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Deliverable D4.4

Report on simulation tests with data from pilots

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Main responsible:	Aikaterini Forouli, HENEX Georgios Papazoglou, HENEX Emmanouil Bakirtzis, HENEX
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Authors and reviewers	
Main responsible:	Hellenic Energy Exchange (HENEX), Aikaterini Forouli, a.forouli@enexgroup.gr Hellenic Energy Exchange (HENEX), Georgios Papazoglou, g.papazoglou@enexgroup.gr Hellenic Energy Exchange (HENEX), Emmanouil Bakirtzis, e.bakirtzis@enexgroup.gr
Author(s)/contributor(s):	HENEX, Aikaterini Forouli HENEX, Georgios Papazoglou HENEX, Emmanouil Bakirtzis UCL, Antony Papavasileiou
Reviewer(s):	EST, Natalia Fano ICOM, Isidoros Kokos

Abstract

This deliverable presents the validation of the three FEVER market mechanisms, namely the day – ahead, intraday and real time market mechanisms with real data from pilots. The market mechanisms have been designed to be scalable and operate in a hierarchical level. Here, the scalability of the proposed solutions is proven by considering data from FEVER pilots with different market structures. Data pre-processing requirements were first defined and communicated to the pilots to enable the integration of different tools. Simulations were executed using actual energy measurements. For the energy measurements acquisition, connectivity with the DSO toolbox has also been established and tested for the Spanish pilot. Additionally, Flex Offers are used to formulate the flexibility orders. Simulations are run under different disturbance scenarios, representing violations in network constraints such as voltage limits violations and/or overloads in distribution lines. Simulations results indicate that the proposed mechanisms exhibit satisfactory scalability and accuracy and are able to efficiently address issues of the distribution network, safeguarding the security of supply and quality of service in the distribution grid. Lastly, for each market mechanism relevant Key Performance Indicators are presented.

Keyword list

Real Life Simulations, Disturbance Scenarios, Pilot Data Integration, Flex Offers, Scalability and Replicability, Flexibility Trading Algorithms, Local Flexibility Markets, Flexibility Aggregator, Distribution System Operator, Distribution Systems, Day – Ahead Market, Continuous Trading, Real Time Trading, TSO – DSO coordination

Executive summary

The aim of this deliverable is to run simulations using data from FEVER real-life pilots in order to validate the scalability and replicability of the FEVER market mechanisms developed under WP4, namely the day-ahead, intraday and real time market mechanisms (DAMM, IDMM & RTMM).

The first step is to define the pilot data requirements in terms of availability and format, in order to achieve a seamless integration to the market models. The minimum data required for the market mechanisms execution are classified in three categories: i) network topology data, ii) energy measurements and iii) order data. Network topology data refer to the characteristics of buses, lines, and transformers that are network specific and independent of the network operating point. Energy measurements can be categorized to measurements of loads, generators and static generators. Flex Offers refer to the active/reactive power of network assets (e.g. loads, storage, power electronics) that can be activated in real time in either upward or downward direction for providing services to the grid (e.g. congestion management). Then, depending on the status of each pilot on the aforementioned items, essential tool development for data pre-processing needed to be done.

Three pilots are examined: the Spanish pilot of Estabanell and two German pilots in the networks of SWW and SWH. The Estabanell pilot network consists of more than 200 Distribution Network (DN) buses, while the pilot networks of SWW and SWH are smaller and comprise of circa 25 buses. For the Estabanell pilot, connectivity with the DSO Toolbox for data acquisition was achieved, while specific snapshots of network operation were provided for SWW and SWH grids. The available flexibility of the network assets was expressed as Flex Offers. There are five flexible assets in Estabanell pilot, four in SWW pilot and three in SWH pilot.

Simulations were run for all three market mechanisms:

- For the DAMM and RTMM model, as data are available only for the DN, the transmission system was simulated by adding slack generators at the DN-TN interface nodes, in order to maintain the power balance. As the pilot data correspond to congestion-free operating points, dummy energy measurement data for non-flexible assets were generated to create artificial congestions. The generated dummy energy measurement data are considered as forecast scenarios of the non-dispatchable load offtake and non-dispatchable generation. Simulation results show that the DAMM manages to activate the required flexibility needed to bring the loading level of an overloaded line back within acceptable limits, as well as solve network under-voltages, while not violating any other constraints of the network. At the same time, activations of flow at the point of common coupling restore the power balance, by indirectly activating flexibility at the TN.
- For the IDMM, disturbance scenarios were also applied, simulating forecasted increases in load/generation in order to induce network violations. For the different pilots, different simulation scenarios were run, in order to resolve under- and over - voltages, line congestions and violations of TSO-DSO schedules in the TSO-DSO connection point. Key findings suggest the need for additional controllable loads to ensure a resilient grid operation. Additionally, the AC sensitivities analysis proves to be a valuable tool for identifying areas for DERs investments based on observed violations.
- For the RTMM, more demanding data processing was necessary, given the nature of the model and the requirements to calculate the net value of the injected or withdrawn power for each load. In terms of simulation results, the real-time platform was able to clear the market and activate the flexible assets optimally.

In terms of KPIs performance, data pre-processing and execution times were kept for all market mechanisms within negligible time limits. In all cases, after the market clearing, congestions are either fully resolved or alleviated given the limitations of available flexible loads. For the DAMM and RTMM which run as welfare optimization models, there is no congestion in the network and thus, most of the offered quantities were fully cleared, maximizing in this way the overall social welfare. Last, the low Lost Opportunity Cost (LOC) metric which is relevant for the RTMM ensures that the dispatch solution and the market clearing prices are consistent and provide the correct economic signals to the participants.

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1 Introduction

1.1 Task 4.3

The objective of Task 4.3 “Simulation of market tools and mechanisms” is the validation of the FEVER novel market mechanisms using dummy data and realistic data from the pilots as soon as those are available. The market mechanisms (day-ahead, intra-day, and real-time) are described and validated with dummy data in Deliverable 4.3 [1]. The aim of this task is to simulate different scenarios of flexibility services, taking into account the distribution grid status as announced by the relevant DSO. The simulations should consider the virtual needs of the DSO and incorporate the DSO grid constraints in the market processes.

1.2 Objectives of the work reported in this deliverable

The main objective of this deliverable is the validation of the three FEVER market mechanisms, namely the day-ahead, intra-day, and real-time market mechanisms with real data from the pilots. The aim is twofold, first to reproduce real simulation scenarios and run market simulations which respect the DSO grid constraints and integrate the virtual needs of the DSO so as to safeguard security of supply and quality of service in the distribution grid, and then to test the scalability and applicability of the proposed market solutions in real life scenarios so that they can be further incorporated into other European Markets.

1.3 Outline of the deliverable

The rest of the deliverable is structured as follows: Section 2 outlines the data requirements identified for integrating pilot data into the mechanisms. It also presents the data provided from each pilot categorized into three main groups: network topology, energy measurements, and order data. In Section 3 simulation results with pilot data for each market mechanism are presented, accompanied by a brief overview of the high-level market design. Special focus is given on data pre-processing and KPIs presentation. Finally, Section 4 draws conclusions regarding the effectiveness of the market mechanism in real life simulation scenarios, while the Annexes present key information to support the reader in understanding the analysis

1.4 How to read this document

As pre requirement for reading this document is a good knowledge of the electricity markets design and operations (e.g. [2] provides an overview) and specifically the design of the FEVER market mechanisms as described in FEVER Deliverable 4.3 [1] . The preliminary analysis on the use of the market mechanisms with dummy data as in [1], and previous basic knowledge on the FEVER pilot description as in [3] and the KPIs description as provided in [4] will contribute to a better understanding of the report’s content.

2 Data requirements

2.1 Input data specification

The minimum data required for the Market Mechanisms execution can be classified in three main categories. These are:

- Network topology data
- Energy measurements
- Order data

Network topology data refer to the characteristics of buses, lines, and transformers that are network specific and independent of the network operating point.

For the buses the requested information refer to:

- the network to which the bus is connected (if relevant)
- a unique index of the bus
- the maximum and minimum voltage of the bus
- the rated voltage of the bus
- indicator of the slack bus
- The voltage magnitude and angle of the slack bus

For the lines the requested information refer to:

- the network to which the line is connected (if relevant)
- a unique index of the line
- the index of bus where the line starts (from bus) and the index of bus where the line ends (to bus)
- the maximum thermal current of the line or the maximum apparent line flow
- the resistance (r), conductance (g), reactance (x) and susceptance (b) parameters of the line Π-equivalent

For the transformers the requested information refer to:

- the network to which the transformer is connected (if relevant)
- a unique index of the transformer
- the bus indexes where the transformer is connected (high and low voltage bus)
- the rated apparent power of the transformer and the rated tap position
- the resistance (r), conductance (g), reactance (x) and susceptance (b) parameters of the transformer Π-equivalent
- the minimum and maximum tap position

Energy Measurements can be categorized to measurements of loads, generators and static generators.

For the loads and static generators the requested information refer to:

- the network (if relevant) and bus to which the load/static generator is connected
- a unique index of the load/static generator
- the active and reactive power of the load/static generator
- information on whether the load/static generator is controllable/in service

For the generators the requested information refer to:

- the network (if relevant) and bus to which the generator is connected
- a unique index of the generator
- the active power of the generator
- the voltage set point of the generator
- information on whether generator is controllable /in service

Order data refer to the orders that can be placed by assets of the network that can activate in real time in either the upward or the downward direction for congestion and balancing purposes.

Here, as order data are used the FEVER Flex Offers, for which the requested information refer to:

- the index of the bus or network ID that the asset is connected to
- the maximum offered capacity for the upward and/or downward activation
- the price for the upward and/or downward activation
- the date and time the offer was created
- The duration and the number of intervals of the offer

A detailed representation of the pilot data requirements in pandapower format is provided in Annex A.

In order to use the above data correctly it is also important to know the assumed network parameters, such as the frequency at which the network is operating and the format of the network data (per unit or analytical). In case of the per unit system model usage, the base power of the network is required.

2.2 Provided pilot data

2.2.1 Spain - Estabanelll

Actual network topology data

The Spanish demo site is a distribution network operated by Estabanelll Distrbution and Mercator and it is located in Catalonia. A detailed description of the Spanish pilot can be found in FEVER Deliverable 7.2 [3].

The detailed topology of the Spanish pilot (location of nodes, lines, transformers, loads and generators) was made available in Pandapower format. It should be noted that the available topological data of the Spanish pilot only concern the DN. No data regarding the topology of the Transmission Network (TN) that the pilot site is connected with is available.

The pilot consists of 227 DN buses, 200 DN lines, 24 transformers, 111 loads and 6 static generators. Five of these loads are flexible. The exact details of the topology (e.g., voltage level of nodes, rated capacity of lines and transformers, nominal or actual power profiles of loads/static generators) or the location and characteristics of the flexible assets (e.g., node, rated capacity) constitute sensitive information owned by Estabanelll, were obtained upon signing an NDA and cannot be disclosed.

Actual measurement data

Several smart meters are connected to the topology involved in the Spanish pilot site. The data from these smart meters are integrated in the FEVER ecosystem via the DSO toolbox. The DSO toolbox is an Application Programming Interface (API) that was developed in the context of WP 6 of FEVER to improve the observability of the distribution network. Using the DSO toolbox, and after creating the mapping between smart meter locations and nodes of the Pandapower model, a model for the Spanish pilot was created that could be updated to reflect the actual measurement of the smart meters installed in the network. Therefore, a realistic representation of the Spanish pilot was available for the execution of simulations.

Actual order data

The type and index of all flexible assets of the Spanish pilot is known. The flexible assets installed in the Spanish pilot are industrial and can only provide upward flexibility (i.e., they can decrease their consumption). Therefore, the quantity of upward flexibility they can provide depends on their forecasted consumption, while the quantity of downward flexibility they can provide is zero. During the demonstration of the Spanish pilot, a fixed compensation was provided for each kWh of upward flexibility provided, which was used as the upward flexibility activation cost. The compensation costs are reported in FEVER deliverable D7.3 [5] .. Data on the forecasted capacity and the activation were provided by INEA, while the available capacity for each asset is known from the pilot data provided by Estabanelll. This information, as well as the locations of the flexible assets were also provided via file sharing.

Table 1: Flex Offers format – Spanish pilot

File	Content
Fever - Controlable loads	***Num*** | *sequential number* ***Name*** | *a load, an on-site electrical production unit name* ***Load type and current rate*** | *single phase or 3phase load and current rate* ***Power*** | *adaptation power of the load, the on-site electrical production unit [kW]* ***Measurement*** | *adaptation power should be measured :* i. yes: adaptation power is changing. ii. no: adaptation power is constant. ***Control*** | *Manual (trafic light) or automatic (force shut down)* ***Usage hours*** | *the time when the asset can be used* ***Flexible operation hours*** | *the total usage time the asset can be used monthly* ***Condition*** | *how the condition of the asset is communicated to the operator | condition must be fulfilled before the load, the on-site electrical production unit can change the adaptation power.* ***Comments*** | *comments about the asset*
ID_table_spanish_pilot_final	***CT*** | *not defined* ***meterID*** | *Anonymized ID* ***nodeID*** | *GIS Node ID* ***Additional info*** | *additional info* ***Filter*** | *filters by region or the industrial clients/flexible assets*

2.2.2 Germany - SWW

Actual network topology data

The required data regarding the network topology and network parameters were provided in a pandapower model format as per Annex A.

Actual energy measurement data

The DSO Toolbox was not used for the SWW network. Instead, the energy measurements were provided for specific operating points of the network.

Actual order data

All required for the simulations data were provided by INEA. Each flexible offer comprises four 15-minute interval parts, whereas all price and maximum capacity-related data were converted to [€/MWh] and [MWh] respectively. The Flex Offers' locations in the network model, namely the bus that each order is submitted, was not provided and thus were arbitrarily chosen.

Table 2: Flex Offers format – SWW

INEA Flex Offer file	Content
offerJson	***id*** | *ID of the offer* ***creationTime*** | *the date and time the Flex Offer was created* ***offerdById*** | *ID of the prosumer* ***numSecondsPerInterval*** | *duration of an interval* ***lowerBound*** | *the maximum offered downward activation [kW]* ***upperBound*** | *the maximum offered upward activation [kW]*

	minTariff | *the price offered for downward activation [€/kWh]* ***maxTariff*** | *the price offered for upward activation [€/kWh]*

2.2.3 Germany - SWH

Actual network topology data

As in the SWW pilot case, all network topology-related required data were provided in a pandapower model format.

Actual energy measurement data

The DSO Toolbox was not used for the SWH network. Instead, the energy measurements were provided by SWH as the maximum hourly consumption [load] and generation [sgen] metered in a whole year.

Actual order data

All required Flex Offers' data were provided by INEA for the SWH pilot case. Each offer consisted of four 15-minute intervals, whereas all data related to the submitted price and maximum capacity were converted to [€/MWh] and [MWh], respectively. The format of the offers is the same as in the SWW case (Table 2).

3 Simulations of market tools and mechanisms

The following table presents a summary of the data availability and simulations runs for each market mechanism. Details on the data preprocessing and simulation results are provided in the following Sections.

Table 3: Summary of data availability and simulations runs

	Spain	**SWW**	**SWH**
Network topology data	Pandapower format		
Flex Offers	• Location • Capacity • Prices • Only downward flexibility/ON-OFF	• Arbitrary locations • Capacity • Prices • Up & downward flexibility	• Location • Capacity • Prices • Only upward flexibility
Energy measurement data	DSO Toolbox	Specific snapshots	Specific snapshots
Market simulations	• **DA** • **ID** • **RT**	• **ID** • **RT**	• **ID** • **RT**

3.1 Day Ahead Market Mechanism

3.1.1 High level market design

The overall market design of the Day-Ahead Market Mechanism (DAMM) has been thoroughly described in D.4.3 [1]. A brief overview of the main DAMM design principles follows. The interested reader may refer to [1] for more details, or to the academic publications [6], [7] and [8].

The DAMM is an auction with a 24-hour optimization horizon. Its main characteristics are derived from existing wholesale DAM (e.g., timing of gate closure, market time unit duration, etc.). Participation in the envisaged market is asset-based, i.e., each market participant places orders for each asset they represent, and not their portfolio of assets as a whole. The DAMM is formulated as a two-stage market. In both stages optimization problems are solved whose goal is social welfare maximization.

The first stage provides an initial schedule for all assets of the network. In the formulation of the first stage, orders submitted by assets located in the DN are aggregated at a substation level (i.e., one buy and one sell order is submitted for each DN, reflecting the aggregate quantities submitted by market participants with assets in each DN), while orders submitted by assets located in the TN are included in the problem formulation as they are. The constraints of the TN are also considered in this stage using the DC approximation. Thus, the resulting first-stage optimization problem is a DC Optimal Power Flow (OPF) that provides the initial schedule for all assets of the TN, and the initial aggregated schedule of all assets in each TN. This is referred to as the initial central market. The aggregated schedule of each DN is then disaggregated on a per-asset basis, using the initial bids each market participant submitted (the aggregation/disaggregation methodology has been described in detail in [9]). During the disaggregation process, flexibility orders for all assets also are extracted, using the initial submitted orders and the initial schedule results.

The second market stage focuses on restoring the feasibility of the schedule on all networks. Having knowledge of the initial schedule of each asset in their control areas, the Transmission System Operator (TSO) and Distribution System Operators (DSOs) can assess whether they should anticipate any congestions in the networks they operate or not. The term “congestions” in this context encompasses all operational issues network operators face, such as over or under voltages, line, or transformer congestions, etc. To assess the possibility of congestion, network operators use the disaggregated initial market results for all assets in their control areas and run power flow simulations for each market time unit. The TSO runs DC power flow simulations, while DSOs run AC power flow simulations. For each Market Time Unit (MTU) and each DN where congestions are anticipated, a Local Flexibility Market (LFM) is triggered. So, a LFM is triggered only for in some DNs where congestions are anticipated, and separate LFMs are triggered for each MTU.

LFMs seek to restore the feasibility of the scheduled injections on a DN level. To that end, they constraints of the DN must considered during the problem formulation. A linearized representation of the AC power flow constraints is used, that has been described in [6]. Indirect flexibility sharing between the TN and each DN is enabled in LFMs via changes of the flow at the point of common coupling. That means that in case there is not enough flexibility within the DN to resolve its congestion issues, assets located in the TN may indirectly provide flexibility via changes of the flow at the interconnection between the DN and the TN. This mechanism and the employed pricing scheme for flexibility at the point of common coupling have been discussed in [9] and [7]. As each LFM is cleared, a final schedule for each asset located at each DN is produced. If no LFM is triggered for a DN or for a market time unit, the initial scheduled injection of an asset is also its final.

A final step of the second stage of the DAMM is required to restore the power balance within the system. As indirect flexibility sharing is enabled in LFMs, the schedule of assets located in the TN may also be subject to change, to accommodate for the necessary flexibility in the DNs. To that end, a final run of the central market is executed, where again each DN is aggregated and modelled as a price-taker (using the final scheduled injections during the aggregation process this time), while assets located in the TN participate to provide the necessary flexibility.

3.1.2 Data processing and simulation results

3.1.2.1 Spain

3.1.2.1.1 Pilot data processing

Topology data

As already mentioned, topological data for a single DN was available in the case of the Spanish pilot. The DN data need to follow the pandapower format in order to be compatible with the DAMM algorithm (as in Annex A). The lack of data regarding the TN where the DN of the demo site is connected to, complicates the execution of the DAMM, especially its first stage. A viable option would be the use of a synthetic TN with which the pilot site would be considered connected to. However, this option was discarded. Simulations using a synthetic TN were executed in the context of D4.3, and therefore would not add any extra value if also repeated here.

Since the goal of this Deliverable is the demonstration of the DAMM using real (or at least as close to real as possible) data, another option was selected. Only the second stage of the DAMM was ran. At the locations where the DN is connected to TNs (which are known), slack generators were added that maintain the power balance of the network and simulate the rest of the power grid. This constitutes a minimal alteration of the topology, keeping it as realistic as possible. Therefore, only the LFM part of the second stage of the DAMM is examined, to assess the ability of the proposed market mechanism to solve congestion issues on a realistic test case.

Energy measurement data

Energy measurements represent the anticipated injection of each asset for each MTU in the optimization horizon for the non-flexible assets. Measurement data from the smart meters installed in the pilot site were available to HEnEx via the DSO toolbox and were analysed for a 3-month period from October 2023 to December 2023. The goal of the analysis was to run power flow analyses using the energy measurements of the actual injections of assets to pinpoint snapshots where the network was facing congestion issues. These snapshots would then be selected and LFMs would be triggered for them, to assess their ability to solve these issues. However, no such snapshots were available. This can be explained due to the fact that the pilot site constitutes a DN in active commercial operation. So, the DSO responsible for the operation of the pilot site always made sure for the safe and reliable operation of the DN, keeping all voltages and line flows well within operating limits. It is worth mentioning that for most market time units the voltage profile is flat for all nodes (i.e., close to 1 pu) and the lines of the network are well within their operating limits (at maximum loaded at 80% of their nominal capacity). This signifies that there is no need for extra congestion management in this particular network.

Therefore, dummy measurement data for non-flexible assets were generated to create artificial congestions. To make the generated data as realistic as possible, the creation of the dummy data was considered in the context of the operation of the proposed market mechanism. It is assumed that the gate-closure for the DAMM is the day preceding the dispatch day (much like an actual day-ahead market works). So, the dummy measurement data we want to use are essentially forecasts for the offtake of non-dispatchable loads or for the generation of non-dispatchable generators. The literature on this topic is vast.

A recent paper [10] investigates the accuracy of load consumption and RES generation forecasts by TSOs in 16 European countries. The paper concludes that most TSOs still have significant errors in their forecasts (in some cases more than 15% for load consumption and up to 30% for RES generation). According to the paper, errors tend to increase linearly with the amount of demand and RES generation. Another research paper [11] concludes that while the forecast errors between solar and wind assets are weakly correlated, the errors between assets of the same technology are highly correlated. This makes sense intuitively, as the generation of RES is highly dependent on the weather conditions that affect the area they are located in, and RES installations of the same type tend to be clustered in areas close to each other. Finally, a strong correlation for load forecasts for individual assets is also expected [12].

The goal is to create a worst-case scenario for the DSO using these error margins that creates congestion issues that may then be solved with the available flexibility. Since the available flexible assets can only provide upward flexibility, overestimating the consumption of loads while underestimating the production of RES can lead to such scenarios. Such a scenario could be realised if, for example, bad weather is expected at the demo site. In this case, load consumption (most of which is residential in the demo site) would be forecasted as increased, to satisfy heating needs. At the same time, due to the cloudiness the PV generation would be increased, and maybe due to strong winds wind generation would entirely halt. In such a case, the DN would heavily rely on imports from the TN, and therefore downstream lines close to the transformers could be expected to overload. A decrease in consumption of the flexible assets (i.e., upward flexibility provision) could alleviate some (if not all) of the overload of these lines.

To generate such a scenario, a decision on how to model the interdependence between the injection of active and reactive power of assets must be made. As aforementioned, the DSO is envisaged to run an AC power flow to investigate whether to trigger a LFM or not. Running an AC power flow requires the knowledge of both the active and reactive power injection/offtake setpoints (or forecasted setpoints, in this case) of all assets. In this case, the forecasted active power setpoints are determined using the actual energy measurements (as accessed from the DSO toolbox), applying a forecasting error to them. The forecasted reactive power setpoint is determined using the simple modelling principles suggested by [13]. Loads are modelled as having a constant power factor, while PVs and wind generators as being able to operate within predetermined reactive power injection limits. Indicative operating regions charts for these types of assets are shown in the following figure.

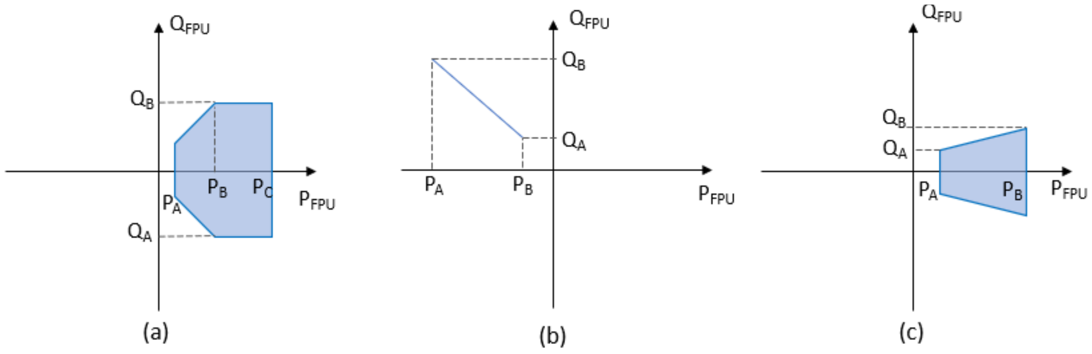

Figure 1. Capability charts of (a) PV plant, (b) load with constant power factor, and (c) wind turbines.

Thus, the synthetic forecasted offtakes/injections are generated by sampling one scaling factor for each asset off a Gaussian distribution and multiplying its measured offtake/injection by that scaling factor. For loads, a Gaussian distribution with a mean value of 1.15 and a variance of 0.05 was chosen, meaning that almost 70% of the forecasting injections will be in the range of 1.1 to 1.2 times (or 10 to 20% greater) the measured offtake. For RES injection, a Gaussian distribution with a mean value of 0.75 and a variance of 0.15 was chosen, meaning that almost 70% of the forecasting injections will be in the range of 0.6 to 0.9 times (or 10 to 40% lower) the measured offtake. The analysis for the 3-month period from October 2023 to December 2023 was repeated using the synthetic forecasted offtakes/injections. The results for a select case are presented in the next section.

Order data

All non-flexible assets are assumed to not have submitted any flexibility offers towards the market. The flexible assets that are located in the DN are able to offer only upward flexibility, i.e., are loads that are able to reduce their consumption. Due to the nature of the assets, are assumed unable to partially reduce their consumption, but instead offer an on/off functionality, i.e., they are assumed to either operate at their forecasted setpoint, or be off. Therefore, for each time interval, their available upward flexibility is equal to their forecasted setpoint. As already mentioned, they are assumed to receive a fixed amount of compensation for each activation of their upward flexibility, which will be their upward flexibility activation cost.

As was explained earlier, some flexibility is also considered to be available at the point of common coupling between the DN and the TN. An amount equal to 1 MWh of upward and downward flexibility quantity was assumed to be available at each MTU. For pricing the flexibility at the point of common coupling, the pricing scheme suggested by [7] was adopted according to which:

- Upward flexibility activation cost at the point of common coupling is equal to 4000 EUR/MWh, and
- Upward flexibility activation cost at the point of common coupling is equal to -500 EUR/MWh.

As explained in [7], using these prices (which are the market ceiling and floor prices in European markets) incentivizes the use of flexibility within the DN and minimizes the flow changes at the point of common coupling between the TN and the DN (thereby creating small imbalances at a system level that can easily be covered by the assets of the TN).

3.1.2.1.2 Simulation results

The following simulation was executed for November 27th 2023. We focus on some specific MTUs of the day that showcase the characteristics and the effectiveness of the DAMM. Starting off with the actual energy measurements from the DSO toolbox for the 11th MTU, the network had the following characteristics:

Table 4: Energy measurements from DSO toolbox - MTU 11

	Active Power (kWh)	Reactive Power (kVAr)
Total load consumption	0.8105	0.06623
Total RES generation	0.0834	0.05952
Max. line loading	85.13%	
Min. Voltage	0.961 pu	
Max.Voltage	1.049 pu	

As can be seen, the network has no violations and no corrective actions need to be taken. By creating the synthetic forecasted offtake/injection setpoints laid out in the previous section for this instance, the characteristics of the network become the following:

Table 5: Energy measurements for line congestion simulation scenario - MTU 11

	Active Power (kWh)	Reactive Power (kVAr)
Total load consumption	0.9726	0.07947
Total RES generation	0.0583	0.04464
Max. line loading	103.16 %	
Min. Voltage	0.951 pu	
Max.Voltage	1.048 pu	

In this case, the thermal limit of one line is violated. Therefore, the LFM must be triggered in order to alleviate the line congestion. The results after the LFM was cleared follow:

Table 6: Simulation results for line congestion scenario - MTU 11

	Active Power (kWh)	Reactive Power (kVAr)
Total load consumption	0.7314	0.03737
Total RES generation	0.0583	0.04464
Max. line loading	94.9498 %	
Min. Voltage	0.968 pu	
Max.Voltage	1.049 pu	

Only one of the five available flexible assets provided flexibility. All the decrease in the total load can be attributed to the flexibility provided by that asset, which decreased its offtake by 0.2412 kWh and 0.0421 kVAr of active and reactive power, respectively. The line that was violated is still the line with the maximum loading equal to 94.95% of its nominal capacity, and is within the safe limit after the clearing of the LFM. One would have expected the final flow of the line to be binding (i.e., loaded at 100% of its nominal capacity). That would have been the case if the flexible assets could partially decrease their consumption. However, in this case the assets are either on or off, and the flow falls below the limit. It is also worth mentioning that the asset that had the most downward flexibility to offer was the one that shut off. Indeed, any other combination of assets shutting down fails to bring the line flow on desirable levels. Finally, all the other limits of the network are respected after the LFM was cleared, and the flow at the point of common coupling was also reduced by 0.2412 kWh to keep the power balance within the network.

So, the proposed DAMM is able to achieve all of its goals when applied to a realistic use case. Specifically, it manages to activate the required flexibility needed to bring the loading level of an overloaded line back within acceptable limits, while not violating any other constraints of the network. At the same time, activations of flow at the point of common coupling restore the power balance, by indirectly activating flexibility at the TN.

Another example highlighting the effectiveness of the DAMM can be found at the 10^{th} MTU of the same day. Starting off with the actual energy measurements from the DSO toolbox for the 10^{th} MTU, the network had the following characteristics:

Table 7: Energy measurements from DSO toolbox - MTU 10

	Active Power (kWh)	Reactive Power (kVAr)
Total load consumption	0.7936	0.0316
Total RES generation	0.0793	0.0588
Max. line loading	79.514 %	
Min. Voltage	0.967 pu	
Max.Voltage	1.048 pu	

As can be seen, the network has no violations and no corrective actions need to be taken. By creating the synthetic forecasted offtake/injection setpoints laid out in the previous section for this instance, the characteristics of the network become the following:

Table 8: Energy measurement for under-voltage simulation scenario - MTU 10

	Active Power (kWh)	Reactive Power (kVAr)
Total load consumption	1.1110	0.04427
Total RES generation	0.0678	0.04912
Max. line loading	96.74 %	
Min. Voltage	0.947 pu	
Max.Voltage	1.047 pu	

In this case, under-voltage is detected at two nodes of the network. Therefore, the LFM must be triggered in order to alleviate the under-voltages. The results after the LFM was cleared follow:

Table 9: Simulation results for under-voltage scenario - MTU 10

	Active Power (kWh)	Reactive Power (kVAr)
Total load consumption	0.9346	0.03163
Total RES generation	0.0583	0.04464

Max. line loading	92.529 %
Min. Voltage	0.951 pu
Max.Voltage	1.048 pu

One flexible asset was activated to provide the necessary flexibility to alleviate the under-voltage, providing 0.1764 kWh of upward active and 0.00574 kVAr of reactive flexibility. As a result, both nodes that previously suffered from under-voltages are now within the acceptable limits (i.e., over 0.95 pu). As was also the case in the previous example, the previously violating constraint is not binding, due to the on/off nature of the assets.

Similar examples were also encountered in other MTUs for this day, and the DAMM managed to resolve them adequately.

3.1.2.1.3 Key Performance Indicators reporting

The following Key Performance Indicators for the DAMM are reported. The reported numbers concern the optimization problem that was formulated for all the MTUs of November 27th 2023 (i.e., they also include MTUs where LFMs were not necessary).

Table 10: KPIs for DAMM

ID	Name	Value
KPI_PUC17_1	% of change of the initial disaggregated market schedules	0.3% (104 assets were scheduled for 24 MTUs each, 8 of them changed for some MTU)
KPI_PUC17_2	Number of power lines on which thermal limits are reached	6
KPI_PUC17_3	Number of nodes on which voltage limits are reached	2
KPI_PUC17_4, KPI_PUC18_2	Optimization execution time	15.3 seconds
KPI_PUC14_1	Conversion time/number of nodes	Network size: 215 nodes, 212 lines Network conversion time: 5 seconds Data reading from DSO toolbox time: 20 seconds (for 24 MTUs)
KPI_PUC18_1	Absolute/relative optimality gap tolerance	0 (no binary variables)
KPI_PUC18_3	Reduction of welfare due to market schedule prequalification	N/A (simulation ran only for DN, no initial market schedule)

As can be seen from the reported KPIs, only a few flexibility activations were required. This is due to the fact that a) due to its ongoing commercial operation, the DN was operating within its operating limits, and b) the employed forecasted method was executed in such a way to produce realistic results.

Besides, LFMs are expected to be used only for a few MTUs per day, since DSOs are able to utilize out of market solutions (e.g., network reconfiguration) to prevent most forms of congestions in their networks.

The numerical performance of the DAMM is adequate, especially considering that the simulations whose numbers are reported were executed on conventional laptop. It should be reminded again that only the second stage of the DAMM was ran, therefore no binary variables were introduced in the market formulation, and as a result no optimality gaps were reported.

3.2 Intraday Market Mechanism

3.2.1 High level market design

For the reader's convenience, a brief overview of the design principles underlying the Intraday Market Mechanism (IDMM) is provided. For an in-depth understanding of the market design the reader is directed to D4.2 [9] and the related scientific publication in [14].

In the intraday framework, a continuous Local Flexibility Market (LFM) has been designed and modelled, serving as a market-based approach to manage Distribution Network (DN) issues. The market operates in a single distribution network and successfully handles the following grid issues:

(a) **Bus voltage violations**: refer to exceeding either the upper or the lower limit of the bus voltage magnitude (overvoltage or under-voltage).

(b) **Line apparent power flow violations**: refer to exceeding the thermal limit of a line apparent power flow.

(c) **TSO-DSO connection bus active power violations**: refer to deviation in the wholesale market schedules of active power injection in the TSOT-DSO connection point.

The above issues are perceived as a result of forecasting errors in the non-dispatchable distributed resources generation and load consumption, errors which do exist between the predictions made in the day-ahead markets and the forecasts in the intra-day market. The proposed LFM engages the Market Operator, the DSO and Flexibility Service Providers (FSPs) and allows the trading of hourly products of active and reactive energy from assets located in the DN. The MO is responsible for the operation of the continuous trading LFM platform and the relevant clearing and settlement activities. The DSO runs AC power flow of the DN when there is a change of the dispatchable assets' market schedule, an updated forecast of the non-dispatchable assets' generation or consumption or change in the distribution network topology as in the case of line outages. When certain types of violations are anticipated, the DSO requests flexibility to solve DN congestion issues, by submitting virtual orders and providing network data in the continuous LFM platform. As the DSO does not own any assets in the grid, DSO orders are considered as virtual orders acting as a flexibility need signal. Virtual orders are orders which can be matched only with FSP orders, and the relevant violation is essentially alleviated by the physical deployment of the flexibility entailed in the FSP order. The FSPs offer flexibility by submitting orders to the LFM platform. There is no nominal minimum bid size, while the maximum quantity should be limited to a level where the accuracy of the AC sensitivities methodology is ensured and is network specific. Minimum and maximum price limits can be imposed to reflect the cost of the market alternatives for solving the congestion (ex. rule-based cost of RES curtailment) or DSO's available means for recovering the transaction costs. In principle, the format of the orders that are submitted in the LFM platform includes the product type (active/reactive), direction (buy/sell), nodal location, the MTU for physical delivery, quantity, and are given a timestamp upon submission. FSPs submit limit orders at a specified limit price; maximum price to be paid in case of buy orders or minimum price to be received in case of sell orders; while the DSO places market orders i.e. quantity-only orders with no specified price that are not visible by FSPs in the orderbook and are matched with the best available FSP limit orders, targeting at the minimization of the congestion relief and voltage support cost. When a new order is submitted, the market platform checks all order combinations that can lead to trades based on a price - time prioritization principle. Orders are either executed immediately or, in case they cannot be matched right away, entered into the order book.

Trade acceptance rules ensure financial and network feasibility:

(a) **Financial feasibility**: Two orders can be matched only if they adhere to a set of financial rules e.g. a sell order can be matched only with a buy order of the same product if the sell order price is lower or equal than the buy order price, etc. The full set of rules is analyzed later on.

(b) **Network feasibility:** Network feasibility is satisfied if a potential trade mitigates the anticipated network constraint violations, without creating new. The LFM transactions respect the network feasibility requirements, and the network feasibility assessment is based on the development of linearized AC sensitivities around the DN operating point (i.e. the exact relationship is approximated via a linearization that is performed around the network's initial operating point), which can lead to fast and efficient sensitivities calculation, using sparse vector methods. The proposed ac PTDFs are suitable for determining the change in the line flows/ node voltage magnitudes, for the changes in the injected active or reactive power of the potential bilateral transactions.

A trade in the proposed LFM implies physical delivery, therefore when a trade is concluded, the MO communicates it to the FSP and DSO who updates the asset market schedule and sends updated network data back to the MO. The trade execution price is defined as the price of the order that was first submitted (order with oldest timestamp), following the same rules that apply in the continuous market Single Intra-day Market Coupling (XBID project). The LFM implementation requires minimum information exchange between the DSO and the MO to respect constitutional limits and to be computationally light and, therefore, suitable for continuous trading applications.

3.2.2 Data processing and simulation results

3.2.2.1 Spain

3.2.2.1.1 Pilot data processing

Topology data

Topology data essential for the IDMM was provided by the pilots. For compatibility with the IDMM model the data need to be in a Pandapower format as presented in Annex A.

Energy measurement data

In the context of the Spanish pilot, a model to access the real metering data available in the DSO toolbox was developed. The collected metering data were converted to Pandapower format for seamless integration with the IDMM model. Hourly energy measurements were obtained for each day throughout the year 2023. Subsequently, AC powerflows were run on all 2023 data to identify any instances of grid violations in the operations. Notably, no violations were found for any dates and hours within the DSO toolbox. In the case study presented below, data from 1 of November 2023, 19.00h were used. Within this dataset, a disturbance scenario was applied to simulate a forecasted increase in load, intending to induce voltage violations. Figure 2 shows the actual energy measurements alongside the applied disturbance scenario, resulting in an under-voltage at bus 40.

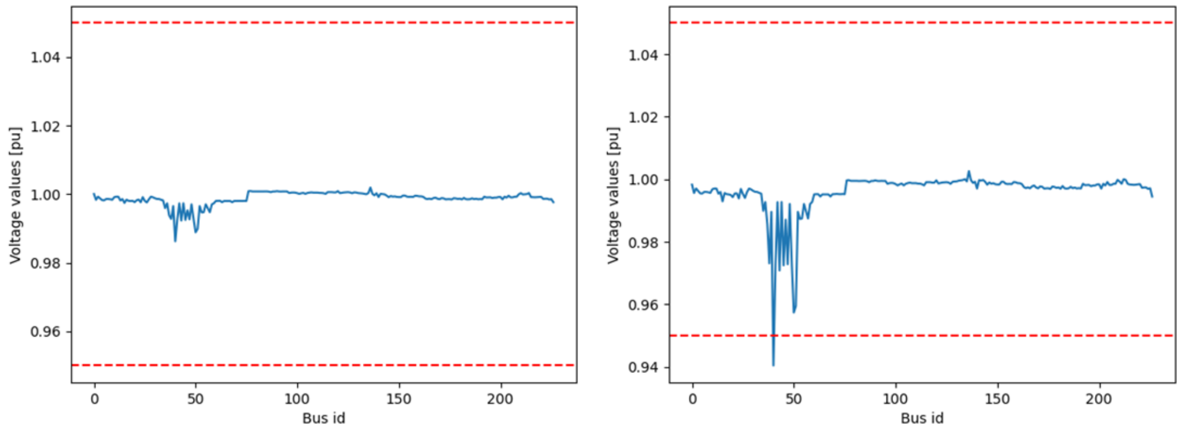

Figure 2: Actual energy measurements and disturbance scenario for Spanish pilot data

Order data

Two types of orders are considered in the IDMM: DSO virtual orders and FSPs orders. DSO virtual orders are calculated by the model for each operating point using the AC sensitivities. On the other hand, FSP orders consist of Flex Offers provided by flexible assets within the network. For the Spanish pilot there are five controllable loads that are located in specific nodes of the DN. These flexible assets can only offer upward flexibility i.e., are loads that are able to reduce their consumption, under a price compensation principle specified by the pilots. According to the IDMM design principles, the DSO virtual orders are submitted as market orders, i.e. quantity-only orders that are not visible by FSPs in the orderbook and are matched with the best available FSP limit orders, targeting at the minimization of the congestion relief and voltage support cost. This means that the financial feasibility of the DSO – FSP trade is always respected, irrespective by the price of the FSP order.

3.2.2.1.2 Simulation results

This section demonstrates how the proposed LFM can effectively address anticipated violations in the Spanish pilot network, with the goal to prove the scalability of the proposed solution and its adaptability in different network topologies and market structures.

As presented in Section 2.2.1, the Spanish network used for the simulations consists of 227 DN buses, 200 DN lines, 24 transformers, 111 loads and 6 static generators, with five of these loads being flexible. The DER generators are modelled with a constant active and reactive power feed-in. The upper and lower bus voltage limits are set at 1.05pu and 0.95pu, respectively. The disturbance scenario selected for the market simulation contains one under-voltage in bus 40, where the initial bus voltage is v_{before} = 0.9404pu.

The IDMM runs the AC power flow and generates DSO virtual orders serving as flexibility requirement signals. The DSO orders are calculated based on the AC sensitivities, as presented in Annex B. Given that FSP flexibility offers are only available in specific nodes of the network, the analysis of DSO orders is limited to the nodes associated with controllable loads.

These are as follows:

Table 11: DSO order quantities for the buses with controllable loads

Bus ID of controllable load	Quantity (MVar)
CL1	74.10
CL2	47.60
CL3	60.64
CL4	**46.99**
CL5	54.82

We assessed the impact of a trade between the DSO and controllable load 4, identifying it as the most effective node among the controllable load locations for addressing the violation. After rerunning the AC power flow, we observed an improvement in under-voltage, with the new bus voltage after the trade being v_{after} = 0.9413pu. However, although the violation was mitigated, it couldn't be entirely resolved with the available controllable loads. Upon examining the AC sensitivities in Annex B, we recognize that a trade in certain nodes could have a more significant impact the violation, leading to a more effective resolution of it. To validate our assumptions, we consider a trade between the DSO and a theoretical controllable load in bus 40. The result of the hypothetical trade is the complete resolution of the violation and an optimal operation in node 40, corresponding to a voltage measure of v_{htrade} = 0.9909pu. These outcomes are very important and can lead to two noteworthy observations. First the findings suggest the need for additional controllable loads to ensure a resilient grid operation. Additionally, the AC sensitivities analysis could serve as a valuable tool for identifying areas for DERs investments based on observed violations.

3.2.2.1.3 Key Performance Indicators reporting

Based on the analysis of D1.2 [4] one KPI corresponds to the IDMM. Results are shown in Table 12. It is important to highlight that in the analysis involving existing controllable loads, the calculation refers to mitigating voltage violations rather than resolving them ($((v_{after} - v_{before})/v_{before}) * 100\%$).

Table 12: KPIs for IDMM – Spanish pilot

ID	Name	Description	Value
KPI_PUC20_1	Percentage of critical events addressed through the intraday market mechanism	Describes the percentage of critical events that are successfully addressed by the intraday market mechanism compared to the total number of critical events produced by the generator/ or by the DSO toolbox in case of the second implementation option	• 0.10% with use of available controllable loads • 100% when considering controllable loads in network nodes suggested by the AC sensitivities analysis

3.2.2.2 Germany – SWW network

3.2.2.2.1 Pilot data processing

Topology data

Topology data essential for the IDMM was provided by the pilots. For compatibility with the IDMM model the data need to be in a pandapower format as presented in Annex A.

Measurement data

For the SWW pilot, specific snapshots of the network were provided in pandapower format for seamless integration with the IDMM model. Within the provided dataset, no violation was identified, and a disturbance scenario was applied which resulted in line congestions and a violation in the schedule of the TSO-DSO connection point.

Order data

Two types of orders are considered in the IDMM: DSO virtual orders and FSPs orders. DSO virtual orders are calculated by the model for each operating point using the AC sensitivities. In this case one DSO order of active power is submitted. On the contrary, FSP orders consist of Flex Offers provided by flexible assets within the network. For the SWW pilot there are four controllable loads that are located in arbitrary nodes of the DN. These flexible assets can only offer upward and downward flexibility. As discussed for the Spanish pilot, as DSO virtual orders are submitted as market orders, DSO – FSP trades are executed immediately at the FSP's best available price.

3.2.2.2.2 Simulation results

The SWW network used for the simulations consists of 21 DN buses, 12 DN lines, 8 transformers, 23 loads and 9 static generators, with four of these loads being flexible. The DER generators are modelled with a constant active and reactive power feed-in. The upper and lower bus voltage limits are considered at 1.05pu and 0.95pu, respectively. The disturbance scenario selected for the market simulation contains two line congestions in lines with ids 13 and 17 and one violation in the TSO – DSO connection point.

The IDMM runs the AC power flow and generates DSO virtual orders serving as flexibility requirement signals. In this case, a DSO active power order corresponding to a flexibility need in the TSO – DSO connection point is submitted. The initial schedule in Table 13 is considered the schedule in the TSO – DSO connection point under normal operation settings, before applying the congestion scenario.

Table 13: TSO – DSO connection point schedule

TSO – DSO connection point

State	P(MW)	Q (MVar)
Initial	-0.00328	-0.04799
Disturbance	0.387995	0.242244

Given that the nodes of the FSP Flex Offers are not specified, an analysis is conducted to propose the most appropriate locations to optimally resolve the identified violations. From Annex C, it is observed that the AC sensitivities for the congested lines 13 and 17 are not zero for buses 0,4,6,7,9,11,12,14,17,18,19,20. From the aforementioned buses, loads and static generators are available in buses 4,11 and so, controllable loads are assumed in these buses. It is noted that both upward and downward flexibility is available.

The line apparent flow for active power offers on buses 4 and 11 are presented in Table 14.

Table 14: AC line sensitivities for offers in buses 4 and 11

Line id	Bus id	$PTDF_{P,from}$	$PTDF_{P,\text{to}}$
13	4	-0.01967	-0.01841
13	11	-0.01967	-0.01841
17	4	-0.01479	-0.01429
17	11	-0.01628	-0.01573

As detailed in the methodology presented in D4.2 [9], in case of a FSP trade, the difference of sensitivities is considered. As the sensitivities of the line apparent flow of line 13 are identical for buses 4 and 11, an FSP trade for Flex Offers submitted in buses 4 and 11 will not have impact in the resolution of the identified line congestion. Similar, for line 17, the impact will be insignificant (~10^{-8}). Given these observations, the line congestions cannot be resolved with bids in the available locations for loads and generators. So, here the focus is on the resolution of the congestion in the TSO – DSO connection point. For that, a trade between the DSO buy order submitted in the TSO – DSO connection point (bus 13), which is equal to P= 0.3913MW, and a BRP sell order in bus 4, equal to P= 0.02375 MW which is the available capacity in the specific location, is considered. Table 15 shows the impact of the trade in the resolution of the violation.

Table 15: Impact of trade in the TSO – DSO connection point schedule

TSO – DSO connection point		
State	P(MW)	Q (MVar)
Initial	-0.00328	-0.04799
Disturbance	0.387995	0.242244
After Trade	0.364216	0.24221

3.2.2.2.3 Key Performance Indicators reporting

The KPI for the resolution of the violation in the TSO-DSO connection point is presented in the following table. In the SWW pilot, even if there is a freedom to select which of the loads will be considered as controllable, the absence of loads in specific locations that could optimally resolve the violation is limiting the effectiveness of the trades.

Table 16: KPIs for IDMM – SWW pilot

ID	Name	Description	Value
KPI_PUC20_1	Percentage of critical events addressed through the intraday market mechanism	Describes the percentage of critical events that are successfully addressed by the intraday market mechanism compared to the total number of critical events produced by the generator/ or by the DSO toolbox in case of the second implementation option	• 6.13% with use of available locations and capacity for controllable loads

3.2.2.3 Germany – SWH network

3.2.2.3.1 Pilot data processing

Topology data

Topology data essential for the IDMM was provided by the pilots. For compatibility with the IDMM model the data need to be in a pandapower format as presented in Annex A.

Measurement data

For the SWH pilot, specific snapshots of the network were provided in pandapower format for seamless integration with the IDMM model. Within the provided dataset, one line congestion and 23 voltage violations were identified.

Order data

The DSO submits virtual reactive power orders as flexibility needs to resolve the voltage violations. The DSO orders are calculated by the model for each operating point using the AC sensitivities. The DSO reactive power orders are shown in Annex D. FSP respond to the DSO flexibility requests by submitting Flex Offers. The Flex Offers dataset provided by INEA consists of three loads that are controllable and can only upward flexibility. Due to lack of information regarding the metering ID of each one of the provided Flex Offers, their location in the distribution network was selected arbitrarily. Again, as DSO virtual orders are submitted as market orders, the financial feasibility of the DSO – FSP trade is always respected, irrespective by the price of the FSP order.

3.2.2.3.2 Simulation results

The SWH network used for the simulations consists of 24 DN buses, 22 DN lines, 4 transformers, 16 loads and 16 static generators, with three of these loads being flexible. The DER generators are modelled with a constant active and reactive power feed-in. The upper and lower bus voltage limits are set at 1.05pu and 0.95pu, respectively. The disturbance scenario selected for the market simulation contains 23 voltage violations (over-voltages). The external grid is considered to be in bus 16.

The IDMM runs the AC power flow and generates DSO virtual orders serving as flexibility requirement signals. Here, DSO reactive power sell orders are submitted, corresponding to flexibility needs for the over-voltages resolution (Annex D). From Annex D it can be noted that the optimal locations for the resolutions of the over-voltages are buses 21 and 15. However, in these buses there are no loads or static generators connected to the SWH network. The next most optimal locations are buses 17,7 and 0. We assume a controllable load in bus 0, which is the only bus with an asset available for flexibility provision. The volumes of available Flex Offers range from 0.01 to 0.1 MVar. Here we examine a trade between the DSO and an FSP Flex Offer in bus 0 with the max quantity (0.1MVar). Results are shown in Figure 3. It is observed that all the over-voltages are resolved.

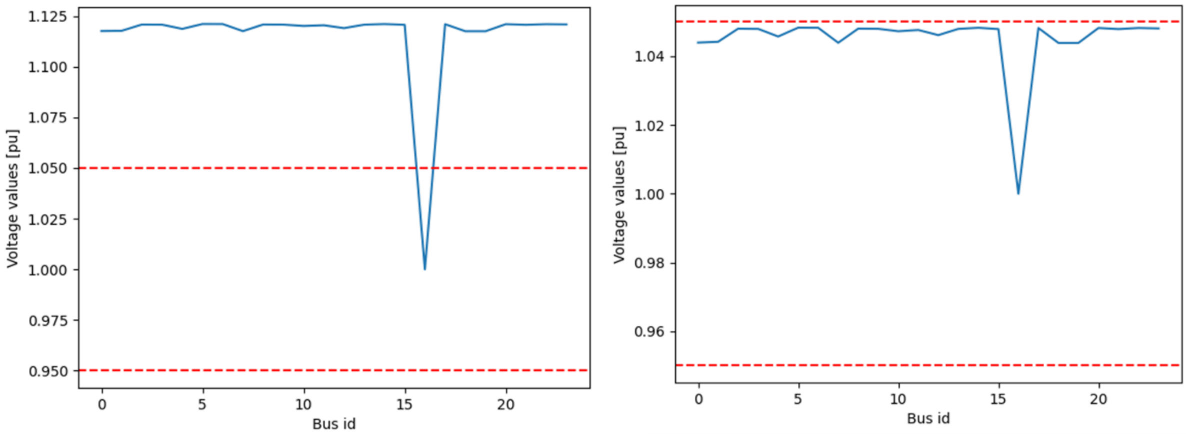

Figure 3: Bus voltage values before and after trade

3.2.2.3.3 Key Performance Indicators reporting

ID	Name	Description	Value
KPI_PUC20_1	Percentage of critical events addressed through the intraday market mechanism	Describes the percentage of critical events that are successfully addressed by the intraday market mechanism compared to the total number of critical events produced by the generator/ or by the DSO toolbox in case of the second implementation option	• 100% - all voltage violations are resolved

3.3 Real Time Market Mechanism

3.3.1 High level market design

In order to meet the TN and DN requirements in the real-time level and exploit the flexibility that can be provided by the Distributed Energy Resources (DERs), a real-time market platform has been designed, modelled and developed. The platform aims at the clearing of the 15-minute real-time market, both in the transmission and distribution level and follows a hierarchical structure, in the sense that the minimum amount of information is exchanged between the TSO and the respective DSO.

In the transmission level the platform successfully handles the following:

(a) **Order clearing**: the participants' submitted orders are cleared optimally, ensuring the maximization of the overall system welfare.

(b) **Residual supply function incorporation**: the flexibility that can be provided from the DERs that are located in the distribution network is exploited through the incorporation of the DNs residual supply function that acts as an additional order in the market clearing procedure.

(c) **Active power flows' determination**: in case that the TN is not modelled through its zonal representation, the network's active power flow constraints are taken explicitly into consideration.

(d) **Market clearing prices' determination**: market clearing prices are determined through uniform pricing approach, where both upward and downward activated orders are remunerated with the same marginal price.

In the distribution level the platform successfully handles the following:

(a) **Order clearing**: the DERs' submitted flexible orders are cleared optimally, ensuring the maximization of the overall system welfare.

(b) **Residual supply function determination**: the flexibility that can be provided by the distribution network DERs is implicitly modelled through the derivation of the DNs Residual Supply Function that is incorporated to the TN market clearing model.

(b) **Active and reactive power balance constraints**: the active and reactive power balance constraints are explicitly modelled, ensuring that the demand is adequately met.

(b) **Active and reactive power flows' determination**: active and reactive power flow constraints are explicitly modelled through the incorporation of apparent power flow limits.

(b) **Market clearing prices' determination**: both active and reactive market clearing prices are determined, providing adequate economic signals to the Flexibility Service Providers (FSP).

The aim of the developed hierarchical model is to cover in real-time the net load in both the Transmission and Distribution network. In this direction and in order to ensure the minimum amount of information exchange, the DSO calculates for each one of the examined distribution networks the implied Residual Supply Function that constitutes the aggregated representation of the underlying flexibility, while fully respecting the network constraints. The derived RSFs are provided to the TSO, who incorporates them in the transmission-level market clearing problem and clears the real-time market. The outputs of this auction-based procedure are the clearing quantities of the submitted by the participants orders, the market clearing prices and the power flow in the TN lines, whose set also contains the lines in the interface between the TNs and the DNs.

The information regarding the optimal power flow that is cleared from or to the DN is then passed to the DSO, who incorporates it as a fixed injection in a power flow model that derives the optimal quantities that should be cleared from the submitted from the FSPs flexibility orders and the active and reactive market clearing prices. To ensure the network flexibility and avoid any line violations, the active and reactive power flows are limited by the distribution network lines' apparent power flow limits.

Flexibility Service Providers submit 15-minute upward or downward flexibility orders to the respective System Operators, whereas there is no specific requirement about the nominal size of the underlying bid.

3.3.2 Data processing and simulation results

3.3.2.1 Spain

3.3.2.1.1 Pilot data processing

Topology data

As mentioned above, the required data regarding the network topology and network parameters were provided in a panda power model format, on which the following adjustments applied in order to run the RTMM:

1. A switchless topology was introduced to the platform that follows the pandapower documentation-based approach. Under this approach the buses that are connected through a closed switch are merged, whereas if a switch is open then it is treated as an open line. The Estabanelll network contains 2 closed switches, which were then removed from the final model input data by merging the adjacent buses.

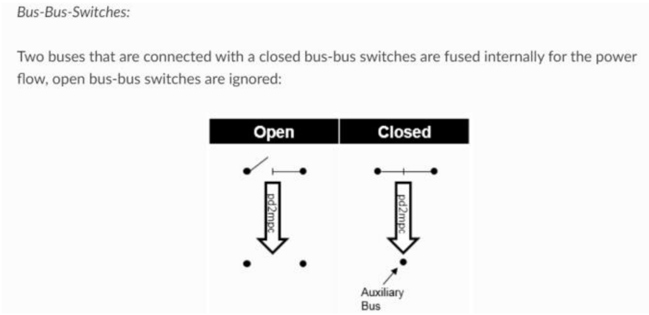

Figure 4: Electric model for bus-bus switches

2. The transformer parameters were converted to the respective resistance (r), conductance (g), reactance (x) and susceptance (b) parameters by applying the formulas that are available from the pandapower documentation and were tested in an AC power flow platform that was developed for this purpose.
3. The given line parameters were converted to the per unit system by applying the formulas that are available from the pandapower documentation and were tested in the beforementioned AC power flow model.
4. In order to calculate the maximum apparent edge flow S_{max} (line or transformer), the maximum allowed line thermal current I_{max} was used, by converting it to the respective line limit through the formula $S_{max} = \sqrt{3} \cdot V_N \cdot I_{max}$, where V_N is the base network voltage. Similarly, the maximum allowed transformer power flow was assumed to be equal $S_{max} = 150\% \, S_{N,transformer}$, where $S_{N,transformer}$ is the rated/nominal apparent power limit of the transformer.

In order to model correctly the whole DN of the Spanish pilot, a dummy node is assumed as the TN (bus 1000) which is connected with the DN through a dummy interconnection. In this node, an additional flexible offer is assumed to provide upward and downward flexible capacity, with a price 1 €/MWh higher than the most expensive offer in both directions.

The upper and lower bus voltage limits were assumed to be equal to 0.95 pu and 1.05 pu respectively, as no such information was provided from the various data sources. Moreover, an active injection of 1.3 MW was assumed to exist in the transmission node, so as to ensure the energy exchange between the transmission and distribution networks. A positive net injection in the transmission bus was selected in order to accommodate the fact that the Spanish network contained only flexible offers for downward activation.

Finally, it was assumed that in the root node of the DN (that corresponds to the bus that is connected to the interface between the transmission and distribution networks) exists a reactive bid of infinite capacity, in ensure the feasibility of the power flow problem.

<u>Energy measurement data</u>

Energy measurement data were extracted from the DSO Toolbox. A specific date was selected arbitrarily (in this case the selected date was 26/8/2023 8:00:00) and the extracted energy measurement data (generation or load) were aggregated to the corresponding node of the pandapower model, according to the grid topology. The reactive power for each meter was given from the API of DSOToolbox in 4 quadrants $(r1, r2, r3, r4)$ and for the calculation of the net reactive power in the panda power model, the formula $reactive_{net} = (r1 - r3) - (r2 - r4)$ was applied, where a positive $reactive_{net}$ corresponds to an inductive load, whereas a negative capacitive value implies a generator. The active power for each examined meter was calculated based on the energy that was imported and exported in the respective network bus. Thus, the net value of the injected or withdrawn active power was derived through the formula $active_{net} = import\ energy - exported\ energy$, where a positive $active_{net}$ parameter means a consumption (load), whereas a negative value denotes a generator (sgen). The platform uses as input the total active and reactive net injection at a given bus, so the formulas $active\ net\ injection = sgen[MW] - load[MW]$ and $reactive\ net\ injection = sgen[MVAr] - load[MVAr]$ were applied.

Order data. In order to be fully compliant with the developed platform, the maximum capacity and the price of each flexible offer had to be converted in [€/MWh] and [MWh] respectively. For each examined bus, flexible offers of variable duration, activation period and capacity were provided. Moreover, one of the aforementioned offers had separate capacity for winter and summer. Due to the selected date, in the simulations presented below, the summer capacity was used. In order to further simplify the examined test case, all flexible offers were assumed to be available for activation simultaneously, and thus an aggregated offer was created for each examined period, with a capacity equal to the total overall capacity of all provided offers.

3.3.2.1.2 Simulation results

The examined Spanish network comprises 224 buses, 223 edges, 110 loads and 3 DERs. The DER generators are modelled with a constant active and/or reactive power feed-in. Based on an analysis that was performed through the developed AC power flow model, it was revealed that initially the network did not have any congested lines.

For the examined scenario, 5 flexible assets were introduced to the Spanish distribution network. The clearing platform prices for the 1st 15-minute interval are listed below.

Table 17: RTMM: Active power clearing price results for period 1 (1st 15-minute interval) – Spanish Pilot Data

Bus	Nodal price	Bus	Nodal price
0	112.43	**39**	113.13
1	112.59	**40**	115.40
2	112.48	**41**	114.21
3	112.54	**42**	115.08
4	112.59	**43**	114.10
5	112.59	**44**	115.41
6	112.55	**45**	114.40
7	112.55	**46**	113.23
8	112.57	**47**	114.19
9	112.59	**48**	113.27
10	112.50	**49**	114.04
11	112.48	**50**	113.82
12	112.48	**51**	114.39
13	112.60	**52**	113.13
14	112.56	**53**	115.56
15	112.96	**54**	115.12
16	112.72	**55**	113.27
17	112.59	**56**	114.07
18	112.60	**57**	115.12
19	112.63	**58**	113.27
20	112.63	**59**	115.02
21	112.59	**60**	112.59
22	112.50	**61**	112.59
23	112.64	**62**	112.59
24	112.48	**63**	112.63
25	112.61	**64**	112.60
26	112.55	**65**	112.60

27	112.75	**66**	112.60
28	112.49	**67**	112.60
29	112.50	**68**	112.63
30	112.53	**69**	112.63
31	112.55	**70**	112.65
32	112.56	**71**	112.61
33	112.59	**72**	112.63
34	112.60	**73**	112.69
35	114.05	**74**	112.61
36	116.31	**75**	112.63
37	115.36	**76**	112.38
38	114.04	**77**	112.38
78	112.33	**120**	112.40
79	112.29	**121**	112.39
80	112.28	**122**	112.39
81	112.28	**123**	112.39
82	112.28	**124**	112.42
83	112.28	**125**	113.02
84	112.27	**126**	112.25
85	112.35	**127**	112.15
86	112.30	**128**	112.02
87	112.39	**129**	111.57
88	112.30	**130**	111.26
89	112.30	**131**	110.94
90	112.38	**132**	110.01
91	112.30	**133**	112.02
92	112.29	**134**	111.93
93	112.33	**135**	111.05
94	112.36	**136**	113.03
95	112.35	**137**	112.23
96	112.31	**138**	114.82
97	112.39	**139**	110.98
98	112.39	**140**	111.69
99	112.37	**141**	110.34
100	112.32	**142**	110.52
101	112.24	**143**	110.60
102	112.01	**144**	110.55
103	112.49	**145**	110.57
104	112.23	**146**	110.56
105	112.31	**147**	110.59
106	112.44	**148**	110.58
107	112.40	**149**	110.58

108	112.39	**150**	110.52
109	112.37	**151**	110.55
110	112.37	**152**	110.57
111	112.53	**153**	110.58
112	112.50	**154**	110.58
113	112.00	**155**	110.58
114	112.24	**156**	110.53
115	112.39	**157**	110.54
116	112.39	**158**	110.56
117	112.39	**159**	110.56
118	112.40	**160**	110.58
119	112.41	**161**	110.75
162	110.75	**204**	110.60
163	110.74	**205**	110.57
164	110.76	**206**	110.57
165	110.69	**207**	110.34
166	110.67	**208**	112.02
167	110.75	**209**	112.02
168	110.76	**210**	110.00
169	110.72	**211**	110.58
170	110.76	**212**	112.29
171	110.77	**213**	110.60
172	110.76	**214**	110.60
173	110.76	**215**	110.60
174	110.69	**216**	110.60
175	110.73	**217**	110.59
176	110.75	**218**	110.59
177	110.75	**219**	110.78
178	110.75	**220**	110.77
179	110.68	**221**	110.75
180	110.69	**222**	110.67
181	110.76	**223**	110.76
182	110.68	**224**	112.63
183	110.76	**1000**	110.00
184	110.74		
185	110.80		
186	110.75		
187	110.67		
188	110.67		
189	110.67		
190	110.57		
191	110.60		

192	110.60		
193	110.60		
194	110.63		
195	110.61		
196	110.61		
197	110.59		
198	110.59		
199	110.68		
200	110.57		
201	110.61		
202	110.59		
203	110.60		

The real-time platform was able to clear the market and activate the flexible assets optimally. There is no congestion in the network and thus most of the offered quantities were fully cleared, maximizing in this way the overall social welfare. In the transmission level, the flexible order is activated in all periods for a quantity equal to 0.9 MWh, aiming to cover the imbalance created by the assumed net injection (1.3 MWh). The remaining energy is then transferred to the distribution network through the clearing of the derived Residual Supply Function, whereas the market clearing price is determined by the activated offer and is thus equal to 110 (€/MWh) in all examined periods. In the distribution level, the active market clearing prices are very close to the transmission level respective prices (in the range of 110-115 €/MWh) whereas the distribution network is uncongested.

Table 18: RTMM: Active clearing quantities and prices for period 1 (1st 15-minute interval) – Spanish Pilot Data

Downward Flex Offer	Bus	Active clearing quantities (MW)	Active clearing prices (€/MWh)
fo1-transmission node	1000	0.90030	110
fo2	125	0.04152	113.52
fo3	134	0.01040	112.24
fo4	138	0.06706	115.63
fo5	140	0.07400	111.97
fo6	136	0.13864	113.53

3.3.2.1.3 Key Performance Indicators reporting

The following table presents various performance indicators. As it can be observed, the overall social welfare has a negative value due to the activation of downward flexible offers. Moreover, the Lost Opportunity Cost (LOC), which is a way of ensuring that the dispatch solution and the market clearing prices are consistent and provide the correct economic signals to the participants is relatively low regarding the overall social welfare.

Table 19: RTMM: Distribution network performance indicators – Spanish Pilot Data

Performance indicators	
Social Welfare [€]	-571.59
LOC [€]	19.39
Constraints violation	none
Non-convex orders inclusion	none
Run time [s]	32.34

3.3.2.2 Germany – SWW network

3.3.2.2.1 Pilot data processing

Topology data

As in the Spanish case, preprocessing of the network topology data and parameters was required to be compatible with the RTMM. For the examined transformers, the resistance (r), conductance (g), reactance (x) and susceptance (b) parameters were derived by applying the formulas from the pandapower documentation to the provided data and were tested in an AC power flow platform that was built from scratch for this purpose, whereas all line parameters were transformed to their per unit equivalent formulation.

For the calculation of the maximum apparent edge flow (line or transformer), the maximum thermal current of the line was used. The aforementioned value was converted to the respective power flow limit through the formula $S_{max} = \sqrt{3} \cdot V_N \cdot I_{max}$, whereas the maximum power flow for the transformer was assumed to be equal to $S_{max,transformer} = 150\%\ S_{N,transformer}$.

In order to properly model the TSO-DSO coordination problem, a dummy node (bus 1000) was assumed to represent the zonal-based transmission network and thus an additional line was incorporated in the input data set, to model the interconnection interface between the transmission network and the root node of the SWW distribution network.

A dummy participant in the transmission network was assumed to bid enough flexible active capacity to make the network feasible balancing wise, while offering the worst price for both downward and for upward activation, with regard to the flexible offers that are available in the distribution level. Moreover, as in all pilots, an additional reactive bid, of infinite capacity and zero price, is assumed to exist in the distribution network root node, for covering the network's reactive requirements. Finally, downward imbalance of -1 MW was assumed to exist in the transmission network, in all periods of the examined trading horizon.

Energy measurement data

For the SWW network the DSO Toolbox was not used, as the energy measurements were sufficient in the provided pandapower model. The platform uses as input the total active and reactive net injections at each examined bus, which were calculated based on the formulas $active\ net\ injection = sgen[MW] - load[MW]$ and $reactive\ net\ injection = sgen[MVAr] - load[MVAr]$.

Order data

Due to the lack of information regarding the provided energy measurements' (load and sgen) duration and the fact that the examined Flex Offers were reported for four (4) 15-minute intervals, it was assumed that each one of the provided energy measurement values corresponds to the respective 15-minute timeframe and remains the same for all of the examined periods.

3.3.2.2.2 Simulation results

The German (SWW) network used for the simulations consists of 22 buses, 21 edges, 23 loads and 9 distributed energy resources (DERs). The DER generators are modelled with a constant active and/or reactive power feed-in. The initial network had no congestion problems, although a positive imbalance at the slack bus was observed when solving the network power flow problem.

For the examined scenario, 4 flexible assets, along with an additional one at the transmission network were introduced to the SWW network. The results of the Real-Time Market platform corresponding to the first 15-minute period of the examined horizon are presented in the following tables.

Table 20: RTMM: Active power market clearing price for the 1st 15-minute period – SWW Pilot Data

Buses	Nodal price	Buses	Nodal price
0	81.00	**11**	81.02

1	80.99	**12**	80.63
2	81.07	**13**	80.86
3	80.91	**14**	80.86
4	81.50	**15**	80.86
5	80.87	**16**	80.86
6	80.86	**17**	81.45
7	80.86	**18**	81.18
8	80.86	**19**	80.84
9	80.86	**20**	80.70
10	80.72	**1000**	81.00

Table 21: RTMM: Active power cleared quantities and prices for the 1st 15-minute period – SWW Pilot Data

Upward Flex Offer	Bus	Active clearing quantities (MW)	Active clearing prices (€/MWh)
fo1-transmission node	1000	0.14730	81.00
fo2	10	0	80.72
fo3	12	0	80.63
fo4	17	0.00190	81.45
fo5	3	0.06333	80.91

The RTM platform was able to successfully clear the market and optimally dispatch the flexible assets. No congestion was observed in the distribution network, maximizing in this way the overall social welfare, which was equal to 75.82 €. Moreover, as it can be observed from the below presented performance indicators' related matrix, the network LOC is minimal, whereas due to the small size of the SWW distribution network, the total execution time is negligible.

3.3.2.2.3 Key Performance Indicators reporting

Table 22: RTMM: Distribution network performance indicators – SWW Pilot Data

Performance indicators	
Social Welfare [€]	75.82
LOC [€]	0.14
Constraints violation	none
Non-convex orders inclusion	none
Run time [s]	1.28

3.3.2.3 Germany – SWH network

3.3.2.3.1 Pilot data processing

<u>**Topology data**</u>

As for the rest of the pilots, all transformer data were converted to the respective resistance (r), conductance (g), reactance (x) and susceptance (b) parameters by applying the appropriate formulas derived from the pandapower documentation and were tested in an AC power flow platform that was built from scratch for this purpose. Moreover, the pandapower documentation was used in order to convert all line parameters into the per unit (p.u.) system, whereas all double lines between buses were eliminated and replaced by their single line equivalent.

For the calculation of the maximum apparent edge flow (corresponding to either a line or a transformer), the maximum thermal current of the examined elements was used. For all lines, the maximum power flow was derived through the formula $S_{max} = \sqrt{3} \cdot V_N \cdot I_{max}$, whereas for the transformer counterpart the respective maximum value was assumed to be equal to $S_{max} = 150\% \, S_{N,transformer}$. For all double lines that got merged into their single line equivalent, the respective maximum limit S_{max} was doubled. For all distribution nodes, the upper and lower bus voltage limits were assumed to be 0.95 pu and 1.05 pu respectively, as no information was obtained regarding this network characteristic.

As in the case of the SWW distribution network, a dummy node was utilized for modelling the external transmission network (bus 1000), where a participant was assumed to bid enough flexible active capacity to make the network feasible balancing wise, while offering the worst price for both downward and for upward activation.

Energy measurement data

The DSO Toolbox was not used for the SWH network. The developed RTM platform uses as input the total active and reactive net injections at the examined distribution network buses, which are calculated through the formulas $active\ net\ injection = sgen[MW] - load[MW]$ and $reactive\ net\ injection = sgen[MVAr] - load[MVAr]$. In order to create nodal net injections, it was assumed that all load and generation data corresponded to the 15-minute interval energy measurements, instead of the original provided hourly interval.

Order data

The provided Flex Offers comprised more than four (4) 15-minute intervals. Since the optimization horizon is assumed to be equal to 1 hour in all pilot test cases, only the first four time intervals were processed and used in the simulations. Due to lack of information regarding the metering ID of each one of the provided Flex Offers, their location in the distribution network was selected arbitrarily. Moreover, it was assumed that in the root node of the distribution network (that corresponds to the bus that is connected to the interface between the transmission and distribution networks) exists a reactive bid of infinite capacity, to ensure the feasibility of the power flow problem. Finally, initial analysis of the SWH distribution network revealed that even though the overall system imbalance was positive, requiring the activation of downward offers, only upward Flex Offers existed in the provided dataset. For this reason, a negative imbalance, equal to 1 MW for each trading period was assumed in the transmission level, to better showcase the upward activation of the flexible assets.

3.3.2.3.2 Simulation results

The German (SWH) distribution network used for the simulations consists of 25 buses, 24 edges (27 edges exist in the provided data but 3 double lines were merged as showcased above), 16 load demands and 16 distributed energy resources (DERs). The DER generators are modelled with a constant active and/or reactive power feed-in, whereas no congestion problems appeared in the initial network (no activation of Flex Offers).

For the examined SWH-related case, three (3) flexible assets (+1 slack bus-external grid) were introduced to the SWH network, along with another dummy participant, who submits its flexible offer in the transmission level (as presented in the dummy data section). The simulation results are presented in the following tables and corresponds to the first 15-minute period.

Table 23: RTMM: Active power market clearing price for the 1st 15-minute period – SWH Pilot Data

Buses	Nodal price	Buses	Nodal price
0	97.19	**13**	97.02
1	97.19	**14**	97.05
2	97.02	**15**	96.79
3	97.02	**16**	100.00
4	97.17	**17**	96.88
5	97.06	**18**	97.15
6	97.05	**19**	97.08

7	97.19	**20**	96.15
8	97.03	**21**	96.74
9	97.02	**22**	96.17
10	97.11	**23**	97.04
11	97.09	**1000**	100.00
12	97.16		

Table 24: RTMM: Active power cleared quantities and prices for the 1st 15-minute period - SWH Pilot Data

Upward Flex Offer	Bus	Active clearing quantities (MW)	Active clearing prices (€/MWh)
fo1	1000	0.24712	100.00
fo2	22	0.04874	96.17
fo3	21	0.01050	96.74
fo4	19	0.06641	97.08

As in the previous cases, the real-time platform was able to clear the market and optimally dispatch the flexible assets. There is no congestion in the network and thus the offered quantities were fully cleared maximizing the overall social welfare. Moreover, as it can be observed from the following table that presents the performance indicators, the Lost Opportunity Cost (LOC) is almost negligible, no constraints are violated, whereas the small size of the SWH distribution network leads to fast execution times.

3.3.2.3.3 Key Performance Indicators reporting

Table 25: RTMM: Distribution network performance indicators - SWH Pilot Data

Performance indicators	
Social Welfare [€]	137.42
LOC [€]	0.22
Constraints violation	none
Non-convex orders inclusion	none
Run time [s]	2.3

4 Conclusion

The proposed market mechanisms and tools have been validated in realistic test cases using real data from the pilots of FEVER. Simulations results indicate that the proposed mechanisms exhibit satisfactory scalability and accuracy and are able to efficiently address issues of the DN. Overall, key findings suggest that increasing the availability of network flexibility assets or diversifying their locations could significantly enhance trade effectiveness. Furthermore, a limiting factor identified was the on/off operation of flexibility assets and the constraint of providing either upward or downward flexibility.

The efficiency of market mechanisms is quantified through KPIs. Specifically, in the context of the DAMM, the reported indicators prove the model's effectiveness in addressing identified violations and its capacity to efficiently clear the market within reasonable timeframes. The findings reveal that the model successfully resolves all identified violations, including line congestions and voltage issues. The market clearance is achieved through optimal power flow execution, ensuring the optimality of results. Additionally, both the preprocessing of network data and the execution are accomplished within negligible time limits. For the IDMM, the AC sensitivities analysis emerged as a valuable tool for analyzing trade impacts without necessitating power flow runs or extensive technical knowledge on network analysis. Also, the AC sensitivities methodology can be used as a tool to identify locations where investments on flexibility assets would be more profitable. As highlighted by the respective KPIs for the IDMM, constraints on the optimal violations' resolution exist due to the limited availability of flexible assets, which are situated in locations that may not have a direct impact on congested network areas. For the RTMM, the proposed tool is able to clear the market and optimally dispatch the flexible assets, ensuring no network constraints were violated. The KPIs analysis proves that the model runs in reasonable execution time and the offered quantities are fully cleared, maximizing overall social welfare. Additionally, the introduction of indicators like the LOC ensures consistency in dispatch solutions and market clearing prices, providing accurate economic signals to participants.

5 List of figures

6 List of references

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7 List of abbreviations

Abbreviation	Term
AC	Alternating Current
API	Application Programming Interface
DAM	Day-Ahead Market
DAMM	Day-Ahead Market Mechanism
DC	Direct Current
DER	Distributed Energy Resources
DSO	Distribution System Operator
DN	Distribution Network
FSP	Flexibility Service Provider
GIS	Geographic Information System
IDMM	Intra-Day Market Mechanism
KPI	Key Performance Indicator
LFM	Local Flexibility Market
LOC	Lost Opportunity Cost
MTU	Market Time Unit
NDA	Non-Disclosure Agreement
PTDF	Power Transfer Distribution Factors
RES	Renewable Energy Sources
RTMM	Real Time Market Mechanism
TN	Transmission Network
TSO	Transmission System Operator

Annex A Network data requirements

An indicative format on the required information to be provided for the DN can be found below. The data are indicatively categorized into seven basic categories: bus. Line, load, generator, static generator, external grid and transformer data, to be in line with the Pandapower format. Data in red represent information that is essential for the model runs, while data with a black font are optional. In each dataset, the network and MTU should be clearly indicated.

File/ Dataset Name	*Content*
bus_data	**Network_id** | integer |ID of the network **bus_id** | integer | ID of the bus **in_service** | boolean | specifies if the bus is in service **max_vm_pu** | float*| Maximum voltage **min_vm_pu** | float | Minimum voltage **name** | string | name of the bus **type** | string | type variable to classify buses **vn_kv** | float | rated voltage of the bus [kV] **zone** | string | can be used to group buses, for example network groups / regions
line_data	**Network_id** | integer |ID of the network **line_id** | integer | ID of the line **c_nf_per_km** | float | capacitance of the line [nano Farad per km] **df** | float | derating factor (scaling) for max_i_ka **from_bus** | integer | Index of bus where the line starts **to_bus**| integer | Index of bus where the line ends **g_us_per_km** | float | dielectric conductance of the line [micro Siemens per km] **in_service**| boolean | specifies if the line is in service **length_km** | float | length of the line [km] **max_i_ka** | float | maximal thermal current [kilo Ampere] **name** | string | name of the line **parallel** | integer | number of parallel line systems **r_ohm_per_km** | float | resistance of the line [Ohm per km] **std_type** | string | standard type which can be used to easily define line parameters with the pandapower standard type library **type** | string | type of line **x_ohm_per_km** | float | inductance of the line [Ohm per km]
load_data	**Network_id** | integer |ID of the network **bus_id** | bus_id | integer | ID of the bus **p_mw** | float| active power of the load [kW] **q_mvar** | float| reactive power of the load [kVar]

	const_i_percent | float| percentage of p_mw and q_mvar that is associated to constant current load at rated voltage [%%] **const_z_percent** | float | percentage of p_mw and q_mvar that is associated to constant impedance load at rated voltage [%%] **controllable** | boolean | specifies if the load is controllable **in_service** | boolean | specifies if the load is in service **name** | string | name of the load **scaling** | float | scaling factor for active and reactive power **sn_mva** | float | rated power of the load [kVA] **type** | string | type variable to classify the load
sgen_data	**Network_id** | integer |ID of the network **bus_id** | bus_id | integer | ID of the bus **p_mw** | float| active power of the element [kW] **q_mvar** | float| reactive power of the element [kVar] **in_service** | boolean | specifies if the element is in service **name** | string | name of the element **scaling** | float | scaling factor for active and reactive power **sn_mva** | float | rated power of the element [kVA] **type** | string | type variable to classify the element
gen_data	**Network_id** | integer |ID of the network **bus_id** | integer | ID of the bus **p_mw** | float | the real power of the generator [MW] **vm_pu** | float | voltage set point of the generator [p.u] **controllable** | boolean | Whether this generator is controllable by the optimal powerflow **in_service** | boolean | specifies if the generator is in service. **Name** | str | name of the generator **Scaling** | float | scaling factor for the active power **sn_mva** | float | nominal power of the generator [MVA] **type** | string | type variable to classify generators **slack** | boolean | specifies if slack **max_p_mw** | float | Maximum active power injection **min_p_mw** | float | Minimum active power **max_q_mvar** | float | Maximum reactive power **min_q_mvar** | float | Minimum reactive power
ext_grid_data	**Network_id** | integer |ID of the network **bus_id** | integer | ID of the bus

	in_service | boolean | specifies if the external grid is in service **va_degree** | float| angle set point [degree] **vm_pu** | float | voltage set point [p.u] **name** | string | name of the external grid **max_p_mw** | float | Maximum active power **min_p_mw** | float | Minimum active power **max_q_mvar** | float | Maximum reactive power **min_q_mvar** | float | Minimum active power
Transformer_data	**hv_bus** | integer | high voltage bus index of the transformer **lv_bus** | integer | low voltage bus index of the transformer **sn_mva** | float | rated apparent power of the transformer [MVA] **pfe_kw**| float | iron losses [kW]** **tap_side**| string | defines if tap changer is at the high- or low voltage side **tap_neutral**| int | rated tap position **tap_min**| int | minimum tap position **tap_max**| int | maximum tap position ** alternatively r,x,b parameters of the Π-equivalent of the transformer can be provided.

*Floats to have up to 6 decimal places

Annex B Spanish Pilot - AC sensitivities

Bus id	$PTDF_P$	$PTDF_Q$
0	0.000321	0.003657
1	0.037792	0.054217
2	0.007763	0.030973
3	0.014784	0.03513
4	0.030683	0.050991
5	0.024294	0.048092
6	0.018259	0.036763
7	0.018259	0.036763
8	0.023829	0.041766
9	0.035906	0.052535
10	0.009748	0.032723
11	0.007793	0.031001
12	0.007794	0.031001
13	0.016693	0.044358
14	0.019601	0.037996
15	0.464921	2.090119
16	0.014962	0.035146
17	0.03081	0.050997
18	0.025967	0.037987
19	0.018933	0.036708
20	0.024282	0.041821
21	0.036016	0.052536
22	0.010197	0.032727
23	0.008515	0.031068
24	0.007834	0.031001
25	-0.09333	-0.02887
26	-0.07388	-0.02506
27	0.019661	0.037987
28	0.007932	0.031129
29	0.010314	0.03322
30	0.014781	0.03513
31	0.017963	0.03649
32	0.01902	0.037477
33	0.035906	0.052535
34	0.01943	0.04594
35	0.468517	2.089635
36	0.465355	2.090237
37	0.478202	2.087162
38	8.211918	4.947574
39	1.454569	3.139453
40	23.71821	8.995014
41	8.216735	4.950499
42	0.465364	2.09026

43	9.2069	5.210362
44	0.465334	2.090239
45	8.222684	4.952674
46	1.464351	3.146518
47	8.216385	4.950194
48	0.466055	2.089967
49	8.211914	4.947578
50	14.34874	6.520666
51	14.28461	6.539165
52	1.454547	3.139427
53	0.474271	2.08833
54	0.474034	2.088302
55	0.466055	2.089967
56	0.468623	2.089672
57	0.474034	2.088302
58	0.466055	2.089967
59	0.465316	2.09024
60	0.03082	0.050998
61	0.03081	0.050997
62	0.03081	0.050997
63	0.022586	0.020988
64	0.025967	0.037987
65	0.025967	0.037987
66	0.025967	0.037987
67	0.025967	0.037987
68	0.022586	0.020988
69	-0.09335	-0.02886
70	-0.09334	-0.02887
71	-0.09333	-0.02886
72	-0.09335	-0.02886
73	-0.09335	-0.02887
74	-0.09333	-0.02887
75	-0.09335	-0.02886
76	-0.01522	-0.00299
77	-0.01522	-0.00299
78	-0.01523	-0.00299
79	-0.01522	-0.00298
80	-0.01522	-0.00298
81	-0.01522	-0.00298
82	-0.01522	-0.00298
83	-0.01522	-0.00298
84	-0.01522	-0.00298
85	-0.01522	-0.00299
86	-0.01522	-0.00298
87	-0.00753	-0.00298
88	-0.01522	-0.00298

89	-0.01522	-0.00298
90	-0.01521	-0.00298
91	-0.01522	-0.00298
92	-0.01523	-0.00299
93	-0.01523	-0.00299
94	-0.01523	-0.00299
95	-0.01446	-0.00247
96	-0.0147	-0.00258
97	-0.01469	-0.00258
98	-0.01462	-0.00253
99	-0.01448	-0.00247
100	-0.01378	-0.00234
101	-0.01459	-0.00249
102	-0.01484	-0.00265
103	-0.01377	-0.00234
104	-0.01448	-0.00247
105	-0.01479	-0.00264
106	-0.01473	-0.00261
107	-0.01469	-0.00258
108	-0.01462	-0.00253
109	-0.01462	-0.00253
110	-0.01484	-0.00265
111	-0.01484	-0.00265
112	-0.01458	-0.00249
113	-0.01377	-0.00234
114	-0.00752	-0.00297
115	-0.00753	-0.00297
116	-0.00753	-0.00297
117	-0.01473	-0.00261
118	-0.01522	-0.00299
119	-0.00198	0.0015
120	-0.00311	0.000437
121	-0.00408	-0.00048
122	-0.00531	-0.00139
123	-0.00726	-0.00285
124	-0.00408	-0.00048
125	-0.00408	-0.00047
126	-0.00351	-0.00067
127	-0.00313	-0.0008
128	-0.00257	-0.00099
129	-0.00276	-0.0011
130	-0.00289	-0.00118
131	-0.00302	-0.00126
132	-0.00312	-0.00133
133	-0.00256	-0.00099
134	0	0

135	-0.00302	-0.00126
136	-0.00301	-0.00125
137	-0.00256	-0.00098
138	-0.00258	-0.00098
139	-0.00302	-0.00126
140	-0.00304	-0.00127
141	-0.00312	-0.00132
142	-0.00314	-0.00109
143	-0.00306	-0.001
144	-0.00313	-0.00107
145	-0.00308	-0.00102
146	-0.00309	-0.00104
147	-0.00307	-0.001
148	-0.00306	-0.00101
149	-0.00306	-0.00101
150	-0.00314	-0.00109
151	-0.00315	-0.00109
152	-0.00308	-0.00102
153	-0.00307	-0.00101
154	-0.00308	-0.00102
155	-0.00307	-0.00101
156	-0.00315	-0.00109
157	-0.00315	-0.00109
158	-0.0031	-0.00104
159	-0.00309	-0.00104
160	-0.00307	-0.00101
161	-0.00319	-0.00105
162	-0.00297	-0.00084
163	-0.00305	-0.0009
164	-0.00271	-0.00077
165	-0.00312	-0.00099
166	-0.00314	-0.00101
167	-0.00304	-0.00089
168	-0.00272	-0.00078
169	-0.00319	-0.00105
170	-0.0032	-0.00106
171	-0.00296	-0.00084
172	-0.00271	-0.00077
173	-0.00288	-0.0008
174	-0.00291	-0.00085
175	-0.00319	-0.00105
176	-0.0032	-0.00106
177	-0.00302	-0.00086
178	-0.00305	-0.00089
179	-0.00291	-0.00085
180	-0.00312	-0.00099

181	-0.00272	-0.00078
182	-0.00289	-0.00083
183	-0.00272	-0.00078
184	-0.0032	-0.00106
185	-0.00317	-0.00104
186	-0.00304	-0.00089
187	-0.00291	-0.00085
188	-0.00293	-0.00087
189	-0.00291	-0.00085
190	-0.0031	-0.00104
191	-0.00308	-0.001
192	-0.00307	-0.001
193	-0.00306	-0.001
194	-0.00299	-0.00094
195	-0.00301	-0.00097
196	-0.00301	-0.00097
197	-0.00306	-0.001
198	-0.00307	-0.001
199	-0.00289	-0.00083
200	-0.00309	-0.00104
201	-0.00302	-0.00097
202	-0.00314	-0.00109
203	-0.00303	-0.00098
204	-0.00303	-0.00098
205	-0.0031	-0.00104
206	-0.00309	-0.00104
207	-0.00312	-0.00132
208	-0.00258	-0.001
209	-0.0047	-0.00112
210	-0.00312	-0.00133
211	-0.00308	-0.0013
212	-0.01444	-0.00246
213	-0.00305	-0.001
214	-0.00306	-0.001
215	-0.00306	-0.001
216	-0.00306	-0.001
217	-0.00307	-0.001
218	-0.00307	-0.00101
219	-0.00317	-0.00104
220	-0.00304	-0.0009
221	-0.00305	-0.00089
222	-0.00291	-0.00085
223	-0.00287	-0.0008
224	0.02247	0.020929
225	0	0
226	0	0

Annex C SWW pilot – AC sensitivities

Line id	Bus id	$PTDF_{P,from}$	$PTDF_{Q,from}$	$PTDF_{P,to}$	$PTDF_{Q,to}$
13	0	-0.0196703	-0.0023119	-0.0184114	-0.0018602
13	1	0	0	0	0
13	2	0	0	0	0
13	3	0	0	0	0
13	4	-0.0196706	-0.0023106	-0.0184116	-0.0018589
13	5	0	0	0	0
13	6	-0.0188377	-0.0022158	-0.0176321	-0.0017831
13	7	-0.0205089	-0.0024054	-0.0191962	-0.0019348
13	8	0	0	0	0
13	9	-0.022052	-0.0025868	-0.0206406	-0.0020808
13	10	0	0	0	0
13	11	-0.0196679	-0.0023124	-0.0184091	-0.0018607
13	12	-0.0135761	-0.0015953	-0.0127072	-0.0012836
13	13	0	-1.00E-07	0	-1.00E-07
13	14	-0.0196712	-0.0023118	-0.0184122	-0.0018601
13	15	0	0	0	0
13	16	0	0	0	0
13	17	-0.0220532	-0.0025868	-0.0206417	-0.0020808
13	18	-0.0196706	-0.0023119	-0.0184117	-0.0018601
13	19	-0.0196705	-0.0023109	-0.0184116	-0.0018593
13	20	-0.0022667	-0.0002661	-0.0021216	-0.0002141
17	0	-0.0162817	0.0047286	-0.015735	0.0049834
17	1	0	0	0	0
17	2	0	0	0	0
17	3	0	0	0	0
17	4	-0.01479	0.0042681	-0.014294	0.0045003
17	5	0	0	0	0
17	6	-0.0141646	0.0040851	-0.0136896	0.0043076
17	7	-0.0147908	0.0042676	-0.0142947	0.0044998
17	8	0	0	0	0
17	9	-0.0147922	0.0042667	-0.014296	0.0044989
17	10	0	0	0	0
17	11	-0.0162801	0.0047282	-0.0157335	0.004983
17	12	-0.0102076	0.0029449	-0.0098653	0.0031051
17	13	0	0	0	0
17	14	-0.0162822	0.0047286	-0.0157355	0.0049834
17	15	0	0	0	0
17	16	0	0	0	0
17	17	-0.0147928	0.0042667	-0.0142966	0.0044989
17	18	-0.0162819	0.0047286	-0.0157352	0.0049834
17	19	-0.0152099	0.004419	-0.0146991	0.004657
17	20	-0.0017042	0.0004918	-0.001647	0.0005186

Annex D SWH Pilot – DSO orders

Order id	Bus id	Quantity	Direction
0	21	1.441986	S
1	15	1.478123	S
2	21	1.478123	S
3	15	1.478123	S
4	17	3.790364	S
5	7	4.709952	S
6	0	4.716918	S
7	0	4.721286	S
8	7	4.723443	S
9	1	4.72653	S
10	1	4.726627	S
11	1	4.731014	S
12	0	4.732129	S
13	7	4.738686	S
14	19	4.750728	S
15	4	4.772072	S
16	4	4.772209	S
17	12	4.776365	S
18	12	4.776503	S
19	4	4.776683	S
20	12	4.780982	S
21	13	4.78721	S
22	3	4.78746	S
23	3	4.78746	S
24	13	4.78746	S
25	13	4.78746	S
26	10	4.788651	S
27	10	4.788791	S
28	4	4.789594	S
29	21	4.789955	S
30	15	4.789955	S
31	3	4.789955	S
32	13	4.789955	S
33	15	4.789956	S
34	21	4.789956	S
35	3	4.789956	S
36	11	4.792605	S
37	11	4.792745	S
38	10	4.793284	S
39	12	4.7939	S
40	11	4.797242	S
41	9	4.797323	S
42	9	4.797323	S

43	9	4.799823	S
44	9	4.799823	S
45	5	4.799871	S
46	5	4.800012	S
47	9	4.801019	S
48	15	4.801021	S
49	21	4.801021	S
50	13	4.801022	S
51	3	4.801022	S
52	6	4.801408	S
53	14	4.801409	S
54	23	4.801447	S
55	8	4.80146	S
56	2	4.801464	S
57	9	4.80147	S
58	15	4.801471	S
59	21	4.801471	S
60	3	4.801472	S
61	13	4.801472	S
62	6	4.801551	S
63	14	4.801551	S
64	23	4.801589	S
65	8	4.801602	S
66	2	4.801606	S
67	9	4.801612	S
68	21	4.801613	S
69	15	4.801613	S
70	3	4.801614	S
71	13	4.801614	S
72	12	4.802376	S
73	5	4.804517	S
74	6	4.806058	S
75	14	4.806058	S
76	23	4.806096	S
77	8	4.806109	S
78	2	4.806113	S
79	9	4.806119	S
80	15	4.80612	S
81	21	4.80612	S
82	3	4.806121	S
83	13	4.806121	S
84	10	4.806225	S
85	2	4.808894	S
86	2	4.808894	S
87	4	4.809014	S
88	11	4.81019	S

89	2	4.8114	S
90	2	4.811401	S
91	2	4.8126	S
92	2	4.813983	S
93	9	4.81399	S
94	21	4.813992	S
95	15	4.813992	S
96	3	4.813992	S
97	13	4.813992	S
98	8	4.814176	S
99	8	4.814176	S
100	10	4.814719	S
101	1	4.816208	S
102	8	4.816685	S
103	8	4.816685	S
104	5	4.817479	S
105	8	4.817885	S
106	11	4.81869	S
107	6	4.819019	S
108	14	4.81902	S
109	23	4.819058	S
110	8	4.819071	S
111	2	4.819075	S
112	9	4.819081	S
113	15	4.819083	S
114	21	4.819083	S
115	13	4.819083	S
116	3	4.819083	S
117	8	4.819271	S
118	8	4.819895	S
119	2	4.819899	S
120	9	4.819905	S
121	21	4.819907	S
122	15	4.819907	S
123	3	4.819907	S
124	13	4.819908	S
125	0	4.821957	S
126	5	4.825989	S
127	23	4.827348	S
128	23	4.827348	S
129	6	4.82753	S
130	14	4.82753	S
131	23	4.827569	S
132	8	4.827582	S
133	2	4.827586	S
134	9	4.827592	S

135	21	4.827594	S
136	15	4.827594	S
137	3	4.827594	S
138	13	4.827594	S
139	7	4.82869	S
140	23	4.829864	S
141	23	4.829865	S
142	23	4.831068	S
143	23	4.832457	S
144	23	4.833083	S
145	23	4.835433	S
146	8	4.835447	S
147	2	4.835451	S
148	9	4.835458	S
149	21	4.83546	S
150	15	4.83546	S
151	3	4.83546	S
152	13	4.83546	S
153	1	4.835743	S
154	10	4.838959	S
155	0	4.841517	S
156	11	4.842946	S
157	7	4.848279	S
158	5	4.850275	S
159	11	4.850678	S
160	6	4.851818	S
161	14	4.851818	S
162	23	4.851858	S
163	8	4.851871	S
164	2	4.851875	S
165	9	4.851881	S
166	15	4.851883	S
167	21	4.851883	S
168	3	4.851884	S
169	13	4.851884	S
170	6	4.852887	S
171	6	4.852887	S
172	14	4.852888	S
173	14	4.852888	S
174	6	4.855416	S
175	14	4.855417	S
176	6	4.855417	S
177	14	4.855417	S
178	5	4.856623	S
179	5	4.856623	S
180	6	4.856627	S

181	14	4.856627	S
182	10	4.856821	S
183	5	4.858016	S
184	6	4.858023	S
185	14	4.858024	S
186	12	4.858088	S
187	6	4.858652	S
188	14	4.858653	S
189	5	4.859154	S
190	5	4.859154	S
191	6	4.85956	S
192	14	4.85956	S
193	23	4.859599	S
194	8	4.859613	S
195	2	4.859617	S
196	9	4.859623	S
197	21	4.859625	S
198	15	4.859625	S
199	3	4.859626	S
200	13	4.859626	S
201	5	4.860365	S
202	6	4.861015	S
203	14	4.861015	S
204	5	4.861762	S
205	5	4.862392	S
206	14	4.863063	S
207	5	4.864756	S
208	4	4.864815	S
209	11	4.867922	S
210	11	4.867922	S
211	6	4.868929	S
212	14	4.86893	S
213	6	4.868931	S
214	23	4.86897	S
215	23	4.868972	S
216	8	4.868983	S
217	8	4.868986	S
218	2	4.868987	S
219	2	4.86899	S
220	9	4.868994	S
221	21	4.868996	S
222	15	4.868996	S
223	3	4.868996	S
224	13	4.868996	S
225	9	4.868996	S
226	21	4.868998	S

227	15	4.868998	S
228	13	4.868998	S
229	3	4.868998	S
230	11	4.870459	S
231	11	4.87046	S
232	11	4.871673	S
233	5	4.872494	S
234	5	4.872677	S
235	5	4.872679	S
236	11	4.873074	S
237	11	4.873705	S
238	6	4.874039	S
239	14	4.874039	S
240	23	4.874079	S
241	8	4.874093	S
242	10	4.874096	S
243	10	4.874096	S
244	2	4.874097	S
245	9	4.874103	S
246	21	4.874105	S
247	15	4.874105	S
248	3	4.874106	S
249	13	4.874106	S
250	12	4.876033	S
251	11	4.876075	S
252	10	4.876636	S
253	10	4.876637	S
254	10	4.877852	S
255	10	4.879254	S
256	10	4.879886	S
257	10	4.882259	S
258	4	4.882789	S
259	11	4.883827	S
260	11	4.884014	S
261	11	4.884016	S
262	10	4.890019	S
263	10	4.890208	S
264	10	4.890211	S
265	1	4.891875	S
266	12	4.893403	S
267	12	4.893403	S
268	12	4.895953	S
269	12	4.895954	S
270	12	4.897173	S
271	0	4.89772	S
272	12	4.898582	S

273	12	4.899216	S
274	4	4.900192	S
275	4	4.900192	S
276	12	4.901598	S
277	4	4.902746	S
278	4	4.902747	S
279	4	4.903968	S
280	7	4.904566	S
281	4	4.905378	S
282	4	4.906014	S
283	4	4.908399	S
284	12	4.909383	S
285	12	4.909579	S
286	12	4.909581	S
287	1	4.909954	S
288	0	4.915823	S
289	4	4.916192	S
290	4	4.916391	S
291	4	4.916393	S
292	7	4.922696	S
293	1	4.92747	S
294	1	4.92747	S
295	1	4.930038	S
296	1	4.930038	S
297	1	4.931267	S
298	1	4.932685	S
299	1	4.933324	S
300	0	4.933363	S
301	0	4.933363	S
302	1	4.935722	S
303	0	4.935934	S
304	0	4.935934	S
305	0	4.937164	S
306	0	4.938584	S
307	0	4.939223	S
308	7	4.940264	S
309	7	4.940264	S
310	0	4.941625	S
311	7	4.942839	S
312	7	4.942839	S
313	1	4.943556	S
314	1	4.943759	S
315	1	4.943761	S
316	7	4.944071	S
317	7	4.945492	S
318	7	4.946133	S

319	7	4.948538	S
320	0	4.949467	S
321	0	4.949671	S
322	0	4.949673	S
323	7	4.95639	S
324	7	4.956595	S
325	7	4.956597	S
326	18	4.95851	S
327	19	9.91702	S
328	18	9.917021	S
329	20	11.24958	S
330	17	12.18029	S
331	17	12.18487	S
332	17	12.18578	S
333	17	12.25772	S
334	17	12.2957	S
335	17	12.40447	S
336	17	12.43937	S
337	17	12.45787	S
338	17	12.45787	S
339	17	12.46436	S
340	17	12.46436	S
341	17	12.46747	S
342	17	12.47105	S
343	17	12.47267	S
344	17	12.47873	S
345	17	12.49905	S
346	17	12.49905	S
347	17	12.50427	S
348	18	12.84629	S
349	18	12.85847	S
350	18	12.87882	S
351	18	13.02286	S
352	18	13.07224	S
353	18	13.21402	S
354	18	13.25963	S
355	18	13.29929	S
356	18	13.29929	S
357	18	13.30622	S
358	18	13.30622	S
359	18	13.30953	S
360	18	13.31336	S
361	18	13.31508	S
362	18	13.32156	S
363	18	13.34325	S
364	18	13.34326	S

365	18	13.3444	S
366	4	13.38858	S
367	12	13.38978	S
368	10	13.39303	S
369	6	13.39358	S
370	14	13.39358	S
371	23	13.39389	S
372	8	13.39399	S
373	11	13.39402	S
374	2	13.39402	S
375	9	13.39407	S
376	15	13.39408	S
377	21	13.39408	S
378	3	13.39409	S
379	13	13.39409	S
380	5	13.39578	S
381	1	13.43166	S
382	0	13.44081	S
383	7	13.45146	S
384	22	13.56003	S
385	7	13.58314	S
386	0	13.59129	S
387	1	13.59822	S
388	4	13.63013	S
389	12	13.64109	S
390	10	13.67237	S
391	11	13.6824	S
392	5	13.70081	S
393	6	13.70347	S
394	14	13.70347	S
395	23	13.70375	S
396	8	13.70385	S
397	2	13.70388	S
398	9	13.70392	S
399	15	13.70393	S
400	21	13.70393	S
401	13	13.70393	S
402	3	13.70393	S
403	19	25.69258	S
404	19	25.71694	S
405	19	25.75765	S
406	19	26.04572	S
407	19	26.14449	S
408	19	26.42804	S
409	19	26.51926	S
410	19	26.59857	S

411	19	26.59857	S
412	19	26.61244	S
413	19	26.61244	S
414	19	26.61907	S
415	19	26.62672	S
416	19	26.63017	S
417	19	26.64312	S
418	19	26.6865	S
419	19	26.68651	S
420	19	26.6888	S
421	20	27.12005	S
422	22	27.12005	S
423	7	27.16628	S
424	0	27.18259	S
425	1	27.19645	S
426	4	27.26025	S
427	12	27.28218	S
428	10	27.34474	S
429	11	27.36481	S
430	5	27.40163	S
431	6	27.40694	S
432	14	27.40695	S
433	23	27.40751	S
434	8	27.40769	S
435	2	27.40775	S
436	9	27.40784	S
437	21	27.40787	S
438	15	27.40787	S
439	13	27.40787	S
440	3	27.40787	S
441	22	28.73096	S
442	17	28.73097	S
443	20	57.46191	S
444	17	57.46195	S
445	17	60.56983	S
446	18	64.0932	S
447	22	92.32666	S
448	22	92.36139	S
449	22	92.36822	S
450	22	92.91354	S
451	22	93.20138	S
452	22	94.0259	S
453	22	94.29048	S
454	22	94.43066	S
455	22	94.43066	S
456	22	94.47983	S

457	22	94.47984	S
458	22	94.50341	S
459	22	94.53055	S
460	22	94.54285	S
461	22	94.5888	S
462	22	94.74282	S
463	22	94.74284	S
464	22	94.78238	S
465	4	101.4855	S
466	12	101.4946	S
467	10	101.5192	S
468	6	101.5234	S
469	14	101.5234	S
470	23	101.5258	S
471	8	101.5265	S
472	11	101.5267	S
473	2	101.5268	S
474	9	101.5271	S
475	21	101.5272	S
476	3	101.5272	S
477	15	101.5272	S
478	13	101.5272	S
479	5	101.5401	S
480	1	101.812	S
481	0	101.8814	S
482	7	101.9621	S
483	17	121.1396	S
484	19	128.1864	S
485	20	184.6532	S
486	20	184.7228	S
487	20	184.7364	S
488	20	185.8271	S
489	20	186.4029	S
490	20	188.0518	S
491	20	188.5808	S
492	20	188.8613	S
493	20	188.8613	S
494	20	188.9597	S
495	20	188.9597	S
496	20	189.0068	S
497	20	189.0612	S
498	20	189.0855	S
499	20	189.1775	S
500	20	189.4855	S
501	20	189.4856	S
502	20	189.5649	S

503	4	202.971	S
504	12	202.9891	S
505	10	203.0385	S
506	14	203.0467	S
507	6	203.0467	S
508	23	203.0515	S
509	8	203.0529	S
510	2	203.0536	S
511	11	203.0536	S
512	9	203.0542	S
513	13	203.0546	S
514	15	203.0546	S
515	3	203.0546	S
516	21	203.0546	S
517	5	203.0802	S
518	1	203.624	S
519	0	203.7627	S
520	7	203.9243	S
521	22	459.1202	S
522	18	485.8273	S
523	20	918.2405	S
524	22	918.2406	S
525	19	971.6508	S
526	18	971.6508	S