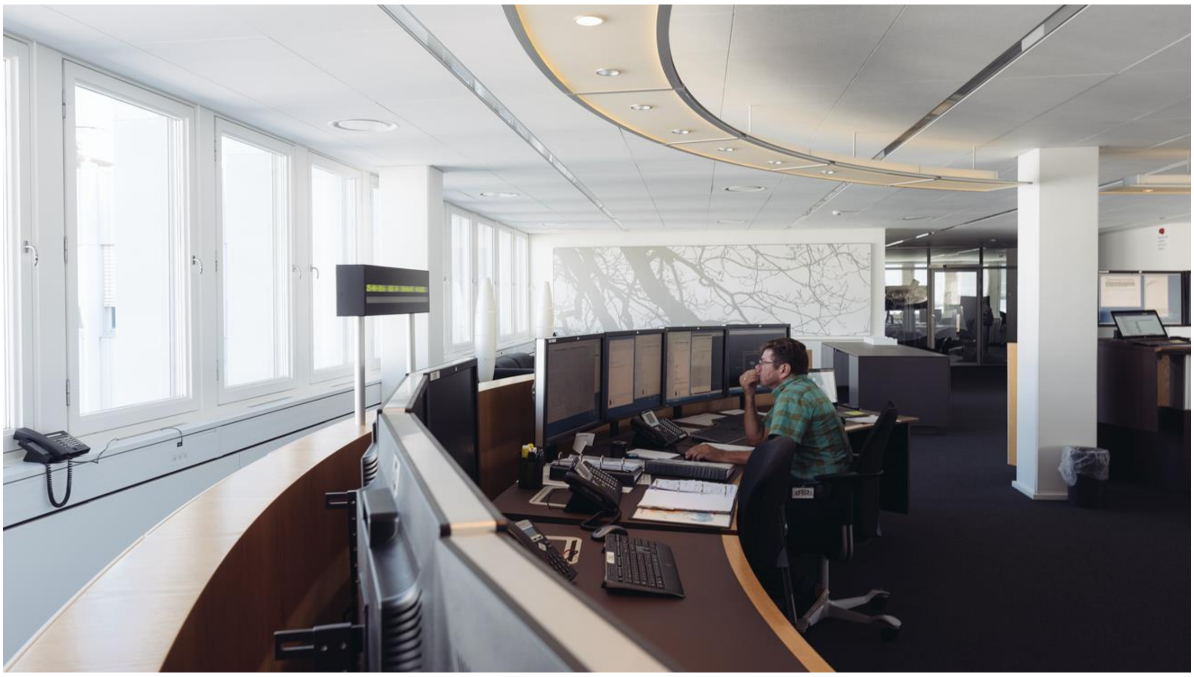
REPORT



Concluding Report

DREM – DSOs' Role in the Electricity Market
Delivery 8.1

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List of abbreviations

AGR	Aggregator
BRP	Balance Responsible Party
BSP	Balancing Service Provider
CDGs	Certified Data Gateway server
CIM	Common Information Model
DMS	Distribution Management System
DREM	DSOs’ Role in the Electricity Market
DSO	Distribution System Operator
ECP	Energy Communication Platform
EIC	Energy Identification Code
ENTSO-E	European Network of Transmission System Operators - Europe
EV	Electric Vehicle
FCR-N	Frequency Containment Reserve for Normal operation
FLECH	Flexibility Clearing House
HTTP	HyperText Transfer Protocol
ICT	Information and Communications Technology
IEC	International Electrotechnical Commission
MADES	Market Data Exchange Standard
mFRR	manual Frequency Restoration Reserve
MJ	MegaJoule
MWh	MegaWatt-hour
OLTC	On-Load Tap Changer
PEX	Cross-linked polyethylene cables
REST	Representational state transfer
SCADA	Supervisory control and data acquisition
TP	Transparency Platform
TPS	Trade Permission System
TRL	Technology Readiness Level
TSO	Transmission System Operator
USEF	Universal Smart Energy Framework
WP	Work Package

1.1 Project details

Project title	DSOs’ Role in the Electricity Market (DREM)
Project identification (program abbrev. and file)	EUDP17-I (ForskEL 12496)
Name of the programme which has funded the project	Energiteknologisk Udviklings- og Demonstrations Program (EUDP)
Project managing company/institution (name and address)	Radius Elnet A/S, Teknikerbyen 25, 2830 Virum, Danmark
Project partners	Radius Elnet, EURISCO, HOFOR, Markedskraft, DTU
CVR (central business register)	29915458
Date for submission	3. April 2020

1.2 Short description of project objective and results

The objective of the DREM project has been to identify and solve market conflicts that influence the DSOs' ability to secure energy supply (i.e. congestion in the distribution grid) caused by trading on flexibility assets in the electricity market.

In order to do so the project has utilized the SYSLAB laboratory at DTU-Risø, the Markedskraft BRP system and the HOFOR FlexHeat flexibility asset with a communication infrastructure developed by EURISCO.

Through a proof-of-concept validation and subsequent "near real-life" demonstration the project has validated the proposed solution design against two scenarios derived from identified conflicts between the DSO and stakeholders in the electricity market.

The experiences and insights from the DREM project will act as a contribution to the discussions regarding the Market Model 3.0 and provides a valuable platform for further studies into the DSOs future role in the electricity market.

Formålet med DREM projektet har været at identificere og løse markedskonflikter der udfordrer DSO'ens evne til at fastholde forsyningssikkerheden da flaskehalse kan opstå grundet handel med fleksibilitetsydelser i energimarkedet.

Til dette har projektet udnyttet SYSLAB-laboratoriet på DTU-Risø, Markedskrafts BRP-system samt HOFORs FlexHeat flex-aktiv bundet sammen gennem en kommunikationsinfrastruktur udviklet af EURISCO.

Gennem "proof-of-concept" og efterfølgende virkelighedsnær demonstration har projektet valideret det foreslåede løsningsdesign op imod to scenarier udviklet fra de identificerede konflikter mellem DSO'en og interessenter i energimarkedet.

Erfaringerne og den udviklede indsigt fra DREM projektet vil blive inddraget i diskussionerne omkring en ny Markedsmodel 3.0 og vil yderligere være en værdifuld platform for yderligere studier af DSO'ens fremtidige rolle i energimarkedet.

1.3 Executive summary

This concluding report provides an overview of the DREM project, its objectives and execution as well as highlighting the main results and conclusions including a perspective on future utilization. A full description of the DREM project execution and results is provided in the various work package deliverables available at the DREM webpage, www.drem.dk.

The DREM project targets congestion problems faced by DSOs in a future energy system where power system balancing services are increasingly provided by flexibility assets connected at the distribution level. This is based on an expected need for flexibility assets at the consumer level to contribute towards balancing the power system, as expressed in the report “Markedsmodel 2.0”. Previous studies have analysed different scenarios for the proliferation of flexibility assets and the corresponding market environment. However, consequences for distribution-level security of supply have not been sufficiently considered - although potential congestion problems have been identified. Based on the above, the DREM project formulates its main objective as *“identify and solve market conflicts that influence the DSOs’ ability to secure the energy supply (i.e. congestion in the distribution grid) caused by trading of flexibility assets in the electricity market.”*
This can be divided into three project objectives that each highlight its own specific part.

1. The DSOs’ future role in mobilising of flexibility assets for balancing the overall grid is clarified and the solution is demonstrated.
2. Proof-of-concept of the technical system integration between flexibility assets, DSO, and BRP based on IEC 61850-7-420 and IEC 62352 standards
3. Outlining technical, economic and communication consequences of interrupting flexibility assets in foreseen and unforeseen scenarios.

The work in DREM has been carried out in five main phases, each building on the results of the previous one: Problem definition, solution principles, solution design, validation and demonstration. The problem definition and solution principles phases were each centred around a series of workshops involving stakeholders across the Danish power industry. The solution design, validation and demonstration phases primarily involved the project participants.

The project has succeeded in addressing all three project objectives. This concluding report provides useful insights into what the future role of the DSOs in the electricity market may look like. The main results of the DREM project are:

- A comprehensive understanding of potential future stakeholder conflicts cases and possible DSO responses.
- A proposal of an efficient, effective and transparent concept for the resolution of stakeholder conflicts at the distribution level.
- Successful proof-of-concept implementation and demonstration of the solution design using the SYSLAB laboratory at DTU-Risø with participation from all parts of the energy sector.
- Successful field demonstration of a Trade Permission System platform including the use of IEC communication standards and alignment to implementations used in the Nordic Balancing Model.
- Assessment of technical, economic and communication consequences of interrupting flexibility assets through a range of field tests using the FlexHeat flexibility asset located in Nordhavn.
- Development of advanced and intelligent FlexHeat controls and standardised BRP, TSO and DSO communication enabling the FlexHeat facility to also act as a frequency containment reserve (FCR-N) for the future benefit of district heating customers in Nordhavn. This result exceeded the expectations set in the project objective.

The conclusions from the DREM project are divided into three main areas.

- Firstly, during the stakeholder dialogue, the project has confirmed that several cases exist in which different actors involved in flexibility from distribution-level assets encounter a conflict of interests. The stakeholders reached a common interpretation of the nature of the issue: The sum of actions by individual flexibility assets changes the observed concurrency factor. Grid problems may occur once this observed concurrency exceeds the concurrency assumed in grid planning for each consumer category.
- Secondly, despite the number, variation and complexity of the identified conflict cases, including sub-cases, the project has succeeded in designing a relatively simple solution which only considers two variants of a general case: One variant for situations anticipated some time in advance (e.g. due to reduced grid capacity during maintenance) and another for unanticipated situations, e.g. due to grid failure.
- Thirdly, the proof-of-concept implementation as well as the following field tests have demonstrated that the concept developed in DREM is implementable and can be used for the intended purpose of mitigating congestion issues in the distribution grid. However, the project could not achieve full test coverage. As a result, a number of aspects requires further validation.

The DREM project results could be used to handle the adverse effects of an increased utilization of the distribution grid, thus the results are potentially contributing to an economically efficient green transition as investments in reinforcing the distribution grid can be reduced. In this context the DREM partners have been invited to contribute the gained experience to the discussions regarding the Market Model 3.0 carried out by the Danish Energy Agency.
Because further studies and demonstrations are needed in order to fully validate the proposed solution, some of the DREM partners have applied for additional funding from Innovation Fund Denmark in order to continue working on the DREM concept.

The DREM project aims to suggest market-based solutions to the extent possible. However, DSO congestion is always a local problem which relates to a specific feeder on the low voltage or medium voltage level. Within the foreseeable future, it will be difficult to operate local day-ahead markets at the level of a single feeder due to the lack of liquidity (i.e. the fact that the proliferation of small flexible assets (e.g. EVs) is still happening much slower than that of larger units.), except in few, very specific cases. Although many small flexibility assets may be installed, we still do not know how many of them will participate in local flexibility markets.

Recently, perhaps due to the above, there has been a pronounced change in the attitude towards congestion mitigation of some Danish DSOs, including Radius, away from day-ahead flexibility markets and towards other solutions such as tariffs and bilateral agreements between aggregators or owners of flexibility assets and the DSOs. This change in view is not shared by the other DREM project participants and does not invalidate the DREM conclusions in any way. An important thing to emphasize is that tariffs, bi-lateral agreements and flexibility markets do not exclude each other. Due to their different strengths and weaknesses and the different classes of problems each is able to solve, they may all co-exist in a future energy system.

1.4 Project Objectives

1.4.1 Background for the DREM project

The project takes departure in the needs for further flexibility assets[1] at the consumer level for balancing the power system as expressed in the report "Markedsmodel 2.0" issued by Energinet.dk. The project addresses the impact from trade on the energy markets on the operation of distribution grids.

Large scale mobilisation of flexibility assets may cause congestion problems on particular radials as well as market conflicts between agents, and the overall socio-economic objectives may be hampered by private financial objectives.

In previous studies of the need for further flexibility assets and existing analysis of corresponding market conditions, the consequences for the security of supply at the distribution level have not been sufficiently considered, although potential congestion problems have been identified by different sources such as the iPower Project, USEF[2], Eurelectric[3] and in several EU documents.

1.4.2 Regulatory state

Today, there is no clear regulatory or market framework in place for procuring flexibility services to support Danish DSO operations.

The Danish Power Supply Act stipulates the activities that a DSO can undertake under a power distribution concession. On the one hand, there is nothing that directly prevents the DSOs from using flexibility actively to ensure efficiency, but on the other hand the concept is not described in the act and consequently the rules and regulations surrounding flexibility are associated with considerable uncertainty.
There are provisions stipulating that the DSO must maintain the technical quality of the network and provisions stipulating that the service should be provided economically efficient. In this respect, activating flexibility for alleviating congestion and voltage problems should be feasible and the DSO can procure flexibility services directly from customers or through aggregators.

The new economic regulation of DSOs implemented from 2018 provides basic incentives for DSO to minimise investments into increased grid capacity. It also provides fundamental incentives to seek more cost-efficient solutions as a replacement for new capacity. But it is not clear how the costs used to procure flexibility services should be handled in the economic regulation. In addition, the current benchmarking model used by the Danish regulator to issue efficiency demands based on the efficiency of the DSO, provide an advantage for investments in capacity (i.e. capex) in comparison to alternative solutions of procuring flexibility services from customers or aggregators (i.e. opex). Hence, the consequences for the DSOs of procuring flexibility services are not clear and are currently associated with considerable uncertainty.

In the Danish market design, there is a need for a clear framework for local flexibility services, which interacts well with the framework for trade in balancing services thus ensuring a balanced supply

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[1] The report contains several references to the term "flexibility assets" which may appear ambiguous since in principle, all consumption could be flexible. In this case, we use the USEF definition (see references) of flexibility as deliberate, time limited changes to the normal energy profile of a consumer.

[2] https://www.usef.energy/

[3] Eurelectric Feb 2013: Active Distribution System Management

and demand in the electricity market. Development of such a technical framework for interaction between the need of DSO's and TSO's for flexibility services must aim at enabling a coherent electricity market for flexibility services.

EU recognise that flexibility services is an important tool to increase utilization of the existing distribution grids and thereby also reduce the need for grid investments. In the Clean Energy Package, that was been passed by the EU in 2018, flexibility plays a key role in achieving more renewable energy sources and more interconnected and efficient energy systems. In the electricity directive of the package it is established that DSOs shall procure flexibility services in accordance with transparent, non-discriminatory and market-based procedures unless the regulatory authorities have established that the procurement of such services is not economically efficient or that such procurement would lead to severe market distortions or to higher congestion. Efficient integration of new loads requires innovative solutions and an appropriate regulatory framework.

Hence, with the Clean Energy Package, the Member States will have to revise national regulation to allow and incentivise DSOs to use flexibility services and energy efficiency measures to improve the efficiency of their operations. This process is ongoing in Denmark and it is anticipated that a law reform including amendments to existing acts will be implemented by the end of 2020. It is anticipated that the law revisions will allow and incentivise DSOs to procure flexibility services which may complement or obviate the need to upgrade or replace existing grid capacity thus supporting efficiency and security of supply of the distribution system. Further it is anticipated that it will also enable support standardisation of market products and services procured to ensure effective participation of all market participants.

1.4.3 Problem statement

This project targets specific problems faced by DSOs in a future energy system where power system balancing services are provided by flexibility assets connected at the distribution level.

1. *Undesirable consequences of trade on Ancillary Markets*
   In a number of cases energy trade load congestion problems may occur in the distribution grid. For example, trading downward regulation service at the time of existing load peak, and trading upward regulation service immediately before load peak of flexibility assets that incur a rebound effect (rebound coincident with load peak).

   The project suggest that the DSO should provide a service in a form of a Trade Permission System to secure that trade on electricity markets is not causing congesting problems in the distribution system. Congestion avoidance is supposed essentially to take place via a communication link to AGR/BRP and TSO.

2. *Undesirable consequences of Arbitrage and other Energy Management services*
   The potential problem arises from the situation where a number of minor flexibility assets are located on the same radial in the distribution grid (like for example a number of heat pumps on the same radial) and in the case they react to a spot market reflected electricity price. In such case, an Aggregator could offer automatically steer the flexibility asset in and out of the price peak.

Releasing all the assets at the same time will cause a simultaneous factor on 1 (so called rebound effect). If the price peak is immediately before load peak, the rebound could coincident with the load peak. As the distribution grid heavily depend on a considerably lower simultaneous factor (typically about 0.4) this could lead to overload in the specific radial.

An additional problem to this case is simply that an Aggregator could on purpose create a congestion problem in the grid with the purpose that the DSO pays the Aggregator for solving the self-induced problem. This is not a sustainable mercantile principle.

3. *Undesirable consequences of spot price products*
   The general development towards spot market reflected electricity prices, following naturally from roll out of hourly meter readings, could potentially cause so called explicit activation of flexibility assets.

   The problem is similar to the one described above with the important exception that no one control the assets. In case the customers are aware of the spot market price variations they could unconsciously cause the same simultaneous factor of 1, when releasing heat pumps after a price peak and this could coincident with load peak. The rebound effect[4] from heat pumps last at least half an hour, and likely more and therefore the coincident is not unlikely.

4. *Measurement and Service Verification conflicts.*
   By enabling DSOs to acquire services, an Aggregator may be contracted to provide services to both the TSO and DSO, complicating the process of service verification. Without clear outlining of how measurements are to be communicated between DSO and TSO, the process of service verification may be unnecessarily complex.

   Quite a number of other market conflicts and ‘grey market’ condition where the DSOs could be instrumental for solution provision could be mentioned. Those issues will be investigated and discussed in workshops during the project in order to determine whether the DSOs are the optimal solution provider.

1.4.4 Project objectives

The main project objective has been to *“identify and solve market conflicts that influence the DSOs’ ability to secure energy supply (i.e. congestion in the distribution grid) caused by trading on flexibility assets in the electricity market.”*

The major part of customer[5] flexibility is traded on the wholesale or the system market. But in some cases, the trade can produce conflicts between the TSO, BRP and DSO. When the TSO or BRPs activate flexibility installed at the distribution grid level and for instance the full grid capacity is not available for some reasons, the DSO can react to unwanted effects of trades in a number of ways and, if unregulated and uninformed, the reaction could be counterproductive to the purpose of the trade. This would lead to a more expensive operation of the power system, since it could cause imbalances or cause the activated flexibility services to not be delivered.

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[4] When heat pumps are interrupted for a while, the room temperature and water temperature decrease. When the heat pump is released for ordinary operation it will start up with full capacity to compensate for temperature drop during the interruption. This is generally referred to a rebound effect or kick back effect.

[5] We are not distinguishing between customers and prosumers. The customers could consume and produce energy.

The solution design studied therefore focus on improved communication between market parties

The main objective was originally divided into three components

1. *The DSOs' future role in mobilising of flexibility assets for balancing the overall grid is clarified and the solution is demonstrated.*
    a. A communication system that enables the DSO to avoid congestion problems in the distribution grid as a potential consequence of trade on the energy markets and Aggregator behaviour is demonstrated.
    b. Furthermore, recommendation for how to optimize such communication system is provided with regard to minimizing overall transaction costs.
    c. Finally, recommendations for DSO role in solving various market conflicts and need for market facilitation and service verification.

2. *Proof-of-concept of the technical system integration between flexibility assets, DSO, and BRP based on IEC 61850-7-420 and IEC 62352 standards*

3. *Aggregator models for aggregation of minor flexibility assets are studied and models are recommended. (Excluded)*

1.4.5 Project execution

In order to achieve the objectives of the project, the following project organisation was established - including milestones and deliveries for each work package.

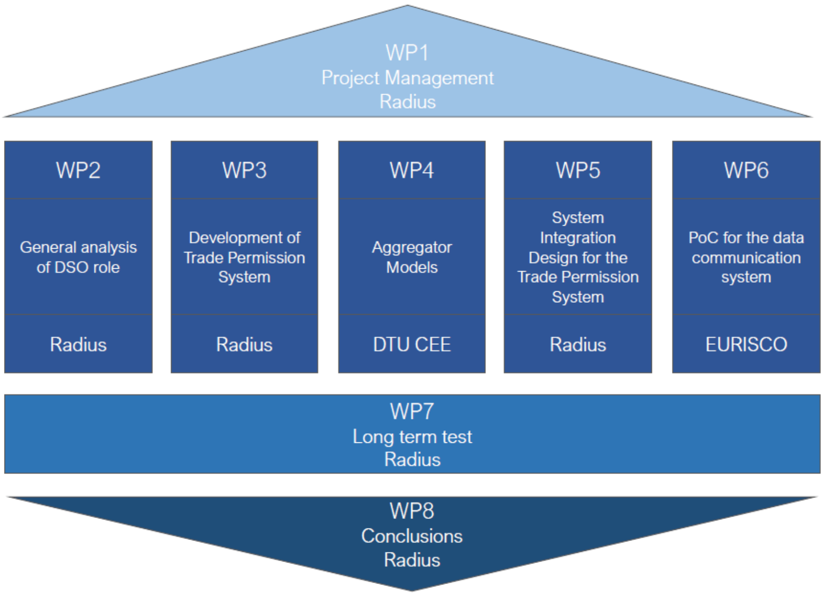

Figure 1: Original DREM project organisation

Changes to project objectives and organisation

Excluding objective no. 3 regarding aggregator models (WP4)

During the project execution achieving the third objective regarding aggregator models was shown to be too challenging to realise as it turned out, that the aggregation of households accumulated disproportional challenges compared to the resources assigned. In addition, the project was unsuccessful in obtaining required dispensation for dual BRP model.

As the third objective was an addition to the core scope of the project, the exclusion of this has not had any consequences towards achieving the main objective of the project of identifying and solving market conflicts - that influence the DSOs' ability to secure energy supply caused by trading on flexibility assets in the electricity market.

Replacing real time market participation with simulation of system markets (WP7)

Originally the project aimed at performing the proof-of-concept on the solution design, using a limited number of real large-scale flexibility assets. However, it turned out not to be possible to identify suitable candidates except for the FlexHeat[6] flexibility asset in Nordhavn, Copenhagen. Furthermore, as the capacity of the single available flexibility asset was under the bid limit for FCR-N and mFRR markets, and the fact that the FlexHeat heat pump weren't able to meet the technical requirements for prequalification[7] at the time in the markets - is was necessary to replace real time market participation with simulated flexibility assets in a laboratory environment[8]. However, Markedskraft agreed to simulate that the asset participated in the FCR-N market by providing activation signals and calculation of market value – which then enabled the project to continue pursuing its objective regarding proof-of-concept and demonstration in "near real-life". Because of this change the project increased its focus towards demonstrating communication flows between market agents and estimation of financial consequences thus introducing a revised third objective of the project

3. *Outlining technical, economic and communication consequences of interrupting flexibility assets in foreseen and unforeseen scenarios. (New)*

As the communication flows between market agents proved to be more complicated to develop than anticipated the change in work packages ended up being an advantage to the project as the proof-of-concept was changed to a laboratory setting thus limiting the adverse effects of the development of communication flows.

Combined reporting of deliverables in WP2 and WP3

During the initial phases of the project, it became clear that the identified deliverables in WP2 and WP3 was closely linked to such an extent that the reporting of the deliverables were to be merged. However, despite this change in reporting the original objectives of both work packages were able to be met, as the workshops conducted resulted in successfully identifying relevant market conflicts as well as a proposed solution design.

Apart from above changes to the project scope and objectives it can be concluded that the project has been able to deliver on all agreed milestones and deliverables. Main results and conclusions are presented in sections 1.5.7 and 0 of this report.

Project risk identification

The project has not surprisingly encountered various challenges during execution, however some are more significant than others and deserve to be addressed in the final report. These challenges were already identified as potential risks early in the project planning phase and as such came as no surprise to the project.

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[6] Heat pump and heating element owned and operated by HOFOR

[7] For technical reasons dispensation could not be given by Energinet.

[8] The DTU-Risø SYSLAB laboratory

1. Creating a common understanding
    - As it is natural in development projects there has among the project participants as well as with external stakeholders, been many discussions and different opinions on how to approach the various phases of the problem. However, these discussions have been taken in good manner and has contributed to a much-increased understanding of the challenges of DSO congestion management.
2. Abandoned and revised work packages
    - As described earlier it has been necessary to abandon one work package and rewrite another as the project has encountered significant challenges in identifying and including flexibility assets for the validation and demonstration phases.
3. Delayed project finalization
    - The project has been delayed by approx. 3 months compared to the original time schedule which is attributed to the changes that have been made to the project scope, as well as an increased complexity in discussions and solutions than originally anticipated. Furthermore, near the end of 2019 the DREM project manager was replaced, which also led to challenges in fulfilling the project scope within the allocated timeframe.

1.5 Project results and dissemination of results

1.5.1 Main activities

The project consisted of five main phases, each building on the results of the previous one: Problem definition, solution principles, solution design, validation and demonstration. The problem definition and solution principles phases were each centred around a series of workshops involving stakeholders across the Danish power industry. The solution design, validation and demonstration phases primarily involved the project participants. Documentation for each phase have been produced in the form of various work package deliverables which are listed in the annex of this report. Work package deliverables will be made available at the DREM webpage, www.drem.dk.

Problem definition phase

The DREM project builds on the assumption that conflicts of interests between stakeholders will occur in a future in which many flexibility assets are deployed in the distribution grid. In the current wholesale and ancillary services markets, Nordpool and the TSO on one side and the BRPs/AGRs on the other side, continuously agree on the dispatch of flexibility assets as a result of trading. The DSO does not play a role in this process as it is not involved in the procurement of electricity or the balancing of the grid. As a result, some instances of flexibility activation as agreed by the market participants may cause problems for the DSO, e.g. because the activation causes network congestion. The term ‘conflict case’ refers to this situation which also today is a known premise for the DSO to operate under.

In order to lay a relevant foundation for subsequent solutions, the project organized a series of workshops with participation by DSOs, AGRs, BRPs, owners of flexibility assets, the regulator and the TSO. The goal was to achieve a consensus on which possible sources of stakeholder conflicts were seen as realistic and probable by the stakeholders, and to work on a precise definition of the circumstances under which the conflicts would occur. Throughout the first workshops, special emphasis was placed on separating the conflict identification phase from the later solution design phase.

As a result of the workshop series, eight conflicts cases were identified. Some of these were further subdivided into different scenarios depending on the legal relations between actors, the nature of the problems caused in the grid (thermal overload, voltage issues) and other factors.

Solution principles phase

Across Europe, traffic light models have been used to illustrate various solutions regimes with regard to congestion management in the distribution grid. Many of these describe rather narrowly scoped solutions specifically addressing one grid issue. However, the model is very useful in describing solution regimes.

A second series of workshops was held in order to achieve stakeholder agreement on the congestion management regime appropriate for each identified conflict case. An extended traffic light model with five categories/regimes was used for this purpose: Interruption of customers without notice (red), long-term agreement with individual customers (orange), short-term service procurement by the DSO (yellow), solutions based on extending grid codes and regulation (green) and DSO-internal technical solutions (e.g. energy storage, OLTCs, grey).

Finally, conflicts and solution types were clustered and specific solutions were formulated, addressing the different sources of conflicts. This resulted in a short set of general principles to be used in the solution design.

Solution design phase

The project participants deemed it important to develop a general solution framework, rather than a set of quick fixes for each of the identified conflict cases. The latter would likely result in an overcomplicated system which would be difficult to operate and progressively harder to extend, if new types of conflicts were to be identified. This was achieved using an iterative design process in which constraints, assumptions, participant preferences and partial solutions from different stages of the stakeholder workshop series were integrated into the solution.

The resulting solution framework can be subdivided into a regulatory framework, a market framework and an operational framework. The regulatory solutions cover a registration requirement for flexibility assets (static information system), a recognition of flexibility assets in the DSOs capacity obligation, a requirement for aggregators to be attached to a BRP and rules covering the impact of DSO interventions. The market solutions include a need for flexibility markets at the distribution level and for rebound to be considered in all definitions of ancillary services involving flexibility assets. Finally, the operational solutions define the components of a Trade Permission System[9] in which a dynamic information broker is used to establish a direct information exchange between AGRs/BRPs and the DSO without leaking sensitive market information.

Complementing the solution framework, the project defined two variants of an operational sequence diagram, covering the required communication between actors for all identified conflict cases: One variant applies if a DSO intervenes due to a planned (foreseen) capacity limitation, such as e.g. a temporarily weakened grid section due to maintenance, or a predictable increase in power flow. The other variant covers sudden (unforeseen) events such as e.g. equipment failure or sudden, localized load spikes due to flexibility activation.

Validation phase

The solution framework, including the Trade Permission System, has been validated through a series of tests against two implementations: One reference implementation consisting of a geographically distributed combination of real-world and emulated components, and a reimplementation within a simulation platform. The tests can be grouped into system integration tests, scenario-based validation tests and simulation-based scenario assessment.

The system integration tests were conducted in a geographically distributed configuration consisting of flexibility assets on a grid feeder and a DSO emulator located in the SYSLAB laboratory at DTU-Risø, a Trade Permission System on EURISCOs premises in Odense, and the MKPlanner aggregator platform at Markedskraft in Aarhus. The tests confirmed the correct operation of all parts of the integrated open-loop system, i.e. without the DSO directly responding to the state of the grid.

The scenario-based validation then closed this loop, allowing the DSO emulator to respond to foreseen as well as unforeseen capacity limitations by announcing constraints, thus validating the ability of the Trade Permission System to mitigate a capacity issue in a concrete scenario. The chosen scenario was based on an urban feeder with multiple supply points, some of which are becoming unavailable due to scheduled maintenance or equipment failure.

In addition to these primarily qualitative tests, simulation-based assessment was used for validating the quantitative impact of the TPS mechanism on flexibility asset operation as well as on distribution network operations, as opposed to scenarios where a TPS is not available. In addition to these key metrics, the assessment observed the impacts on heat loads being served or undersupplied and whether the available interventions were sufficient to relieve congestion situations. The simulated scenario was based on real-world data from a feeder in Nordhavn.

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[9] The term *Trade Permission System* is not a concrete digital platform but a conceptual term describing the communication flow and roles of the participating agent.

Demonstration phase

The operation of the validated system was planned to be demonstrated on two occasions: During a public event held at DTU-Risø in June 2019, and as part of the final event in Nordhavn which currently has been postponed due to the 2020 COVID-19 crisis.
The first event consisted of three demonstrations. All three used the same system configuration, consisting of a long, reconfigurable grid feeder with distributed flexible loads, a simplified emulation of a "DSO control room", a remote Trade Permission System and a remote instance of an aggregator trading platform controlling some of the flexible loads. The first demonstration established a baseline case in which the activation of flexibility causes a congestion problem in which load shedding is the DSOs only course of action. The second and third demonstrations then showed the DSOs use of the TPS to mitigate a foreseen and an unforeseen congestion problem, respectively, as well as the aggregator's response and the resulting congestion relief.
The second and final event is planned to include a demonstration of the final development stage of the Trade Permission System and of the data communication between the various market participants as well as an on-site visit to the HOFOR FlexHeat facility.

1.5.2 Conflict case identification

Conflict case identification was carried out as part of WP2 and reported alongside the proposed solution design (WP3) in the report *"DSO Role in Market conflicts - Workshop Report on Analysis of the DSO role in Market Conflicts"* finalized in April 2019. This section presents the main results of WP2 regarding conflict cases.

Approach

The project aims to suggest market-based solutions to the extent possible. However, DSO congestion is always a local problem which relates to specific feeders on the low voltage or medium voltage level. Within the foreseeable future, it will be difficult to operate local flexibility markets at the level of a single feeder due to the lack of liquidity, except in few, very specific cases. In some cases, constraints on response time may not allow for open market solutions using current technology.

Therefore, the DSO may have to simply limit the activation of flexibility assets in certain cases. The newly approved EU electricity regulation permits this solution if no market-based solutions are available (Article 12).

Solving congestion issues is complex since it involves conflicting interests of several parties that may not have an incentive to share information. Furthermore, since not all relevant players in the power system necessarily share the same objectives, it is difficult to reach consensus on how to solve the stated problem. The approach taken in this project has been to involve representatives from all parties in the energy sector in a series of workshops in order to secure that all interests were covered.

Representatives from the energy sector have participated in identifying the conflict cases. The work was initiated by a larger workshop, which allowed all +20 representatives in the energy sector[10] to participate. After the workshop a smaller working group was formed that concluded the identification of the conflict cases.

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[10] Energy sector participants included various companies, institutions and regulatory authorities.

Main Assumptions

Many of the conflict cases cannot be observed yet in today's grid due to a lack of volume or demand, i.e. the penetration of flexibility assets is not high enough to cause serious grid impact. A central assumption behind all cases is a future energy system where the installed capacity of flexibility assets is significant, seen from the perspective of the entire power system as well as when considering a single feeder. This does not mean that the presented problems are only applicable at a single feeder level, but that they can appear at different levels of the distribution system.

For all cases it is assumed that customers are exposed to an incentive signal reflecting the spot price variations. The incentive signal may also contain other components, such as e.g. the CO2 footprint.

The general market setup for flexibility trade is assumed to follow the model shown in Figure 2: Assumed market set-up for flexibility trade. In this model, the traditional way of operating the energy markets is expanded to include a new role (the aggregator) as well as opening for the DSO acquiring services through a local flexibility market. Such a flexibility market would offer services so that the DSO can solve congestion problems or voltage issues.

The traditional setup with BRPs interacting with the wholesale energy markets and the ancillary service markets is kept as it is today, but in this expansion, they also act as intermediaries between flexibility aggregators and the wholesale energy and ancillary service markets. It is assumed that BRPs trading flexibility do not have direct access to individual flexibility assets; instead, assets are pooled and managed through an AGR. The flexibility BRP and the AGR (and energy retailer/supplier for that matter) are not necessarily separate entities. The TSO purchases ancillary services through a market where the BRPs offer their services. At the same time, the BRPs interact with the wholesale energy markets in order to purchase energy for their customers or sell energy from their production plants (if they are BRP for production units). It is assumed that the AGR does not need to bid into the DSO flexibility market through a BRP, since the energy volumes traded in flexibility markets are small.

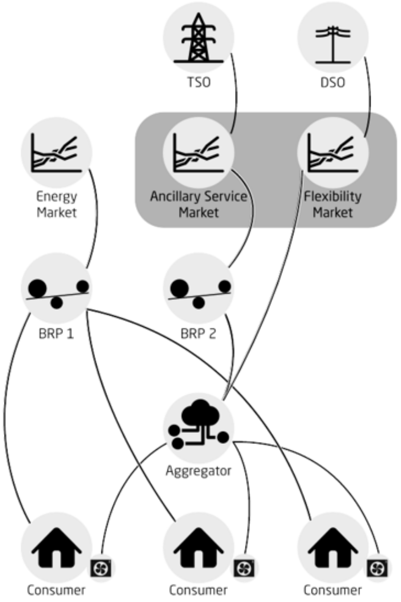

Figure 2: Assumed market set-up for flexibility trade

In addition, we assume that remote submeters are installed such that all flexibility assets can be individually metered (either through parallel, serial, or virtual metering) such that a BRP is associated to the general uncontrollable household load and a second BRP can be associated with the flexible load. Furthermore, it assumed that the DSO has a sufficient number of remote meters in the low-voltage grid to enable load flow analyses and to predict congestion points.

Conflict cases

Initially eight market conflict cases each containing various numbers of scenarios were identified during a series of workshops. The conflict cases can be distinguished by the prescribed DSO response. Some of the conflict cases are further subdivided into sub-cases, depending on the set of actors and the relations between them. This means that some conflict types appear similar but are still different between individual sub-cases in terms of DSO response.

A detailed description of all conflict cases including graphical representation can be found in the work shop report[11] whereas the annex in this report is limited to containing the identified cases including an outline of their operational characteristics[12].

Conflict case dependencies

Some conflict cases can lead to other cases depending on the reaction from the DSO and under certain circumstances.

- The most simple and common conflict case 4 (TSO-DSO conflict), where the TSO activates a number of flexibility assets simultaneously at the time of the load peak, could lead to case 3 (Rebound) in case of upward regulation and if all flexibility assets attempt to regain the lost energy after the activation period. This could also lead to case 8 (In-feed overload) if the simultaneous activation lowers the load on the feeder below the expected minimum at a time with maximum renewable energy infeed.
- Conflict case 4 (TSO-DSO conflict) could also lead to case 8 (In-feed overload) in case of downward regulation if a negative rebound lowers the load on a feeder with high renewable in-feed.
- Conflict case 4 (TSO-DSO conflict) could also lead to case 5 (DSO counteracts flexibility activation) if the activation of flexibility assets is uncoordinated due to the lack of communication between parties. Likewise, conflict case 7 (BRP self-balancing – DSO) could lead to case 5 if the DSO reacts without coordinating with the other parties.
- Conflict case 2 (Explicit demand response) could lead to case 8 (In-feed overload) if an AGR’s simultaneous control of a fleet of flexibility assets lowers the load at a specific feeder below the expected minimum level.

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[11] DREM deliverable D.3.3: ”DSO Role in Market conflicts - Workshop Report on Analysis of the DSO role in Market Conflicts”

[12] Sub-cases can be found in work package deliverable D3.3: “Workshop Report on Analysis of the DSO role in Market Conflicts”

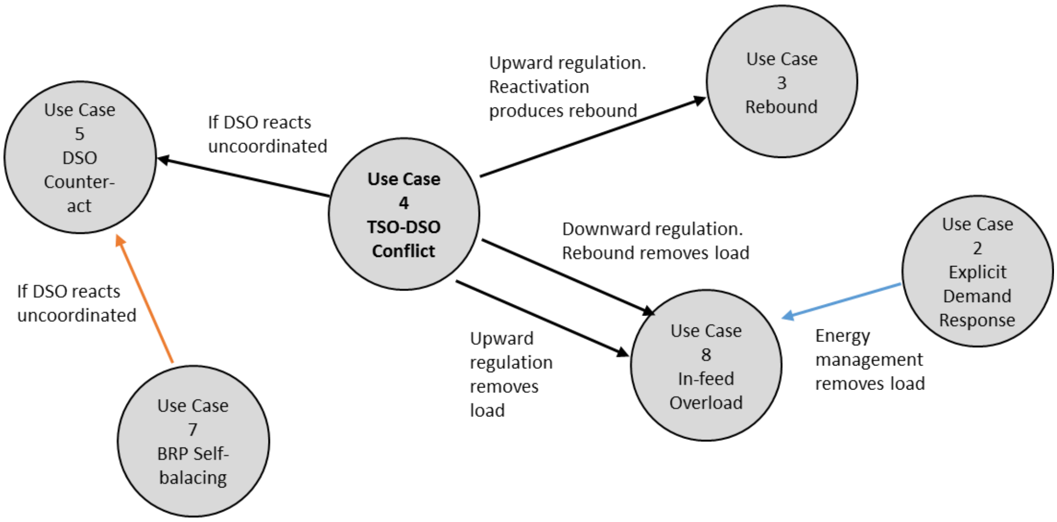

Figure 3: Overview of inter-relations between conflict cases

1.5.3 Solution regime and design

Traffic Light Solution Concept

We have identified the following solution regimes which primarily derive from the workgroup discussion of relevant solutions regimes in a Danish context and which we believe offer the most complete picture. The colours selected do not directly map to those in the USEF document, but the overall framework is the same.

Table 1: Traffic Light Solution Concept

Red	Interruption of customers without notice in order to mitigate a critical (e.g. force majeure) situation in the grid. Could be commanded by the TSO. No agreement with customers concerning interruption.
Orange	Long term contract with specific customers who own a flexibility asset. The contract may be concluded on the basis of a direct bilateral negotiation or based on tendering if more flexibility assets exist on the same feeder.
Yellow	The DSO issues a tender for immediate downward or upward regulation of load on a specific feeder. This will happen on relatively short notice (day ahead at most) facilitated by a fast track system.
Green	DSO congestion avoidance mechanisms directly based on grid codes or other regulatory tools, which enable the DSO to prevent congestion.
Grey	Technical solutions implemented by the DSO which do not involve customers or other agents; e.g. energy storage facilities, re-configuration of the grid, and OLTCs.

The grey solution regime is always a possibility where the DSO has such technology installed. This work focuses on market solutions and therefore the grey regime will not be discussed further.

Likewise, the red solution regime is always a possibility and serves as the last line of defence for the DSO. When everything else fails and a situation becomes critical, the DSO has the possibility to disconnect one or more customers to protect the grid or to prevent a blackout for a larger number of customers. This is a force majeure situation and therefore, the red solution will not be considered further.

The traffic light model was used for gathering solutions into solution regimes and to analyse which scenarios could be viable. The analysis was performed through a series of workshops and showed that the traffic light solution regimes are consistent throughout the sub-cases, which means that the number of practical solutions is reduced considerably[13].

From the study of conflict case scenarios, the following general trends were recommended:

1. When the scenario concerns the wholesale market and should be predicable at least one day ahead (but maybe more), the solution should be market based. Whether the Yellow or Orange solution regime is viable depend on the situation. The Yellow solution regime require a liquid market narrowed to the relevant feeder to be relevant for a DSO. It will still take some time for sufficient amount of flexibility assets to emerge for such liquid market and in the near future the Orange solution regime may be the most relevant.
2. When the scenario concerns the system markets only a narrow window is open to act for the DSO. The conflict is assumed to occur almost momentarily. However, the DSO are not necessarily required to act instantly. For instance, PEX cables can manage 117% overload in up to 50 hours, but some switching gear may only manage overload in less than one hour. The choice of solution regime depends however, not only on the time for managing a market solution, but also the fact that market solution by nature includes activation of a counteractive flexibility asset, which in the case of trading on system markets only create a new conflict. The green solution regime is therefore the preferred approach that allow the DSO simply to interrupt an ongoing trade. Scenario 5.2 is a special case, which is at least theoretical possible but maybe never would be preferred by the DSO.
3. When the scenario concerns BRP self-balancing, the orange solution regime would still be eligible even though the situation occurs momentarily, as counteracting the activated flexibility asset of the BRP will not neutralize the objective of the BRP (unless it is the same BRP for the DSO activated flexibility asset).

Above general trends are summarized in Table 2.

Table 2: General scheme of recommended trends

Day ahead	Wholesale market	(Green)	Yellow	Orange
Momentary	Self-balancing	Green		Orange
Momentary	Balancing market	Green		(Orange)

Solution design

Based on the set of solution regimes, a solution design was proposed. The design is based on a combination of interventions in three identified domains

1) Regulatory (R),
2) Market (M)
3) Communication/operation (C).

The proposed design includes communication sequences for responses to two general classes of events. The focus on the design of the solutions has been to make framework solutions, such that

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[13] For the detailed analysis of solution regimes is referred to the workshop report.

the solutions are of a general nature and not kludges that may eventually complicate the operation of the system in the future. In the following subsections we define the framework solutions. Each of these solutions have been indexed by an acronym, e.g. R-1 for the first regulatory proposal, yet we stress that the following proposals must be viewed as one global solution that will address all conflicts listed in the previous chapters. Table 3 gives an overview of these solutions.

Table 3: Summary of the framework solutions proposed by the DREM project[14]

Solution acronym	Solution name
R-1	Registration of flexibility assets
R-2	Redefining the DSOs installed capacity obligation
R-3	Aggregators must be attached to a BRP
R-4	DSOs are not required to reimburse for trade interruptions
R-5	DSOs are not responsible for redispatch impact
M-1	Use of flexibility markets for DSO services
M-2	Redefinition of services to include rebound
C-1	Establishing a dynamic information broker for allowing the DSO to communicate limits to BRP/AGR
C-2	AGR/BRPs submit operational schedules

We have divided the solutions into those necessary for a base solution, and those that could be optional. Specifically, the registration of flexibility assets in a common database (R-1) is necessary for the DSO being able to estimate how much flexibility exists in its system. This allows for:

- The DSO to know how much capacity it must make available (R-2),
- How much flexibility it can buy as a service (M-1),
- Allow the DSO to send relevant limitations on the DSO installation numbers through the dynamic information broker (C-1).

Furthermore, the establishing of a dynamic information broker (C-1) partially depends on the existence of a DSO service market (M-1). In order to avoid market gaming, the DSOs must be held free from responsibility for trade interruptions (R-4) and redispatch impact (R-5).

Furthermore, the correct functioning of a DSO service market (M-1) depends partially on the AGR being associated with a BRP (R-3), such that the DSO does not cause imbalances in the system by activating flexibility. At the same time, the inclusion of the rebound as part of the service definition (R-3) depends partially on the existence of DSO service market (M-1, for the definition of DSO flexibility services with rebound) but should also be applied to the definition of ancillary services (the TSO service market). Finally, the optional communication of operation schedules by the BRP/AGR to the DSO (C-2) depends on there being an actual system to communicate these schedules (C-1). These necessary and partial dependencies are shown graphically in Figure 4.

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[14] For the detailed description of framework solutions is referred to the workshop report.

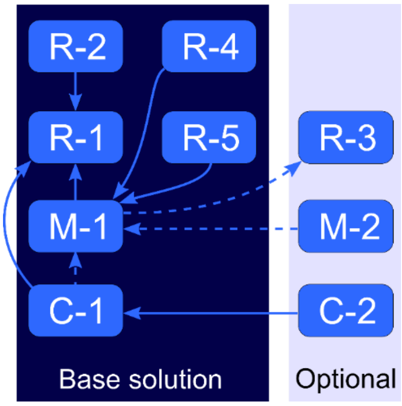

Figure 4: Graphical representation of the base solution and optional solutions.
(Solid arrows represent necessary dependencies and the dashed arrows represent partial dependencies)

One of the main conclusions from the workshops was that the DSOs were not interested in interfering or validating market transactions between AGR/BRPs and the wholesale market (as it is done in the USEF setup). Thus, a solution was formulated where the DSO could communicate relevant grid constraints to the AGR controlling flexibility assets under a given metering point. This communication is envisioned to occur through a Trade Permission System, which contains two new elements: a dynamic information broker and static information regarding the available flexibility assets. R-1 proposes that the static information should be kept in a common database, for example the Energinet DataHub, and the dynamic information broker could be a module running on a FLECH-like flexibility market.

This solution (in conjunction with R-1, R-2, M-1, and C-2) addresses conflict cases 2, 4, 5, 7, and 8, in that it avoids a conflict as long as the AGR/BRP respects the imposed limitation of the DSO when bidding into other markets. Figure 5 shows an overview of how the Trade Permission System would fit into the proposed setup.

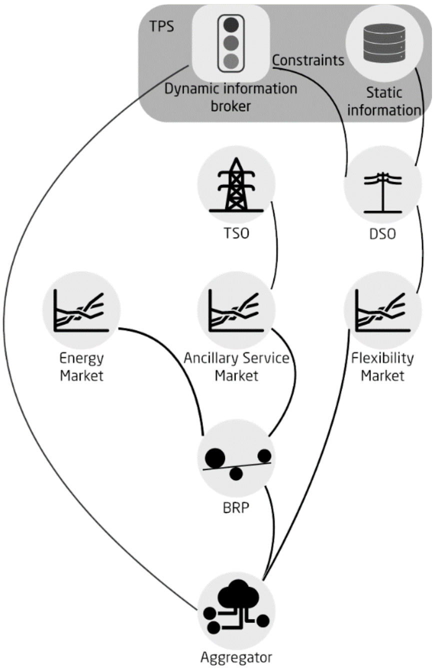

Figure 5: Architectural overview of the Trade Permission System with respect to the market setup.

Communication Sequences

The communication sequences of the solution design differ dependent on which solution regime is considered.

Market trade sequence

The Yellow and the Orange solution regimes are considered as market solutions. At present, where very few flexibility assets are represented at each feeder that is available for the DSO, an activation contract may be established on basis of bilateral negotiation. Still, prices are formed on basis of the interests under free market conditions. But as the market liquidity increases, it will make sense to make use of the mechanisms such as the Flexibility Clearing House.[15]

DSO limitation sequence

Whenever situations arise where the DSO needs to communicate limitations in its grid, the capacity limitations are sent out through the dynamic information broker. Figure 6 shows how these limitations can be estimated and pushed out to the appropriate AGR.

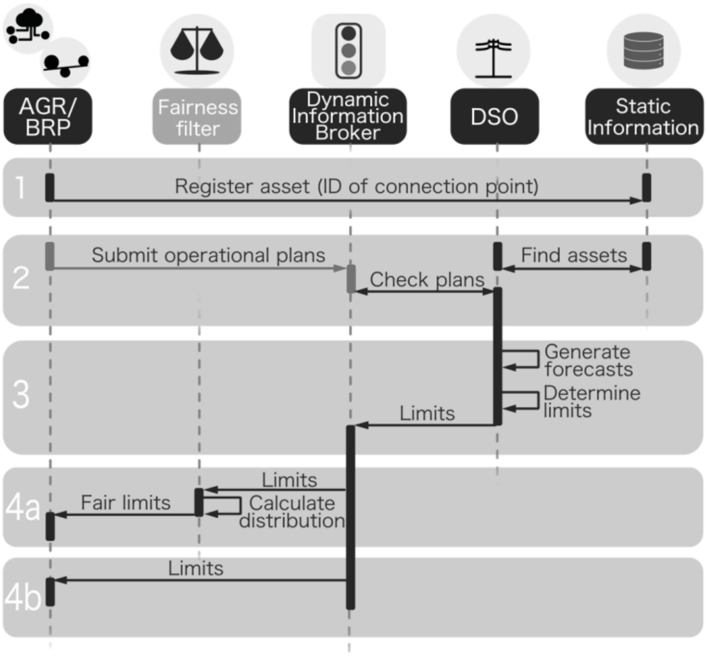

Figure 6: Message Sequence Diagram depicting the order of signals and messages to be exchanged in order to communicate the DSO limitations or orders.

The same system can be used in cases where the limitations occur due to sudden faults. These sudden limitations are pushed through the same system. Thus, the information broker can also be used for unforeseen capacity issues due to faults in the system. In such a case, the information model and the DSO actions are different, since the emergency signal would either be a “stop all flexible assets”, “start all flexible assets”, or “maintain current load as it is”. These signals are sent in order to avoid brownouts.

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[15] For the detailed description of the market trade sequence is referred to the workshop report and the iPower project.

1.5.4 Implementation

As part of WP5, the project developed a reference implementation consisting of a geographically distributed combination of real-world and emulated components. The reference implementation was later used for system integration testing, scenario-based validation and demonstration within the project.

The reference implementation consisted of the following elements:

- A portfolio of flexible loads connected to a distribution grid at the SYSLAB laboratory on DTU-Risø campus.
- An instance of the MKPlanner aggregation platform, operating at Markedskrafts site in Aarhus and controlling the portfolio of loads.
- A Certified Data Gateway Server (CDGs) on EURISCOs premises in Odense, emulating an aggregator-internal command and control infrastructure by facilitating the standards-compliant, real-time exchange of measured data and control commands between MKPlanner and the flexible loads.
- The distribution SCADA system at SYSLAB, monitoring power flows in the distribution grid.
- An instance of the proof-of-concept Trade Permission System developed for the DREM project and operating on EURISCOs infrastructure.
- A simple proof-of-concept emulation of a DSO, able to detect network congestion situations based on SCADA data and to submit requests to the TPS.

Figure 7 shows an overview of the main components as well as the interactions between them. These components and the communication interfaces used to exchange information are identical to how the DREM project would envision a real-world deployment, with the following exceptions:

- An aggregator (here Markedskraft) would normally utilize its own command and control infrastructure for controlling the assets in its portfolio. The use of third-party infrastructure (CDGs) in the reference implementation was chosen for convenience and speed of deployment and does not affect the validity of the proof-of-concept.
- The DREM concept requires a static information system and a dynamic information broker. DREM proposes to implement the static information system as an extension to an existing system-wide customer registry (for example the DataHub) whereas the dynamic information broker is an entirely new infrastructure. In the reference implementation, the TPS includes both the static and dynamic parts of the system as the proposed registry extension does not exist yet in the real world. Like the previous exception, this does not affect the validity of the proof-of-concept.
- The DREM project did not attempt a full integration with a DSO’s operational systems (DMS and SCADA) - this would have far exceeded the scope of the project due to the strict requirements for security and reliability. Instead, a DSO emulation has been devised, implementing three heavily simplified functionalities: Submission of a planned capacity limit to the TPS, real-time detection of congestion based on a threshold applied to SCADA measurements, and submission of unplanned capacity limits to the TPS as a response to congestion events. Real-world operational implementations of congestion detection and limit submission have been left to future work at a higher TRL.

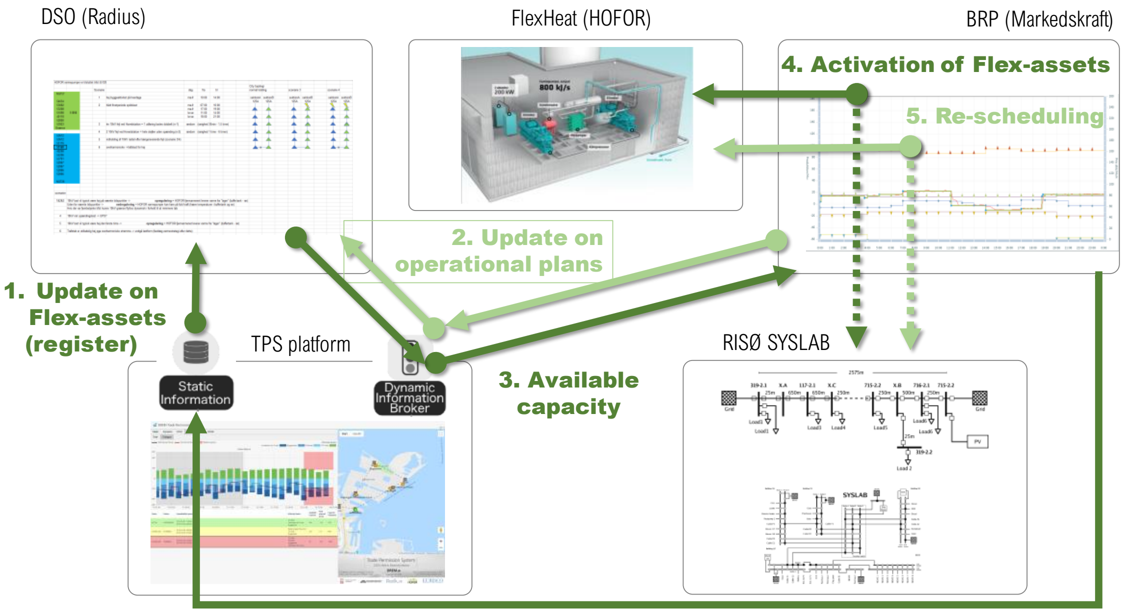


Figure 7: Actors and basic sequence of operation

Transparency Platform

In 2015, ENTSO-E launched a new central transparency platform (TP), providing access to pan-European electricity market data for all users, across six main categories: Load, Generation, Transmission, Balancing, Outages and Congestion Management. From the very beginning of the project, the ENTSO-E Transparency Platform, despite its different scope with a focus on inter-TSO power exchange, has inspired the TPS concept for the distribution grid.

Among the main differences between the TPS platform and the ENTSO-E Transparency Platform, is the distinction and role of the Static Information System and Dynamic Information Broker in DREM, and the DREM project’s focus on only two different scenarios – foreseen and unforeseen congestion.

Among other concepts originating from the ENTSO-E TP, the TPS has been able to build upon the IEC-62351-503 specification for reliable transportation of data between parties in the energy sector, also known as MADES. MADES is used to facilitate all communication between the individual TPS modules. DREM has been able to reuse a reference implementation of MADES developed by UNICORN for ENTSO-E, including the ECP-Endpoint, ECP Broker and ECP Component Directory. This has greatly reduced the development cost and time required to produce a working MADES network implementation.

Figure 8 shows the basic architecture of the TPS. For the purpose of simplifying the communication paths in the diagram, the ECP Component Directory has been left out.

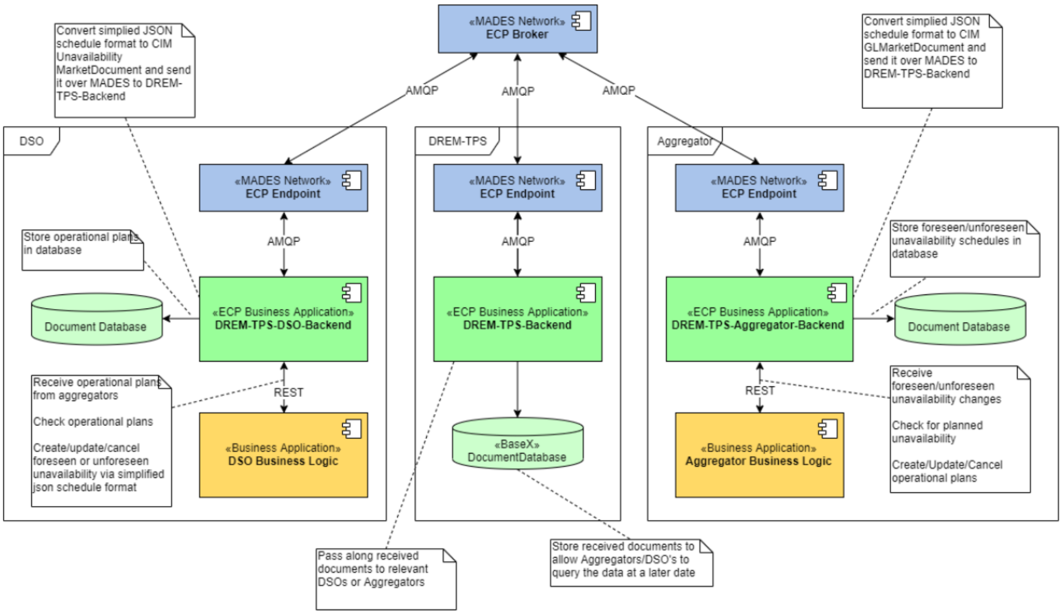


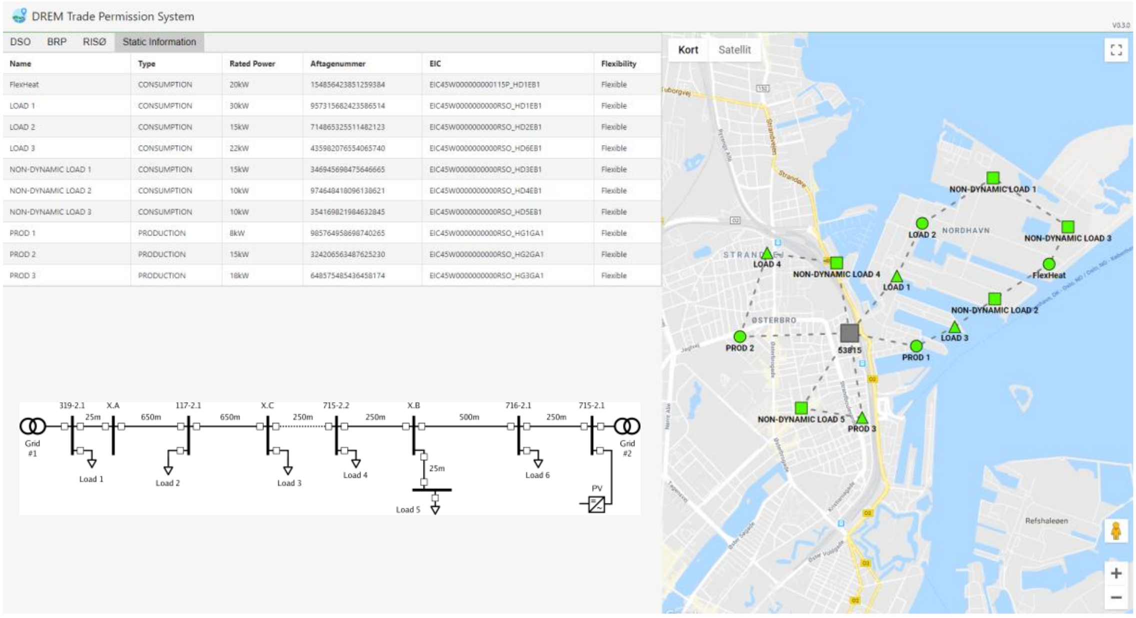
Figure 8: TPS platform architecture

The DSO and Aggregator communicate with each other by sending data to the TPS backend, using the respective ECP Endpoint. The TPS backend is then responsible for distributing the received CIM documents to all relevant parties. This prevents any one party from attempting to game the system by selectively sending data to individual actors unfairly.
Once a CIM document is received, it can be directly processed by an AGR/BRP or a DSO's business application, if connected directly to the ECP Endpoint, or it can be pre-processed by their respective backend application. The data is then exposed using a REST/HTTP web interface.

User interface

A web-based user interface has been developed to monitor and control the TPS platform. This user interface has also been used for visualisation purposes during the first demonstration event. The user interface consists of several pages, each providing access to the data in the Static Information System, schedules submitted by the AGR/BRP, capacity limits submitted by the DSO and measured data from the flexibility assets, as seen by the CDGs. (In a real-world TPS, asset measurements would not be available).

Figure 9 shows a snapshot of the Static Information System data corresponding to the flexibility assets on the SYSLAB grid. The grid topology of the laboratory grid used in the proof-of-concept evaluation (bottom left) has been chosen to emulate that of a fictitious distribution feeder loosely based on the distribution grid in Nordhavn (map on the right, feeder loop east of the grey substation).
The table on the top left lists the identifiers, types and rated flexibility of all registered assets. A unique EIC code allows for an unambiguous mapping of flexibility assets between the DSO and BPR domains.



DREM Trade Permission System

Name	Type	Rated Power	Aftagenummer	EIC	Flexibility
FlexHeat	CONSUMPTION	20kW	154856423851259384	EIC45W000000000115P_HD1EB1	Flexible
LOAD 1	CONSUMPTION	30kW	957315682423586514	EIC45W0000000000RSO_HD1EB1	Flexible
LOAD 2	CONSUMPTION	15kW	714865325511482123	EIC45W0000000000RSO_HD2EB1	Flexible
LOAD 3	CONSUMPTION	22kW	435982076554065740	EIC45W0000000000RSO_HD6EB1	Flexible
NON-DYNAMIC LOAD 1	CONSUMPTION	15kW	346945698475646665	EIC45W0000000000RSO_HD3EB1	Flexible
NON-DYNAMIC LOAD 2	CONSUMPTION	10kW	974648418096138621	EIC45W0000000000RSO_HD4EB1	Flexible
NON-DYNAMIC LOAD 3	CONSUMPTION	10kW	354169821984632845	EIC45W0000000000RSO_HD5EB1	Flexible
PROD 1	PRODUCTION	8kW	985764958698740265	EIC45W0000000000RSO_HG1GA1	Flexible
PROD 2	PRODUCTION	15kW	324206563487625230	EIC45W0000000000RSO_HG2GA1	Flexible
PROD 3	PRODUCTION	18kW	648575485436458174	EIC45W0000000000RSO_HG3GA1	Flexible

Figure 9: DREM TPS and link to DTU-Risø implementation and test

Figure 10 shows the currently active flexibility asset schedules as submitted by the AGR/BRP (black line) compared to the actual flexibility asset responses (red line), both before (shaded grey) and after (white background) the operating hour. Additionally, the individual unit contributions to the overall flexibility asset response are represented by blue (load) and green (production) stacked areas. In a real-world TPS, only the submitted schedules would be available. For demonstration and visualisation purposes, the TPS includes the flexibility asset response data which would otherwise be restricted to internal use by the AGR/BRP.

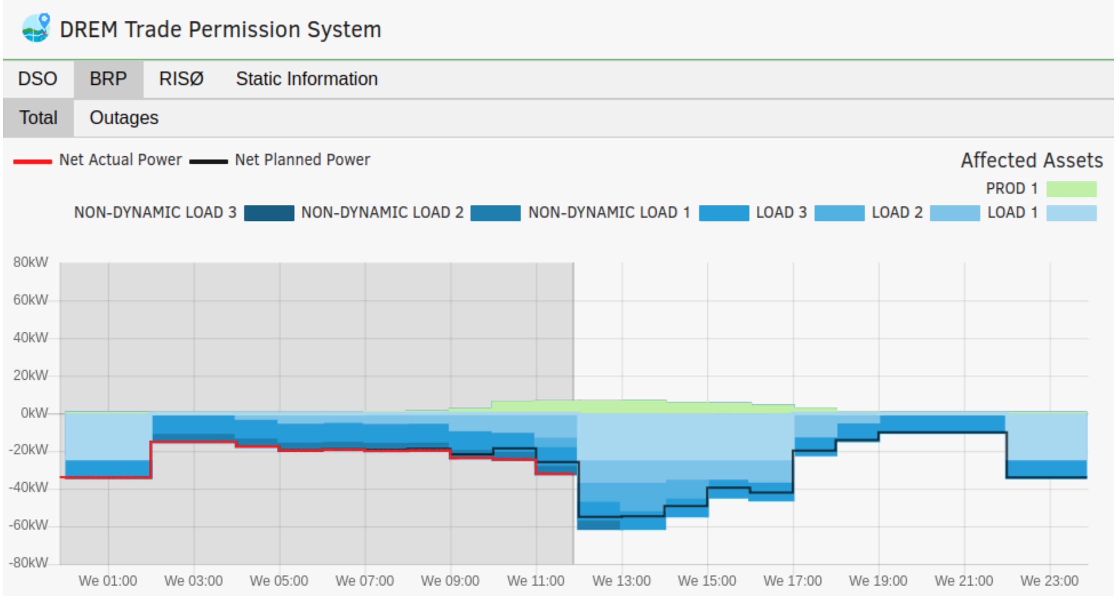


Figure 10: DREM TPS and graphics for BRP planned and actual power

Figure 11 shows a similar situation as seen by the AGR/BRP, in a screenshot of the MKPlanner dispatching and planning developed by Markedskraft. This specific situation is an electricity consumption plan for the FlexHeat facility 24 hours ahead by the green line and the red line is the spot price forecast. This tool is described in more detail in the WP7a report.

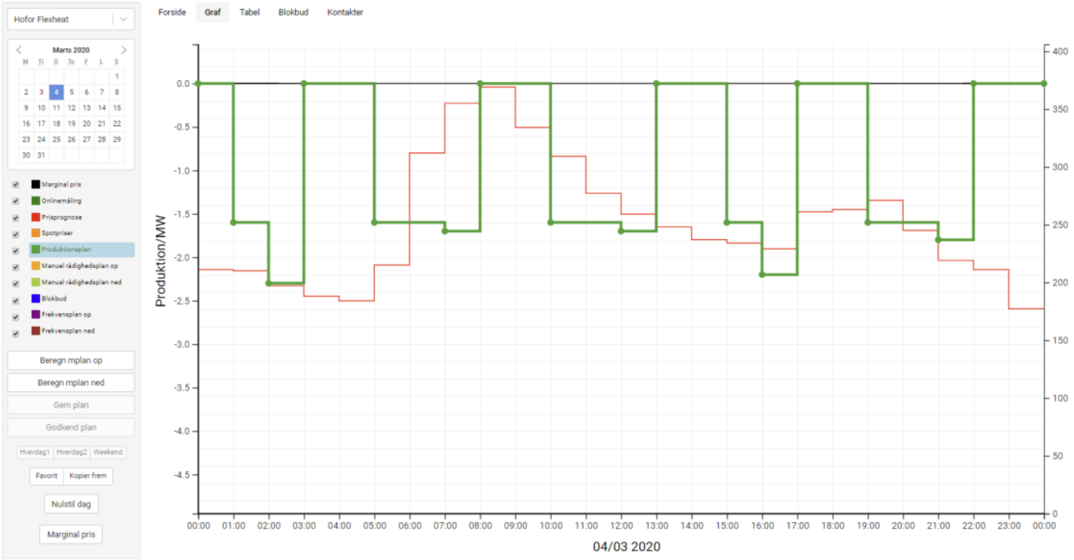


Figure 11: MKPlanner operation tool from Markedskraft

Implementation at the FlexHeat site

For the second part of the testing and demonstration effort, the flexibility assets and grid at the SYSLAB laboratory were replaced with the real-world FlexHeat heat pump operated by HOFOR and installed in Radius' distribution grid in Nordhavn. This motivated a different setup as shown in Figure 12. Here, an interface was developed to connect the FlexHeat flexibility asset directly to the BRP platform using IEC 61850 as a standardized means of communication.

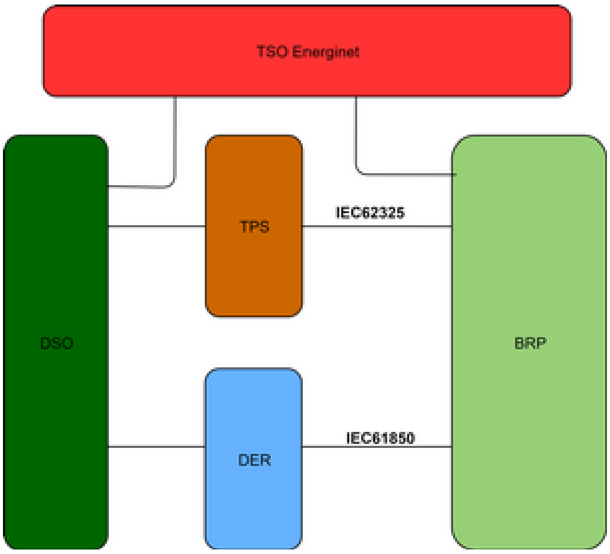


Figure 12: Implementation for the FlexHeat setup

For more information, see deliverables D6.1, D6.2, D6.3 and D7a.

1.5.5 Validation

From the beginning of the project, the availability of small household flexibility assets was identified as a risk factor as mentioned in the risk assessment section of the detailed project plan (D1.1). Despite efforts to recruit a portfolio of residential heat pumps, the project had to abandon the original plan for WP4 (Mobilising Flexibility Assets / Aggregator Models).

Investigation of aggregator models for households was the main objective of WP4 and was seen as a natural extension to the core project objective of solving conflicts between actors in the electricity sector. However, when initiating the relevant activities, a number of series challenges arose. The original plan of recruiting small household flexibility assets available through the EnergyLab Nordhavn project in Copenhagen was deemed impractical due to the lack of volume, the coordination effort with other activities in EnergyLab Nordhavn and the larger than expected modifications to existing command and control systems. Instead, the project investigated the inclusion of households with domestic heat pumps in North Zealand.

This effort created its own set of challenges. As a result of unbundling, Radius does not have any means of maintaining lists of heat pump customers, which types of heat pumps are installed at customer premises, or which energy suppliers these heat pumps are contractually linked to. Furthermore, an active selection of energy suppliers for participation in the project (in order to reduce the number of involved parties) would not be permitted in the context of functional unbundling. The only viable option of individually addressing customers to ask for their equipment and willingness to participate was considered possible but amounting to a large effort.

Another challenge was presented by the need to aggregate across several balance responsible parties, requiring the BRP participating in the project (Markedskraft) to act as a kind of meta-BRP, aggregating the response from multiple other BRPs external to the project. The present regulation regime in Denmark does not provide for this type of model and would have required dispensation which the project was not able to obtain.

Another issue was related to the requirement for certified metering for flexibility assets participating in flexibility services traded by BRPs. For residential heat pumps, this would require the installation of a separate smart meter at the connection point of the flexibility asset. In private households with limited space in existing breaker cabinets, this would often require the installation of a second breaker cabinet and a significant rewiring of the household installation. This was deemed to be financially prohibitive, as well as being a significant barrier to customer acceptance. The project applied for dispensation in order to be able to use device-internal metering data during the test period, but this was not granted.
This was considered the final straw, and the aggregation of household-level flexibility assets was not pursued further in the project.

The project also had plans to include multiple large-scale flexibility assets in the demonstration phase. A large heat pump and electric heating elements in the district heating system as well as combustion air blowers in power plants were recruited for participation in the demonstration phase. However, the introduction of larger flexibility assets to the system market was less straightforward than expected.

Performing a thorough analysis of the interrelation between the baseline operation of a flexibility asset and the requirement for engagement in the market in a financially viable way significantly exceeded the resources assigned to the task. This issue is left to future work.

The lack of a portfolio of real-world flexibility assets led to a rethink of the entire validation approach. It was decided that a large part of the proof-of-concept validation could be performed satisfactorily in a laboratory distribution grid. DTUs participation in the project enabled the use of the SYSLAB laboratory at DTU-Risø campus for this purpose. Furthermore, in order to validate certain aspects of the system which would be difficult to reproduce in a laboratory, HOFOR agreed to make the “FlexHeat” district heating unit in Nordhavn (800 kJ/s heat pump + 2x100 kJ/s electrical boilers) available to the project. Finally, an expansion of scenarios to be validated would be made available through a purpose-built simulation tool which in itself would be validated against testing data from the FlexHeat system.

Validation stages

As a result of these changes, the project performed the validation of the proof-of-concept in four stages:

- **System integration validation:** A number of integration tests were conducted to validate the correct flow of information between the four entities involved in the proof-of-concept system: The AGR/BRP’s operational platform, the flexibility assets in the laboratory grid, the TPS and the (emulated) DSO. The scope of the tests was limited to the interaction with the Dynamic Information Broker, i.e. not including the Static Information System. It was assumed that the DSO "already knows" the flexibility assets it is requesting capacity limitations for. For the purpose of the validation, the control loop remained open at the DSO side, i.e. there was no link between the flexibility asset setpoints, and the capacity limits requested by the DSO emulator. The information exchanges were validated in stages beginning with the correct integration of the asset controls and measurements with the BRP platform. Subsequently, the DSO’s ability to submit planned and unplanned capacity limitations to the TPS as well as the BRP’s ability to receive limitation notices from the TPS were confirmed. Finally, the entire open-loop chain was validated by testing the response of flexibility assets to capacity limits issued by the DSO.

  A more detailed description of the integration tests is found in deliverable D6.3.

- **Scenario based validation:** The objective of scenario-based validation is to confirm the ability of the Trade Permission System to mitigate a capacity issue in a concrete scenario. Like in the integrated system validation, the scope is limited to the interaction with the Dynamic Information Broker. The main difference is that the control loop is now closed at the DSO side, i.e. the emulated DSO continuously monitors power flows across different locations on the feeder, and issues capacity limit requests to the TPS if the capacity of the feeder is exceeded.
  The grid topology for the test is chosen to emulate an urban distribution feeder which can be supplied from transformers at both ends and is equipped with a disconnector at about half its length (between load 3 and load 4 in Figure 13). This enables the feeder to be operated in its normal configuration as two independent half feeders with the disconnector open, each supplied through its own transformer. In case of e.g. a transformer fault at one end, the disconnector can be closed, enabling all customers to be supplied from the other (unaffected)

end. In this configuration, the capacity of the feeder will be reduced and may require DSO intervention.

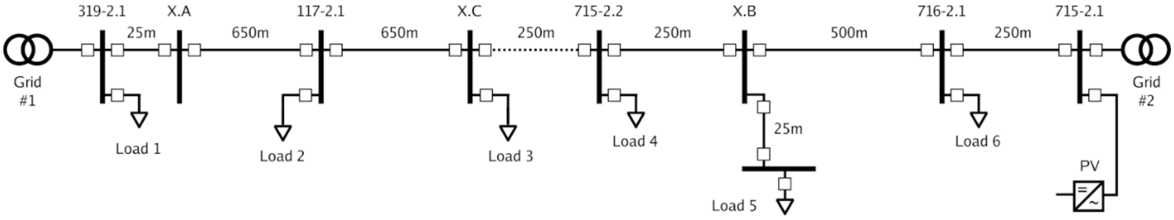


Figure 13: "Nordhavn" feeder mapping to the SYSLAB distribution grid

Measurement instruments providing voltage, current, active and reactive power measurements on a 1-second basis are available at 25 different points throughout the feeder (red arrows in Figure 14). This enables precise voltage and power profiles to be recorded for the duration of the test. The system's response to both foreseen and unforeseen capacity limitations was validated by generating a combination of base load profiles and flexible load schedules which would be well within the capacity of the two divided half-feeders but would exceed the capacity the grid-side half when the feeder is supplied only from one side. This single-sided configuration was created by changing the position of the two circuit breakers marked with blue arrows in Figure 14. Both in the foreseen and the unforeseen case, the DSO issues a capacity limitation for the affected units, and the AGR/BRP responds by rescheduling.

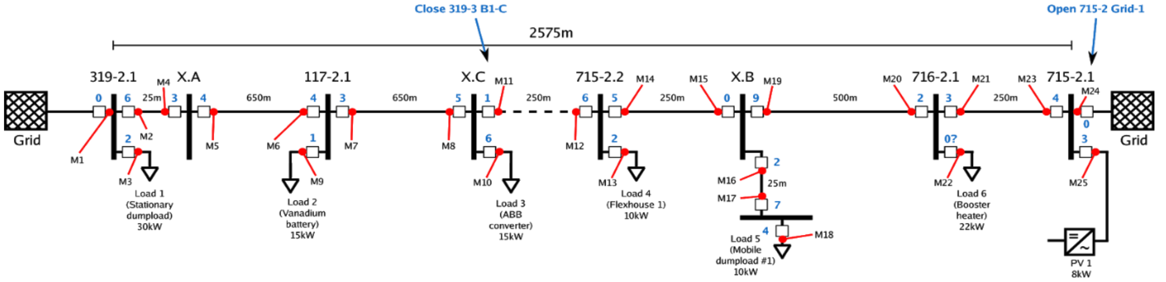


Figure 14: SYSLAB distribution grid with current measurement points and breakers used for topology changes

A more detailed description of the validation tests is found in deliverable D5.1.

- **End-to-end validation:** The end-to-end validation test builds on the proof-of-concept established in the previous validation steps, but validates the ability of the system to function within the operating constraints of a real-world flexibility asset, i.e. where DSO requests for flexibility reduction have to be aligned with three already existing objectives of operation: Meeting the heat demand of a district heating network, and providing flexibility services while being economically beneficial to the asset operator.
  As discussed in the previous section on implementation, a different, standards-based system is used for the direct communication between AGR/BRP and the flexibility asset. This setup is very similar to how a real-world flexibility asset would be controlled as part of an aggregator's portfolio, compared to the simplified communication setup used for laboratory testing. For this reason, one of the aims of the end-to-end validation has been to test the applicability of existing standards such that e.g. different types of heat pumps with different ways of applying capacity constraints could be handled by the same communication interface.

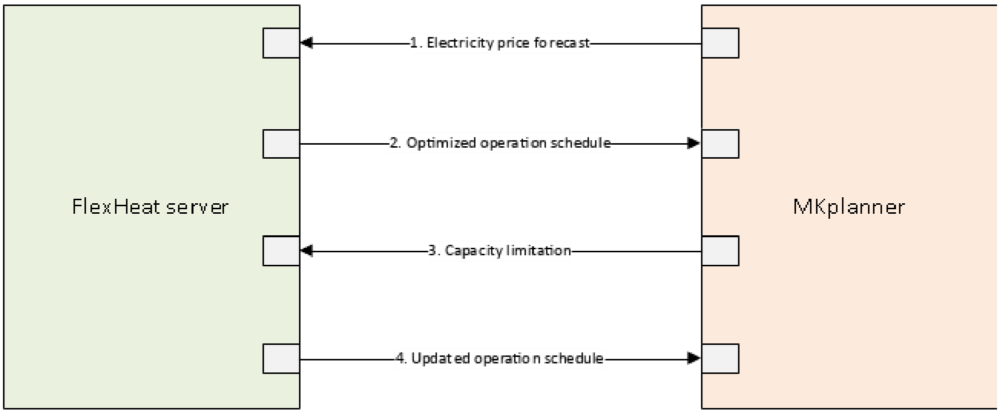


Figure 15: Communication requirements between AGR/BRP and a flexibility asset (FlexHeat)

A field-test scenario was executed on site, and further economic optimization and extensions were performed afterwards to provide a more general perspective on the scenarios. These analyses considered trading on day-ahead markets only, indicating conflict case 5 and 8, as well as scenarios which included ancillary services (conflict case 4).

Before the validation tests, a prefeasibility study indicated that the increased heat production costs would be in the range of 150-550 DKK/MWh due to capacity limitations by the DSO, whereas the field tests yielded a range of 30-1460 DKK/MWh. When responding to foreseen capacity limitations issued by the DSO, it was possible to intelligently reschedule the heat pump to optimally operate around the congestion. Production costs in these scenarios ranged from 2 DKK/MWh to 325 DKK/MWh, depending on whether the heat pump could be rescheduled, or a supplementary oil boiler had to be started to meet the heat demand.

On the BRP side, the automated rescheduling of the FlexHeat asset as a response to both foreseen and unforeseen scenarios was successfully demonstrated.

A more detailed description is found in deliverable D7a.

- **Simulation-based scenario assessment:** The main objective of the simulation-based assessment has been to quantify the overall impact of the TPS mechanism on flexibility asset operation as well as on distribution network operations, as opposed to scenarios where a TPS is not available. The system configuration for this assessment replicated the configuration of the end-to-end test with a grid loop based on an actual network feeder in Nordhavn, a DSO, an aggregator and a flexibility asset. The flexibility asset was modelled on HOFOR’s FlexHeat system, with a two-level control system to represent both physical dynamics and predictive optimization. In order to emulate random faults locations, the model included the individual cable segments in the feeder. This setup allowed the simulation to be validated against the real-world FlexHeat configuration and is depicted in Figure 16

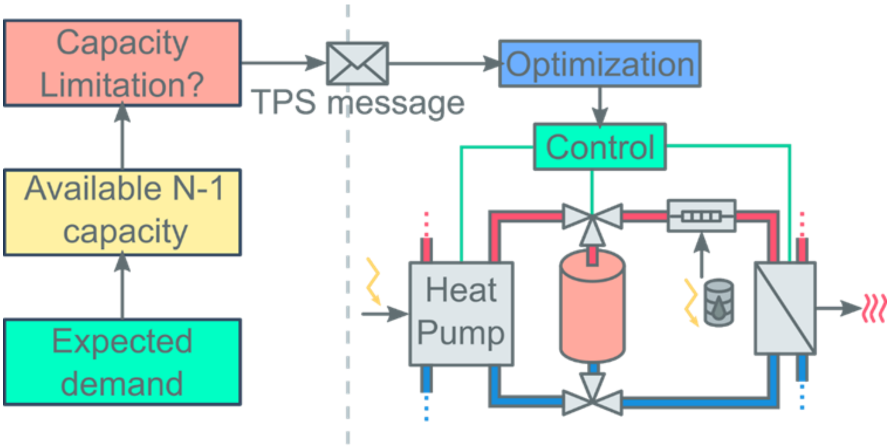


Figure 16: Structure of the simulation tool

The simulator generates DSO requests automatically based on expected congestion. The TPS messaging functionality is emulated such that the aggregator (predictive optimization) receives DSO restrictions either on a day-ahead basis (foreseen capacity issue) or immediately (unforeseen capacity issue). Scheduled set-points are exchanged with the local controller. In line with the overall project scope, the design of aggregator solutions for multiple household level flexibility assets has been excluded.

The increased pressure in the distribution grid is modelled by reducing the available grid capacity, which corresponds to increasing coincidence factors[16] caused by an increasing ratio of flexibility assets replacing non-flexible assets. TPS capacity limitation messages are issued in 2 of 150 simulated N-1 for a capacity scaling of 60%, which is just below to the current N-1 peak consumption (at 68%). At 45% capacity scaling, corresponding to 20% of load replaced by flexibility assets, 15 of 150 N-1 simulated scenarios lead to capacity reduction requests which can well be met by the available flexibility assets at this level. A further reduction of capacity scaling or coincidence factor increase leads to unreasonable levels of capacity limitation.

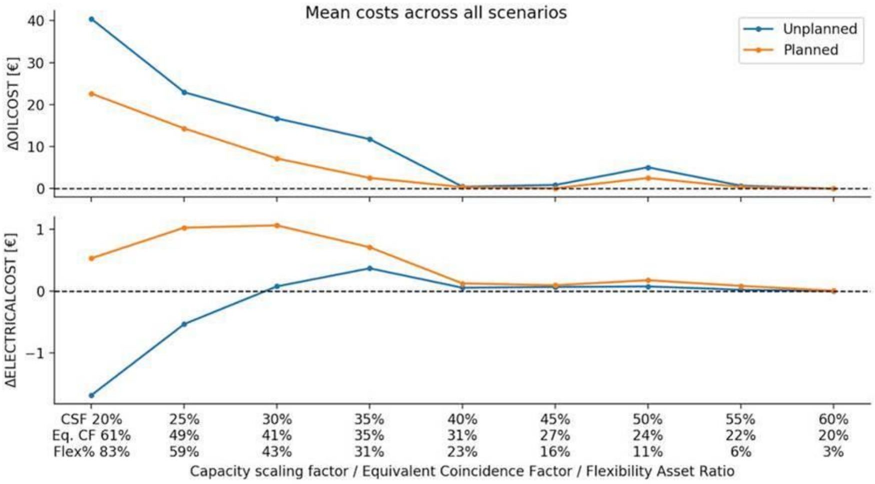


Figure 17: Mean simulated operation cost increase per level of reduced grid capacity / increased coincidence factor / Percentage of Load replaced with Flexibility Assets (from right to left)

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[16] Also known as the concurrency factor

Figure 17 shows the summarised (weighted mean) results of the operational impact of capacity restrictions on estimated FlexHeat operation cost, relative to the same scenario without restrictions. The cost increase is shown separately for changed electricity procurement cost and additional oil firing cost, which becomes necessary when electricity is restricted. Even once line capacities are reduced below 65%, costs to operate the FlexHeat system do not increase significantly until line capacities are reduced below ca. 40%. Thus, operating flexible assets to offset grid investment is expected to be feasible for this range down to about 45% of the present capacity.

A more detailed description is found in deliverable D7b.

1.5.6 Demonstration

Mid-project demonstration at DTU-Risø

The first demonstration workshop was held as a full-day event at the SYSLAB laboratory on DTU-Risø campus, in collaboration with Intelligent Energi (iEnergi). About 50 participants attended a program alternating between presentations and live staged demonstrations.

After an introduction and context setting by Helle Juhler-Verdoner (iEnergi) and welcome by Poul Brath (Radius), the initial presentations covered the perspectives and motivations of the different actors: The BRP perspective was provided by Markedskraft, outlining the importance of communication in the coordination between the markets and flexibility assets. Radius provided insights into DSO operations and how their decision-making may be impacted by the introduction of more flexibility assets without coordination. HOFOR as a Flexibility Asset operator presented scenarios for the costs incurred by foreseen and unforeseen capacity restrictions.

The four demonstrations built upon each other, from a presentation of the demonstration setup to a real-time demonstration of one of the conflict cases, to a walk-through of the proposed solution. Multiple large visualisation screens allowed the audience to follow the state of the aggregator trading system, the transactions on the TPS, the real-time state of the laboratory grid and the flexibility assets connected to it, and the view of the (emulated) DSO as the demonstrations progressed. The first demonstration showed how Markedskraft uses its operational system to monitor, schedule and activate a flexibility asset on the SYSLAB grid. In the second demonstration, the audience was familiarized with the distribution grid replicated in the laboratory. A simulated fault caused the demonstration feeder to be reconfigured into a weaker topology with all loads being fed from one end of the feeder. It was shown how this action caused an overload of the feeder, against which the DSO would not have any remedies short of load shedding.

The final two demonstrations then introduced the TPS as an additional tool allowing coordination between DSO and aggregator/BRP. The same overload case as in the previous demonstration was used to show the working of the TPS mechanism for a foreseen and an unforeseen capacity constraint. It was successfully demonstrated how the overload condition could be relieved after the DSO submitted capacity constraints to the TPS, and the AGR/BRP responded by adjusting the flexibility asset’s operating schedule.

Picture 1: Oliver Gehrke (DTU) presents Demo 2 with a live feeder loop reconfiguration.

Picture 2: Jesper Holm (Markedskraft) and Jacob Dall (EURISCO) present Demo3/4, where Markedskraft receives restrictions via TPS and updates the operating schedule of consumption units using MKPlanner.

Before the final two demonstrations, a presentation explained the stakeholder driven solution process carried out by DREM: the formulation of conflict cases, the derivation of case-by-case solutions based on the traffic light model, and the consolidated design leading to the final Trade Permission System requirements, including the derived communication sequences for foreseen and unforeseen capacity restrictions.

The main approach to communicating capacity restrictions developed within DREM was based on inputs to the design process from several DSOs. During the discussion slot after the end of the demonstrations, it was confirmed that the DSO representatives in the audience acknowledged the need for Flexibility Asset registration and for BRP signalling, as suggested by DREM requirements R-1 (Registration of Flexibility Assets) and C-1 (Dynamic information Broker for capacity restrictions). It was furthermore established that the business case for a DSO would be difficult if all BRPs would have to be reimbursed for all trades interrupted or cancelled by TPS interventions. Therefore, the DSO should not reimburse the BRPs (in line with requirements R-4 and R-5). Responding to this viewpoint, a representative from BRP EnergiDanmark argued that BRPs would find themselves in a problematic situation if unpaid interruptions were to become standard practice by Danish DSOs. As the BRP business revolves around trading, revenue depends on delivery of energy at a specific time and price. If energy is not delivered or at a different time the BRP incurs higher costs, both from asset operation (asset owner reimbursed) and suboptimal (market) prices. The BRP can therefore not afford to reimburse the asset owner if not reimbursed by the DSO. If a DSO interrupts the execution of an active ancillary service contract by a BRP, the asset owner is still expected to be paid, but the BRP might incur penalty payments from the TSO. This would collapse the entire business model around flexibility trades in the DSO grid.

In this context, the preliminary assessment of the cost and feasibility of the response to TPS restrictions gained during the tests involving HOFOR's FlexHeat asset were positively received. The implied costs of deviating from optimal operating plans were discussed. BRPs considered the preliminary results to be relevant for starting to estimate the marginal cost of interruptions and operating restrictions. The results were also seen as relevant for DSOs in order to calculate realistic prices for DSO services.

Another insight from the discussion was that DREM requirement R-2 (Redefining the DSO’s installed capacity obligation) would be a more complex effort. The “required capacity” is not specifically defined in the regulatory framework, and as a result, the responsibility for a specific adjustment cannot be traced back to a particular actor. An intense discussion erupted regarding the fairness of grid tariffs, because the investment cost for large overcapacities (e.g. due to a concentration of high power EV chargers in a wealthy neighbourhood) would be socialised by grid tariffs if these were not supplemented by active grid management at the same time.

Final conference in Nordhavn

The final DREM conference was originally planned for March 26th, 2020 at the EnergyHub showroom in Nordhavn, Copenhagen. However, due to the COVID-19 pandemic it has been postponed and will be scheduled at a date after the submission of this report. Therefore, this section is limited to discussing the plans for the final conference and the expected value to the participants.

The conference aims to present the results and insights gained since the mid-project workshop to a wide range of representatives from the Danish energy sector. About 50 participants are expected to attend. As a demonstration component, an on-site visit to the HOFOR FlexHeat facility is planned, including a demonstration of the final development stage of the Trade Permission System and of the data communication between the various market participants.

Although the solution to DSO congestion challenges developed in the DREM project has already been built upon feedback from a broad range of actors in the energy sector through a series of stakeholder workshops, the mid-project workshop has demonstrated that further valuable professional feedback can be obtained once a more coherent solution is presented to an audience. Therefore, one of the primary objectives of the conference is to collect such feedback for the second half of the project. This applies in particular to the limitations of the demonstration scope: Although the concept has been developed for a larger number of actors, the field demonstration has been limited to a single AGR, DSO and flexibility asset. While the laboratory demonstration and the simulation effort were able to go beyond these limitations, care must still be applied when drawing conclusions from the demonstration results.

1.5.7 Summary of project results

This section has its focus on the conceptual, technical and commercial results of the DREM project. In order to do so we address the three project objectives that were stated in section 1.4.4.

Realisation of project objectives

1. *The DSOs' future role in mobilising of flexibility assets for balancing the overall grid is clarified and the solution is demonstrated.*
    - The future role of the DSO has been discussed at several workshops with key stakeholder participation leading to a comprehensive understanding of the challenges and possible DSO responses. From this improved understanding a range of stakeholder conflict cases have been identified and dependencies analysed.
    - An efficient, effective and transparent concept for resolution of stakeholder conflicts at the distribution level (i.e. congestion problems) has been proposed.
        - The developed concept and corresponding solution design have exceeded expectations as is has shown to be coherent, encompassing a broad range of stakeholders and cover a wide range of scenarios.
    - At the centre of the solution design is the Trade Permission System that introduces a "Dynamic Information Broker" as well as a need for static information regarding the available flexibility assets.
    - Demonstration of the solution design have been successfully performed at DTU-Risø with participation from all parts of the energy sector.

2. *Proof-of-concept of the technical system integration between flexibility assets, DSO, and BRP based on IEC 61850-7-420 and IEC 62352 standards*
    - A technical proof of concept implementation for the TPS platform has been successfully performed.
    - IEC standards have as planned been used as a basis and with alignment to implementations used in the Nordic Balancing Model by the Nordic TSO's.
    - The proof-of-concept has however only been performed assuming a single aggregator and this lack of multiple aggregators on the same radial reduces the complexity of the tested solution and could to some extend question the validity of the proposed TPS platform.
    - Furthermore, the proof-of-concept did not include integration to the DSO. This integration was instead simulated and could likely be an area of further investigation into the validity of the proposed TPS platform.

3. *Outlining technical, economic and communication consequences of interrupting flexibility assets in foreseen and unforeseen scenarios.*
    - Through a range of field tests using the FlexHeat facility owned and operated by HOFOR the project has been able to assess both technical, economic and communication consequences of interrupting flexibility assets.
    - In the tests, two scenarios were investigated; a foreseen scenario, in which capacity limitations were known a day-ahead, and an unforeseen scenario, in which real-time capacity limitations were enforced.
    - In the unforeseen scenario a local fault in the DSO grid was simulated though a purpose-built python script, and within 4 seconds, the flexibility asset and TSO were informed about the fault by the BRP, and within 2 minutes, the flexibility asset would be limited to fulfil the enforced capacity limitation, proving real-time data communication with the DREM system.
    - A pre-feasibility study indicated that the increased heat production costs in the unforeseen scenario would be in the range of 150-550 DKK/MWh, whereas the field-tests indicated a range of 30-1460 DKK/MWh. Here, the foreseen scenario test results proved an intelligent way of rescheduling the heat pump to optimally handle DSO congestions – the scenarios then ranged from 2 DKK/MWh to 325 DKK/MWh depending on whether it was carried out through a rescheduling of the heat pump or a need to start the oil boiler.
        - It is thus vital for the DSO to at least deliver 24 hours ahead signals to ensure that the costs do not accelerate due to imbalances and utilization of oil boilers.
        - These results are only for a specific flexibility asset, and other flexibility assets need to be tested to have a broader view on the economic consequences.

Results exceeding the original project objectives

As the DREM project progressed and it became clear that the only available flexibility asset was the HOFOR FlexHeat facility it was also possible to single in and focus on an increased understanding of the possibilities of the facility in respect to the energy markets. This has led to developing advanced and intelligent FlexHeat controls and standardised BRP, TSO and DSO communication enabling the FlexHeat facility to act as a frequency containment reserve (FCR-N) and at the same time to a large extend act as a flexibility resource to the DSOs effort to avoid congestion problems in the distribution grid.

The results have thereby demonstrated that there exists a potential revenue stream for the FlexHeat facility that enables HOFOR to reduce the heating costs in the district heating system in the Copenhagen area. Furthermore, the results are due to the level of standardisation in communication flows applicable to other heat pump systems, such as the newly installed additional HOFOR heat pump, which has a heating capacity of 5 MJ/s.

Answers to the problem statement

The issues stated in the problem statement have been addressed and possible solutions have been proposed, validated and tested in a near real-life setting.

1. *Undesirable consequences of trade on Ancillary Markets*
    - The project has through the identification of several conflict cases and corresponding development of a Trade Permission System demonstrated a way to avoid the potential undesirable consequences caused by trades on flexibility assets in the electricity market.

2. *Undesirable consequences of Arbitrage and other Energy Management services*
    - The DREM project has addressed this potential problem as the conflict case identification in included the issue of the rebound effect caused by the activation of “Energy management services” (case 3) or “Explicit demand response” (case 2). When one or more aggregators simultaneously are re-engaging flexibility assets this can potentially lead to an increased concurrency factor on a specific feeder thus causing grid congestion.

3. *Undesirable consequences of spot price products*
    - This situation has been addressed through the identification of conflict cases where the “Implicit Demand Response” case (case 1) deals with consequences of several household customers simultaneously respond to an external stimulus such as variations in the energy price or tariff.

4. *Measurement and Service Verification conflicts.*
    - The DREM solution concept proposed two principles which solve such conflicts by design:
        1. Capacity limitations issued via the “Dynamic Information Broker” refer to directly measurable active power limits; as this value is directly related to the registered flexibility asset capacity (proposed to be registered in a common database - for example in the DataHub as "Static Information") it is directly verifiable.
        2. To ensure that this quantity is directly measurable by requiring that all flexibility assets are individually metered, and data is sent to the DataHub. It has been established that the metering frequency of smart meters (ca. 15 min) offers a sufficiently high resolution. In critical cases smart meters can be configured to also report maximum or minimum values.

Lessons learned

The project has resulted in a wide range of lessons learned all of which cannot be included in this concluding report. Instead is referred to the work package deliverables with the major leanings highlighted below

1) The chosen approach of working with a broad range of stakeholders from the early phases of the project through the entire concept definition phase has been a large effort, in terms of both project time and resources. However, this turned out to be a good investment as many difficult questions were collected and could be answered up front, instead of appearing during the implementation phase of the project. This has resulted in a consistent and well thought out concept which reflected a consensus between the different stakeholders.

2) Recruiting household-level flexibility assets for a field test is still a very large hurdle to take for a demonstration project in Denmark, even with a DSO and a commercial aggregator as project participants. In the writing phase of a project proposal, the focus is often on the perceived difficulty of the tangible parts of the system, such as the ICT setup needed to enable remote communication. In DREM, the last straw turned out to be the cost of meeting the regulatory requirements for adding certified metering to existing residential heat pump installations.

3) Developing a first prototype in the laboratory - here done as an "emergency fallback" when the field test could not be conducted - should have been included in the project from the beginning since it enabled testing with few operational constraints and a high iteration frequency.

4) Developing a business case for the flexibility of larger assets like the FlexHeat system still require a significant amount of adaptation to the operating conditions of the individual assets, not the least on the side of the asset owner. The development of standardized calculation models may be an important enabler for making more flexibility available, once the low hanging fruits have been picked.

5) Conducting the proof-of-concept and real field-testing has been very valuable for consolidating the concept, especially with respect to data exchange. Some questions concerning roles and responsibilities essential to the DREM concept did not present itself before precise specifications had to be defined prior to the implementation phase.

Questions in opposition to the DREM results

During the execution of the DREM project the understanding of how future market models, agents and interactions will impact the role of the DSOs in the energy market has evolved resulting in different views among stakeholders was well as within project participants. Below is listed a range of questions to the project assumptions and results which may be put forward in opposition to the DREM results.

Uncertainty in the need for a solution to market conflicts

The main assumption of the DREM project is that DSOs will experience an increase in congestion problems in the distribution grid due to the increased utilization of the distribution grid. This increases the likelihood of markets conflicts (i.e. congestion problems) when flexibility assets connected to the distribution grid is used in balancing the overall energy system at TSO level. However, congestion problems due to trades on the energy market is not the case at DSO-level today and it is uncertain to what extend this will be a problem going forward as the future utilization as well as the number and size of flexibility assets are unknown. Current views among DSOs, including Radius, is that it can be questioned whether markets conflicts call for a solution in the form of restrictions on trades in the energy market, if a solution is needed at all or if other solutions are more cost-effective, e.g. market-based bi-lateral service agreements or even increase in capacity in the distribution grid when large flexibility assets are connected. The financial evaluation from a DSO perspective have not been part of the DREM project scope and hence this remains to be analysed. The current view between Danish DSOs and Energinet is that in cases of conflicting interests it must be up to the owners of flexibility assets based on their preferences to decide which party to serve based on clear price signals from both the DSO and the TSO. The choice of the flexibility owner will then have an impact on either the DSO or TSO ability alleviate their problem.

Market conflicts and consequences to the validity of the proposed solution
As mentioned, several market conflicts including additional sub-conflicts were identified which also poses an inherent risk to the project as these markets conflict may not fully represent all possible variations of conflicts in the market. One example of this is cases of multiple aggregators or flexibility assets with the same feeder that combined causes congestion problems with the distribution grid. Furthermore, despite the subsequent design validation and demonstrations in WP5-7 are based on scenarios derived from identified market conflicts, tests have not included all aspects of the conflict cases which may limit the validity of the project results to only these scenarios.

The complexity of the proposed solution
The suggestion solution design is a somewhat complex solution design that has embedded challenges if implemented in real-life due to its complex communication set-up and significant data flows. This type of solution can be justified if the liquidity of the flexibility market related to the distribution grid is relatively high, but until we reach this point there may be other alternatives that are better suited to the DSOs. These solutions however may come with its own disadvantages such as the low degree of transparency in market-based bi-lateral flexibility agreements which may lead to financially in-optimal solutions for the DSOs and increasing lack of transparency for new BSP[17] business models.

Lack of flexibility assets and DSO integration imposes limitations to the conclusions made
The fact that it was not possible to obtain more than one flexibility asset meant that test results had to be scaled up to some degree. This upscaling had to be based on many assumptions and conclusions from this cannot as such be considered valid without further studies.
Furthermore, it has not been possible to implement a DSO SCADA system integration in the proof-of-concept and this has caused the project to simulate instead of using real systems. This simulation has had a negative effect on the project progression as the development of time simulation was time consuming. This reduces the strength of the overall demonstrations made, however it does not diminish the results that were derived from the project.

Risk of adverse market behaviour
With the proposed solution there exist a risk of adverse market behaviour which may occur when an aggregator both causes the congestion problem in the distribution grid through its trade in the energy market and is the one that subsequently is compensated for alleviating the problem. The answer to this problem is not part of the DREM solution design and will have to be somehow be addressed before the TPS solution could be relevant to put into practise.

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[17] New market actor role which is expected to utilize flexibility in the DSO grid with new business models, e.g. heat pumps, electrical vehicles.

Dissemination of results

The DREM project results have been disseminated by various measures of which some have already taken place and others are planned to take place in the near future[18]. This includes the primary dissemination of results[19] that will take place at the final DREM conference originally scheduled for March 26th. The conference haven been postponed and is yet to be rescheduled.

Other dissemination activities are:

- DTU-Risø workshop with wide energy sector participation included validation and discussions of the solution concept in a very realistic laboratory setting
- Lessons learned and proposed solution design used in discussions with TSOs and market platforms as a possible future flexibility market at the DSO level.
- Several dissemination activities in the Danish national standardization committee (S-557) which will continue also after the project has ended.
- DREM results regarding the utilization of the FlexHeat flexibility asset presented as part of HOFOR guided tours at the FlexHeat facility in Nordhavn. Participants included both national and international stakeholders from universities and the industrial sector.
- An article in a professional paper (e.g. GridTech) is to be published in connection with the final DREM conference which is yet to be rescheduled.
- As part of the DREM project DTU is to publish the concept in the form of a scientific paper (D8.4).
- DTU continues to promote the concept towards key actors in the Danish power sector (ENS, Energinet, DSOs) in the context of relevant fora.

Furthermore, all results, work packages deliverables and the final report will be made publicly available at the DREM website, www.drem.dk.

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[18] Some dissemination activities have been postponed due to the COVID-19 health crisis in the fall 2020

[19] This is the D8.3 deliverable of the DREM project

1.6 Utilization of project results

Commercial utilization

No commercial results have yet been established which are directly derived from the DREM project. However, the results from the DREM project is of great value to communicate for the commercial partners of the project and some partners have preliminary plans of future projects with clients where the take-a-ways from the DREM project may be utilized. An example of this is EURISCO that will offer consulting and software system integration for TSO, DSO, BRP and facilities with grid connected assets. This will be for both IEC 62325 and IEC 61850 technologies and for conceptual development in general related to the concept of Transparency between grid and market operators

Contribution to realize energy policy objectives

The DREM problem statement is derived from the assumption that a combination of an increased utilization of the distribution grid and the needs for further flexibility assets at the consumer level for balancing the transmission grid could result in a situation where trades on the energy markets will impact the operation of distribution grids through local congestion problems. In other words, the DREM project addresses how to potentially handle a derived effect from electrification of the Danish society which is widely accepted as a main driver of achieving a transition to carbon neutrality. As the DREM project results could be used to handle the challenges of an increased utilization of the distribution grid the results are also potentially contributing to an economically efficient green transition as investments in reinforcing the distribution grid can be reduced.

In order to have such an effect the project results will first have to be implemented in a future market design and in this context the DREM partners have been invited to contribute the gained experiences to the discussion regarding the Market Model 3.0 carried out by the Danish Energy Agency. This invitation indicates that the DREM project results to some extend are valid.

An additional result from the DREM project have been the further validation and demonstration that large-scale flexibility assets such as the FlexHeat asset can be used in sector-coupling hereby improving the efficient of the energy system and leading the reducing the costs of carbon neutrality.

Scientific utilization

The DREM project have not included Ph.D. students, however the development work performed on the simulation platform can be used in other research projects, national as well as international. DTU expects to extend its use towards more complex scenarios over time.

Utilization in further work

A range of the DREM partners have together with Bornholms Energi applied for additional funding from the Innovation Fund Denmark in order to continue working on the DREM concept including how DSOs from a planning and operational point-of-view can address the increase of flexibility assets in the distribution grid simultaneously with a higher utilization of the distribution grid. The application states that *"the GridHub project aims to modernize the DSO toolbox across planning and operation while maintaining a system point of view, coordinating the needs of unit owners, aggregators, balancing responsible parties and system operators. The project will develop tools that can identify congested parts of the network. These will be supplemented with a mechanism for alleviating congestion, e.g. by imposing dynamic limits on the flexibility of units in certain network segments in coordination with market actors. Finally, the project will evolve network planning procedures to take the operational improvements into account."* Furthermore, the GridHub project will also further develop the DREM conceptual framework and plans to include DSO integration as well as testing using multiple (app. 10) flexibility assets.

1.7 Project Conclusion and perspective

Conclusions from the DREM project

1. *Conflict cases*

   During the stakeholder dialogue, the project has confirmed that several cases exist in which the different actors involved in flexibility from distribution-level assets encounter a conflict of interests (i.e. contract violations, power quality issues, financial loss or even disconnection of customers) which cannot be resolved due to a lack of information. This is most prominent in the relation between BRP and DSO: The BRP does not know how its dispatch of flexibility assets impact the distribution grid, and the DSO does not know which customers are under flexible control, and by whom.

   The project has identified 8 conflict cases and analysed the corresponding actor relations. This work has greatly improved the understanding of the dynamics and high degree of complexity of trades on flexibility assets in the electricity market - not only to the project participants but also to the many stakeholders at the workshops conducted as part of the project.

   The stakeholders reached a common interpretation of the nature of the issue: The sum of actions by individual flexibility assets changes the observed concurrency factor. Grid problems occur once this observed concurrency exceeds the concurrency assumed in grid planning for each consumer category. It was agreed that concurrency factors close to 1 may realistically occur for some asset classes under certain circumstances.

   While the project focus had initially been on congestion leading to asset overload (high current), the process revealed that almost all conflict cases also exist in a variant where voltage management is the main concern.

2. *Solution design*

   Solving congestion issues is complex since it involves conflicting interests of several parties that may either not have an incentive or are outright prohibited from sharing information. One of the conclusions from the solution design process is that improving the information flow between parties will require a neutral entity as a facilitator/broker in order to e.g. allow anonymized communication with the aggregator of a flexible asset without disclosing the existence of their business relation.

   Another conclusion was that DSOs are not interested in interfering with or validating market transactions between AGR/BRPs and the wholesale market, as suggested by USEF. Therefore, DREM proposes a solution where the DSO can communicate grid constraints to the AGR. This should ideally occur before market closure, such that the AGR can take these constraints into account when bidding but may also be used on short notice in emergency situations.

   Between the design and implementation stages, the participants recognized the need for a fair distribution of the burden of capacity limitations in cases where several AGRs/BRPs are present in a grid section for which a limitation has been issued. A "fairness filter" was added to the concept; however, the definition of concrete algorithms ensuring fair burden sharing was out of the scope of the project, and probably within the realm of regulatory action. The project has limited itself to creating a place in the concept where such algorithms can be inserted once defined; however, the DREM concept will be applicable even without fair burden sharing.

   Despite the number, variation and complexity of the identified conflict cases including sub-cases, the project has succeeded in designing a relatively simple solution which only considers two variants of a general case: One variant for situations anticipated some time in advance (e.g. due to reduced grid capacity during maintenance) and another for unanticipated situations, e.g. due to grid failure.

3. *Proof-of-concept and demonstrations*
   The proof-of-concept implementation as well as the following field tests have demonstrated that the general concept developed in DREM is implementable and can be used for the intended purpose of mitigating congestion issues in the distribution grid. However, the project could not achieve full test coverage. As a result, a number of aspects will require further validation.
   Two of the most obvious of these aspects are related to the integration of the system into DSO operations. Firstly, the project did not define procedures for congestion detection. Due to a lack of real-time measurements in the distribution grid, this is not a trivial problem left unsolved. Secondly, procedures for determining appropriate capacity limits to be applied by control room staff once congestion is detected, have not been investigated. In all tests, the corresponding DSO actions have been emulated as if the DSO knew the answer to these questions. These issues are sought to be addressed in the proposed GridHub project.
   Furthermore, the validation tests covered situations with multiple flexibility assets and a single aggregator (in the laboratory) as well as a single asset and a single aggregator (in the field). The concept has not been tested against a scenario with multiple aggregators on the same feeder, although the main difference would be the activation of the burden sharing mechanism ("fairness filter") mentioned above.
   The laboratory tests and the implementation done for the demonstration workshop at DTU-Risø provided a valuable opportunity for creating a first proof-of-concept while enjoying the benefits of a controlled environment, such as a fast turnaround time and flexibility in the setup. Experience gained in the lab proved very useful for the next test, using a real-world flexibility asset located in Nordhavn.
   The Nordhavn test demonstrated that restrictions imposed by the DSO did not negate the ability of the flexibility asset to trade in various types of markets, both in foreseen and for unforeseen scenarios. Probably the most important finding from the FlexHeat tests is that significant notice is required for certain types of flexibility assets in order to enable the delivery of DSO-services of high quality at a competitive price.
   The DREM Proof-of-Concept enhances cross market actor signalling and enables DSO data exchange with operators by constructing embedded communication lines in a transparent and coordinated manner. This is known as the “The Polluter Must Pay Principle” and is in line with the Clean Energy Package article 51 that determines EU DSOs to adopt best practices for coordination of distribution systems with data exchange between operators and coordination of distributed energy resources. Additionally, signalling between power market actors may become necessary in the future when multiple BRP and BPS emerges, this is argued in the Nordic TSO paper, which discusses Clean Energy Package implementation of third-party aggregators as a prerequisite when introducing the BSP role and enabling demand response initiatives.

Perspective

The DREM project aims to suggest market-based solutions to the extent possible. However, DSO congestion is always a local problem which relates to a specific feeder on the low voltage or medium voltage level. Within the foreseeable future, it will be difficult to operate local day-ahead markets at the level of a single feeder due to the lack of liquidity (i.e. the fact that the proliferation of small flexible assets (e.g. EVs) is still happening much slower than that of larger units.), except in few, very specific cases. Although many small flexibility assets may be installed, we do not know how many of these would participate in local flexibility markets.
Therefore, the DSO may have to simply limit the activation of flexibility assets in certain cases which is possible without interfering with system balancing due to the limited size of the local DSO challenge compared to the overall system. System challenges can in these cases be alleviated by other means in other areas of the grid. The newly approved EU electricity regulation permits limiting the activation of flexibility assets in certain cases if no market-based solutions are available (Article 12).

Recently, perhaps due to the above, there has been a pronounced change in the attitude towards congestion mitigation of some Danish DSOs, including Radius, away from day-ahead flexibility markets and towards other solutions such as tariffs and bilateral agreements between aggregators or owners of flexibility assets and the DSOs. This change in view is not shared by the other DREM project participants and does not invalidate the DREM conclusions in any way. An important thing to emphasize is that tariffs, bi-lateral agreements and flexibility markets do not exclude each other. Due to their different strengths and weaknesses and the different classes of problems each is able to solve, they may all co-exist in a future energy system.

The political goals in Denmark have not changed with respect to increasing the share of renewable energy in the production mix and the electrification of transport and heating. Neither have the assumptions underlying DREM. The DREM project asks questions and provides solutions that extend into the future of the system services market. Due to this, the ideas developed in the DREM project are included in the discussions on the Market Model 3.0, and may become an integral part of the ambition outlined in the Energy Agreement's overall letter of intent:

"Denmark must have the most integrated, market-based and flexible energy system in Europe with efficient use of energy across the electricity, heating and gas sectors and with a continued high security of supply."

2. Annex

- List of deliveries
    - D1.1: Detailed project plan
    - D2.2, D3.1 and D3.3 (all combined): Workshop Report on Analysis of the DSO role in Market Conflicts
    - D4.1: Abandoned
    - D5.1: System integration design for the Trade Permission System
    - D6.1: Data communication analysis and requirement revision
    - D6.2: Proof-of-Concept report
    - D6.3: Data communication test report
    - D7a: Test of interrupting flexible assets
    - D7b: System Integration and Scenario Assessment Report
    - D8.1: Concluding Report
    - D8.2: Articles (published in connection with postponed DREM conference)
    - D8.3: DREM Conference
    - D8.4: Scientific dissemination (in planning)