 (1-3 hours)
Fresenius Kabi Heat pumps, life science industry	1	0.5 MW, min 0.1 (1-3 hours)
Uppsala Region Reserve power	1	8 MW (≥1 hour)
Participating from winter 21/22		
Akademiska Hus Reserve power	1	0,5 MW
Uppsala municipality (Aggregator Tvinn) colling for ice skating rink & swimming pool	2	0.08-0.12 MW (1-3 hours)
Participated winter 19/20 and discontinued after winter 19/20		
EV Charging (housing)	1	0,025 MW
Participated winter 20/21 and discontinued after winter 20/21		
Älvkarleby hydro power	1	60 MW, min 5 MW

During the first two winters of CoordiNet operation, 3,3 GWh and 6,6 GWh of flexibility were cleared, accordingly. This reduced to 0,1 GWh in the third and final winter of 21/22 as the unprecedented threefold increase in spot market price meant major flexibility resources went unused. Key performance indicators of the Uppland demonstration, for the three winters, is provided in Figure 11. For the full list of 20+ performance indicators for each individual winter and demonstration area the reader is referred to D4.7.1 [19].

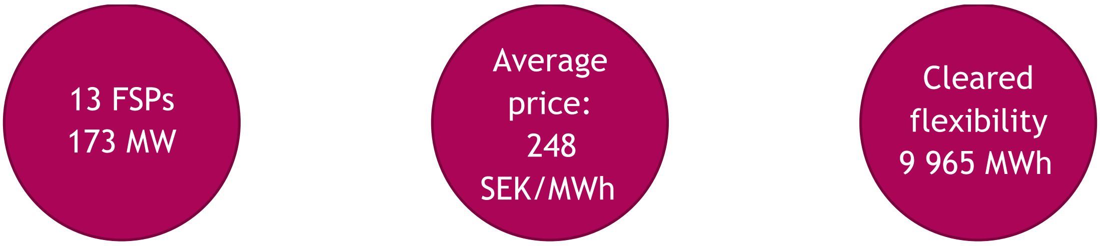


Figure 11 Key market figures for Uppland for the winters of 19/20, 20/21 and 21/22.

2.3.2. Skåne

Skåne (Scania in English) is the southernmost province of Sweden with a population of 1,3 million. The region has insufficient capacity to meet an increased demand for expansion (both residential and offices), new industries and E-Mobility. In the region, several customers have been awaiting increased capacity or connection in the recent years, threatening urban development and economic growth in the region. Here as well, the closing of local CHP production further increases the need for withdrawal from the transmission grid. The TSO is not able to increase the subscription level for the regional DSOs without grid reinforcement, which in turn also affects the local DSOs. The necessary grid reinforcements will take up to 10 years to solve. The situation is further complicated due to technical and regulatory dependency to the interconnector between Sweden and Germany. 600 MW of the TSO transmission line capacity through Southwestern Skåne is allocated for the Baltic Cable export to Germany, which terminates at the TSO substation in Arrie that is also E. ON's connection point with the TSO. A limited demonstration was performed with a large-scale CHP in 2015-2016 (this CHP is nowadays mothballed) but no other routines or bilateral contracts were up until the start of CoordiNet in place to manage flexible loads.

The main power feed to Skåne comes down along the west coast from the nuclear power plant, Ringhals, south of Gothenburg towards the TSO substation in Söderåsen (see Figure 12). The area is also greatly dependent on regional and local wind power. The consumption load in Skåne is primarily concentrated to the west and southern part of the region. The power is distributed from the transmission grid in the above mentioned Söderåsen substation as well as former nuclear site Barsebäck (decommissioned in 1999 and 2005) and from the two substations Sege-Arrie. Additional capacity is supplied from Northern and Eastern

Sweden through the substation at Hurva (see right side of Figure 12). However, it is the power lines between Söderåsen-Barsebäck and Barsebäck-Sege that constitute the main bottle necks for power supply to Western and Southwestern Skåne.

In total, Svenska kraftnät supplies southwestern Skåne with 1350 MW through 400 kV transmission. Of this, a capacity of 600 MW is reserved for export using the Baltic Cable as it is not allowed to discriminate between domestic and foreign customers. These 600 MW have been reserved following the ruling of a 2011 European court case between Danish Energy and the Swedish TSO [20]. Traditionally, the TSO had at times reduced the available trade capacity for the market on the cables to Denmark. However, the restrictions meant that the large regulation volumes required for the wind power production in Eastern Denmark (Jylland) could not be acquired through short-term trade with Sweden and Norway [21]. Four price areas were also created in Sweden in 2011 with the Southernmost price area, SE4, in which Skåne is situated, having a deficit of production.

Also, the closing of local CHP production in 2019, following increased taxes on combined heat and electricity production, raised the need for power withdrawal from the transmission grid. Taken together this has led to a situation where the TSO is currently not able to increase the subscription level for the regional DSOs without grid reinforcement. The regional grid owners have in turn denied an increase of the subscription level for the local DSOs until all ongoing grid strengthening is in place.

The main population centres and transmission network in the Skåne region is depicted in Figure 12.

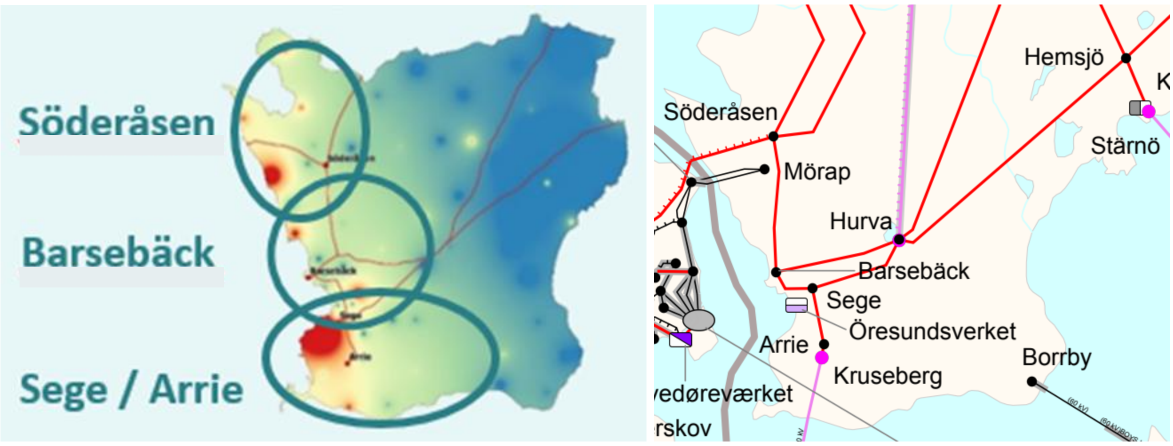


Figure 12: Population's density and transmission network in Scania region (right figure shows a grid map depicting international interconnections extracted from ENTSO-E).

Svenska kraftnät and E.ON are in parallel to the medium- and long-term capacity enhancement activities also introducing a 7-point program with near term measures during the period 2020-2021. These measures include enhanced network protection scheme for interconnections, load reduction capabilities reconfiguration of 400 kV substations and dynamic line rating on some transmission lines. Together these measures will allow to increase the supply to the area with about 400 MW.

Given the current transmission constraints in Skåne, three main areas were targeted for the capacity market: Söderåsen with Helsingborg as main population centre, Barsebäck with Landskrona and Sege/Arrie which supplies Malmö and the southernmost part of Skåne.

With respect to the main Skåne flexibility market for congestion management in Southern Skåne, power is supplied through Sege (S1) and Arrie (S2) transmission substations before reaching the southern parts of Skåne and extending across the sea via the Baltic cable, Figure 13.

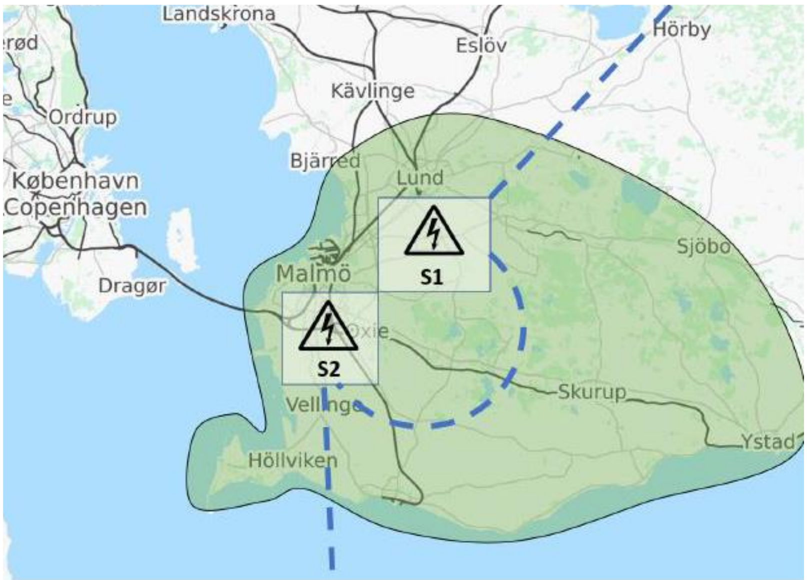


Figure 13: Extent of Sege and Arrie substation transmission in Skåne, with dashed line showing main HV supply from TSO.

During the CoordiNet demonstration several new transmission lines were introduced that affected the capacity in Skåne. A new 2* 600 MW HVDC cable to Hurva was inaugurated in July 2021 (the Northern parts of this link was inaugurated already in 2015). While the increased transmission capacity may contribute towards decreased price area differences between bidding zones SE3 and SE4, it will not allow for an increased supply in to the Western and Southwestern Skåne. All in all the new HVDC link will increase the capacity to the Swedish electricity markets southernmost price area with 800 MW (from 5400 MW to 6400 MW) with the TSO stating that the full capacity cannot be used due to N-1 requirements and other limitations in the western coast of Sweden that the TSO expects to be solved only around 2030 [22]. To supply additional power to the population in Western and South-western Skåne, capacity increase is required in the regional grid power lines from Hurva that are planned to be finalised until 2024 [23]. In 2021, during the CoordiNet project, two new export cables from Norway to UK and Germany (North Sea Link and Nordlink each 1400 MW) were taken into partial operation which together with closure of nuclear power units on the west coast created new east to west power flows and increased exposure to continental electricity prices that made the spot market electricity price in Skåne increase fourfold from the first to last CoordiNet winter (from average Nov.-March in 19/20 of 297 SEK/MWh to 1297 SEK/MWh in 21/22).

Examples of flexibility resources in the Skåne demonstration is presented in **¡Error! No se encuentra el origen de la referencia.** with the full list of FSPs in Skåne presented in **¡Error! No se encuentra el origen**

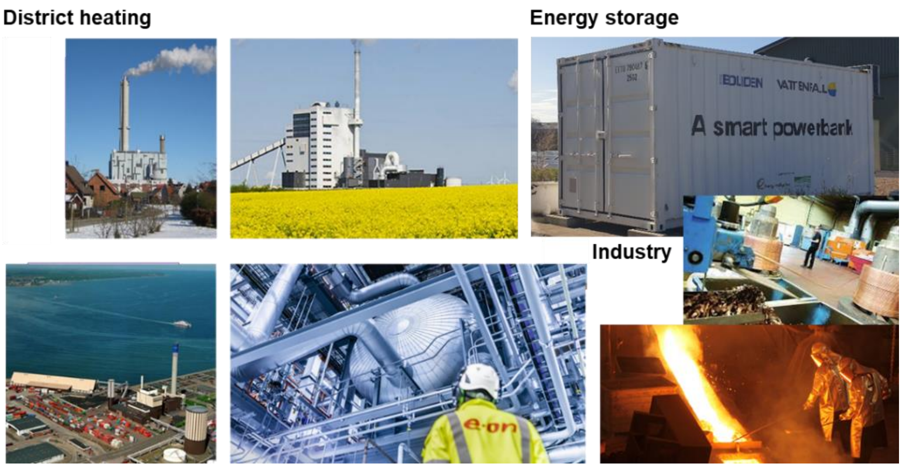


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Figure 14: Examples of District heating plants and 0,48 MW/1 MWh battery participating in the Skåne flexibility market for congestion management.

Table 4: Flexibility service providers in the Skåne congestion management demonstration

Flexible Resource	Number resources	Volume (duration)
Participating since winter 19/20		
Kraftringen* Heat pumps, district heating	3 facilities w. 3 pumps	13 MW
Participating since winter 20/21		
Uniper Öresundsverket Diesel genset	1	0,75 MW
Boliden Begsöe (Vattenfall Elanläggningar) Energy storage, recycle. Plant	1	0.45 MW, 1 MWh
Participating since winter 21/22		
Ngenic Aggregator, residential heat pumps	5	0,5 MW
Öresundskraft Värme Electric boiler, district heating	1	9 MW (89 MW 20/21)
Participated and is continued after winter 19/20		
E.ON Heating and cooling aggregator	1	0,1 MW
Participated before and discontinued after winter 20/21		
Bornholm Energi* Diesel genset	1 facility with 10 gensets	60 MW
E.ON Sjölunda* Heat pumps, district heating	1 facility w.4 pumps	15 MW
Ystad Energi AB* Diesel genset	1	0.5 MW
BEFESA / Scandust Industry, steel dust recycling company	1	18 MW
Electrokoppar/Elcowire (aggregator Entelios) Industry, copper rod casting and copper wire drawing	Multiple facilities	3,6 MW

During the three winters CoordiNet was operated, 206 MWh flexibility was bought by E.ON from 12 different FSPs with a total flexibility capacity of 188 MW, see Figure 14. Most of the traded volumes were traded during times of non-critical needs for flexibility and hence, the main purpose of these trades was to test the operational and market processes. The low actual need for flexibility was due to the fact that the redundancy of the transmission grid allowed the TSO to grant E.ON temporary subscriptions in times of high-power offtake from the TSO grid.

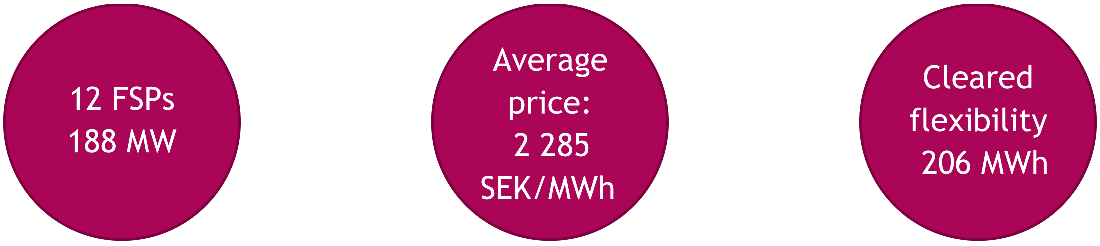


Figure 14 Key market figures for Skåne. Total or capacity and cleared volume for all three winters of 19/20, 20/21 and 21/22. Price is the mean of the average price per winter.

2.3.3. Gotland

Gotland has a large share of renewable sources providing 50% of the electricity consumption on an annual basis for the island's 60 000 inhabitants. The island is connected to mainland Sweden through an aging HVDC link. RES installations were increasing but stopped owing to difficulties connecting new installations due to operational security. As with the other demonstration sites, power demand is expected to increase. In the near future, it is feared it will not be possible to electrify large industrial sites. Also, electrification of the transport sector needs more capacity during peak season, which is currently not possible.

In the near future it is feared that it will not be possible to electrify large industrial sites. Although the DSO anticipates that electrification of personal cars can be manageable, the local high-power demand for electrifying ferries, heavy transport etc. can become a challenge and may require more capacity. The local grid in the Gotland region is depicted in Figure 15.

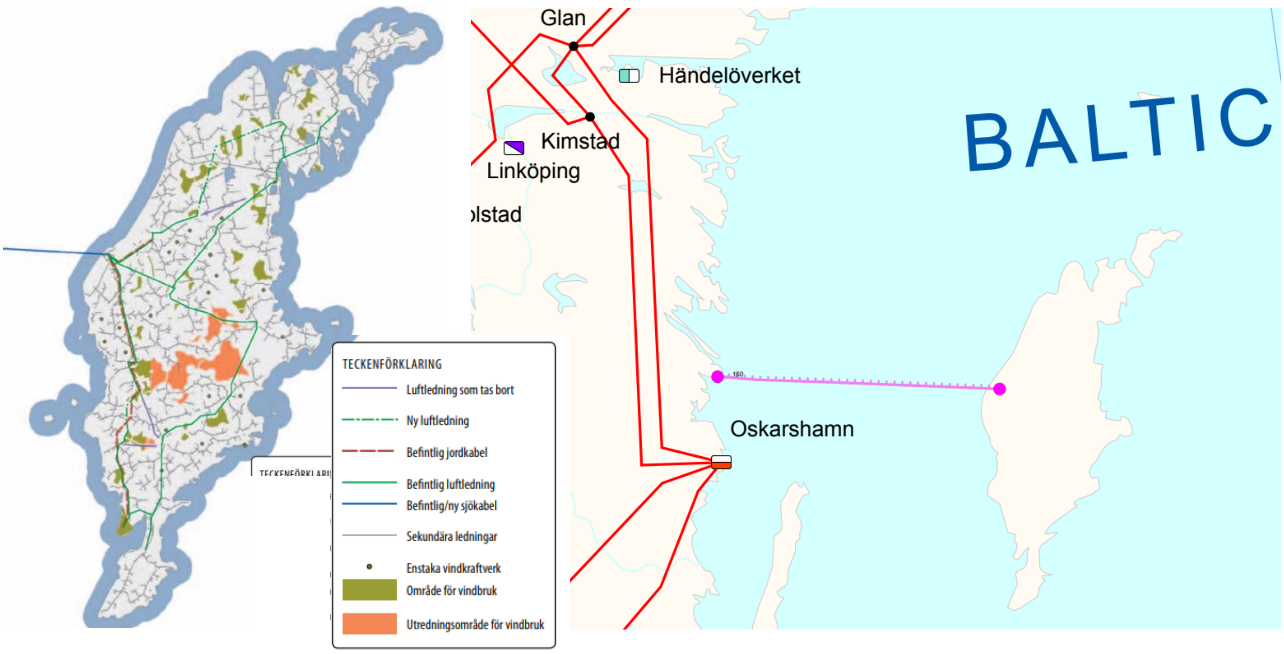


Figure 15: Overview of the Gotland grid [24] (right image shows extract from ENTSO-E grid map showing HVDC link, which is run by the region DSO, Vattenfall, and not directly connected to the transmission network).

The island was connected to mainland Sweden with the world's first HVDC connection in 1954. The original link is no longer in use and has been replaced by two monopolar HVDC links. The first replacement link was a 150 kV "HVDC classic" connection with a capacity of 130 MW that went into service in 1983, followed in 1987 by a second monopolar link, with a transmission capacity of 130 MW. The existing HVDC links, that are not designed for bi-directional energy flow and the inversion of the required power flow, are accompanied by reduced security of supply when exporting power from the island. To reduce the number of changes in the direction of the power flow a margin is also ensured so that the power flow is not too close to zero. Further, the aging HVDC connection may trip due to fault conditions such as lightning strikes in neighbouring grids, resulting in several black outs of the whole island in the last 2-3 years. Due to increased risk of black outs with the HVDC link, a moratorium on new connections of large-scale wind and solar (>43,5 kW) is in place since September 2017.

Even though this HVDC link will keep the frequency of the island, the DSO in Gotland must be prepared to handle some issues TSOs would typically be responsible for, i.e., balancing and inertial response. The Gotland DSO has a subscription limit towards Vattenfall that owns and operates the HVDC and its substations on both sides. This limit is equivalent to the maximum load of the island or about 180 MW for import of power to the island [25]. To ensure a more frequent operation of the Gotland flexibility market for congestion management it was decided to implement a 155 MW limit in the market platform for the first winter that was subsequently lowered to 125 MW in the second winter of 2020/2021. Flexibility is cleared when the forecast indicates violation of this limit.

On Gotland both a flexibility market for congestion management is operated that is like those in Uppland and Skåne with resources (left side of Table 4) as well as a peer-to-peer market like that in Västernorrland and Jämtland.

Table 4 Flexibility service providers in the Gotland congestion management and peer-to-peer demonstrations

Flexible Resource Congestion management	Number resources	Volume (duration)
Participating since winter 19/20		
GEAB Värme Electric boiler, heating company	1	20 MW, min 5 MW (≥1 hour)
GEAB Värme Heat pump, heating company	1	4 MW, min 4 MW (≥1 hour)
Whiskyfabriken Electric boiler, Industry	1	0.25 MW, min 0.05 (2-4 Hours)
Participating since winter 20/21		
Vattenfall Värme* gas turbine, reserve power	1	40 MW, min 5 MW (≥1 hour)
Vattenfall Värme* diesel genset, reserve power	1	40 MW, min 5 MW (≥1 hour)
Ryftes refrigeration system, farm	1	0.5 MW, min 0.1 MW

Flexible Resource Peer to peer	Number resources	Volume (duration)
19-23 April 2021 (production and load)		
GEAB Värme Electric boiler, heating company	1	20 MW, min 5 MW (≥1 hour)
GEAB Värme Heat pump, heating company	1	4 MW, min 4 MW (≥1 hour)
Whiskyfabriken Electric boiler, Industry	1	0.25 MW, min 0.05 (2-4 Hours)
11-15 October 2021 (capacity swapping, production)		
Stugyl Wind Park	1	27 MW (≥1 hour)
Storugns Wind Park	1	4,5 MW (≥1 hour)

During the three winters CoordiNet was operated the cleared volumes in Gotland was 654 MWh the first winter to diminish to 82 and 0,4 MWh the final winter. The key market data are summarised in Figure 16.

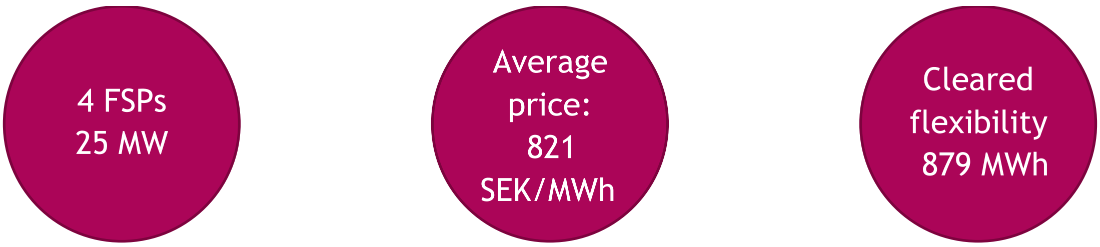


Figure 16 Key market figures for Gotland. Total or capacity and cleared volume for all three winters of 19/20, 20/21 and 21/22. Price is the mean of the average price per winter.

2.3.4. Västernorrland/Jämtland

Västernorrland and Jämtland region experience temporary constraints during periods of maintenance on the TSO lines that result in limitations of wind and hydro power generation. This typically happens 15 to 25 times per year and has a limited duration in time ranging from a few hours up to a week or two.

By trading (buying or selling) capacity by the hour, the actor can optimise production and/or consumption when operating under temporarily decreased subscription levels (i.e., the maximum grid load threshold as set by the regional DSO or the TSO). For example, during low wind periods wind power producers in Västernorrland and Jämtland can sell their unused capacity to make an extra income. The buyer could be a hydro producer that can increase production above its temporary constrained subscription level, leading to financial gains.

There were only a few planned maintenance periods in the Västernorrland and Jämtland regions. After engaging with potential actors for the P2P market within each area, E.ON chose to setup the market around two maintenances that were planned for late summer/autumn of 2020. The network maintenance was planned to reinforce the transmission grid, leading to temporary limitations of transmission capacity. The actors within this area are mostly hydro and wind power producers, managing facilities (flexibility assets) ranging from 1 to 100+ MW in production capacity.

The transmission grids in Västernorrland and Jämtland region are depicted in Figure 16. The market actors selected to participate in the P2P demonstration are producers with assets connected to the Rätan substation (see Figure 16).(see Figure 17).

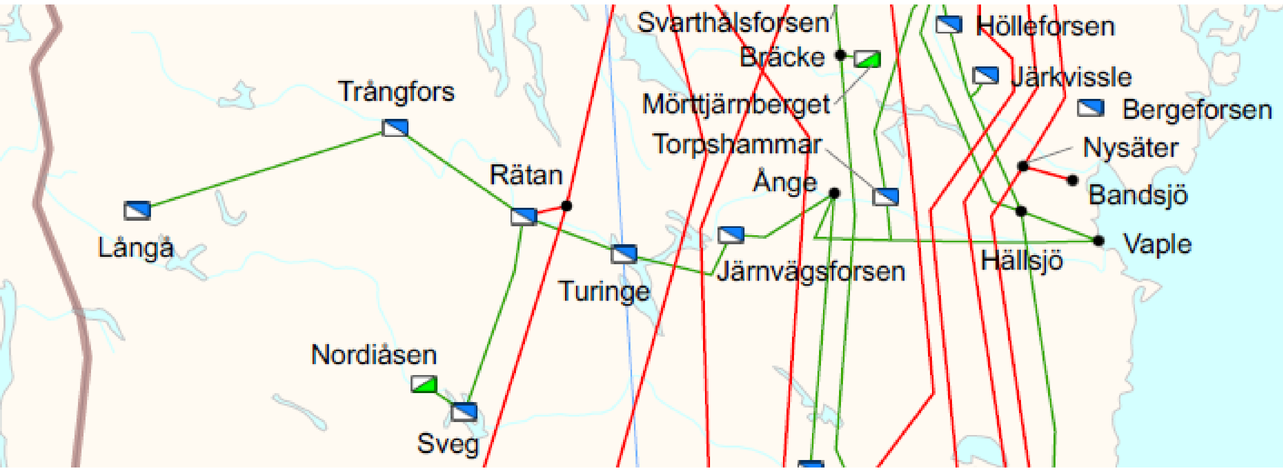


Figure 17: Area map showing affected substation at Rätan in Jämtland. (Extract from ENTSO-E grid map. Blue/white boxes are hydro power plants, green/white boxes wind parks.)

Flexibility resources for the peer-to-peer trials in Västernorrland/Jämtland included wind and hydro plant that could swap production capacity with the grid if not needed by one or the other resource. The list of FSPs in Västernorrland/Jämtland is presented in Table 5.

Table 5 Flexibility service providers in the Västernorrland/ Jämtland peer-to-peer demonstrations

Flexible Resource	Number	Flexibility volume (duration)
Autumn 2020 (capacity swapping production)		
Jämtkraft wind turbines	1	78 MW
Uniper hydro power	2	96 MW
Wallenstam wind turbines	2	16,5 MW

During the CoordiNet project, one P2P pilot was conducted in this area. The limited number of pilots here was due to the dependence on suitable grid maintenances. Even so, a successful test proofing the concept was conducted in the autumn of 2020 with three participating FSPs with a total capacity of 242 MW participated, as summarised in Figure 18.

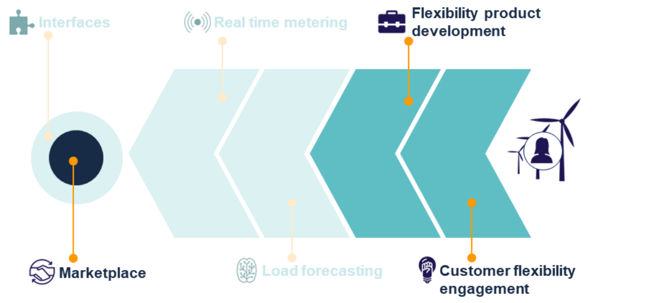
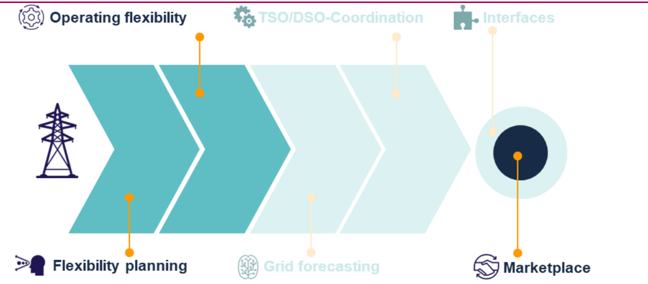
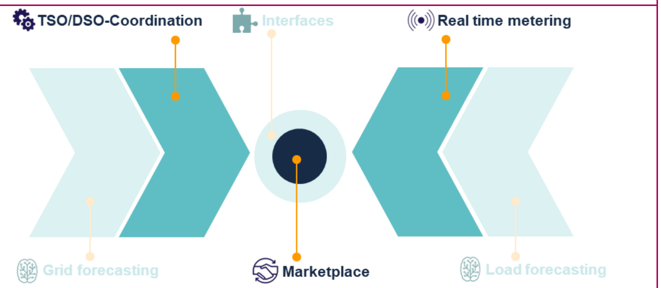
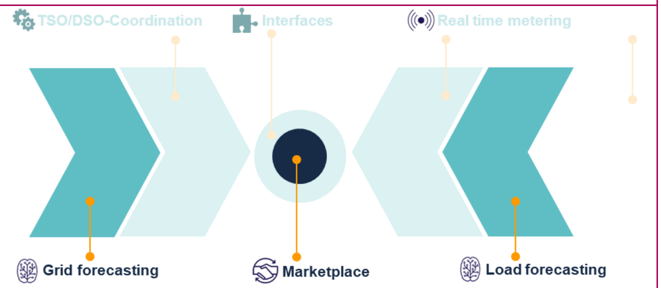
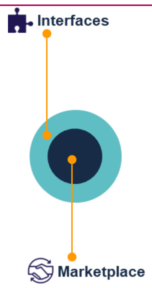
Figure 18 Key market figures for Västernorrland and Jämtland peer-to-peer market. Total or capacity and cleared volume for all three winters of 19/20, 20/21 and 21/22. Price is the mean of the average price per winter.

2.3.5. Further Information

Detailed information about the results of the Uppland, Skåne, Gotland and Västernorrland/Jämtland demonstration can be found in D4.7.1 (sections 6.1 and 6.2) with further information and insights on the first winter presented in D4.5.

3. Ten abilities to unlock flexibility

The Swedish demonstration is focused on a holistic approach to unlock flexibility. In the scope of the marketplace new tools abilities were developed to solve issues with congestion management and other distribution and transmission grid needs. The ten abilities in Figure 5 of section 1.2 developed in the Swedish CoordiNet projects have shown a more dynamic and digital way for DSOs to utilise flexibility for the operation of the electricity network. These abilities are presented in the following subsections.

Section	*Content*	Ability covered
3.1	*Unlocking flexibility:* Develop products and engage customers	
3.2	*New DSO abilities:* Operating and planning flexibility	
3.3	*Developing abilities:* Coordination and real-time metering	
3.4	*New abilities using machine learning:* Forecasting and baseline	
3.5	*Realisation of flexibility market:* Market platform and flex tool	

3.1. Unlocking flexibility: Develop products and engage customers

The first activities undertaken by the Swedish CoordiNet consortium was to define the products for flexibility market for congestion management and embark on a campaign to recruit existing and new customer to provide flexibility.

3.1.1. Customer engagement

Paramount to the success of the Swedish CoordiNet flexibility market has been active work to engage and train potential flexibility Service Providers (FSP). Active and continuous dialogue with flexibility providers was done through seven stakeholder forums, each with between 30 and 180 participants as well as well local meetings organised by demonstration site. Through one-to-one interviews, the feedback from the FSPs was collected and a summary of responses after the first winter season in 2019/2020 is included in this section.

Engagement of flexibility service providers was done following the AIDA model [26] as described in Figure 19 and in the CoordiNet customer-engagement plan D4.3.2 [27].The sequence of activities undertaken to recruit and engage flexibility providers is outlined Figure 20.

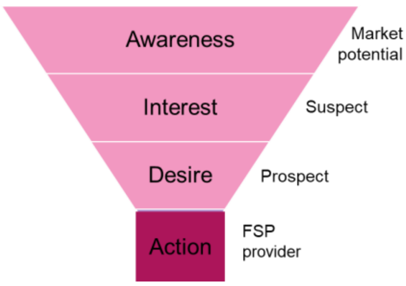


Figure 19 Customer engagement steps following CoordiNet customer engagement plan

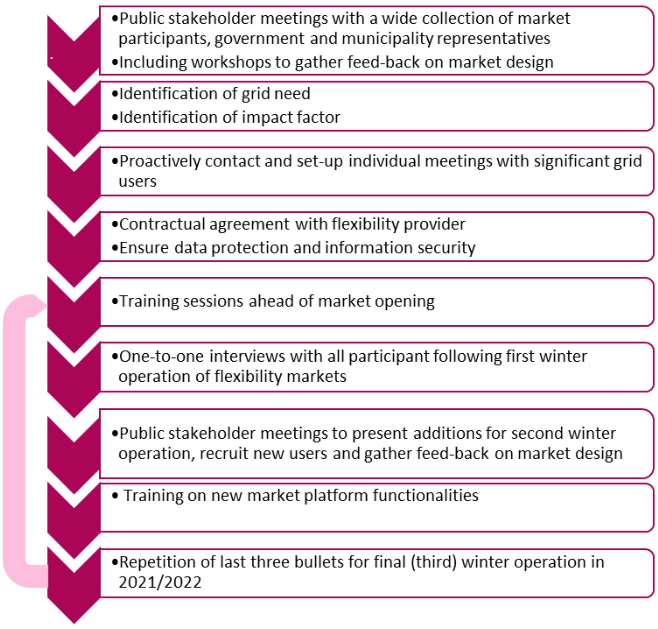


Figure 20 Activities to engage flexibility service providers

3.1.2. Congestion management product

Definition of products for the demonstration campaigns are defined in CoordiNet report D1.3 and were common for the Swedish, Greek and Spanish demonstrations. The following products were identified in the Swedish CoordiNet demonstrations:

- Congestion management – reserved, long-term bids (BUC-SE-1a): This is a capacity-based product procured for congestion management services at a certain availability price which is then activated when the service is needed and called upon by the relevant system operator. This product is defined to cope with structural constraints and procured in seasonal or long-term contracts.
- Congestion management - non-reserved, free bids (BUC-SE-1a): This is an energy-based product procured for congestion management services day ahead or intraday. Remuneration was

complemented with a capacity-based availability contracts to compensate for the uncertain demand and hence income from energy compensation. This product copes with sporadic constraints.
- Congestion management – peer to peer market (BUC-SE-1b): This is a distributed market exploiting blockchain technology to allow an individual party to perform and bill provision of flexibility) directly (i.e., peer-to-peer) with another party, independently of the DSO.
- Balancing – non reserved free bids forwarded to TSO mFRR market (BUC SE-3): This is an energy or capacity product through which the TSOs ensure, in a continuous way, the maintenance of system frequency within a predefined stability range. The manual frequency restoration reserve is the last of five frequency products to be activated by the Swedish TSO following a frequency deviation event and is a pure energy-based product.
- System services and flexibility services investigated for Gotland (BUC SE-2): With only a High Voltage Direct Current (HVDC) link to the mainland the island of Gotland has its own frequency that needs to be managed by the DSO, independent to the national balancing.

An overview of the used products in the various demonstrations is shown in Figure 21. The full list of attributes for the products can be found in D4.7.1, table 4 [19] and D4.1 [1].

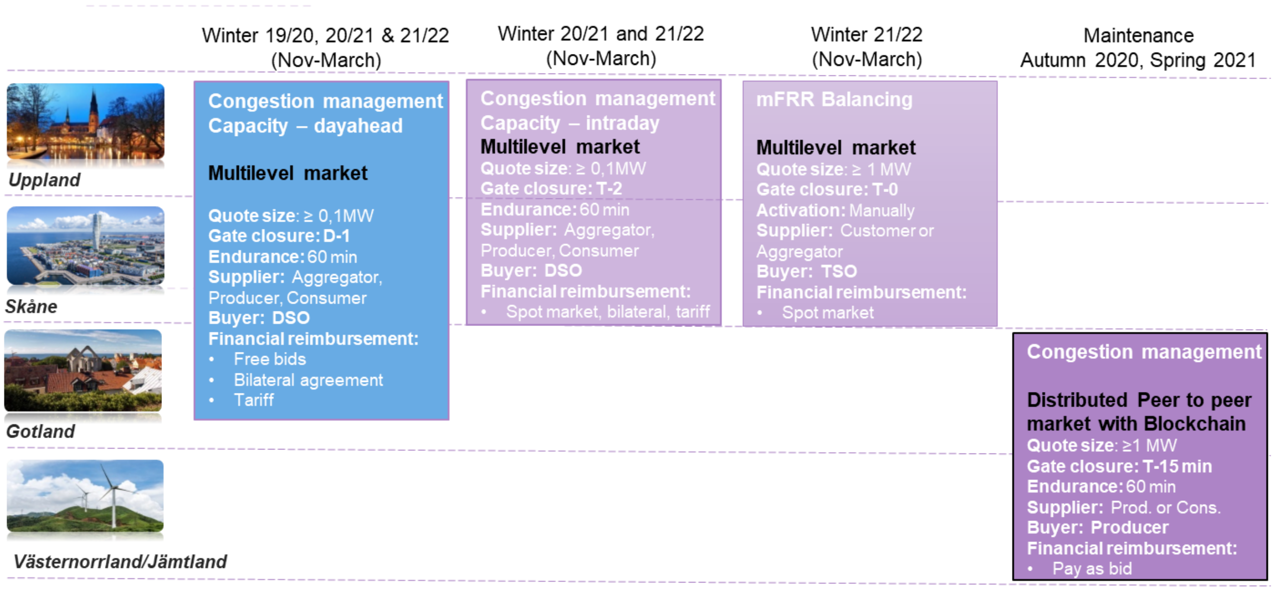


Figure 21: Markets and their respective products in the Swedish demonstration

In the Uppland and Gotland demonstrations energy-only payment was used for the winters of 2019/2020 and 2020/2021 which was complemented with weekly and seasonal availability contracts for the third and final winter of 2021/2022, while Skåne introduced availability contracts already in the second winter of 2020/2021. Cascading funds from EU were used as an additional compensation to encourage availability on the market from small ad innovative FSPs. The various forms of availability compensation developed and tested in the different regions and for the different winters is described in section 5.2 of D4.7.1. Indeed, the necessity of available contracts for the weather dependent volume of required flexibility is a key finding of the Swedish CoordiNet demonstration. Although relatively high volumes of flexibility were cleared on some markets, most of the volume was from one or a few significant grid users. Ensuring more actors are present is important to close the market liquidity gap. Likewise, it is important to ensure that FSP will bid when the flexibility is most needed, i.e., during times of high congestion, typically during cold periods lasting over several days. As the tests of the initial season with energy-only reimbursement were not seen as successful, testing tenders for availability contracts became focus for the later winters.

3.1.3. Balancing products

“Balancing” means the actions and processes through which the TSOs ensure the maintenance of system frequency within a predefined stability range, as set out in Article 127 of Regulation (EU) 2017/1485 [28]. The system responsible in Sweden is the TSO, Svenska kraftnät, who is both responsible for keeping balance in the grid and operates the national balancing markets. Today the markets are manual frequency restoration reserves, mFRR (Nordic energy activation market), automatic restoration reserves aFRR (capacity market), as well as two products for frequency containment reserves: FCR-N for normal operation and FCR-D for disturbances. A new Fast Frequency Response (FFR) was also initiated starting in June 2020. In the Swedish demonstration, the goal was to have forwarding of bids to the manual frequency restoration market, mFRR, which suits flexibility providers who can participate often. The overall idea is that enabling participation in multiple markets would

a) make DSO able to access resource that otherwise would “reserve” their flexibility for national balancing market
b) encourage smaller actors to invest in becoming a flexibility provider through helping them access the several times higher potential income from these balancing markets.

Unfortunately, no FSP initially wanted to participate in the mFRR due to the minimum level of 1 MW during one-hour, time-consuming prequalification and uncertain business case with the minimum level of 1 MW being a pilot. For the final winter, the 5 MW/20 MWh battery in Uppsala was prequalified for mFRR but the TSO was unable to integrate it due to delay with the security review. Another battery of 0,48 MW 1 MWh in Skåne did, however, successfully display possibility to participate in CoordiNet in parallel to another TSO frequency balancing market called FCR-D down (with 0,1 MW minimum bid size). This later case showed the success of the time coordination scheme from CoordiNet and shows the way for more actors to participate in both congestion and balancing markets in the future.

The flexibility market for (previously manual) frequency restoration reserve, mFRR, is used by the TSO as a tertiary regulation method and is manually activated by the TSO in order to alleviate the automatic frequency regulation methods and restore the frequency to 50.00 Hz. The mFRR market is also the balancing market in Sweden with the largest amount of MW procured per hour. Typically, this product is offered by hydro plants but as the share of intermittent power production and consumption increases, the need for a wide range of frequency regulation providers becomes greater. The mFRR is a market that is used often with energy-only compensation.

The reason for selecting the mFRR market is that this market is used for both balancing and TSO congestion management. The mFRR product also has similarities with the CoordiNet flexibility products for congestion management in that both have duration time (one hour), relatively slow activation time (100% within 15 minutes for mFRR) and the expected likelihood of low investment cost in steering equipment. A difference is that the mFRR limit on the lowest bid size is 5 or 10 MW (depending on price area location in Sweden), which at the beginning of the project was identified as a barrier for many potential FSPs. The TSO made an exception, allowing FSPs within the CoordiNet demonstration to have a limit of a minimum 1 MW. To participate in the mFRR market, the FSP must also pass a pre-qualification process required by the TSO, but this process is time-consuming and therefore somewhat simplified for those with forwarded bids from CoordiNet.

Forwarding unused bids from the CoordiNet market to the TSOs balancing market as mFRR bids was successful. The challenge when integrating mFRR bids from CoordiNet into the existing trade between the BRPs and the Swedish TSO, Svenska kraftnät, was not to disturb the ordinary trade.

The ordinary market procedure for trading mFRR is that the BRPs continuously submit a list of bids to the TSO until gate closure at 45 minutes before delivery every hour. The BRPs can alter the bid list until gate closure, which means that the BRPs may add, remove or in other ways changes the bids until the last submission when the gate is closed. The TSO then looks through the submitted bid lists BRPs have submitted, accepts and activates bids according to the merit order list.

CoordiNet received acceptance to submit the forwarded flexibility bids to the mFRR market under the name of the BRP. A technical problem that arose was that the list of forwarded bids from CoordiNet overwrote the original BRP bid list when submitted to the TSO. In order to solve the issue, the TSO created a functionality as an intermediary between the CoordiNet market, the BRP and the TSO bid submission system. The new functionality produces a list of bids from the bids forwarded from CoordiNet, at the same time, the functionality also accesses the list produced by the BRPs that are prequalified for mFRR through CoordiNet, as this risk being overwritten and creates a copy of the continuously updated bid list. Just before market closure, the function integrates the list forwarded from CoordiNet with the list from the BRP and submits the combined list to the TSOs mFRR market.

The ordinary process for the mFRR-market procedure, the challenge when forwarding CoordiNet bids, and the solution implemented to overcome the issue are illustrated in Figure 22.

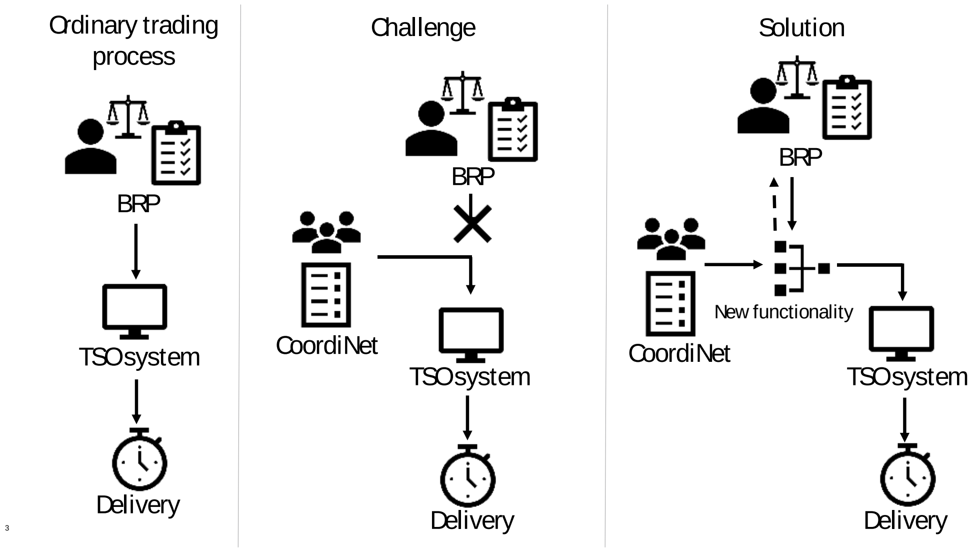


Figure 22 Ordinary market procedure for mFRR, the challenge in CoordiNet, and the solution implemented in CoordiNet

Traditionally, the responsibility for mFRR is regulated in the agreement between the TSO and the respective balance responsible party (BRP) for each asset supplying mFRR. However, since the flexibility market platform developed by E.ON is not a balance responsible party (BRP) itself, the responsibility for activation and settlement had to be regulated in the respective agreements between the FSPs and the DSOs, so that the FSPs can ensure that their BRP is informed and takes responsibility for the delivery and settlement. The fact that each bid on the mFRR market must be tied to a single BRP hinders the platform to aggregate bids from several FSPs in order to reach a higher bid volume. (This challenge will potentially be solved by the planned introduction of the new role called “balance service provider”, BSP).

For Gotland a detailed analysis was made to understand which flexibility and system services should be used to handle wind power and new solar as well as to improve power quality and security of supply. The results of these investigations are presented in section 4.7 of report D4.1. These products are summarised in Figure 28 but were only investigated without full-scale market trial.

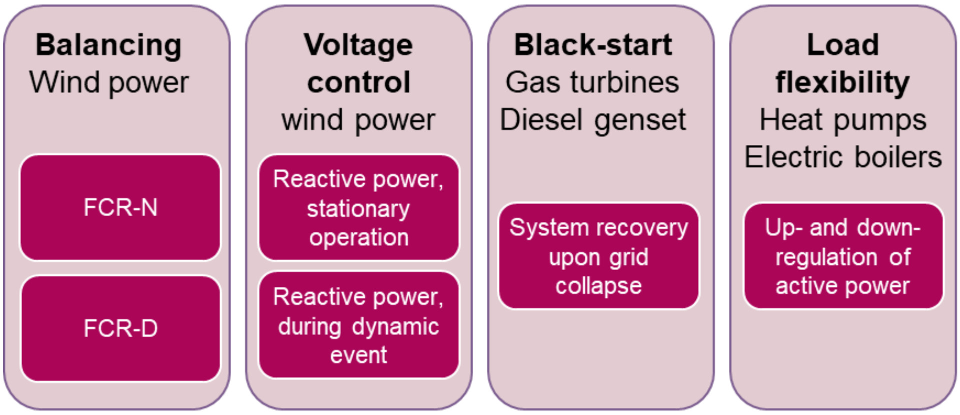


Figure 23: Summary of identified possible grid service for the Gotland demonstration.

There were also some unforeseen positive results from working with balancing markets in Gotland, Uppland and Skåne.

- In Gotland, the discussion on mFRR market resulted in the discussions to allow FSP from Gotland to participate in the mFRR market. Historically, resources on the island of Gotland have not been allowed to participate on the national frequency regulation market.
- The mFRR pilot in Uppland resulted in a definition of role and responsibilities when a local flexibility market is forwarding unused bids to the mFRR market. This can and will be reused until future regulation on how to integrate markets is decided by national regulators and in the upcoming EU grid code on flexibility. Another benefit is the possibility to accept limit on prequalification bid size of 1 MW instead the mFRR limit on prequalification bid size of 5 or 10 MW (depending on price are location in Sweden). Also, the prequalification is time-limited with a simplified process.
- One customer in Skåne coordinated the FCR-market with the local flexibility market. This experience will be evaluated in future dialogue on national market design. The FSPs solution to deliver both on CoordiNet flexibility market for congestion management and frequency containment reserve is described in detail in D4.7.1 [19] and not further repeated here.

3.1.4. Peer-to-peer markets

The peer-to-peer market enables optimisation of resources by trading capacity between producers without any intermediate parties. Geographical areas for the market were the island of Gotland, which is connected to Vattenfall Eldistribution regional grid through a DSO owned HVDC link, and Västernorrland and Jämtland. The primary actor in this process is the Flexibility provider. In both cases congestion may occur due to excess production. The use cases are slightly different in the two demonstrations.

- On Gotland the purpose of P2P trading is for the wind power to produce more during curtailment periods by initiating additional electricity consumption to mitigate the surplus of production. Although curtailment of wind production may occur during the entire year, it is during the HVDC links revision that curtailment is most likely to occur. The P2P actors will be the Gotland wind producer's association and the local district heating unit. The DSO gives information on curtailment periods and is not a part of the peer-to-peer market.
- In Västernorrland and Jämtland a P2P market is also created as a way of handling congestions in the grid during planned maintenance. The actors here are only producers, which within this area mostly consist of hydro and wind power producers. The commodity that actors trade on the market was set as "grid space", i.e., excess capacity. Either the wind producer will sell unused capacity when the wind is not strong, or the hydro plant may opt not to produce up to its curtailed capacity limit if the capacity can be sold to the wind producer, that otherwise would have to reduce production. The market here is setup around two periods of planned maintenance on the TSO part of the grid, leading to limitations on power levels. These constraints are planned for late summer/autumn of 2020.

The differences in the peer-to-peer markets in Gotland and Västernorrland and Jämtland are illustrated by Figure 24 and Figure 25.

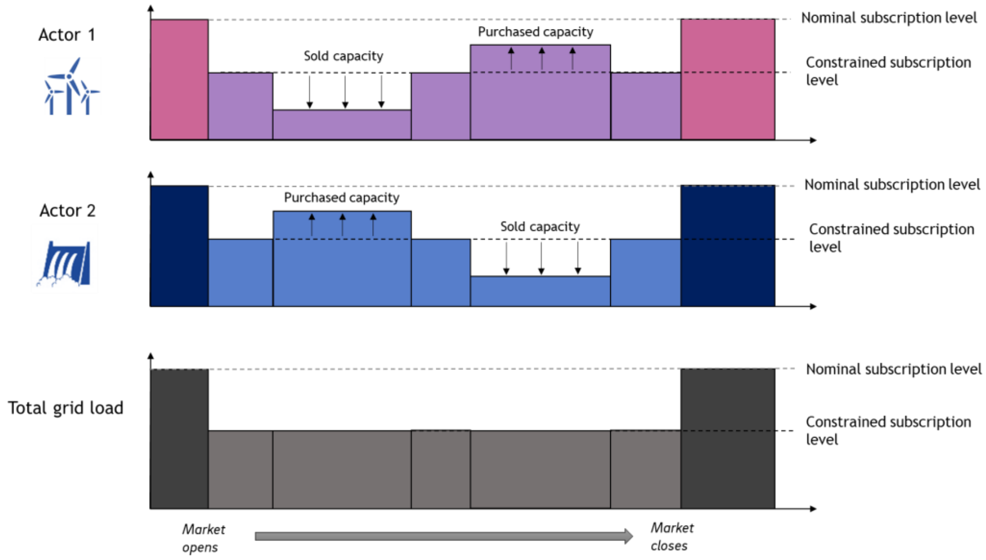


Figure 24: Illustration of two flexibility providers acting on a Västernorrland and Jämtland P2P market during a temporary constraint, showing capacity trading and the relation to subscription levels.

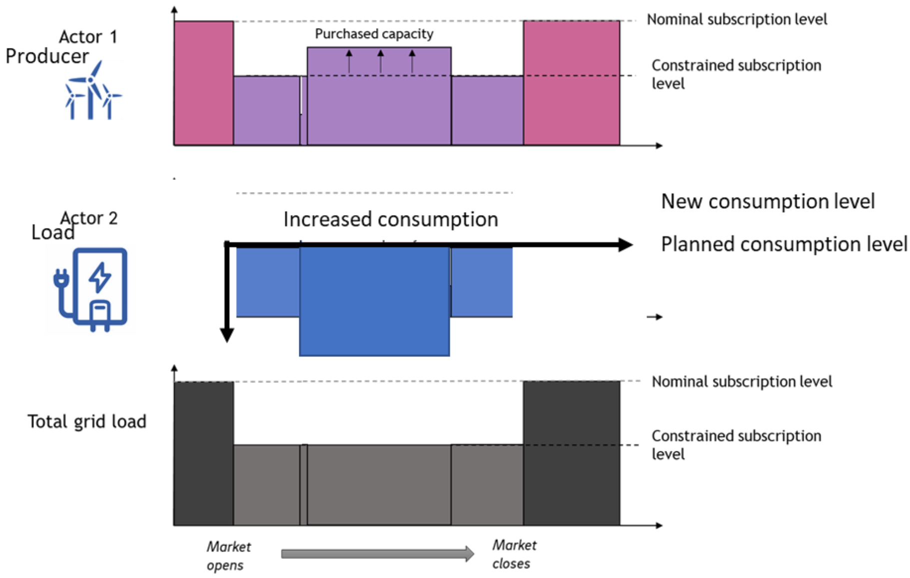


Figure 25: Illustration of two flexibility providers acting on Gotland P2P market during a temporary constraint, showing increased consumption to equal non-executed DSO curtailment command, and the relation to subscription levels.

In CoordiNet, the purpose of the peer-to-peer markets was to reduce curtailment of renewable power production in times of grid maintenance. The grid maintenance in the demo areas typically occurs for a couple of days, once or twice per year. Currently, there is no reimbursement for production loss for the units affected by the maintenance. A peer-to-peer market could be a way for the producers to increase their allowed output capacity during the maintenance and thereby sell more power and hence, reduce their economic loss due to the maintenance.

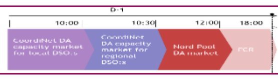
In the peer-to-peer demonstrations, the utilisation of blockchain for both tamperproof recording of transactions, and hence contracts between the peers, as well as validation of contract fulfilment was tested. These blockchain applications could not be tested thoroughly as the validation requires actual measurements from the trading assets which in both the case in Västernorrland and Gotland could not be delivered. Even so, the results that can be drawn from the tests are that the concept was indeed successful but that the need for these kinds of applications probably arises when there is high market liquidity with several different assets and companies trade with each other.

Through the CoordiNet demonstration it become apparent that national taxation is hindering the take-off of the peer-to-peer market. While the merits of such market may seem straight forward (avoiding wind curtailment by purchasing increased heat production at district heat plants) the reality showed something else. The transfer of energy from one sector (as electricity) to another (as heat) implied tax and cost effects that essentially killed the profitability of the scheme. Here, the different actors’ grid fees played a role but even more detrimental was the presence of a non-transferable consumption tax on domestic heating companies electricity input that, together with VAT on delivered heat, implied a “double consumption taxation” on both the input and output of the heating companies. While biofuels as a heating source have no similar tax, it made it impossible to compete with heating from biofuels as they are not taxed with (non-transferable) VAT. Thus, the additional income from avoided wind curtailment become smaller than the incentive required by district heat companies to run the electric boilers. Further study of peer-to-peer markets in regulatory sandboxes should be performed as peer-to-peer markets raise questions about taxation, electricity trade and grid tariffs.

3.1.5. Lessons learned

Through dozens of open workshops, articles in all major trade magazines and discussions with leading energy actors like the energy agency, market inspectorate, research institutes, universities, wholesale electricity retailers, aggregators, multiple local DSO as well as grid customers including district heating companies, real-estate owners, industries, energy storage operators. We dare to say that the CoordiNet demonstration has had a far-reaching impact on the Swedish energy sector. Close stakeholder interactions and sequential development have been the key to the success of the Swedish CoordiNet demonstration. From the start, external stakeholders have contributed to the market design and business rules. The lessons learned with respect to the developed product and customer engagement is summarised in Table 6. While areas of future work are outlined in Table 7.

Table 6 Learnings with respect to product development and customer engagement

Area	Learnings	
Business - for DSO/TSO	Compatibility with regulation is required, for DSO to use flexibility services on market-based terms. DSO needs to know that the flexibility will be available when most required	 *”We believe that a way to promote flexibility services maturity is to combine a market with free bids with availability remuneration. Compensations to flexibility providers need the right balance between availability and activation remuneration”*
Business incentive - for flexibility provider	Flexibility providers need to know if the investment in planning, process development and technical infrastructure will pay off. A business case with free bids is insufficient for customers to invest time and money to get the ability to be flexibility providers Even flexibility providers that already participate in other markets have set up costs to participate in the DSO market Ability to participate in markets for balancing and congestion management simultaneously	
Liquidity	The financial incentive for the FSP to participate in the flexibility market is weak because of the varying need of the DSO to purchase flexibility, a need that depends on both weather and changing conditions regarding limitations in the grid Participating on a flexibility market is something “early adopters” are doing and still a long way to go before the rest of the grid customers follows Prequalification for and participation on flexibility markets must be simple and FSP communication, contracts for power of attorney etc standardised Volume on the flexibility markets for congestion management was not always sufficient, Competition among bids was not good enough with lower level of bids available than hoped from smaller flexibility providers	
Market design	Important to put the DSO/TSO markets in the timeframes of the current energy markets and all balancing markets	

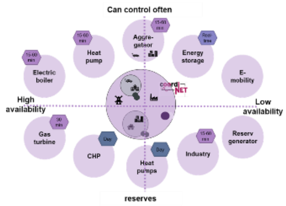
Practical experiences - Flexibility providers	Several flexibility providers underestimated the effort and time needed for preparation to provide flexibility Certain flexibility providers can only participate on a day-ahead basis, e.g., industries and district heating Other flexibility providers prefer to provide flexibility closer to the delivery hour, e.g., aggregators or energy storage Digitalisation, giving the possibility for bidding and calling through automated interfaces, was asked for and has been developed Standards for the market message, metering data and baseline are needed to save time in prequalification and obtain interoperability Standard for power of attorney especially when households have flexible resources is needed to save time and money for DSO and FSP	

Table 7 Areas identified for future work with respect to product development and customer engagement

Area	Future work
Continued operation of markets	The CoordiNet flexibility market for congestion management will continue even after the termination of the EU project. The local flexibility market in Uppsala will continue in winter of 22/23 demonstrating free bids and availability renumeration day-ahead In Skåne the largest marketplace in Sege/Arrie will continue while the markets around the other two TSO connection points will be terminated due to decreased congestion there. The participating local DSOs in Skåne (Landskrona Energi, Kraftringen and Öresundskraft) as well as Uppland (Uppland Energi) will be able to use the platform for local markets, if they so desire. CoordiNet has inspired the establishment of other local flexibility markets. The local flexibility market in Stockholm, sthlmflex, will continue for winter of 22/23. The Gotland market will not continue. In Gothenburg a pilot called "Effekthandel Väst" has started.
National, standardised, product definition	All participating DSO in the different markets as well as other interested DSO's now have a dialogue and knowledge exchange on different issues related to flexibility services. Inspired by the Swedish CoordiNet demo a standardised product definition for flexibility has been developed. The work was launched during 2021 and is based on the IEC 62325 Common Information Model (CIM) mandated by European Commission in M490 [43] for electronic market data interchange within the Europe Union [44]. A proposal of terms and conditions for the product market-based procurements of electrical grid capacity as a flexibility service has been developed that will be the basis for the system operators first draft presented to the national regulator.
Extended coordination with other balancing and energy markets	During the execution of the CoordiNet project in 2019-2022 new types of potential flexibility resources have emerged like EV chargers and batteries. Some retailers have been looking at the aggregator role. Independent aggregators have started to establish themselves with services to balancing market, wholesale market, local flexibility market and customer services such as peak-shaving and control of indoor temperature. During the CoordiNet project it has become apparent, for involved partners in the Swedish demonstration, a need to extend the DSO-TSO coordination to additional markets. For example, the FSPs operating batteries expressed that they also consider frequency containment markets (FCR) and not only the frequency restoration market (mFRR) included in the CoordiNet coordination scheme. A disruptive change has been the high energy prices that appeared in the winter of 2021/22. This was initiated first through new east to west power flows through Sweden created by two new 1 400 MW HVDC links from Scandinavian to central European synchronous areas and later by escalating energy prices due to the Ukraine crisis. Sweden has a high degree of sector coupling between heat and electricity due to district heating plants with electrical co-generation. Therefore, the high electricity prices resulted in changes in priority between electric and non-electric heat source effecting a change in the volume of bids and the need for DSO purchase. Impact from variation of electricity prices and from increased participation on existing and new balancing markets of both behaviour of FSP's and customers in general reflected in DSO grid need has been observed. If customer behaviour is changed so that they differ from planning criteria of the DSO this will affect the operational situation for the DSO and the information needed to obtain a good forecast. Local flexibility markets can help the DSO to handle this changing behaviour of customers. We have made important learnings within CoordiNet, but we need further analysis and dialogue with market actors to fully understand the situation.
Ensure large new loads are flexible	Discussions with providers of emerging loads using electrolyser or for production of e-fuels: Also, further discussions with operators of data centres and E-Mobility to find what form of flexibility products are most suitable for their organisations and assets.
Harmonising among the 150 Swedish DSO and thousands of potential FSPs	A common place for matching FSPs and DSOs: An interface where potential FSPs could get information about flexibility and register their interest and where DSOs could announce their need for flexibility; volumes, market areas and bid specifics would be of great benefit. This is especially important since the Swedish power grid is structured in a way so that several DSOs could operate in the same geographical area, but at different voltage levels in the distribution network. A neutral or third-party could then provide a common information channel for all DSOs and promote a market-based method for procurement or tendering of flexibility.

Stakeholder interaction resulted in a market design where different markets coordinate in time and in a business model where the DSO buys flexibility mainly day-ahead but can be complemented by intraday trading. In this way, the flexibility service is as much as possible called for before the day-ahead spot market and mainstream energy and ancillary services markets are disturbed only when required to compensate for deviations during the day of delivery. The DSO thereby has a business use case where a grid state estimation forecast makes it possible to call for flexibility day-ahead, working proactively to alleviate grid congestion that has strong correlation with temperature, while still adapting to unforeseen changes in load and availability of flexibility resources. A peer-to-peer market has also been set-up that during periods of maintenance in the grid will allow producers to either trade capacity rights with each other or initiate increased consumption of other users to allow them to produce more.

3.1.6. Further reading

CoordiNet report D4.1 [1] describes the products in the Swedish demonstration in further detail.

The initial customer engagement activities performed are described in detail in D4.5 [28]. Feedback from FSPs was also collected through one-to-one interviews with 15 of 17 FSP participating in the first winter season in 2019/2020 together with interview with four aggregators after the second winter of 2020/2021. This feedback can be found in D4.7.1 [19] that goes through the drivers, lead-time, challenges as well as commercial and technical terms for the FSP and aggregators participation in the market. The FSP experience with participation in the flexibility market for congestion management is also summarised a CIRED 2021 paper [29].

As described in D4.4 [30] and D4.6 [31] an iterative development of the market tool was performed with considerable changes made between each winter's operation to the market tool.

3.2. New DSO abilities: Operating and planning flexibility

Both Vattenfall Eldistribution and E.ON Energidistribution have initiated business development projects or even new departments to incorporate flexibility into their daily operations and processes. These initiatives cover the full set scope from planning to control room. Contractual obligations to provide flexibility through availability contracts have helped DSO to allow more connections.

A further conclusion is that the business case for participating with only free bids was not sufficient for many grid customers to invest the time and money to become flexibility providers. This has been the feedback from several service providers involved in the Swedish demo. The uncertainty of the amount of the cleared volumes will vary heavily from year to year due to the weather. As the flexibility providers need to know the investment in planning, process development and technical infrastructure will pay-off, they need to have reassurance for their investment. Here the right balance between availability and activation remuneration needs to be found. The way found to best promote flexibility services maturity is to combine a market with bids with availability remuneration. As the flexibility need varies greatly and the congestions is often only temporary (until the grid has been physically reinforced), the possibility to combine revenues from several markets for both flexibility and TSO ancillary services is crucial to strengthen the FSP business case.

Furthermore, in order to avoid the FSPs investing unnecessary time in placing flexibility bids during periods with no flexibility needed from the DSO, there is a desire that the DSO instead places buy orders which the FSPs reply to by placing matching bids. This could potentially also result in larger volumes available at the market during times with an actual need for flexibility. At the beginning of the project, information about when the DSO needed flexibility was deemed to be information that could affect the energy spot market and hence the initial market was set up so that the FSPs should send bids even though the DSO hasn't indicated a need for flexibility. However, this reasoning has been questioned as information such as forecasted temperature and wind are accessible information to anyone. This process was tested to some extent during the last winter season by the weekly contracts offered by both E.ON and Vattenfall and will likely continue to be used and further developed. The demand for the DSO initiated market is especially important in markets with an infrequent or seldom need for flexibility.

A question that arises if the market is initiated by the DSO and dependent on that the FSPs replies with sell orders first after the DSO has sent a bid request or buy order, is whether the DSO can trust and rely on that there are flexibility volumes at the market and that they are sufficient. The DSO needs to know that the flexibility will be available when most required and that it is profitable to use, compared to other solutions. The uncertainty regarding this is a major barrier for the implementation of flexibility markets as an alternative to other congestion solutions.

Also, the DSO needs to be sure of the business case compatibility with regulation for using flexibility services on market-based terms. If the benefits and costs of flexibility are not allowed to be regarded as, or like, a grid asset, flexibility will in most business cases never be a cost-effective solution for the DSO. The uncertainties regarding future regulation are another barrier for the utilisation of flexibility markets. Further issues involve:

- Change management to achieve acceptance and utilisation of local flexibility markets in DSO and TSO organisations.
- Definition of business models and future planning and operation models able to benefit and value the increased efficiency resulting from the coordination between TSO-DSO-customers.

3.2.1. Lessons learned

The development of the platform and the flexibility market by a DSO has proved to be extremely valuable in competence development, mindset and promoting a corporate culture understanding flexibility. The lessons learned with respect to the developed operating and planning abilities was:

- One of the more difficult and time-demanding issues was handling data management and security, central hub for all data proved valuable
- Visualisation on platform greatly increased visibility of the upcoming grid situation for control room operators
- Flexibility services day-ahead is dependent on accurate grid state forecasting and requires production plans of major loads
- Developing and operating the platform as an integral part of the DSO grid planning and operations provides an understanding of needs, changes and possibilities when acting DSO with higher level of visibility
- Production plans and metering data from significant grid users are critical to producing good quality in grid forecasts and to make the correct decision about flexibility need

CoordiNet introduced a more flexible way of using capacity and controllable resources. However, for the control room operators traditionally used to acting “in the now” the market coordination requirements for day-ahead planning were transformational and challenging. CoordiNet required operators trained to be on stand-by and provide fast response to sudden changes to abide to fixed timeslots for clearing of bids the day before. One question is if the operators should be making the decision to activate flexibility or if new “back-office” functions should be created for this. This new role would still have to coordinate with grid operators, share forecast information and be well informed of contingency plans and reserve power feed contingency options that affect market volumes. This new role could, on the other hand, be better trained to abide to market rules and be more attentive to FSP constrains and preferences within their more planning and market-oriented approach to activation of capacity.

Use of a traffic light system to indicate to FSPs if congestion management was also proposed. This is in order to encourage FSPs to place bids when most required. In the Swedish demonstration it was seen that initial enthusiasm and bidding frequency dwindled with the lack of cleared bids and that hence insufficient bids were on the market when congestion occurred. This was mitigated with temperature dependent availability contracts and a function in the flex tool that allowed grid operators to press a button to initiate sending of e-mail and/or text messages to request bids from FSP, but a traffic light system could provide further notifications of when flexibility is wanted.

3.2.2. Further reading:

The lessons learned from introducing flexibility markets both within the participating DSO and Sweden can be found in D4.5 [1]. While this report focuses on these abilities' additional findings after the first winter are in D4.1 [1] and D4.7.1 [19] with the main findings repeated in the various sections of this report.

3.3. Developing abilities: Coordination and real-time metering

Metering values for flexibility resources and significant grid users are collected through integration with DSO metering system (E.ON) or sent to DSO through a metering hub from communication gateway from external (so called IoT) provider (Vattenfall). In addition, substation measurement is gathered from the supervisory Control and Data (SCADA) systems used in the DSO control rooms. This is described in D4.5 [28] and not further delt on in this report.

The coordination scheme is the time-coordination between CoordiNet flexibility market for congestion management and existing electricity wholesale markets (section 3.3.1) and balancing and balancing (section 3.3.2). For the peer-to-peer market descriptions the reader is referred to the further reading section 3.3.3.

3.3.1. Market timing and coordination between markets

From the aggregator's bidding perspective, two main market types have been tested in CoordiNet, namely day-ahead (operated in the first winter of 2019/2020) and intraday (from winter 2020/2021). This is in addition to the traditional reserves operated as long-term bids, which are also to be integrated in the CoordiNet demonstration. The distinction between these forms of flexibility contracts is largely linked to the procurement cycle but also to the distinction between capacity and energy products, which will be described in section 4.1.3. All CoordiNet markets are designed to fit into the schedules of the existing energy markets. Through the developed TSO-DSO cooperation framework the CoordiNet local day-ahead market closes at 10:00 and the regional DSO market at 10:30, ahead of the national day-ahead market that closes at 12:00.

The goal is to clear flexibility as much as a possible day ahead. However, after closure of the CoordiNet market the load forecast is updated hourly. If the new forecast or unforeseen changes in network, load or production, result in the subscription limits being exceeded, additional flexibility may be cleared on the CoordiNet intraday market. The intraday market opens after the TSO FCR market has closed at 15:00 and is available until two hours before delivery time. After closure of the national day-ahead market and one hour before delivery hour, CoordiNet bids not cleared in local or regional DSO flexibility markets for congestion management may be forwarded to the mFRR market as shown in Figure 26. Forwarding to the mFRR market requires pre-qualification of each flexibility resource individually without any aggregation allowed.

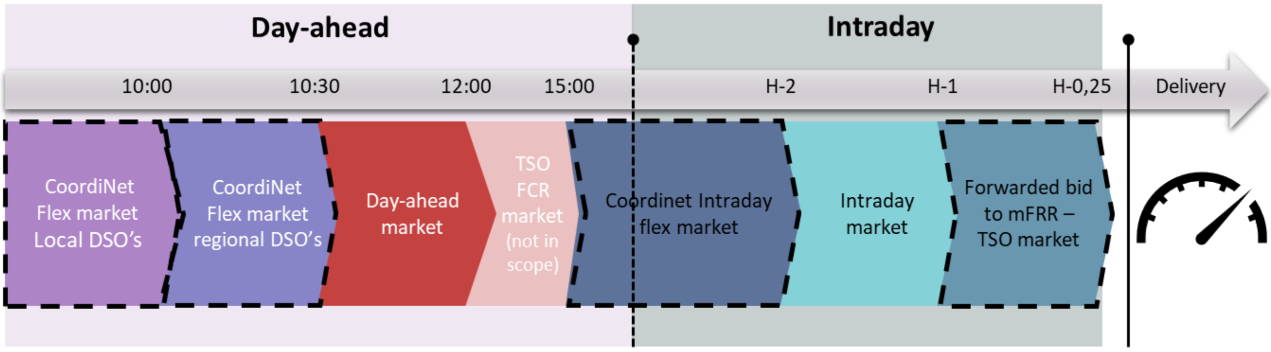


Figure 26: Market closure times in Swedish demonstration.

The market is thus designed to allow multiple opportunities for flexibility to be procured, as well as time slots for the balance responsible party of the FSP to modify bids on national markets to stay balanced. The possibility for a bid to be forwarded is illustrated in Figure 27 for larger (1 MW) resource prequalified by the TSO for the mFRR market.

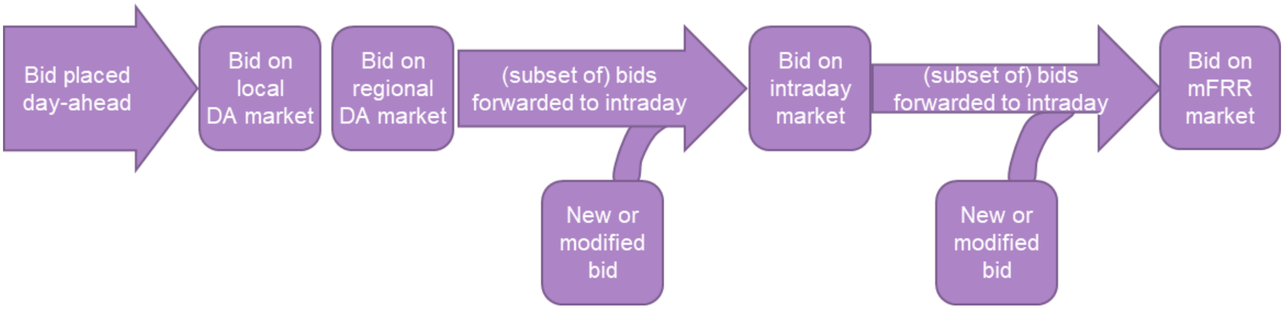


Figure 27: Possibilities for bids to be forwarded between CoordiNet markets.

Deeper dialogue with FSPs revealed that owners of many of the new types of resources like batteries and EV chargers, as well as mature aggregators, preferred the frequency containment reserve market, FCR-D. The reasons for their preference for FCD are multiple:

- Can participate in FCR market with only 0,1 MW (instead of 1 MW for mFRR)
- Can participate in FCR market for only 20 min endurance (instead of 1 hour for mFRR)
- The clear capacity nature of the market where capacity can be sold all hours of the year
- The small energy demand as the activation occurs seldom for the rare and short-lived periods when the frequency is outside of its normal operating window i.e., <49,9 Hz or over >50,1 Hz. This typically only occurs for a few seconds and normally only a few times per month. This means the state of charge of a battery is impacted only marginally for all practically conceivable power system events. (Only in extreme grid collapse event is the frequency likely out of 49,5 to 50,5 HZ range requiring full activation period of 20 minutes).

3.3.2. Forwarding to balancing markets

Unsold flexibility from the resource, a 5MW energy storage facility in Uppsala capable of around 20MWh of discharged power output per day, originally offered for intraday trading in Uppsala regional market, was forwarded to TSO as mFRR bids and the exchange was logged in the platform, as shown in Figure 28 below. The mFRR test was successful and demonstrated the practical feasibility of connecting local flexibility markets with TSO balancing services in Sweden.

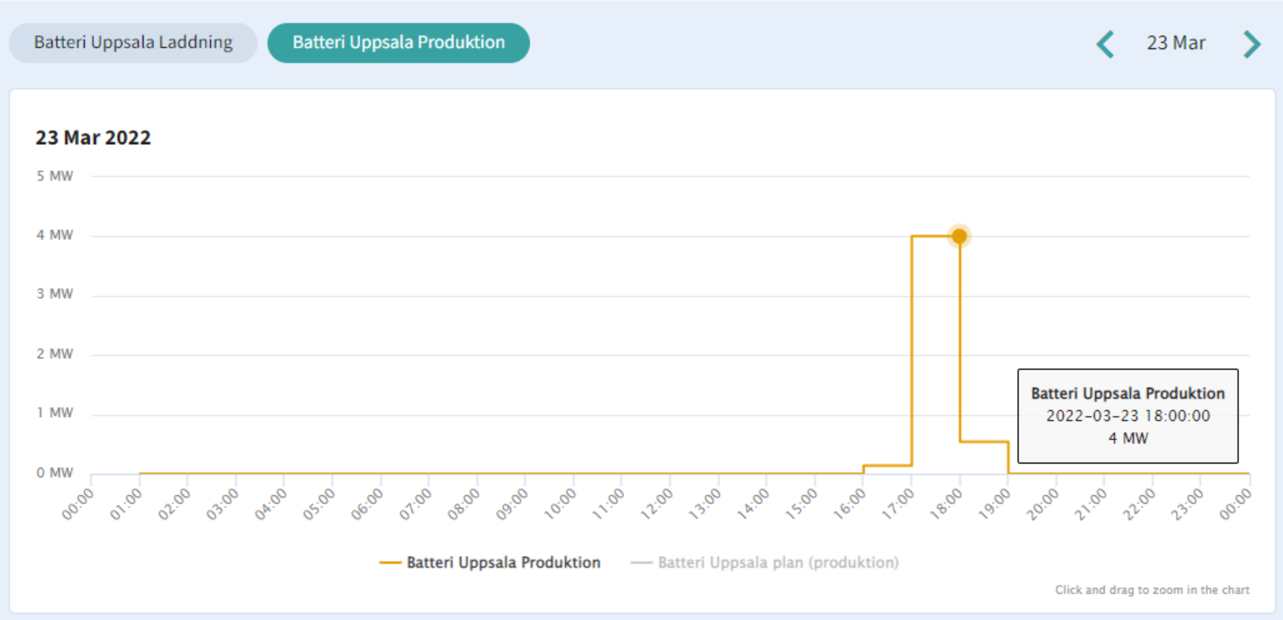


Figure 28: Chart view of metered production from the battery resource

The simultaneous participation on CoordiNet and the FCR-D balancing market was successfully demonstrated by one resource in Skåne (a 0,48 MW/1 MWh battery). The following text describes the experience of this flexibility provider which developed the solution as a project financed partially with public funding from the Swedish Energy Agency and hence with non-confidential results. This coordination with also the FCR balancing market is further described in D4.7.1 [19] section 5.3 and was made possible by the double auctions of the FCR market shown in Figure 29. Bids were placed on the FCR-D down market in the first capacity auction that closes 15:00 two days before delivery. If the batteries bid was cleared day-ahead in CoordiNet the FCR bids can be cancelled by sending a rebuy request to the TSO in the second FCR-D capacity auction that closes 18:00 hours D-1.

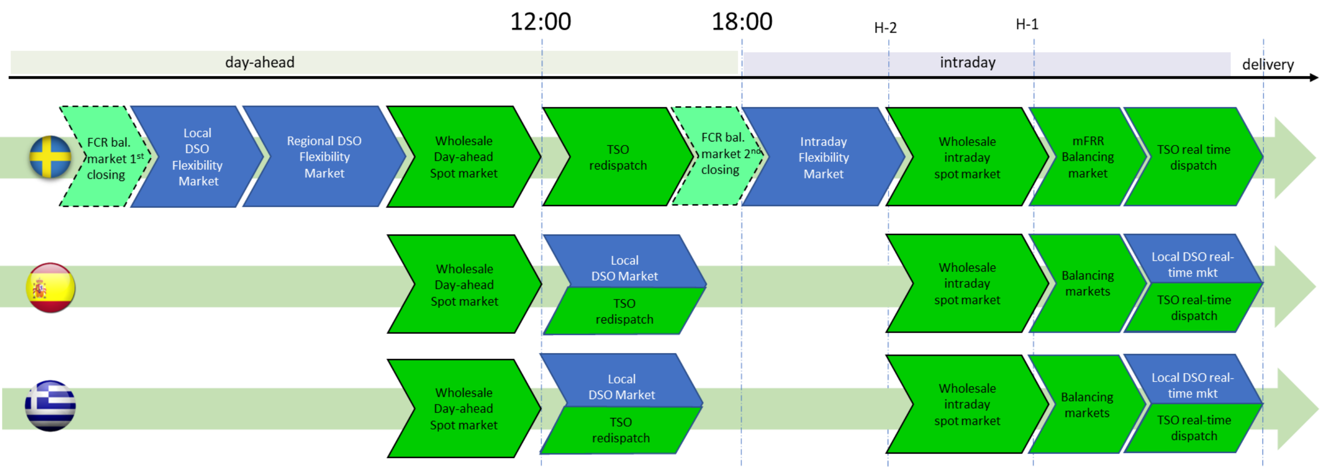


Figure 29 Market timing of CoordiNet and TSO balancing markets. (The times in the figure for FCR-D auctions are 00:30 and 18:00 hours D-1 of the coming FCR-D market timing, not 15:00 D-2 and 18:00 D-1 as was the case when test was performed.)

3.3.3. Further reading:

The market coordination scheme is described in the initial learnings of CoordiNet found in D4.6 [28]The frequency balancing products on the Swedish market are described in D4.1 [1] with a detailed description of the coordination with mFRR market in D4.6 [31] and with the FCR-D market in D4.7.1 [19].

The time coordination between peer-to-peer trading times and the actors' routines for production planning and bidding was also carefully studied and can be found in D4.1 [1] with full process description of al exchanges in section 4 and all tool support in section 5. The outcome of the peer-to-peer markets are provided in D4.7.1 [19] section 6.7.

3.4. New abilities using machine learning: Forecasting and baseline

Central to the operation of a flexibility market is accurate grid and load forecasting which is presented in section 3.4.1- To evaluation delivered flexibility a comparison is made with a times series of what the resource power would have been without activation of the flexibility. This is called a baseline and can either be a schedule of planned resource use before market closing or a forecast of the resources power made either by the external forecast service provider or by the FSP themselves. The baseline is covered in section 3.4.2.

3.4.1. Forecast

The goal in the demonstrations was to clear flexibility as much as a possible day ahead. This requires an accurate forecast of grid load to minimise additional clearing of flexibility on the intraday market, and/or to decrease the "security margin" of additional flexibility required to be procured day ahead to stay within the grid subscription limit.

The grid status forecast is a necessary input to understand the potential need of flexible resources to optimise the grid situation. Expected consumption is needed to identify available capacity. This is a requisite to manage and plan the use of available flexibility. Similar methods and algorithms were applied to both forecasting methods which operate on a time horizon from the next hour up to the next 2-3 days at hourly resolution. Without accurate forecasts, the right amount of flexibility cannot be assigned at the right time.

With the day ahead trading normally taking place between 9 and 10 o'clock, the forecast needs to give accurate estimates of the load 15 to 39 hours ahead of time. In the Swedish demonstration, the forecast is based on machine-learning techniques trained with measured data, as described in separate report D4.3.2 [32]. When forecasting a target grid-point, input is in general measurements at secondary substations, multiple weather forecasts and calendar information of weekdays and holidays as well as the target timeseries itself. Multiple models based on artificial neural networks are trained and evaluated in a method optimizing the predictions for different time steps.

The forecasting support in the market platform operator tool was divided into two separate solutions since the two involved DSOs decided to test different approaches to produce the forecast. The two DSOs have identical business use cases. Forecasting for E.ONs flexibility market for congestion management was initially delivered by the University of RWTH Aachen in the form of software module to be used in an internal forecasting tool. Forecasting for Vattenfall markets were delivered as a service with actual load forecasts by a commercial company, Expektra. Thus, the report of developed forecast, D4.3.2 [32] constituted an exchange of techniques, experiences and approaches from academia and industry. Figure 30 illustrates the different approaches used for the two demos with the different steps of the forecasting process. Initially, historical data is fetched and verified. In both E.ON and Vattenfall cases observation data are provided to the forecasting model provider. Then model training and testing is conducted by RWTH and Expektra. Testing includes to create different alternative forecasting models and evaluate performance and decide which model to use. Next step is to use these models in operation to create forecasts. This step includes running models with current weather forecasts and continuously re-train models with new data. Finally, the actual forecasts are uploaded to the CoordiNet market platform. The main difference between the two solutions is the handover where E.ON manages the subsequent steps of running forecasts, adapting new data, re-training models and uploading predictions to platform. Expektra handles these steps in the Vattenfall solution.

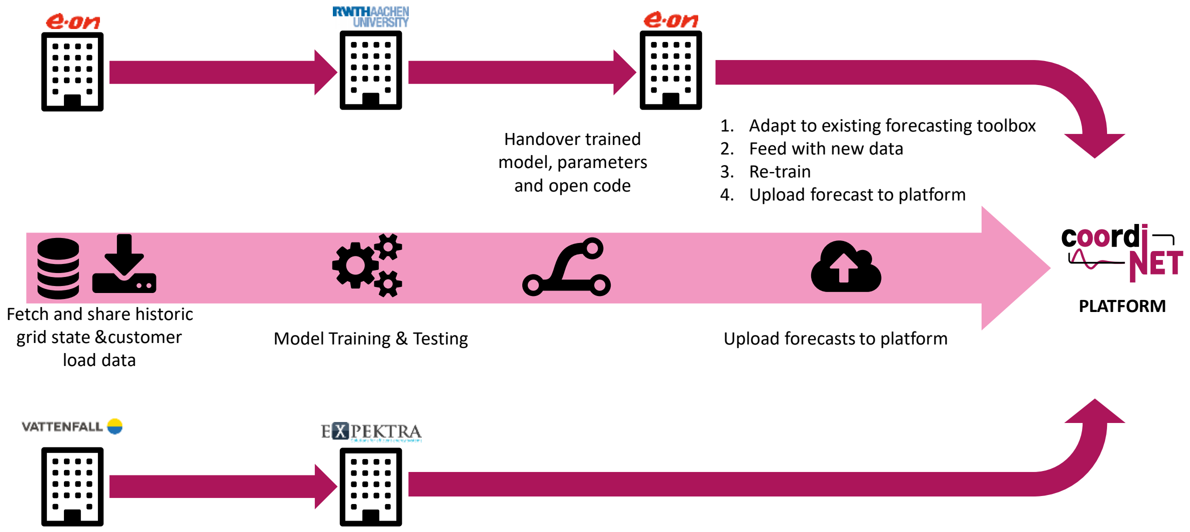


Figure 30: Workflow of model training and platform integration

Throughout the three winters of the demonstration the forecast underwent a series of changes and improvements covered in detail in D4.7.1 [19]. This included using production and consumption plans for significant grid users (Figure 31), compensating measured time-series for machine training with the impact of delivered flexibility and switching to specific trained machine learning models in cases of unusual network loading, not encountered by the training data.

A considerable implementation between the first and second winter was the introduction of day-ahead trading requiring forecast to be sent each hour. This allows the DSO to procure additional flexibility to compensate for any underestimation of the grid need in the day ahead forecast where the intraday prognosis will be updated to avoid systematic errors (Figure 32) and allowing improved accuracy near the hour of delivery (Figure 33).

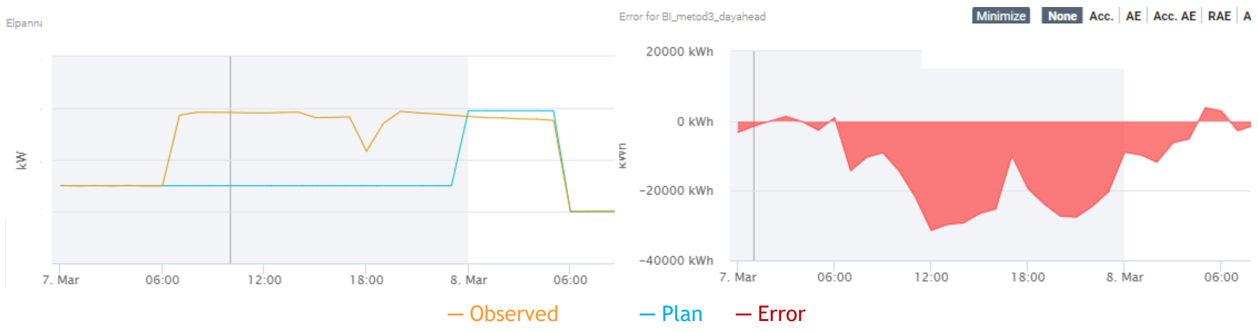


Figure 31 Example of forecast error induced if significant grid user deviates from production.

C). Day-ahead accumulated forecast error D). Intraday accumulated forecast error

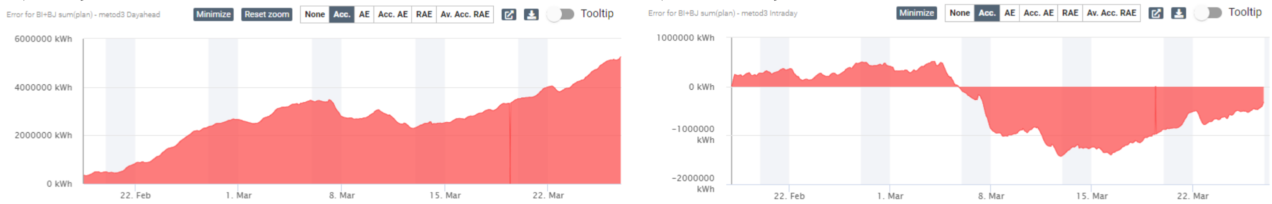


Figure 32 Error for day-ahead and intraday forecasts for Uppland, 2nd half of 2020/2021 winter.

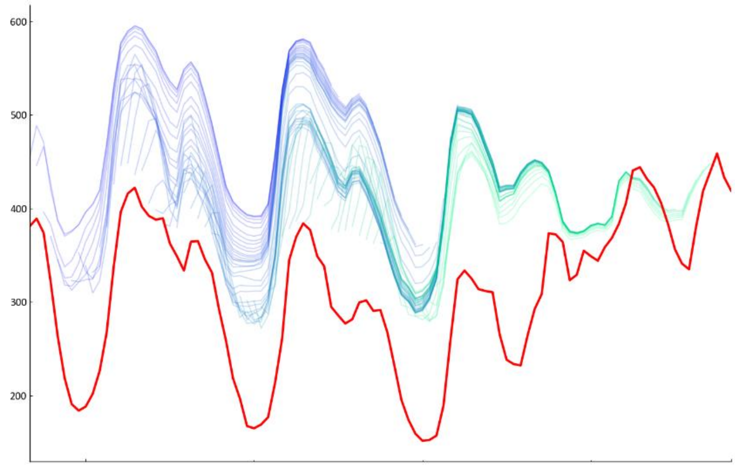


Figure 33: Forecasts (40-hour duration) distributed over time, ranging from blue being the oldest forecast, to green being the newest 40-hour forecast. The red line shows the actual load at the connection point

3.4.2. Baseline

The baseline is defined as the power consumption or production if no flexibility is bought or activated. Hence, this leaves space for interpretations. Throughout the three years the CoordiNet project was operated different methods for verification of cleared bids were discussed with the FSPs and internally within the participating DSOs. Several verification methods have been discussed:

1) Deviation from production plan
2) Monitor resource/aggregation control system commands
3) Historical baseline (including comparable day and rolling average)
4) Trust
5) Compare forecast with the metered outcome
6) Meter before, meter after
7) Zero baseline. E.g., for reserve power no production is taken as output, unless flexibility is cleared)

To illustrate how difficult, it can be to judge the extent of to which cleared flexibility is delivered to examples are provided. Figure 34 shows a successfully executed bid with a load reduction of 200 kWh for four hours. The cleared bid was only about a twentieth of the full load. As the consumption of the industry has no major dependence on the ambient temperature the execution of the bid can be validated by direct comparison with adjacent workdays. For the housing estate in Figure 35 the load is heavily dependent on the heating need and thus the ambient temperature. The cleared bid was here about half the maximum load. Even without weather correlation, it can be assessed that there was not a successful execution of the cleared bid.

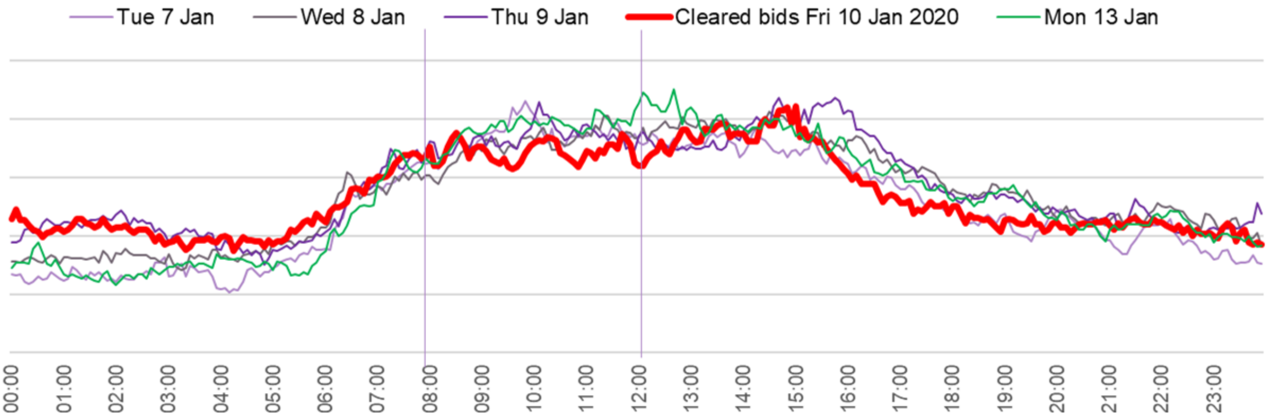


Figure 34: Example of successfully executed cleared bid. Observed load on day with cleared bid (thick red line). Comparison with load profile for four adjacent workdays (thin lines). The bid is here 1/20th of the max load.

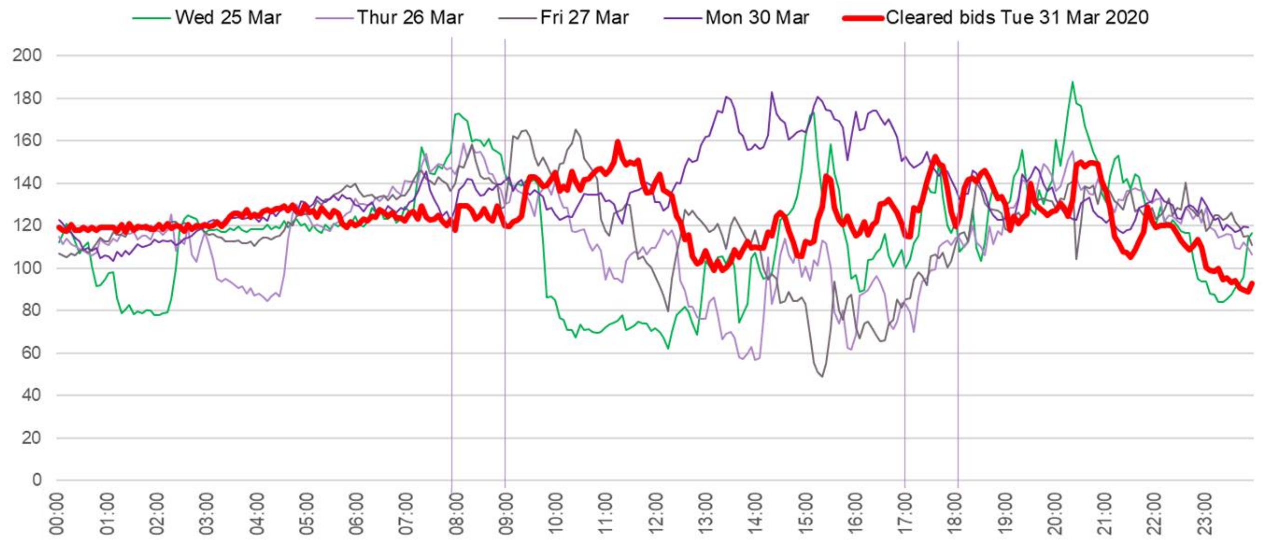


Figure 35: Example of non-executed cleared bid. Observed load on day with cleared bid (thick red line). Comparison with load profile for four adjacent workdays (thin lines). The load is heavily temperature dependent making analysis more complex, yet the expected halving of load is clearly not present.

Also, production plans come with significant drawbacks: not all sellers can (or will) provide them, they require the buyer to trust the seller not to manipulate the plan to game the market, etc. Validating the bids received from the smaller industry and apartment building heat pumps is therefore a challenge. Given the large spectrum of different types of FSPs in the Swedish flexibility market for congestion market it is unlikely that one method of evaluation of bid execution will fit all.

As this was an experimental market with many FSPs participating to learn, driven by motivations other than economic gains, it was decided to avoid penalties for missed activation of cleared bids. For the first season's demonstration, in winter 2019/2020, it was therefore decided to simply base the validation of bids from smaller FSP on trust. For the winter of 2021/2022 the platform was enhanced with two methods to automatically create a baseline and use this to evaluate delivered flexibility as a basis for payment.

In some regards, it would be beneficial for the DSO to receive the latest updated baseline. However, the settlement process is designed in a way so that the actual delivered flexibility is based on the baseline that was valid when the purchase was made, i.e., if flexibility was bought day-ahead, the baseline to settle against is the baseline provided day-ahead. The conclusion from this is that communication is very important and that there might be a need to capture several baseline updates in the platform.

A further complication of the automated approach arose during February and March of 2022, when the weather was frequently changing from mild to cold. For resources with a high temperature dependency trading flexibility on a day-ahead basis, where the offered volume is based on forecasts generated a day in advance, the actual available flexibility upon the time of delivery might differ from what was offered the day before. With an automated approach, where the offered flexibility is calculated and automatically sent to the market, these volumes might be challenging to deliver in full. It could also be vice versa, that the resource can deliver more flexibility than offered day-ahead. It should therefore be considered whether these kinds of automated, temperature dependent flexibility resources should participate on an intraday market rather than a day-ahead market.

3.4.3. Lessons learned

With respect to the developed forecast and baseline abilities the below learning were made in the Swedish CoordiNet demonstration:

<u>More accurate grid state and load forecast:</u> Considerable improvement in accuracy of the forecast was made during the CoordiNet Swedish demo (see D4.3.2 [42]). While the mean Root Mean Square Error (RMSE) error of 5% achieved in normal operation may be a challenge to decrease further the accuracy in extreme situation could likely be improved. The target would be to improve forecast in the following situation: i) rare low temperature events with small amount of previous data for the machine learning algorithms to be trained on and ii) unusual grid configurations when the pre-defined impact factors (power transfer distribution factors determining how various substation power flows are impacted by FSPs) become misleading. Here a digital twin of the grid, or function to switch forecast model based on grid state linked, could be beneficial. In other words, the question is if the continuous grid capacity calculations done by a TSO are required for the DSO as well, or if it can be maintained the simplified approach of the Swedish demonstration with its advantages of understandability and ease of use for the FSP.

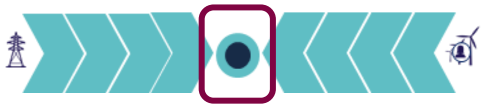
<u>Improved baseline methods:</u> This will be an important theme in the future learnings in the local flexibility markets and in the dialogue of flexibility service providers.

3.4.4. Further reading

A dedicated CoordiNet report, D4.3.2 [32] covers developed and deployed machine learning software for Customer load Forecasting and Grid state forecasting. D4.6 describes the implemented baseline used as default in the market platform, as well as FSP possibilities to upload their own calculated baseline, in the form of a production/consumption plan.

Within the Swedish demonstration both a commercial forecast service provider was used (Gotland and Uppland) as well as academic partner (Skåne) providing only the methodology with the machine learning and process implemented within the flexibility platform tool itself. The experience with these two very different approaches for implementing forecasts are included in the lessons learned report, D4.5 section 5 [28].

3.5. Realisation of flexibility market: Market platform and flex tool



The CoordiNet platform can be divided into four parts based on their respective user groups:

1. *A DSO interface/flex tool for visualisation of actual and forecasted grid loads in congested areas:* This tool is utilised by the grid operators of all Swedish CoordiNet DSOs in order to act more

proactively and to see when and how much flexibility to buy and activate. An algorithm providing the grid operator with recommended actions has also been implemented in the platform. A communication connection with the TSO has been integrated, which enables the DSO grid operator to send requests about temporarily increasing the agreed subscription limits (maximum allowed load).

2. *A market tool enabling trading between DSOs and flexibility service providers has been developed and launched:* This market interface supports continuous trading which allows the relevant market operator to set up its own market rules regarding trading windows. Furthermore, the platform ranks and matches the orders according to a merit order. It is also possible to apply an "impact factor" to the orders which then enables the DSO to procure flexibility located in the correct position in the grid topology to relieve the relevant congestion. The market platform is integrated to the TSO marketplace for frequency regulation (mFRR). The market platform allows for data extraction which is useful for e.g., invoicing and follow-up.
3. *An interface for FSPs to send and schedule flexibility orders and baselines:* This interface is integrated with the market tool and allows for the FSP to see their current and historical meter readings as well as matched orders and order history. The FSPs can also export this data and connect to an API allowing an automated way of sending orders, meter values and baselines.
4. *A market platform for Peer-to-Peer trading:* This enables the DSOs to introduce grid bottlenecks due to e.g., maintenance in the grids. The introduction of a bottleneck creates a market where the affected power consumers and producers can trade capacity between themselves.

3.5.1. Market and operator platform for congestion management

The market platform is designed by an in-house team at E.ON with requirements placed by E.ON, Vattenfall and the DSO on the island of Gotland, Gotland Energi AB (GEAB), which is a subsidiary of Vattenfall.

In the market platform three different roles are defined:

- Owner – can create/purchase bids and do limit organisation administration.
- Contributor – can create/purchase bids.
- User – view only.

As shown in figure 3, users are tied to organisations which are either a FSP who own flexibility resources, or a DSO associated with substations. It is possible for users to belong to multiple organisations with different user roles. However, a single organisation cannot act simultaneously as a DSO and FSP in the same market. The markets are defined using the impact factors (by ENTSO-E called power transfer distribution factor) which indicate the change of power flow in a substation caused by the resources changed power output[2].

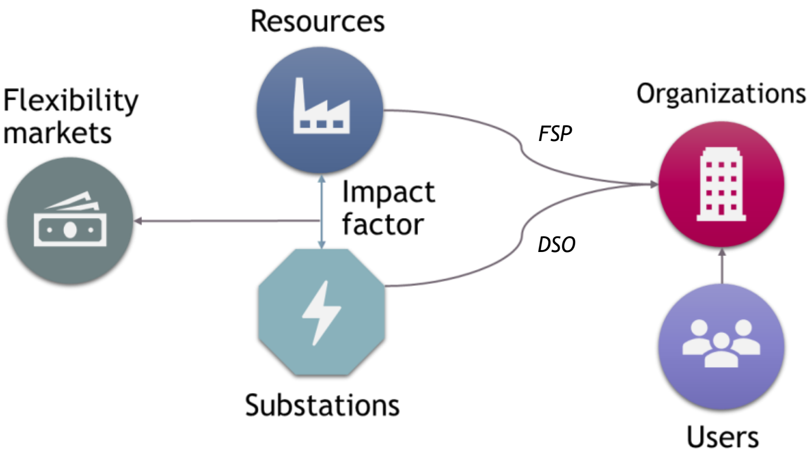


Figure 36: Schematic overview of main platform entities and their relations

[2] For a description of impact factors, see D4.1 section 4.2.3.

The boundaries of markets are structured around where the substations are geographically and the resulting grid topology. If a resource has a calculable electrical impact on a substation, it has the potential to participate in a market. The price of the market bid will then be divided by the impact factor to achieve the cost per MW of changed power flow in the substation which is used in the merit order list. To cater to the dynamic nature of power distribution the impact factors are defined as a time series that can be updated hourly, even if they static impact factors representing high consumption flow patterns were used in the demonstrations.

The market platform in the Swedish CoordiNet demonstration can conceptionally be divided into two parts:

1. A market tool that manages flexibility bids and performs final market clearing.
2. A flex tool which calculates the weighted (after impact factor/ PDTF) merit order list and recommends an optimal purchase to solve grid congestions

These two tools are integrated into CoordiNet but can conceptually be separated (as is the case in the CoordiNet inspired sthlmflex market in Stockholm, where the market tools are the external Nordpool owned trading platform while the flex tool is the same as in CoordiNet).

The flex tool component of the market platform integrates with the TSO tool called SUSIE that is used by Swedish TSO to request temporary subscriptions. The market tool has a link with mFRR market platform to forward unused bids of resources that are prequalified for TSO mFRR market. A simplified overview of the components of the market platform is shown in Figure 37.

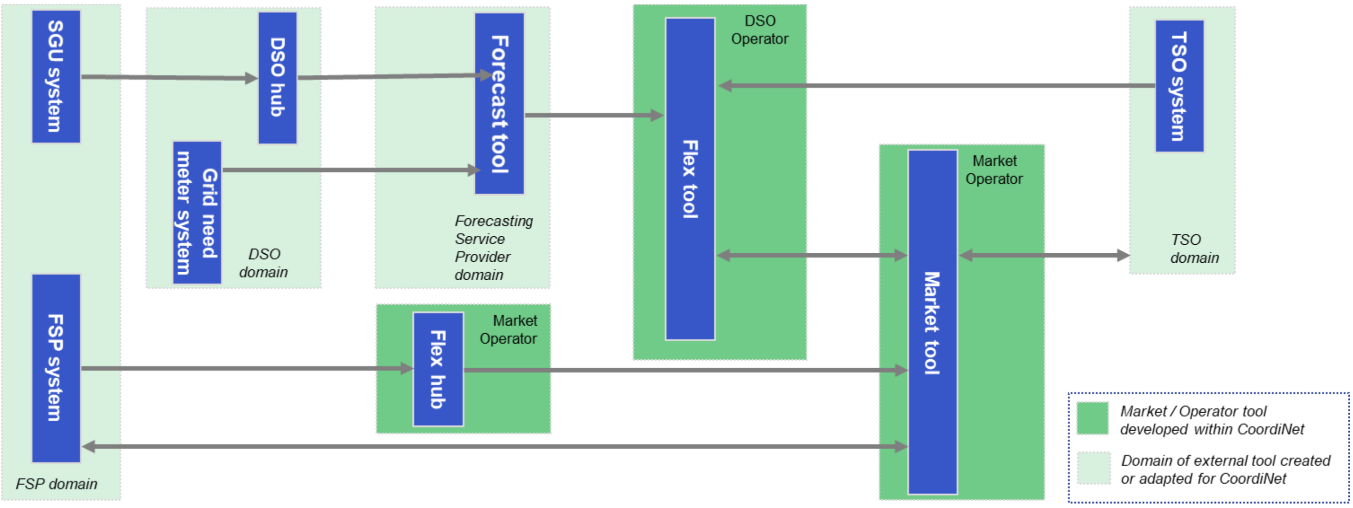


Figure 37: Components of CoordiNet market and operator platform

Once a DSO operator detects a subscription violation, whether forecasted or imminent, they can use the flexibility market tools to manage the congestion. Depending on the status of the regional the first option is to apply for a temporary subscription. If there are multiple substations that need temporary subscriptions the manual handling can be cumbersome or even complex, so the flex tool features a functionality for getting a configurable recommendation based on the load forecast, see Figure 40.

To increase market transparency and user convenience, a common trading overview was also implemented as a page that both FSP and DSO organisations could access. It shows all available orders for a selected day, listed per hour and ranked according to merit order.

3.5.2. Market platform for peer-to-peer market

A Peer-to-Peer trading platform has also been developed. This enables the DSOs to introduce grid bottlenecks due to e.g., maintenance in the grids. The introduction of a bottleneck creates a market where the affected power consumers and producers can trade capacity between themselves. Block-chain is used to document all transactions and metering values required for validation of delivery.

3.5.3. Interfaces

Information exchange for TSO-DSO coordination activities, approaches and solutions is shown in Figure 38. The IT-architecture and model of interactions with the market platform is provided in an annex of D4.1 [1] with section 5.4 of the same report presenting the business, function, information communication and component layers according to the IEC 63200Smart Grid Architecture Module, often referred to as SGAM.

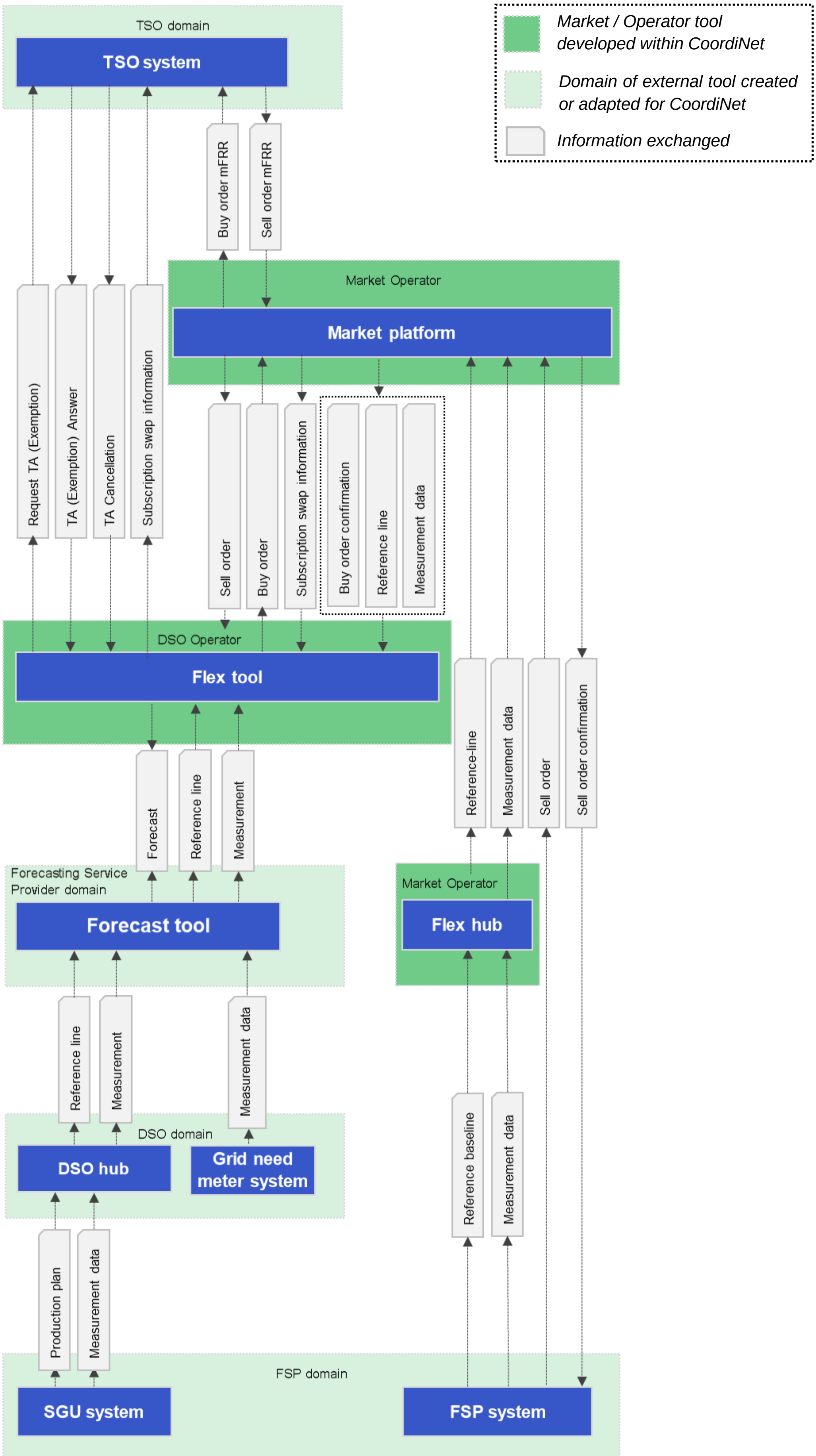


Figure 38 Information exchange between external systems and CoordiNet market and operator platform

3.5.4. Message specification using CIM IEC 62345 information model

The increased dialogue between TSO and DSOs in the CoordiNet project has led to discussions and enhance cooperation and innovation that has reached beyond the envisioned deliveries in CoordiNet. A joint TSO, DSOs and market platform operators project to define business requirements specifications and IEC 62325 CIM mapping for regional flexibility markets in Sweden was initiated. Common work on the first version of a national product catalogue for flexibility services has started spring of 2021 with its first draft delivered in 2022.

Within the national project for standardisation of flexibility product definition it was decided to define information exchange using the IEC 62325 common information model (CIM). FSPs offer flexibility services to multiple markets both in Sweden and abroad. In order to reduce the barrier of entry for FSPs, a standardised way of offering, purchasing and validating flexibility was essential. The spin-off market and sthlmflex project asked third party consultant firm to assist in standardising the interface and communications between platforms, based on the Common Information Model (CIM) as defined by IEC 62325. Input was provided during 2021 by participating DSOs and TSO, by the external market platform provider used in sthlmflex, NODES, and by E.ON Energidistribution as developer of DSO operator tool (which was the same tool as used within CoordiNet).

Starting with the CoordiNet actors and roles these were linked to the Harmonised Electricity Market Role Model, developed by ENTSO-E, ebIX® and EFET. The work continued with definition of business use cases (BUC). Based on the identified BUCs, sequence diagrams were created to understand the digital documents exchanged between the systems used by different actors and roles in the market. As a final step the digital documents that had the highest update frequency were selected for mapping from existing, proprietary formats to CIM. Based on this mapping the relevant CIM ontology was identified.

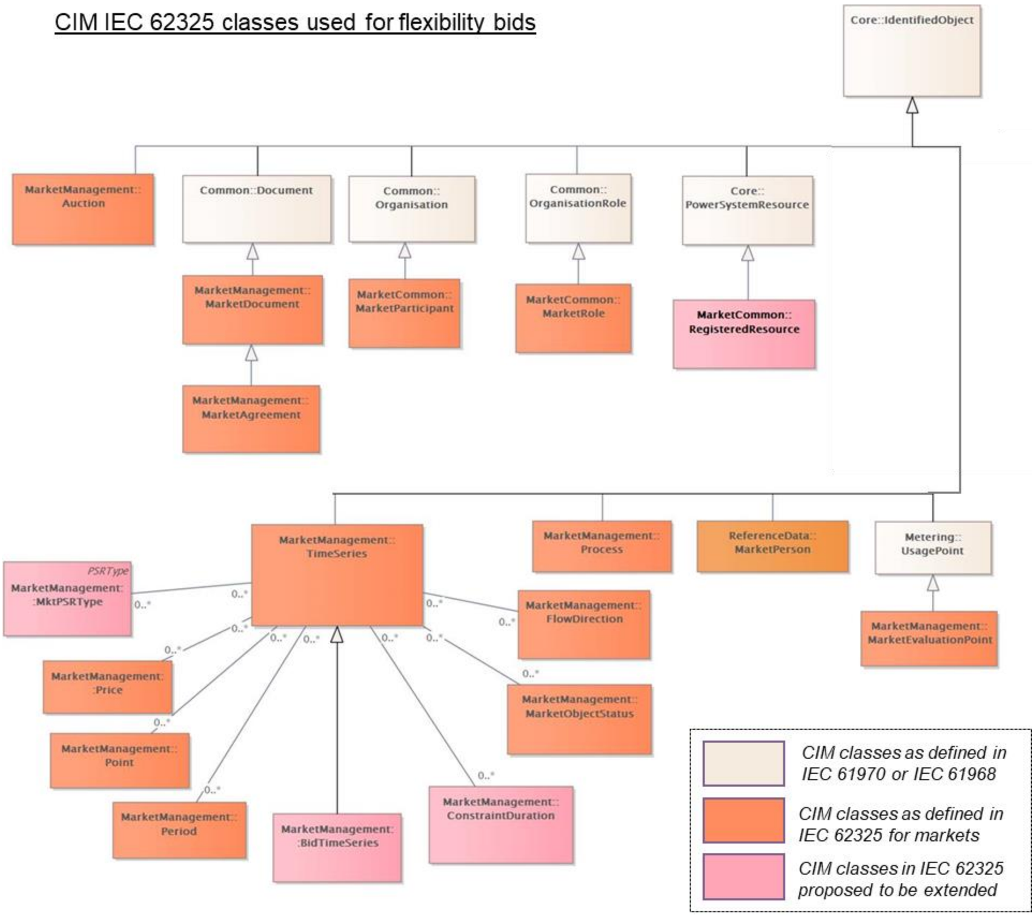


Figure 39 Market message information proposed for flexibility bids in Swedish national product definition using CIM (IEC 62325)

3.5.5. Further reading:

The market platform will continue to be used for flexibility trading but also to be integrated with other platforms, such as Nodes within Sthlmflex and TSO markets. Automation is also expected to increase, which is necessary to support the integration of intermittent power generation that requires new and more advanced tools for participating actors.

The Swedish demonstration strived for an iterative approach with modifications of products and market rules for each winter season. The main changes made based on the FSP initial response were:

- Additional incentives and remuneration models were requested and subsequently introduced, such as firm bid agreements or that a DSO could create buy orders that FSPs could fulfil. This helps mitigate the economic uncertainties associated with a mild winter where the demand for flexibility is lower than expected.
- There was a need for more dynamic bidding, e.g., an asset is available for clearing during a fixed number of hours but flexible on start time within the day. The FSPs reasoned this would enable them to offer additional flexibility in the market. The market platform was modified to include more advanced bid strategies. However, the additional possibilities for the construction of bids did also come at a price of complexity and needs to be further evaluated.
- Additional methods for estimating a baseline from which delivered flexibility were calculated.

The full list of developed platform functionalities can be found in CoordiNet report D4.6 [25]. Insights to the iterative development of the tool can also be gained from previous reports on platform development in D4.2.2 [26]. Those specifically interested in the block-chain implementation for the peer-to-peer market are referred to [27]. Experience from operation of the market and DSO flexibility tools can be found in D4.5 [28] and D4.7.1 [29].

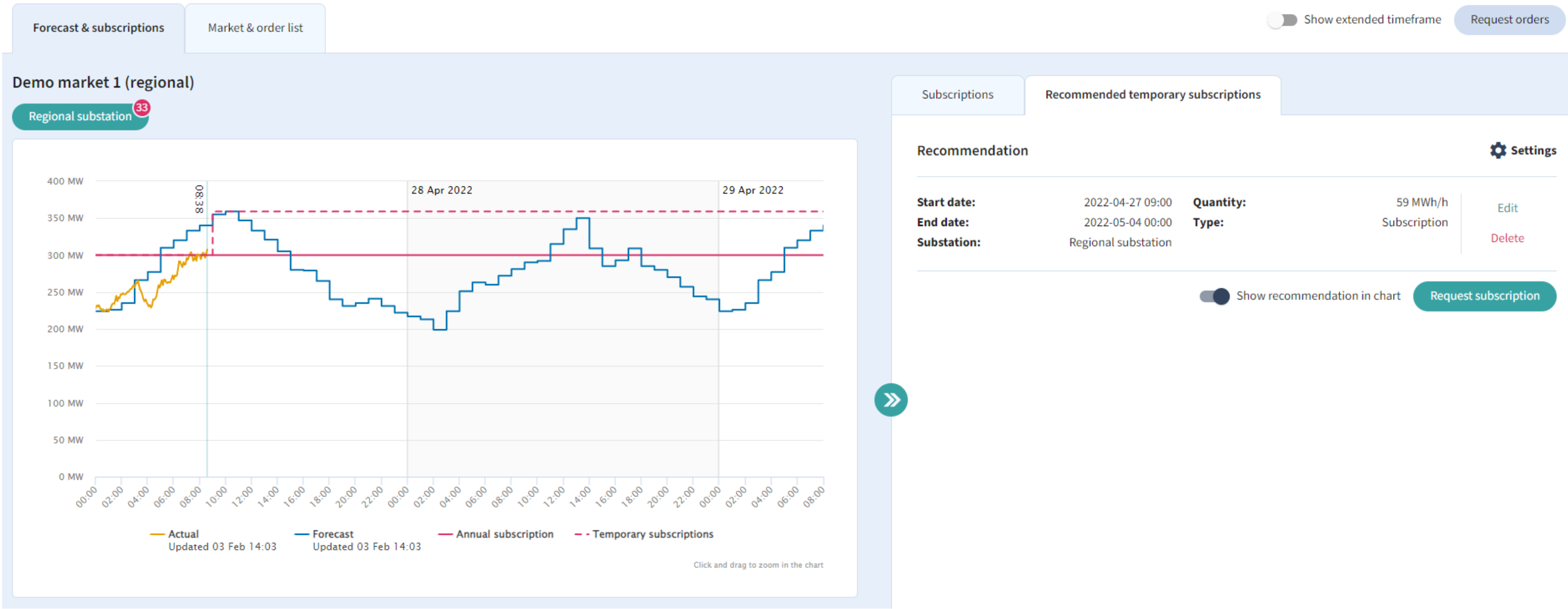


Figure 40: DSO operator view with visualisation of substation data: Forecast (blue), measured power (yellow), subscription level (solid red) and recommended subscription rise (red dotted). In case of forecasted violations of the subscription limit, a counter (with value 33 in above figure) will display the number of forecasted overruns for the relevant substations during the current and next days (48 hours in total).

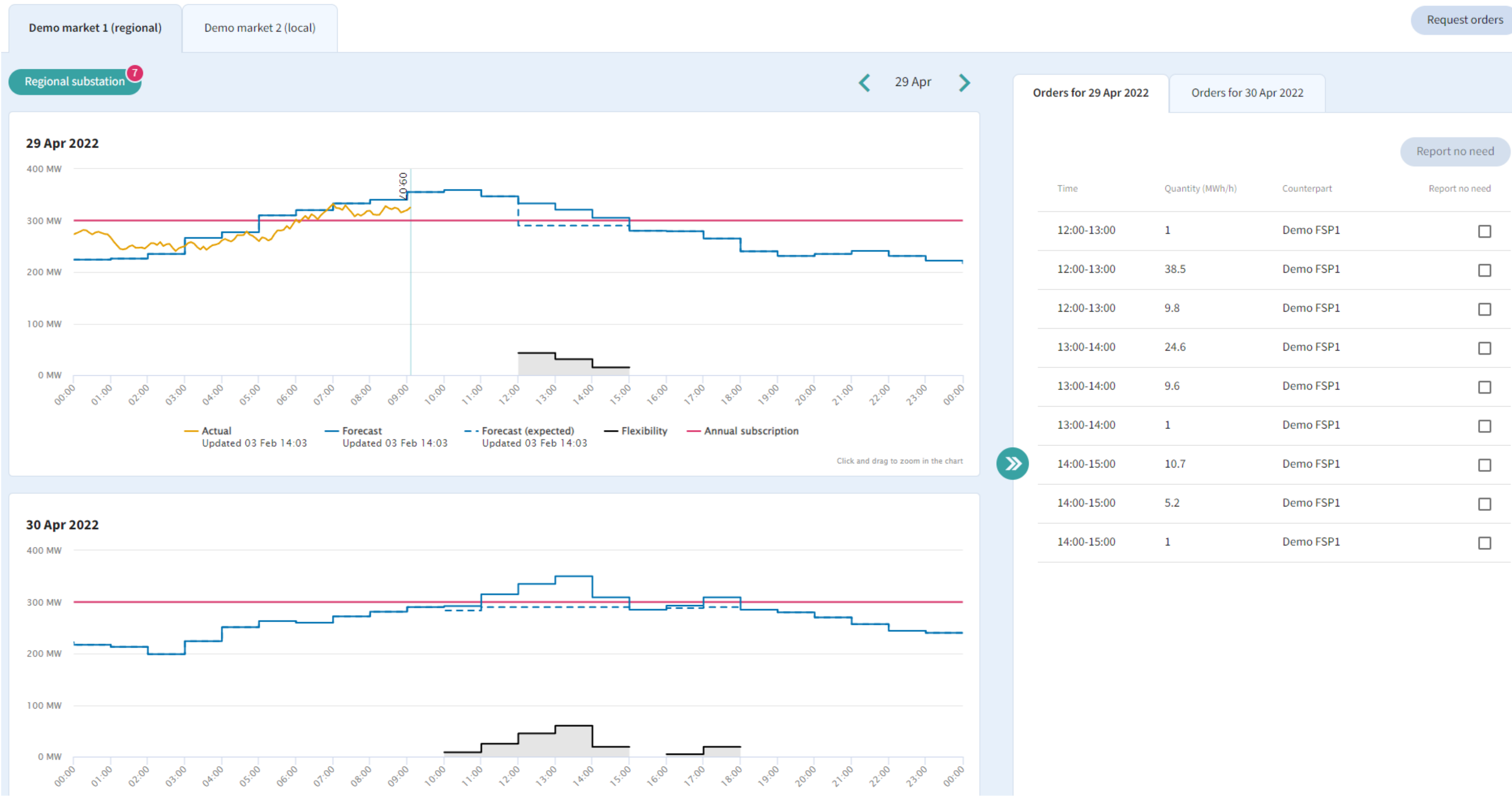


Figure 41: DSO substation monitoring after clearing of flexibility, visualising expected outcome of flexibility deliveries. The operator can also select 'no need' to renders the flexibility as no longer required and send a customised email message directly to the FSP.

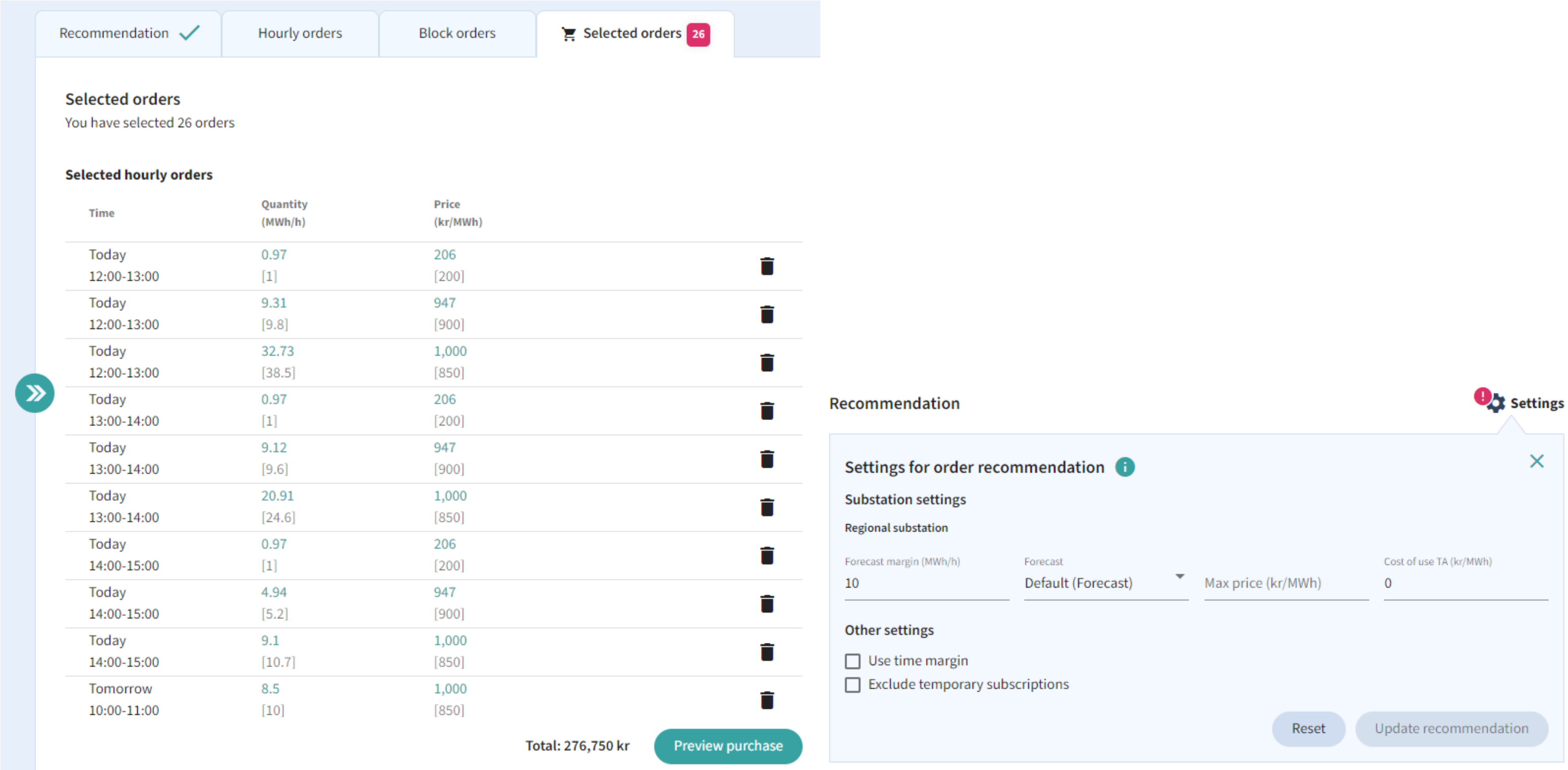


Figure 42: Once the selection of flexibility orders has been made by the platform (according to merit order list), the operator can preview and then finalise the purchase (left). Individual orders can also be removed with the trashcan icon, if e.g., operator has knowledge of an asset's unavailability. Settings for DSO allow to add a margin to the forecast values to hedge against errors, change forecast (e.g., for intraday instead of day-ahead); set a maximum price for the flexibility (right).

Figure 43: Main view of FSP home page, visualising available real-time and baseline data for resources, as well as any upcoming deliveries.

My orders

Order date ↑	Remaining quantity (MWh)	Sold quantity (MWh)	Cancelled quantity (MWh)	Unit price (kr/MWh)	Buy/Sell	Asset	Delete
2022-04-23 07:00 - 2022-04-23 08:00	5-10	0	0	900	Sell	Demo consuming asset 3	✕
2022-04-23 07:00 - 2022-04-23 08:00	28-28	0	0	5,000	Sell	Demo producing asset 2	✕
2022-04-23 07:00 - 2022-04-23 08:00	4-4	0	0	10,000	Sell	Demo producing asset 1	✕
2022-04-23 07:00 - 2022-04-23 08:00	10-20	0	0	2,500	Sell	Demo consuming asset 2	✕
2022-04-23 07:00 - 2022-04-23 08:00	1-1	0	0	200	Sell	Demo producing asset 3	✕
2022-04-23 07:00 - 2022-04-23 08:00	10-55	0	0	850	Sell	Demo consuming asset 1	✕

Items per page 10 131 - 140 / 148

Figure 44: Overview page for Flexibility providers with list of sell orders created

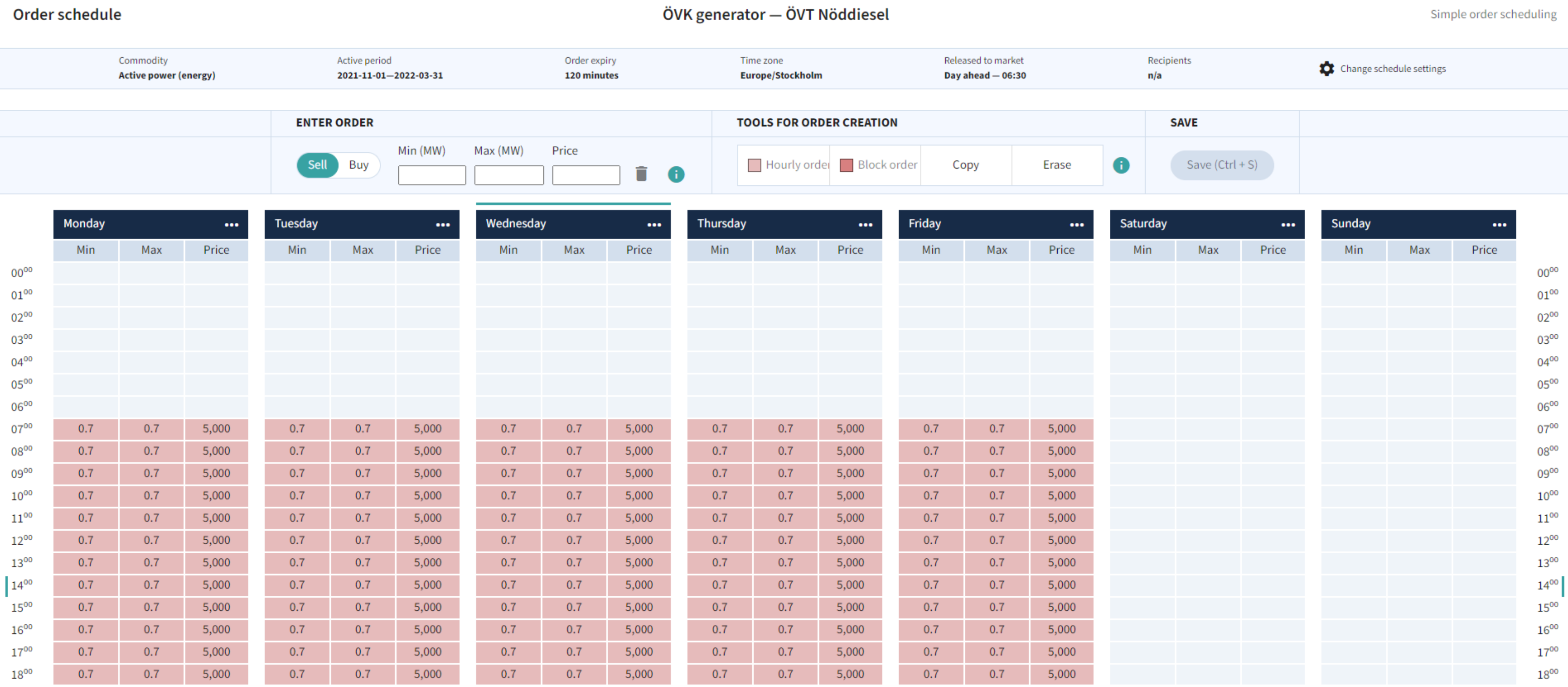


Figure 45: Scheduling sell orders for weekly recurrence (prices in SEK/MWh). Expiry time for each order is configured in a schedule, allowing for various coordination schemes. The orders themselves are typically generated in the morning for day-ahead trading but could also be created week-ahead and on specific days. In this example the FSP can sell the same amount of power for 07:00 to 20:00 on Monday through Friday each week. The schedule will generate orders daily until the activity period end date is reached (31st of March).

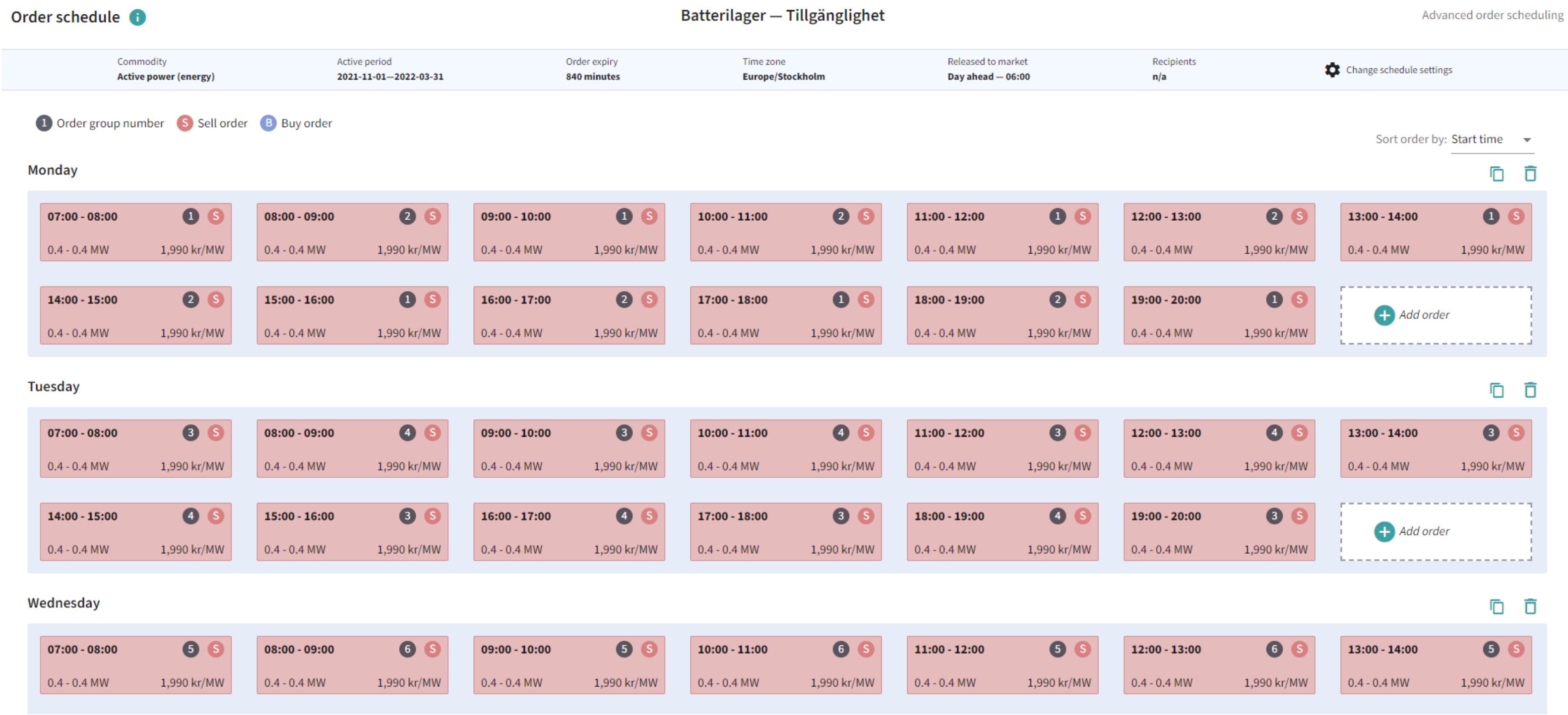


Figure 46: Grouped sell orders on advanced scheduling page. In this example a 1 MWh battery with 0,48 MW peak power can offer production (i.e., battery discharging) for two hours at a time, The order groups allow the DSO to clear any two consecutive hours. The matching of any order in a group will remove the remaining orders of that group from the market, reducing the risk of a grid operator buying flexibility that the FSP could not deliver.

To increase market transparency and user convenience, a common trading overview was implemented as a page that both FSP and DSO organisations could access. It shows all available orders for a selected day, listed per hour and ranked according to merit order (from lowest to highest price), as in figure 9 below.

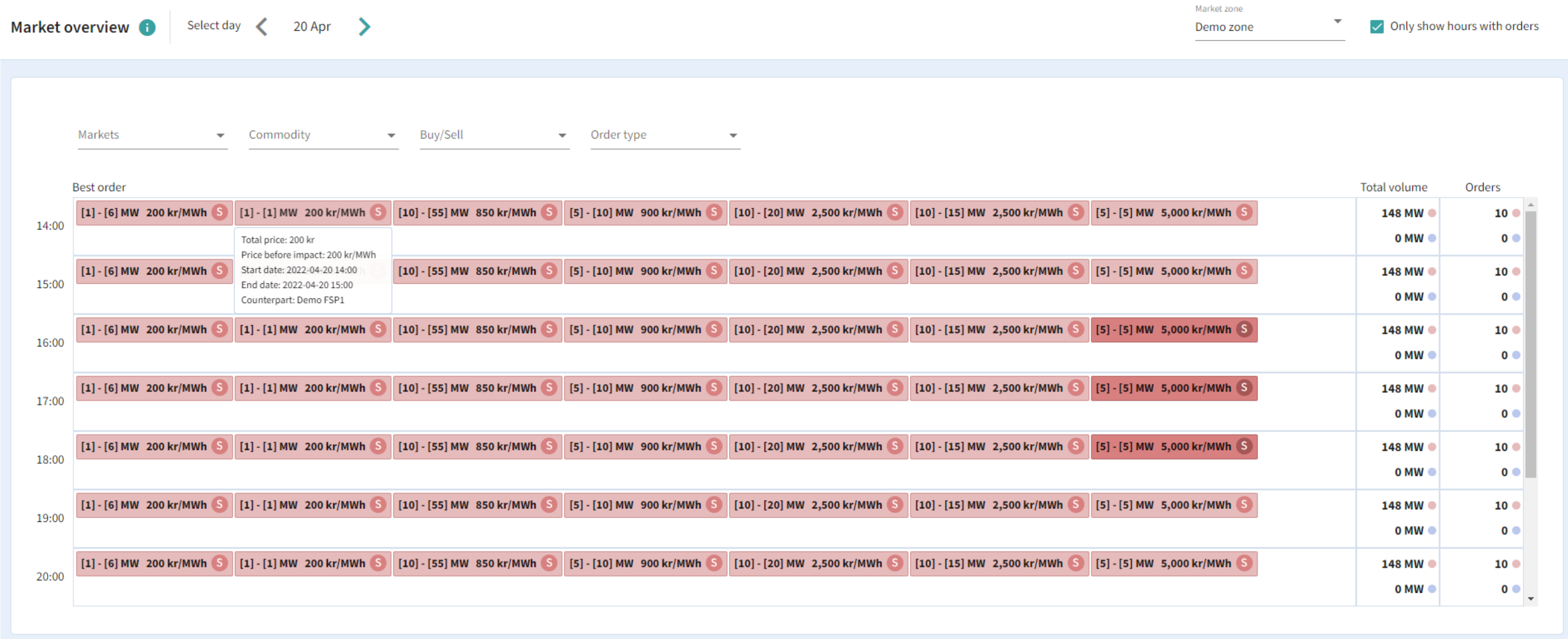


Figure 47: Market overview with ranked sell orders

To provide platform users with an overview of aggregated trading data, a statistics page is available, as shown in Figure 48 right.

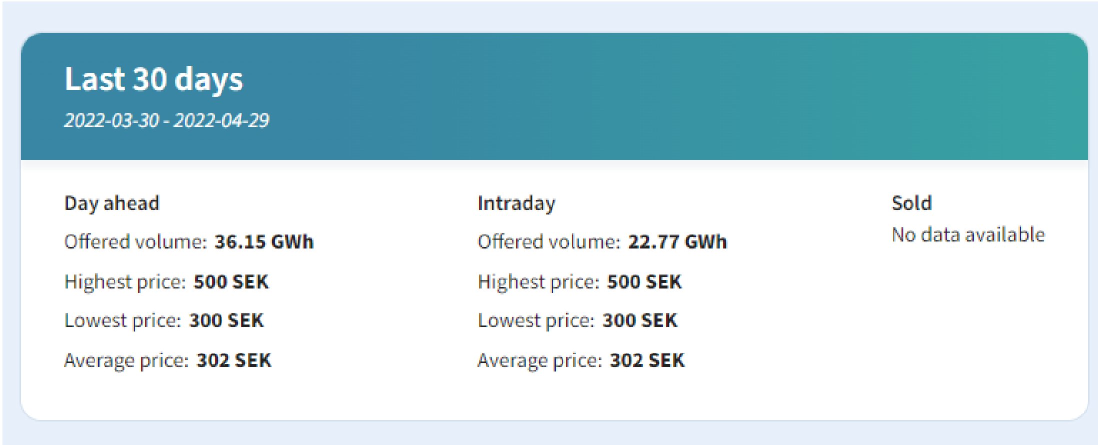


Figure 48: Monthly statistics for a market zone with price levels and volumes (example data from demo markets)

Ex-post analysis of delivered flexibility is available. The baseline is defined as the power consumption or production if no flexibility is bought or activated. The deliveries are validated by comparing this baseline with metered data and order matches, as shown by the right most column in figure 31.

Transaction time ↓	User	Quantity (MWh/h)	Unit price (kr/MWh)	Total price (kr)	Buy/Sell	Start date	End date	Asset	Counterpart	
2022-03-25 10:22	OC#48#ngenic_lkf	0.11	1,000	110	Sell	2022-03-26 08:00	2022-03-26 09:00	LKF aggregat	E.ON Energidistribution	100 %
2022-03-24 09:45	OC#48#ngenic_lkf	0.14	1,000	140	Sell	2022-03-25 07:00	2022-03-25 08:00	LKF aggregat	E.ON Energidistribution	83 %
2022-03-24 09:45	OC#48#ngenic_lkf	0.14	1,000	140	Sell	2022-03-25 17:00	2022-03-25 18:00	LKF aggregat	E.ON Energidistribution	81 %
2022-03-23 10:09	OC#48#ngenic_lkf	0.17	1,000	170	Sell	2022-03-24 07:00	2022-03-24 08:00	LKF aggregat	E.ON Energidistribution	84 %

Figure 49: History of purchases for aggregated heat pumps in March 2022, with delivery percentages. The baseline used for the evaluation of the delivered flexibility can be selected per resource. It can either be the planed consumption/production delivered by the FSP or the

4. Market outcome

Besides the ten key abilities, developed platform and products covered in Chapter 3 the results of the CoordiNet Swedish demonstration reside in the learnings from three winters open, non-discriminatory, calls to contract flexibility. This chapter covers the demand and supply on flexibility markets for congestion management. Section 4.1 presents the factors influencing the DSO demand for flexibility to mitigate congestion while section 4.2 covers the supply of flexibility on the market, i.e., the markets liquidity. Demand and supply meet in a market price covered in section 4.3.

4.1. Market Demand: Factors influencing DSO need for flexibility

The major factor influencing the amount of flexibility the DSO requires in the Swedish flexibility market for congestion management is the average ambient temperature. This temperate dependence of Swedish electricity consumption is largely due to extensive use of heat pumps and other electricity-based sources for spatial heating. Thus, congestion is largest during the wintertime. The winters differ; there are warm, cold and very cold winters (ten-year winter). While some metrics can be directly compared between winters, like number of active FSPs and available MW of flexibility, comparison of other results between winters is dubious due to the strong temperature dependence of load in the Swedish grid. It is therefore important to keep in mind the weather characteristics of each winter when comparing results, as seen for Uppsala in Figure 50, the number of hours below -5°C can in Uppland varies from 3% to 36% of the total hours between November to March:

- The first CoordiNet winter in 2019/2020 was the warmest on record with few and relatively short colder periods.
- The second winter started mild but had a strong cold spell in February 2021, during which flexibility on the market was insufficient to meet congestion needs.
- The third winter was the coldest of the three, with the most hours below 0°C. However, the electricity prices skyrocketed and became on average 3-4 times higher than the previous winter which reduced FSP resource usage and hence availability of flexibility from some significant grid users.

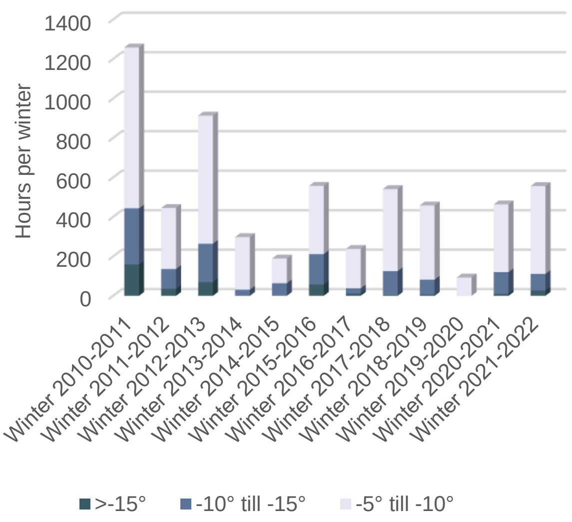


Figure 50 Number of hours below <5°C for the last 12 winters in Uppsala. The percentage of hours below -5° varied from 3% to 36% of the hours between November and March.

The impact of cleared flexibility on the power flow of a grid can be shown in multiple ways. One way is to compare the power outage per hour with the permissible power, here the TSO subscription limit (see Figure 51). This shows for a four-week period during the first CoordiNet winter how cleared flexibility contribute to keeping the subscription limit, with only small violations (red circle) due to forecast error or difficulty for FSP to deliver cleared flex. Larger surpass of subscription may occur in days with insufficient market bids, such as was the case for Feb. 14th in Figure 51.

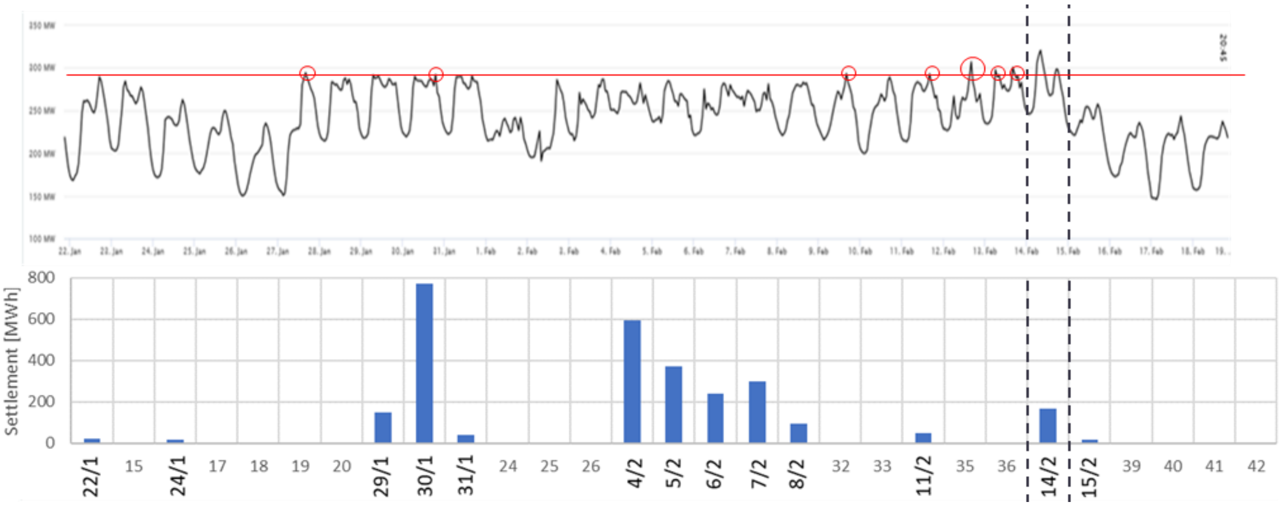


Figure 51: Cleared volume of flexibility in Uppland (top graph), forecast (middle) and the measured sum of power flow at the two regional DSO and TSO connection points (bottom). The period from 22nd January to 19th of February 2020 is shown.

To quantify the demand for flexibility in a market a good tool is the duration curve. A duration curve orders all hours of the year according to the power flow. This highlights the number of hours the flow is near or above a specific level. By applying different "what if" scenarios and calculating e.g., the theoretical flow without cleared flexibility how much of the congestion that was mitigated by the market. The duration curve is exemplified for Uppland in Figure 52. The markets need for flexibility was between 114 to 329 hours (out of 3624 in a winter). This is the number of hours when the power flow, measured in MWh per hour, is over the TSO subscription limit. From the left-most part of the duration curve in Figure 52 can be seen that:

- The first winter of 19/20 in Uppland had 140 hours when power flow, without cleared flexibility, would have been above subscription limit with a peak at 114% of the annual subscription limit. The total flexibility demand of 1711 MWh)
- The second winter of 20/21 in Uppland had three times as many hours when flexibility was required as the first (329 hours) albeit roughly the same peak demand (118% of the annual subscription limit). The total flexibility demand was roughly three times higher 4 941 MWh)
- The third winter of 21/22 had the highest peak demand (128% of annual subscription limit) despite the lowest hours of required flexibility (114 hours). The total DSO demand of flexibility in Uppland was therefore only slightly higher than the first winter (2 345 MWh)

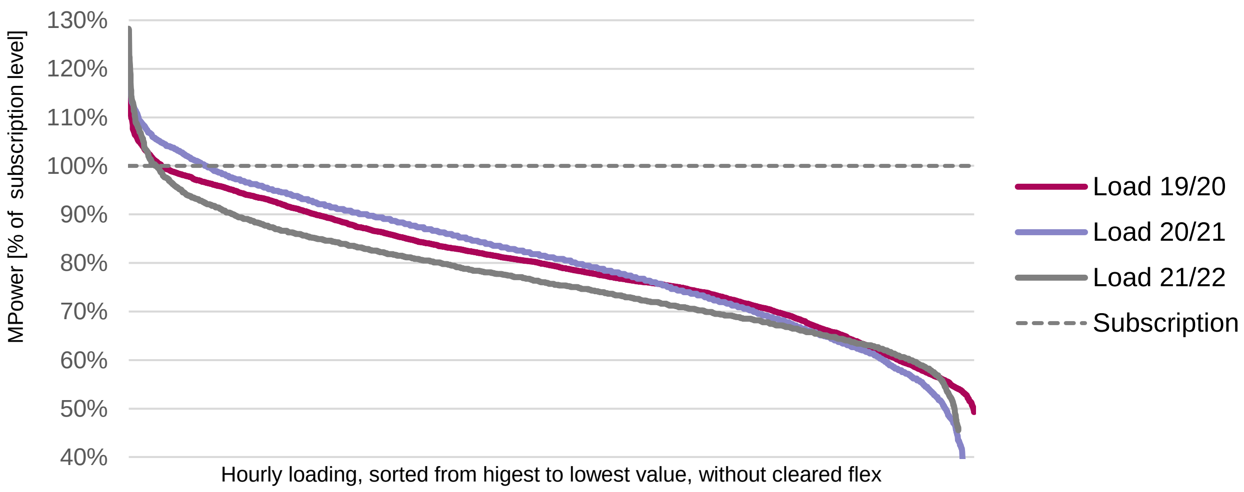


Figure 52 Duration curve for Uppland for the months of Nov. to March for winters 19/20, 20/21 and 21/22. (All hours recalculated to represent flow without cleared flex.)

Looking at the most loaded hours in the duration curve the effect of cleared flexibility becomes visible. In Figure 53 an excerpt of the duration curve is provided for Uppland in the second winter showing the 300 hours with the highest power flow. In Figure 53 the decrease power in the hours with most congestion is visible (volume 2). This is the fraction of the cleared flexibility of 2,54 GWh that contributed to reduction in subscription surpass. The remaining power outtake above the subscription limit (volume 1) can be split into two volumes indicating what the flow could have been if also available but higher-priced flexibility had been cleared in a situation where temporary subscription increase had been denied by TSO (volume 1a).

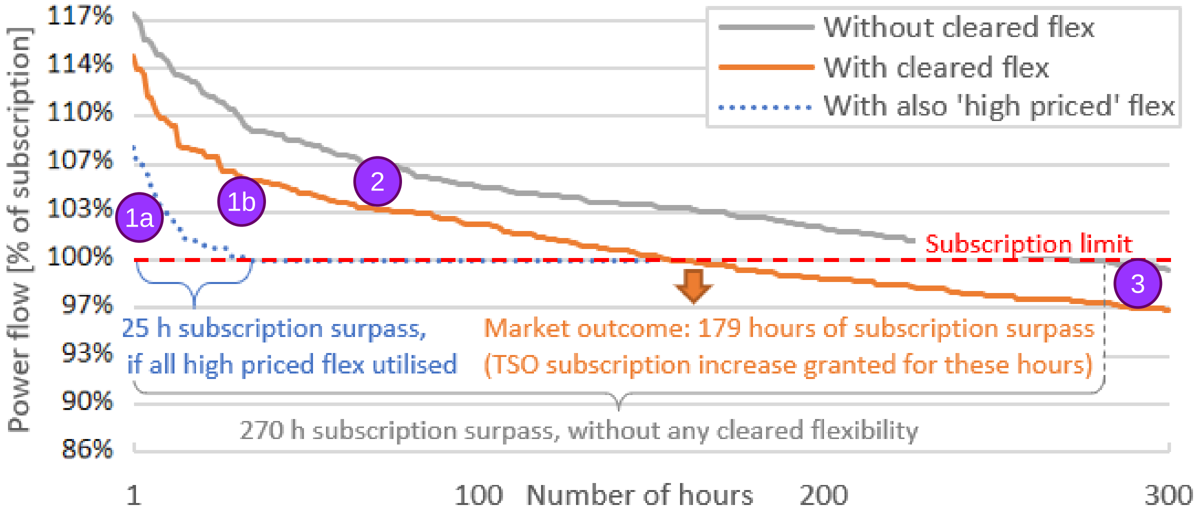


Figure 53 Load Duration curve for winter of 2020/2021 at the two TSO connection point for Uppland demonstration.

Acting primarily day ahead that forecast error implies that the amount of flexibility needed to ensure subscription is not violated is not known exactly. Therefore a "security margin" (volume 3 in Figure 53) is required. This can be seen as the flexibility volume needs to be cleared to ensure 1 MW of subscription surpass. For the winter of 20/21, this number was 1,6 MW to avoid 1 MW congestion. This decreased from the first winter when just over 2 MWh of flex needed to be cleared to mitigate 1 MWh of subscription surpass.

4.2. Market supply: liquidity

A finding from the third and final winter of 2021/2022 was that utilisation of some flexibility resources is dependent on energy prices and their flexibility may therefore not be available in times of high electricity prices, albeit they will not either contribute to surpass of subscription level. For the last winter, the availability of low-cost flexibility diminished. To understand this decline in market liquidity, it is required to also analyse the electricity price, whose average hourly spot market price more than tripled for the last winter (116 SEK/MWh on average in Nov. 2021 to Mar. 2022, compared to 39 SEK/MWh in 20/21 and 28 SEK/MWh in 19/20, see Figure 54). In Skåne, in another price zone more susceptible to continental European electricity prices the increase in wholesale electricity price was even greater.

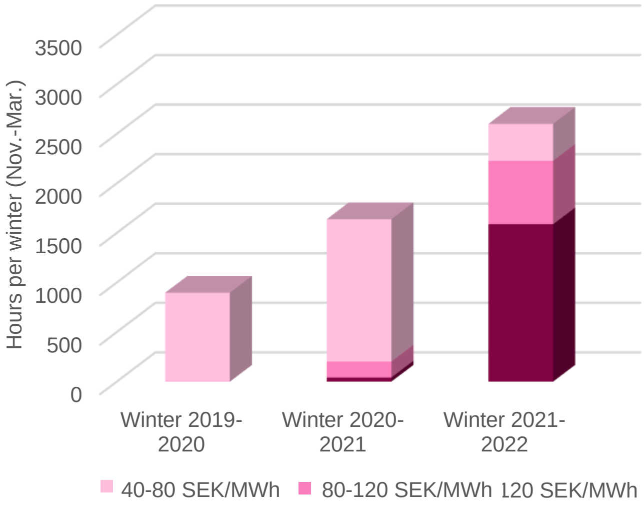


Figure 54 Hours with high electricity prices for the three CoordiNet winters. Spot market prices for SE3 from Nov. To March. (The rest of the 3624 hours per winter are priced below 40 SEK/MWh.)

Table 8 shows that the main flex resources in Uppsala (an electric boiler of the district heating company) used 1/3 of the hours of the previous winter. It was used only night-time when electricity prices remained at 20/21 and 19/20. Due to the correlation between energy price and consumption, the boiler was not used during any of the 114 hours surpassed of the subscription limit. Hence only smaller flexibility providers were present. High priced flexibility did exist with more than 24-27 MW the hours, but it was not profitable for DSO to clear as TSO granted temporary subscription on all occasions, see Annex A for further explanation).

Table 8 Comparison of electricity price when the electric boiler was used

Winter	Hours used (>1 MWh/h)	Hour's electricity price <35 SEK/MWh	Av. Electricity price Nov-Mar
19/20	>1500*	2179	28 SEK/MWh
20/21	1527	1641	39 SEK/MWh
21/22	522	950	116 SEK/MWh

** Data only available Jan-Mar 2020. Usage Jan.-Mar 20 was 995 h compared to 821 h for same months in 2021*

During the first winter in 2019/2020, the liquidity of the flexibility congestion management market was lower than hoped. Many FSP underestimated the effort and time to provide flexibility and several FSP bided less often than hoped. For the winter 2020/2021, a considerable task was to get the FSPs to more regularly supply bids, as well as reaching out to more FSP to participate. Participation from more flexibility providers as well as more bids was achieved for the second winter of 20/21. For the final winter of 21/22 the number of bids from smaller actors was largely maintained (see report D4.7. [19]), even if the volume of cleared bids dramatically decreased in all markets.

CoordiNet report D1.3 [34] recommends that market designs are evaluated against certain criteria such as market liquidity. Liquidity is a measure of the ability to buy or sell a product – such as electricity - without causing a major change in its price and without incurring significant transaction costs. An important feature of a liquid market is the presence of many buyers and sellers willing to transact at all times [35]. The best measure of liquidity is the number of bids available to purchase. When evaluating the available bids, it is important to distinguish between two different price levels corresponding to two different business cases. One for peak-shaving when it is cheaper than the overlying subscription cost and one for peak-shaving when the grid situation in unnormal. This is referred to as low and high price bids. A complicating factor in the evaluation is the fact that some FSP's place bids only after communication from the buyers that bids are needed.

In the case of small local markets, like in the Swedish flexibility markets for congestion management, there is a risk of high market fragmentation which could limit liquidity [34]. For congestion management ENTSO-E champions the notion of a common bid submission and coordination process to optimise market participation and market liquidity. ENTSO-E further recommend that market design should strive to minimise the number of different bidding processes and non-coordinated products and achieve maximum liquidity, considering system requirements, technical capabilities and commercial interest of the providers, for example [36]. Likewise, The TSO wants to increase the liquidity of the balancing market [37].

Within the Swedish demonstrator, a key goal was to have many FSP bidding frequently on the market. Considerable investments have been made by DSOs in stakeholder interactions, streamlining processes and simplifying contracts to make "on-boarding" of potential FSP. The goal is to encourage new and existing market stakeholders to take up the role of flexibility provider, thus ensuring market liquidity. The driving concept behind the cascade model of the market and the market biding developed has been to provide simplicity. Forwarding of bids to mFRR is developed as a free of charge service to make the participation in local markets more attractive and hence increase liquidity on also the local markets. Further efforts to increase liquidity have allowed technical trials with as wide as a possible source of different flexibility resources.

As identified in CoordiNet D1.3, a key advantage of an integrated market, overarching the TSO, DSO and commercial parties, is the potential to reach high levels of liquidity. High liquidity can be expected since multiple buyers and high volumes of providers of flexibility are participating in a single market. Furthermore, owners of flexibility do not have to go through an extensive decision process to assess the most optimal market platform to provide their flexibility. More competition on the seller-side of the market generally results in a more efficient market operation and a more optimal market equilibrium [34]. That said, the primary goal of the Swedish flexibility markets for congestion management coordination scheme is the set-up of correct arrangements to guarantee an efficient market operation for DSO grid needs coordinating with existing markets – all in a manner that is technically feasible today. In Sweden, the existing flexibility providers mainly exist in rural areas. The DSO grid needs occur in urban cities where there is no existing flexibility from TSO markets to share with DSO grid needs.

Despite the above-described measures to increase liquidity of the flexibility market for congestion management it became apparent availability compensation would be required. With the threefold variation in both number of hours flexibility is required and volume of DSO flexibility demand from winter to winter an energy only market for congestion management (as proposed by the European Commission) is questionable. Flexibility providers requested a more predictable source of income to make the commitment required for the DSO to be able to count on flexibility for network planning. As experienced in the third and final winter not only the DSO demand varied considerably, but also the flexibility providers' supply. The solution introduced first in the Skåne markets for the second winter was availability contracts described in section 3.1.2 and further described in D4.7.1 [19].

4.3. Market price: intersection between demand and response

According to basic economic theory demand and response meet on a market price. During the three winters of the CoordiNet project two distinct combinations of price and volume emerged. The two combinations of price and volume can be seen in Figure 55. With flexibility available below the MWh fee when temporary subscription is approved (240 to 280 SEK/MWh depending on TSO connection point) large volumes will be procured, if available. This is the case for Uppland in the far right of Figure 55. In such a market, congestion be relieved further with some high-priced flexibility resources, like reserve power, that were present on the market for the 2nd and 3rd winters. However, since a temporary subscription increase was granted by TSO on all occasions during the winter, there was no economic incentive on behalf of the DSOs to clear such high-priced flexibility.

With only high-priced flex (in parity with the 2800 SEK/MWh penalty for going over subscription level when TSO does not permit a raise, smaller volumes are procured (Skåne, Gotland and most other compared congestion management markets in Figure 55). The market situation becomes different, and the DSO will only buy flexibility when the TSO denies temporary subscription increase. This results in small volumes of high-priced flexibility.

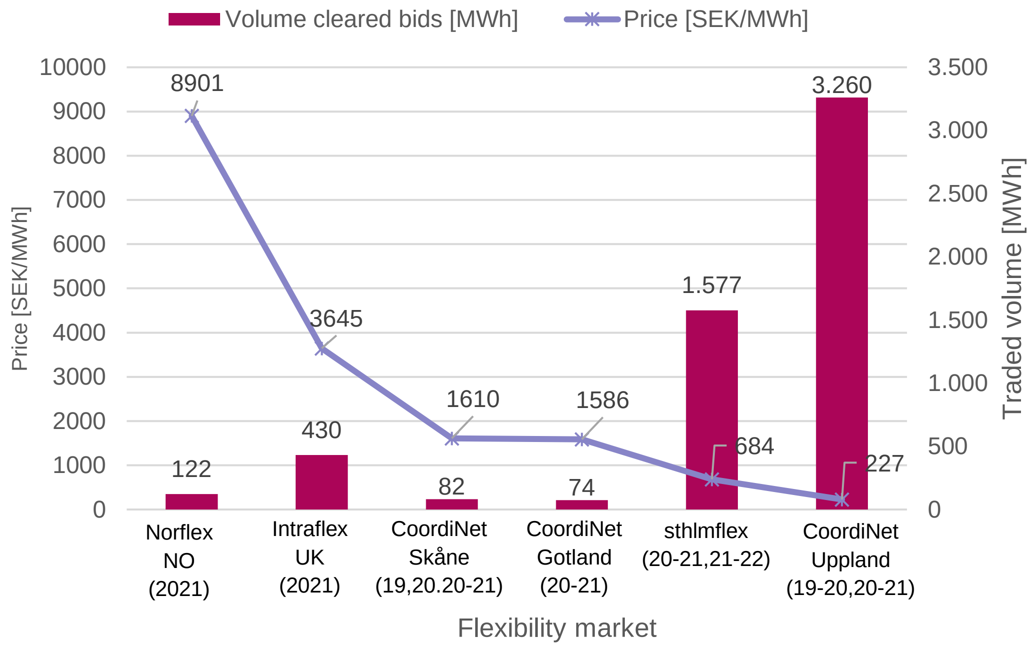


Figure 55 Average flexibility price and cleared volume of flexibility for the three Swedish CoordiNet markets compared to similar flexibility markets for congestion management. Data for UK and Norwegian flexibility markets from Node's market data [68], according to [38].

4.4. Further reading

Within the CoordiNet consortium some two dozen key performance indicators (KPI) were developed, the full list of results for the demonstration can be found in D.4.7.1 [19] with definitions of the KPI found in D1.6 [39].

5. Anticipated benefits from demonstration

The demonstration was a success with three years of open calls to contract flexibility. Coordination has shown multiple benefits that together has led to more efficient use of the grid. Additional customers have been able to be connected and risk for curtailment of existing customers has been decreased.

However, several barriers to efficient TSO-DSO coordination were found:

- TSO and DSO tariffs, as wells as regulation, are today not designed for a DSO purchasing flexibility services.
- FSP's price signals are locked into heat, electricity and grid sector.
- Unlocking flexibility is still an immature business This makes it unfeasible to rely on price evaluation alone.

Capacity products for day-ahead, intraday and peer-to-peer have been developed and demonstrated in multiple markets for three years. Both free bids, weekly flexibility contracts and seasonal flexibility have been tested. The platform allows for extraction of settlement data.

A platform architecture has been developed that is split into i) market tool for flexibility providers that construct the merit order list, ii) a flex tool used by DSO operators that estimated need of flexibility and provides the decision support for clearing and iii) integration to TSO subscription system and mFRR market.

In the Horizon2020 proposal, the 3 overarching goals for CoordiNet were articulated in 8 Objectives. These consortium-wide objectives were adapted to 10 aims from the Swedish demonstration formulated by Vattenfall and E.ON after consultation with Swedish partners. The assessed fulfilment of these aims is summarised in Table 9.

Table 9. Fulfilment assessment of the 10 aims of the Swedish demonstration

#	Aims of the Swedish CoordiNet demonstration		Self-assessment Swedish demonstration
A1	Enable city and economic growth through a new way of using capacity more flexibly over time.	Yellow	Three regional demonstrations have been run for three winter seasons. Two demonstrations have run peer-to-peer market. Products have been developed in an iterative way to include both DA, ID and P2P markets. Flexibility is used to plan for new customers, but formal network planning routines taking flexibility into account still to be established.
A2	Flexibility market established on which flexibility providers can offer capacity and DSOs can clear this additional capacity, when needed.	Green	DSO utilises the flexibility service to lower peak demand in the grid during the winter season from November to March.
A3	Standardised market products were developed and incorporated into DSO operations and grid planning perspectives, as well as customer routines.	Green	These goals are achieved within the large-scale demonstrations and the learnings and products have been adopted into new and continued activities in the DSO such as sthlmflex (for Vattenfall) and Switch (for E.ON).
A4	Market Design and coordination between TSO and DSOs.	Green	Standardised products have been developed together with the TSO. Time coordination has allowed simultaneous participation in DSO congestion and TSO balancing markets.
A5	Digital market established, supported by real-time data and machine learning models to forecast customer and grid behaviour.	Yellow	Both grid state & load forecasting using machine learning techniques from both academic and commercial providers have been tested and incorporated into flex tool used by DSOs, allowing new power flow analysis capabilities.
A6	New types of actors from local DSOs participating with flexibility.	Green	Both municipal actors, industries and aggregators have signed up. A large variety of different types of flexibility providers and resources have been incorporated into an open technology-neutral market.

A7	DER like energy storage and wind as well as small-scale customers through aggregation participating with flexibility supported by real-time data and forecasting for customer and grid behaviour.	Green	From domestic houses, industry, district heat plants to batteries a large variety of flex have been added (477 MW/7 GWh). Several aggregators have been involved in the demonstration and received cascading funds to further develop their services towards DSO and markets. Another identified potential was in extending to distributed storage and heat pumps, allowing prosumers and small consumers to access the flexibility markets as well.
A8	Contribution to national and local goals for climate and renewables (due to electrification in industry, heat and transport sector the challenge is to handle the new influx of connection demand to already fossil electricity mix) as well as economical utilization of assets.	Green	A more digital and efficient use of the grid has been demonstrated with an increase of sector coupling between heat and electricity production. These achievements will support the decarbonisation of transport and industry through electrification.
A9	Digital peer-to-peer market in place to enable trading, planning and economical transactions.	Green	Successful proof of concept was made. Although volumes were low the solution proved to be ready for wider adoption.
A10	A marketplace that provides a cost-efficient way for including local flexibility resources to provide ancillary services to DSO and TSO	Yellow	By also taking regional constraints into account as a pricing factor a more holistic approach to reaching cost efficient grid utilisation has been demonstrated.

The CoordiNet flexibility markets for congestion management will continue even after the termination of the EU project and has its follow-ups markets in Stockholm and Gothenburg region.

All participating DSO in the different markets as well as other interested DSO's now have a dialogue and knowledge exchange on different issues related to flexibility services. A proposal of terms and conditions for the product market-based procurements of electrical grid capacity as a flexibility service has been developed that will be the basis for the system operators first draft presented for the national regulator.

Both DSO's Vattenfall Eldistribution and E.ON Energidistribution have initiated business development projects to incorporate flexibility into businesses system operations and processes. These initiatives cover the full set scope of abilities from planning to control room.

6. Conclusions – Experience and learnings for upcoming winter seasons

The Swedish CoordiNet demonstration showed a more dynamic and digitalised way for DSOs to utilise flexibility for the operation of the network. The use of flexibility has proven that flexibility can successfully alleviate network congestions, given that market liquidity is high enough. Ten abilities needed for flexibility markets have been developed. This involves grid load forecasts, product and prequalification criteria, baseline methodology, business models, time coordination with other markets and an interface for trading flexibility. The dialogue between grid customers, flexibility service providers, aggregators and DSOs has been active resulting in mutual understanding on how to utilise flexibility in local and regional markets. Furthermore, sector coupling between the electricity and heating sector is increased, utilising the energy system more efficiently. TSO-DSO coordination has been a catalyst for enhanced cooperation and innovation resulting in several activities to enhance the Swedish market structure for flexibility services.

A holistic approach was taken to develop the flexibility markets in the Swedish CoordiNet demonstration. This required development of a range of support tools, processes and integrations, summarised in Figure 56.

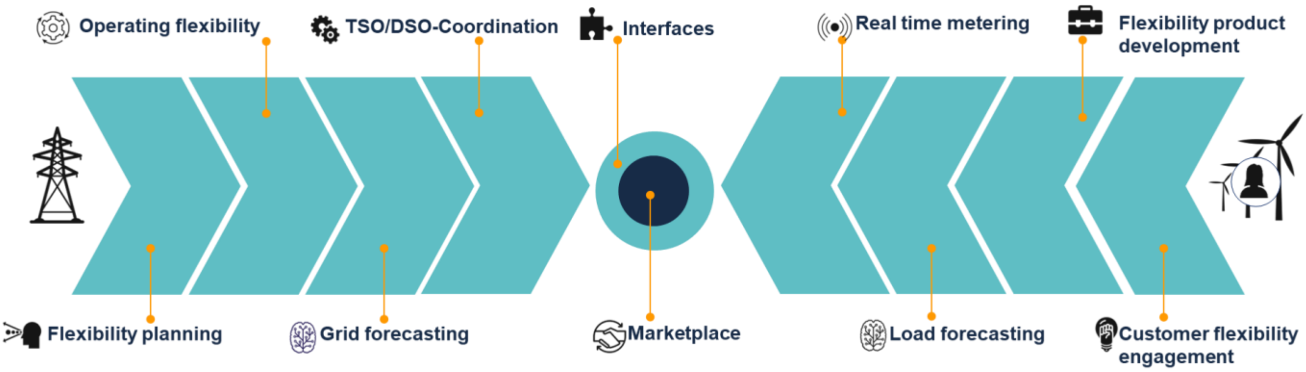


Figure 56. A holistic approach on transformation, multiple technologies and perspectives are needed to drive change in order to achieve a local flexibility market where TSO/DSO (left side) can meet with flexibility providers (right side).

The abilities on the FSP and DSO/TSO side are as vital as the marketplace itself to unlock the full potential of flexibility and enable a marketplace that provides a cost-efficient way for including local flexibility resources to provide ancillary services to DSOs and TSO. The demonstration has also revealed that flexibility is not a one for all silver bullet for solving all DSO issues related to increased demand for connection. Neither is a flexibility market an easy step for a DSO to setup or flexibility resources to join. Participation has been a multi-year learning curve and flexibility service providers needed longer time than anticipated to set up internal processes, legal contracts and agreements with DSO, their balance responsible parties and energy traders. The remuneration-based energy compensation has not been sufficient for some flexibility providers, requiring experiments with different forms of capacity compensation and cascading funds to secure participation from certain resources. Obtaining a high enough liquidity of the local flexibility markets has been a further challenge.

As well as forming the model for new flexibility markets in the two largest regions of Sweden (Stockholm and Gothenburg) CoordiNet congestion management markets in Uppland and parts of Skåne will continue for the coming winters. The CoordiNet project has also created a several added values including:

- All participating DSO in the different markets as well as other interested DSO's now have a dialogue on national level for knowledge exchange on different issues related to flexibility services.
- A proposal of terms and conditions for the product market-based procurements of electrical grid capacity as a flexibility service has been developed that will be the basis for the system operators first draft presented for the national regulator.
- Both DSO's Vattenfall Eldistribution and E.ON Energidistribution have initiated business development projects to incorporate flexibility into businesses system operations and processes. These initiatives cover the full set scope of abilities from planning to control room.

As the European network codes and regulatory framework for flexibility services becomes clearer the CoordiNet demonstrated abilities can be used also for so called implicit flex (like dynamics tariffs) and explicit flex like non-firm connection agreements, in addition to the long- and short-term market-based flexibility service described in CoordiNet.

Adoption of the ten abilities outlined in this report the DSOs can act as a distribution *system* operator (DSO) and not merely as a distribution network operator (DNO). The main differences between DSO and DNO are summarised in Figure 57.

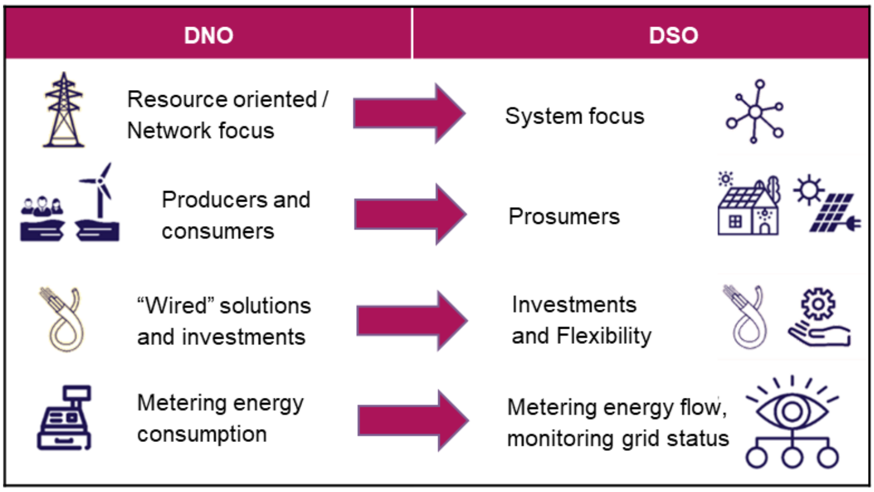


Figure 57 Development from distribution network operator to system operator, resulting from the ten abilities to unlock flexibility

To conclude from a TSO perspective, CoordiNet has made flexibility into one of the tools that Swedish TSO works with to enable grid connection. Much of the work that has been put into CoordiNet has been used within a similar market set up in the capital region of Stockholm and CoordiNet continues to inspire the work with flexibility in Sweden. Flexibility and the lessons learned from CoordiNet is one of the tools that Swedish TSO now works with to provide grid capacity in a cost-effective and fast way e.g., to enable large industrial investments in the North of Sweden that request tens of GW of new capacity. Using flexibility instead of traditional grid reinforcements also adds the opportunity to use less land and resources for grid capacity i.e., less use of raw materials.

From the DSO perspective CoordiNet has demonstrated the abilities required for the DSO to become an active 'System Operator' and purchase flexibility services. This provides major benefits for the DSO through new possibilities to use the infrastructure for electricity and heating in a more coordinated manner unlocking existing flexibility. In the future, this will also strengthen the capability to cope with new kinds of loads in the grid like electric vehicle charging and renewable energy. The in-house development of the platform and the flexibility market has shown to be extremely valuable in competence development, mindset and culture. Acting as a System Operator the DSO gains the ability to use the grid more efficiently.

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