D6.5. Peer-to-peer marketplace demonstration: Final evaluation report and lessons learnt

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Abstract
This deliverable 6.5 summarizes the results of task 6.1 and 6.2 in Demo Area 2. The deliverable includes the evaluation of the demos with respect to the use-cases, transparency in data communication and control, the correctness of transactions and the transaction capacity.

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ACRONYMS AND ABBREVIATIONS

ALM	Added local market
BC	Base case
ESF	Expected shortfall
FR	Flexibility related (bid)
LM	Local market
LpTVr	Loss per traded volume ratio
OLM	Only local market
VD	Voltage deviation
WC	Worst case
FSP	Flexibility Service Provider
DSO	Distribution System Operator
TSO	Transmission System Operator
DNUT	Dynamic Network Usage Tariff
IoT	Internet of things
POD	Point of Delivery (connection point of a grid user)
LV	Low Voltage Grid (0.4 kV)
MV	Medium Voltage Grid (11kV / 22 kV)
IEGSA	Interoperable pan-European Grid Services Architecture

Executive summary

The deliverable D6.5 from work package 6 of the INTERFACE project is the final report that summarizes the progress and results of Demo Area 2 “Peer-to-peer trading” Demo. It is divided into two parts and includes Task 6.1 "Asset-enabled Local Markets" Demo and Task 6.2 "Blockchain-based TSO-DSO flexibility" Demo. From the perspective of Task 6.1, the electricity trading in local neighbourhoods between consumers and local parties has been achieved. The main aims and objectives of T6.1 are providing a data-driven, simulation-based demo of a realistic local asset-enabled energy market, where transactions beneficial for the distribution grid are facilitated via dynamic pricing (DNUT – dynamic network usage tariff), the state of the network is monitored by the Integrated Asset Condition Management system (IACMS), which allows real time estimation of component loadability values, the demonstration of a local market that runs based on data, provided from 3 sites (2 in Hungary, 1 in Slovenia), local distribution system operators are involved to provide grid and consumption/production data. Other objectives include the establishment of the theoretical and computational background of an asset enabled local electricity market platform the definition of the structure and elements of the IT implementation, the establishment of data connections towards the demo sites (DSOs) and the establishment of data connections towards the IEGSA platform.

From the viewpoint of Task 6.2, the focus was on trading flexibility services amongst TSOs, DSOs and Flexibility service providers (FSPs). We then elaborated on the simulation methods, the current market scenario, the problems faced by each stakeholder in the electricity market and proposed solutions to the problems. An emphasis on the reasoning behind the solution was provided, the technology was chosen and a detailed architecture of the platform was provided. Furthermore, we presented the results of each demo by evaluating them based on multiple factors. We have also identified KPIs for the tasks and provided an assessment of the achieved KPIs. The socio-economic analysis and the tasks value chain is explained. Finally, we present our thoughts, the exploitable results and lessons learnt while developing the project.

1 Introduction

This deliverable D6.5 from Work Package 6 of the INTERRFACE project summarizes the results of the following two pilots in Demo area 2: Peer-to-peer trading.

(1) Asset-enabled local markets (T6.1)
(2) Blockchain-based TSO-DSO flexibility (T6.2)

To deliver a high-quality project, the WP6 work was started in the beginning of 2019, much earlier than the official date in the Grant Agreement in Jan 2020. Thus, progress of WP6 and pilots were completed ahead of the plan. The demonstration activities of Asset-enabled local markets (T6.1) took place in Slovenia and Hungary and were led by Elektro Ljubljana. The demonstration activities of Blockchain-based TSO-DSO flexibility (T6.2) took place in Romania and Bulgaria and were led by EMAX. Actively involved were energy and IT implementation experts, representatives of various project partners and TSOs/DSOs.

1.1 INTERRFACE Objectives

The P2P demonstration activities will contribute to achieve the overall objective of the INTERRFACE project and particularly, they address the following objectives:

1. To mitigate the local grid congestions (branch overloads) and to activate the local flexibility resources for system balancing services through innovative platforms, operated by TSOs and DSOs in a coordinated manner.
2. To promote the integration of DERs into the electricity markets, demonstrate mechanisms and platforms leading to the establishment of a seamless pan-European market and empower all market participants to provide energy services in a transparent and non-discriminatory way.
3. To test the state-of-the-art digital technologies, such as Blockchains and IoT, for peer-to-peer energy transactions that promote local markets and smart asset management.
4. To engage consumers into electricity markets with clean energy flows based on a user- operator "alliance" that offsets the variability of renewable energy with effective demand response, active control, distributed storage and peer-to-peer local markets.

The objectives of WP6 are (a) to demonstrate automated peer-to-peer marketplace for energy exchanges among TSO-DSO-consumers based on the grid assets capability, (b) to demonstrate a TSO-DSO flexibility market platform deploying blockchain-based with smart contract and smart billing and (c) to test compatibility level with existing power exchange platforms. The whole demonstration was established in D6.1 with the market model and use/business case setup and the IEGSA concept.

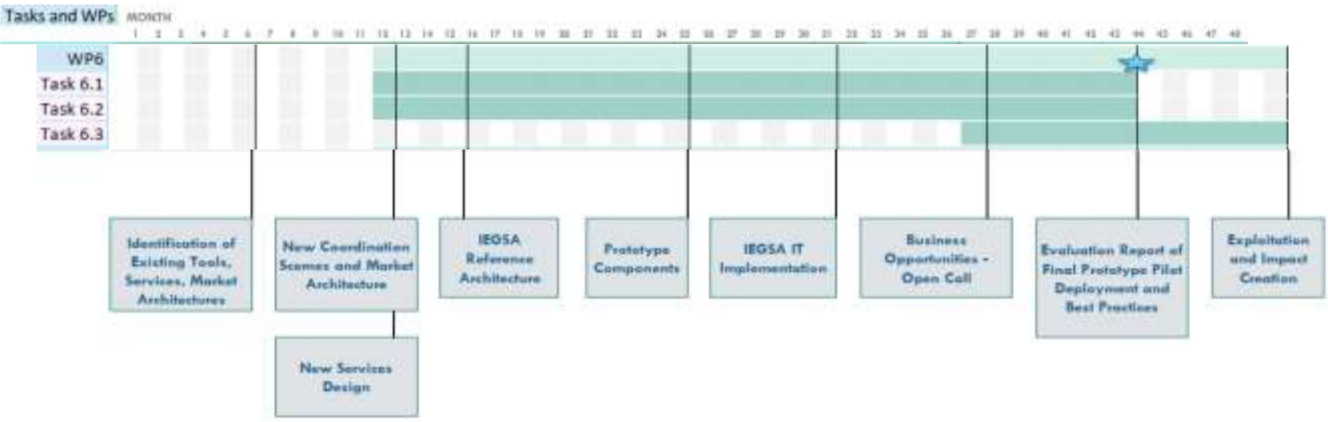

Figure 1: WP6 objectives and time plan

1.2 Objectives of 1st P2P demo - Asset-enabled local markets (T6.1)

The main objectives achieved in the Asset-enabled local markets demo is the synthesis of a local Peer-to-Peer (p2p) market that enables consumers to buy electricity from local parties other than their local utility and to offer their renewable (mainly household size) generation for sale to other parties in the local neighbourhood. The second key objective achieved in this demo is to create the trading framework in a way, which on the one hand minimizes the undesired effects of local transactions by the application of a dynamic network usage tariff (DNUT), facilitating transactions resulting in beneficial network flows, and on the other hand constantly monitors critical network components to provide real-time estimations about their actual load-ability. The latter function is performed by the integrated asset condition management system (IACMS).

Congestion management: The DNUT based trading facilitates only those specific local transactions whose flows alleviate network congestions. This approach in addition aims to reduce network losses and contribute to the increased voltage stability of the distribution grid.

1.3 Objectives of 2nd P2P demo – Blockchain-based TSO DSO flexibility (T6.2)

The main objective of Blockchain-based TSO DSO flexibility marketplace (EFLEX) is to demonstrate trading of flexibility services amongst TSOs, DSOs and Flexibility service providers (FSPs) in a transparent, secure and cost-effective manner. The aim is to look for ways to help DSOs/TSOs to be more flexible and more directly engaged in managing energy flows on the network. EFLEX streamlines the needs of both TSO and DSO on the same platform. The pilot demonstration was carried out in Bulgaria and Romania and the main focus achieved are the following:

Congestion management: Demonstrated a TSO-DSO congestion management platform facilitated by Blockchain technology providing a solution to (a) reduce the overload of network, (b) reduce investment in costly hardware/network upgrades, or even power outages in the short term and (c) enable participation of distributed generators and other flexibility assets (electrical loads, storage, EVs) on the distribution-grid level to ensure system stability.

TSO-DSO Coordination: Demonstrated a marketplace that (a) validates the viability of data transfer between TSO and DSO for the future scenarios and (b) optimizes the processes and actions through effective signalling and sound coordination by scheduling visibility, increasing transparency and interoperability. This is to be achieved with the support of Blockchain-based smart contracts and distributed ledger technology.

2 Asset enabled local markets (T6.1) – summary of demonstrations

During the demonstration of asset enabled local markets, along with the necessary market design and algorithm development, a framework and an IT platform solution was developed, which provides an environment for important development tasks such as functional testing, sensitivity and use case analysis. The demonstrations were carried out on 4 sites from 3 DSOs:

- Elektro Ljubjana (ELJ) – Gradisce and Besnica;
- MVM DÉMÁSZ (NKM/MVM) – Zsombó;
- E.ON Dél-dunántúli Áramhálózati Zrt. – Bóly.

The 3 partners had quite different data inputs for the demonstration. The project developed a common modelling method and interfaced the different datasets from the DSOs. Then the data sources were interfaced with the framework. The integration with the IEGSA platform provides possibilities towards the extension of this solution. This section summarizes the key developments, results and offers a discussion on the applicability as well. Section 2.1 presents the elements of the architecture, Section 2.2 shows the validation procedure for the grid models, then Section 2.3 presents the IACMS model, 2.4 presents the different scenarios that were tested, Section 2.5 covers the evaluation of the complete set of all 4 pilot cases, Section 2.6 more specifically presents the results and the evaluation of the Slovenian pilot case, Section 2.6 covers the results and the evaluation of the Hungarian Pilot cases and finally, Section 2.8 provides a summary and conclusions.

A local market platform from was introduced, on which peer-to-peer transactions can be executed. The platform is basically a marketplace, where both supply and demand orders can be placed and hit by prosumers of the network. The bidding/hitting mechanism can be manual or automatic, depending on the preferences of a prosumer. The traditional retail market can operate in parallel with this platform, thus allowing the participation to be voluntary. However, trading on the local market obliges the participants to consume or produce the transacted energy.

The operation of the local market is similar to the intraday wholesale electricity market: energy (min. 1 Wh) can be traded in a continuous manner for 15-minute periods of a day, starting from the previous day until gate closure, which precedes physical delivery by 1 hour. The settlement is carried out after energy delivery, taking market data and measurements into consideration.

2.1 Demonstration framework

The framework was created aiming towards a fully operating structure where the infrastructure is modeled properly, participants can make bids, and the effects of the transactions can be included in the dynamic network usage tariff calculation.

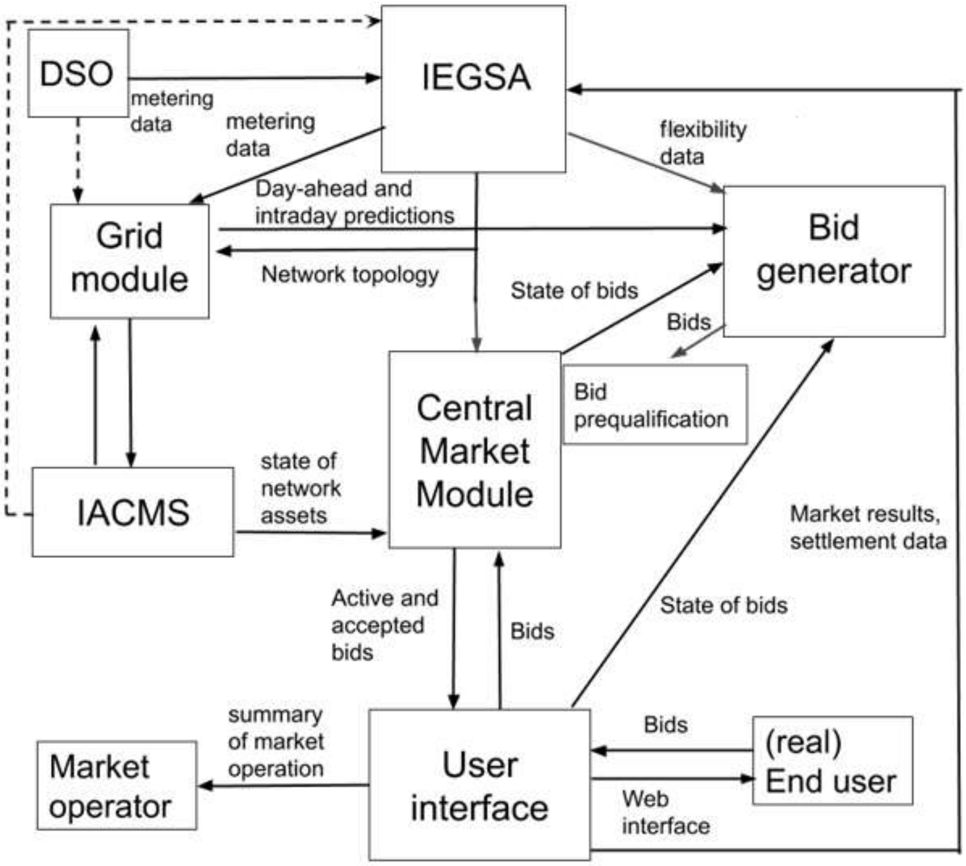

Figure 2: Modular architecture of the implementation

The modular structure of the proposed local market scheme is summarized in the figure above, where the modules of the system and the information flow is depicted. The grid module, the market module, and the bid generator are discussed in detail in the following subsection. 'IEGSA' stands for the 'Interoperable pan-European Grid Services Architecture', which is a common platform developed in INTERRFACE project. In the specific use case for asset-enabled local market, IEGSA stores the grid data, and the metering data necessary for base-case power flow calculations and receives the market results from the Central Market Module. It serves the purpose of interoperability as well, therefore it also shares data to the market module and receives data of the user activity as well. Active users may submit their bids through the User Interface of the system, while for passive participants, the bid generator simulates the bidding behavior. The IACMS is the abbreviation for the Integrated Asset Condition Management System, which continuously monitors the system components (e.g. lines and transformers) in order to provide up-to-date loadability data for the market transactions (the operational details of IEGSA, IACMS and the process of bidding are not the subject of this study, but presented in Deliverable 6.1 - "Technical requirements and setting of microgrid local electricity markets demo – IACMS technical specification and in D3.3 INTERRFACE System Reference Architecture"). The dashed lines (between the DSO – grid module and IACMS – IEGSA) represent a one-time data share (initialization of attributes) between the functional elements.

2.1.1 Principles of dynamic network usage tariff (DNUT)

Every transaction induces flows on the local network, which can be categorized either as burdening flows, meaning that the flows cause even greater load on lines, or relieving flows, in which case the flows reduce pressure on the grid.

The dynamic network usage tariff (DNUT – €/MWh), is a tool of incentivization in the local market, which is either added to or subtracted from the total energy clearing price of a given order, observed by the corresponding bidder. On the one hand, the tariff can be consistently lower than standard network charges, because the transmission network is not used, thus increasing the number of local market participants. On the other hand, it serves congestion management purposes and ensures adequate voltage values through incentivizing such transactions (or submission of orders) that are advantageous from the perspective of the grid operator.

This tariff consists of three main elements:

- deviation in nodal voltages;
- branch flows;
- and overall network loss.

For every pair of participants, and both flow directions, a DNUT value is calculated with the usage of a representative measure of energy transaction (i.e. fixed transaction volume), thus creating a DNUT matrix by the size of the number of prosumers. Trading between identical nodes (two prosumers on the same network node) has minimal effects on the grid, which are neglected. Therefore, the diagonal of the aforementioned DNUT matrix is set to zero. The calculations of the other elements in the matrix use the charges mentioned above and the estimated state of the system as a result of the fixed transaction. The charges consist of limiting and linear components. Nodal voltages are constrained to be in the nominal ±10% interval in order to ensure sufficient quality of service, while branch currents are constrained in order not to surpass the rated currents of the given lines of the grid (rated current has been determined by the IACMS module).

The linear components account for the physical effects of energy transactions. A cost is calculated for every node based on how much the voltage amplitude is changed, and for every line based on how much the amplitude of the phase current is changed. Costs are also assigned to the deviation in network losses (estimated by line losses using calculations from line resistances and currents).

The resulting DNUT can either be positive or negative, based on how the network is affected by the transacted energy. In the case of accepted transactions, both participants (seller and buyer) pay 50% of the calculated DNUT.

2.1.2 Definition of flow types

In the framework, there are three ways to handle the power flow resulting from a transaction, which are described based on Fig. 3. The applied methods should be selected depending on the activity of prosumers.

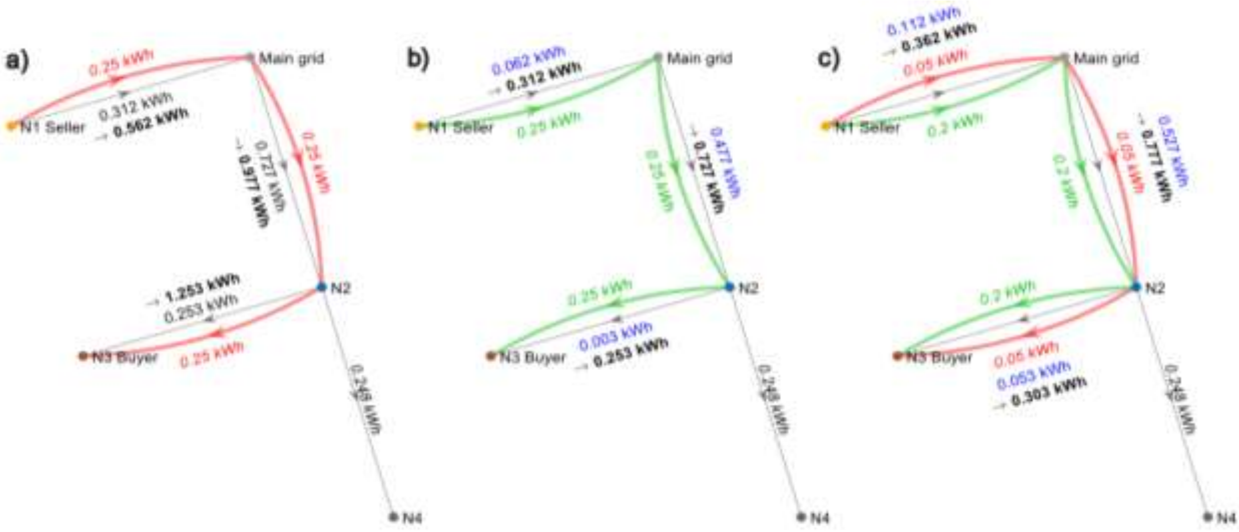

Figure 3: Excessive (red), nominated (green), unnominated (blue), and resulting physical (bold) flows in the model

In Fig. 3 a) the transaction is treated as an excessive flow (in red), which is added to the forecasted base case. This approach assumes active consumers who react to price signals on the platform (e.g. cheap energy generates more demand) resulting in a new energy flow. Each trade creates a new system state, which will be the reference for further transactions. The DNUT matrix must be recalculated accordingly. The state-of-the-art local market models use this approach to estimate the physical effects of transactions. This is referenced as zero base case (ZBC) market throughout this document.

The method in Fig. 3 b) considers the transaction flow to be a part of the estimated base case, thus creating a nominated (green), and a remaining, unnominated (blue) flow. In this case, it is assumed that the market participants trade only their forecasted energy consumption/generation on the market platform to gain surplus. Each trade leaves the system state unchanged, and the initial DNUT matrix should not be updated. However, if a transaction exceeds the estimated base case, excessive flows are introduced similarly to Fig. 3 a).

The mixture of these two options is applied in Fig. 3 c), which is assumed to consider prosumer behavior more precisely. The ratio of nominated and excessive flows can be altered through the defined overflow ratio. In this example, the value of this ratio is 0.2, which means that 80% of the transaction is nominated from the base case, while the remaining part is added to the network flows.

2.1.3 Market framework validation in simulations

In this section, the operation of the local market is briefly presented and validated through market simulations for one specific quarter hour (QH). The aim of these simulations is to show the attributes of the local market framework. The ZBC market approach is used as a benchmark to our method.

Before the implementation for the national demonstration sites, the local market concept was tested on the IEEE European LV test feeder, which also contains the neutral line. 55 loads are present in the system, each of them connecting to one of the three phases, which introduces asymmetry in the simulations. An earthing resistance of 30 Ω is considered at the prosumers' side. The network topology and consumption/production data are shown in Fig. 4-5.

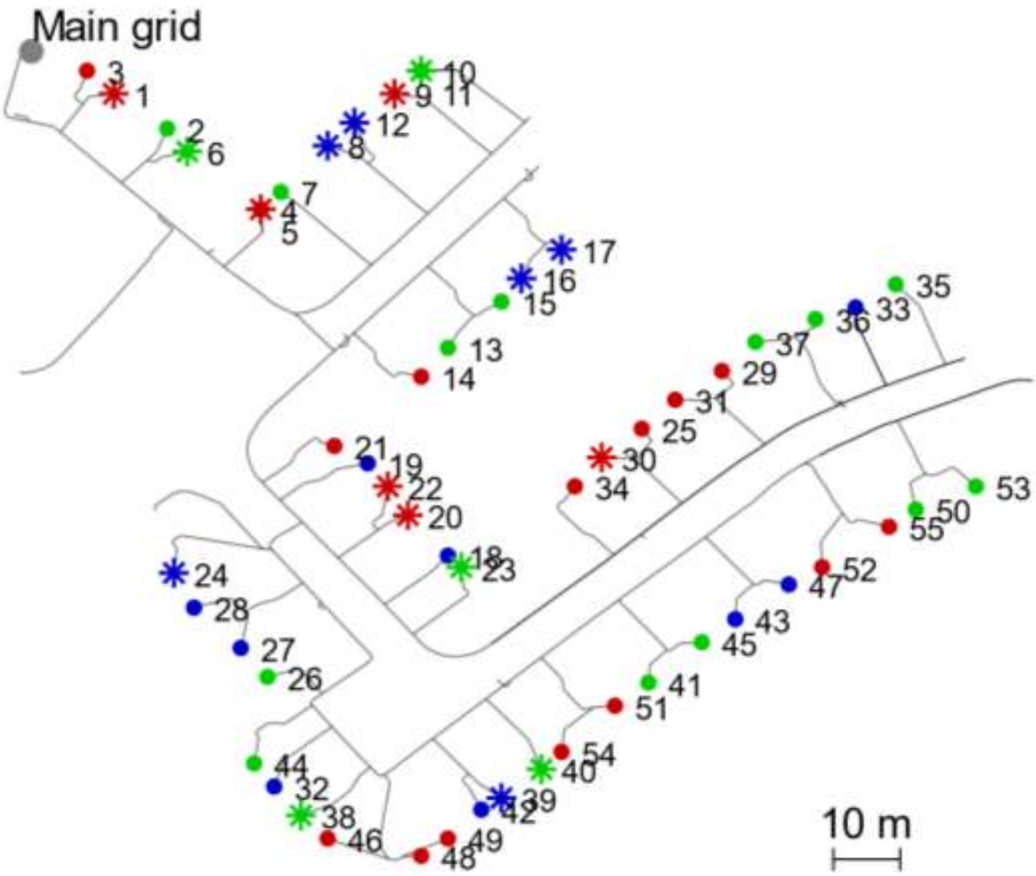

Figure 4: Network model with single-phase prosumers (red – phase a, green – phase b, blue – phase c, producers are marked by asterisks)

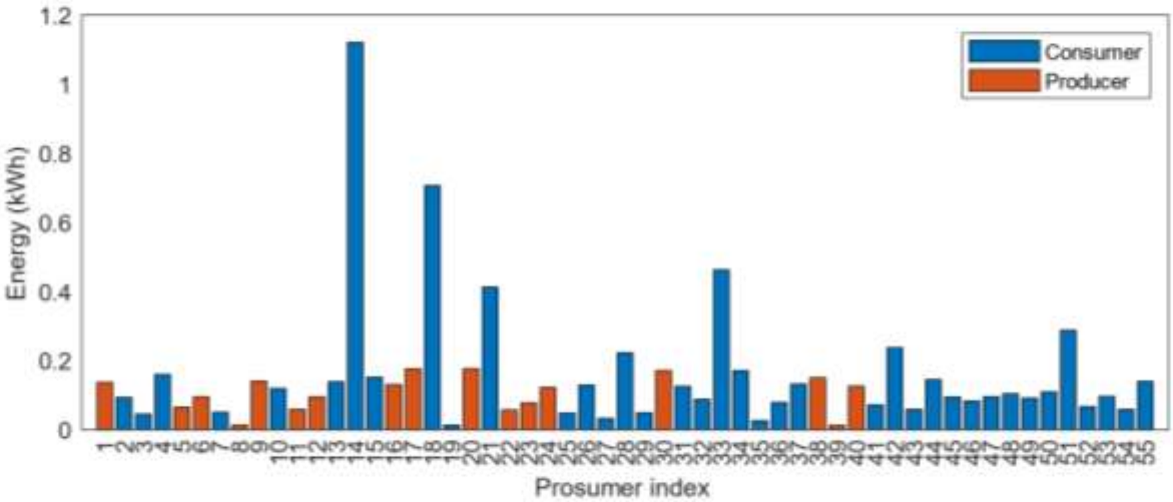

Figure 5: Base case produced (red) and consumed (blue) energy by prosumers in the given QH

The effect of growing prosumer participation ratio (PPR – the ratio of prosumers trading on the local market to all prosumers in the network) is evaluated through a Monte Carlo simulation for both the ZBC approach and the local market framework. A single market simulation is carried out 100 times, using a different set of orders. The participating prosumers submit exactly one order in each iteration. The change of the surplus relative to the number of participating prosumers over the course of the simulation is depicted in Fig. 6.

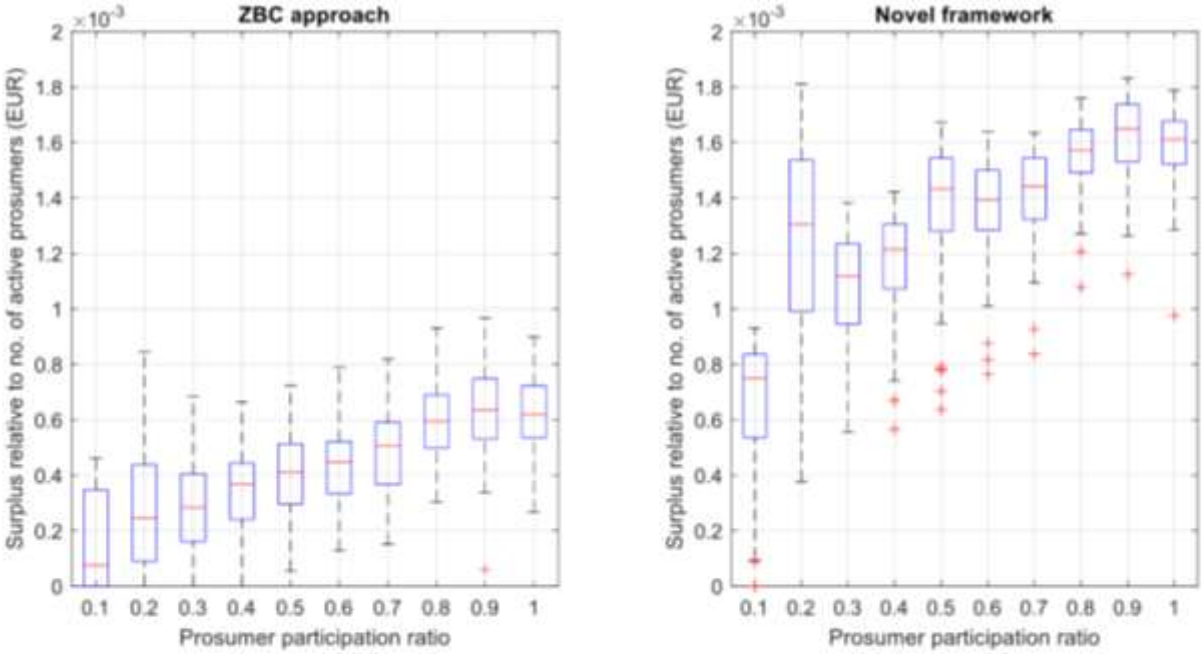

Figure 6: The change of surplus in the system as a result of increasing PPR in Monte Carlo simulation

In general, the surplus increases with growing participation ratio, which translates into increasing relative surplus curves in both cases. The rate at which the relative surplus is growing is not constant due to several factors that are altered randomly during the simulations. This rate is influenced by the ever-changing ratio of active producers to active consumers, and the order in which trade orders are submitted and thus matched.

Because of the good (estimated) state of the network (considering all prosumers), on average a 2.6 times higher relative social welfare value can be reached through considering the base case energy injections compared to the ZBC approach. This is also shown in Fig. 7, where the average of the sum traded volumes on the markets are depicted.

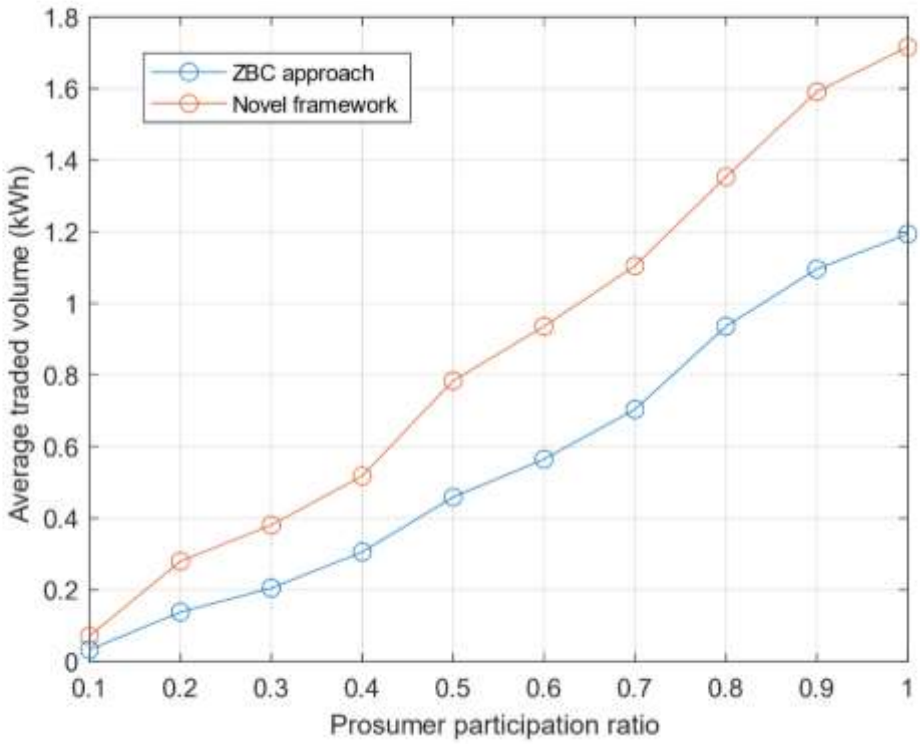

Figure 7: Mean sum traded volumes considering the two market approaches

The results show that the DNUTs influence the market transactions in such a way that is beneficial from the network perspective, while local generation (in a consumption-heavy area) has been incentivized. It can be also concluded from the simulations that the initial state of the system has a vast influence on DNUTs, and thus local trades.

Regarding the novelty of this concept, results proved the ability and viability of the proposed market structure to fulfill the following contributions:

- The LV market platform is proved to be operable parallel to a working traditional retail system.
- The proposed DNUT structure fully considers the network state and energy flows resulting from the transactions on the local market and the estimated base case of the retail market. Furthermore, through DNUTs the platform is able to handle potential changes in the behavior of prosumers (e.g. transitioning a part of their power consumption from retail to the local market platform).
- Instead of blocking unfavorable transactions or punishing participants for burdening trades during the settlement process, the platform incentivizes participants before entering the transaction. The market is not only competitive per se, but the DNUTs also promote network-friendly transactions for a prosumer by being lower for bids placed at favorable (e.g. neighboring) nodes.

2.2 Grid model validation

The grid module is designed to generate a unified grid representation, which helps to convert raw grid topology information into a pre-defined data structure. The model output is standardized, the numbering of the elements is used uniformly by the other modules of the framework. This transformation guarantees that the local market framework is independent of the network size and topology and minimizes the malfunctions of parametrization. The grid module requires standardized input datasets as follows:

- network topology data (graph representation);

- parameter table of line types (impedance calculation);
- attribute table of prosumers (load/generation constraints).

Due to the different types of input data received from demonstration partners, the mentioned data structures are filled with data manually, since not every demonstrator store their data in a Common Information Model format yet. When the preliminary tasks are accomplished, the execution of the grid module starts with the buildup of the network graph representation. This representation is a definite connection structure of the line elements with a corresponding length parameter and line type. The grid module reads the parameter table of the line types and links the corresponding physical parameters to the graph representation of the line. Consequently, the data used for the topology representation include line attributes (impedance per length, length, type definition), transformer electrical data, switching & protection devices, voltage, and current measurements. The developed model is a 4-wire representation which considers asymmetry, as it is an important factor for low voltage networks.

Then in the next step, the program places the prosumers on the graph according to the original topology information. Data sources include consumer smart metering data, synthetic load profiles (where 15-minute resolution measurements are not available), distributed generation measurements. This is provided by two pieces of information stored in the attribute table of the prosumers: (i) linked graph number, and (ii) the distance of the designated entity from the start node of the graph (each line element has a start and end node). At the end of this step, the physical parametrization of the network is terminated, and the full grid representation can be created. For this reason, the grid module is able to compute the admittance matrix of the network, which is essential for further simulations. The results are stored in separate variables. The phase assignment of the loads is based on measurements and can be refined with further data available in the system.

Local trading of the prosumers is only feasible if the grid infrastructure can handle the market requirements. Therefore, to calculate the base of the grid factors that are constraining the market actions, reliable models are needed. The discussed Slovenian demonstration site is located in Gradišče. The spatial expanse of the grid is noticeable with 8 separate circuits and 154 consumers covering the whole LV side of a transformer with 160 kVA rated power. Due to the highland environment, each circuit is relatively long with a moderate number of junctions. In all consumer connection points, metering devices provide active power and voltage measurements in the 3 phases, respectively. The graph representation of the case study grid is shown in Fig. 2.

The result of the grid calculation process is twofold: it defines the physical representation of the demo sites and provides an estimation for the day-ahead flows. The latter method is based on historical data (statistical approach), and there is a possibility to use stochastic parameters and a higher number of simulations to increase the visibility of possible customer behavior. It is important to note that estimating the day-ahead profile of consumers or prosumers is a difficult task per se, but with around 50 connection points per LV circuit, the power flow calculations could be seen as representative.

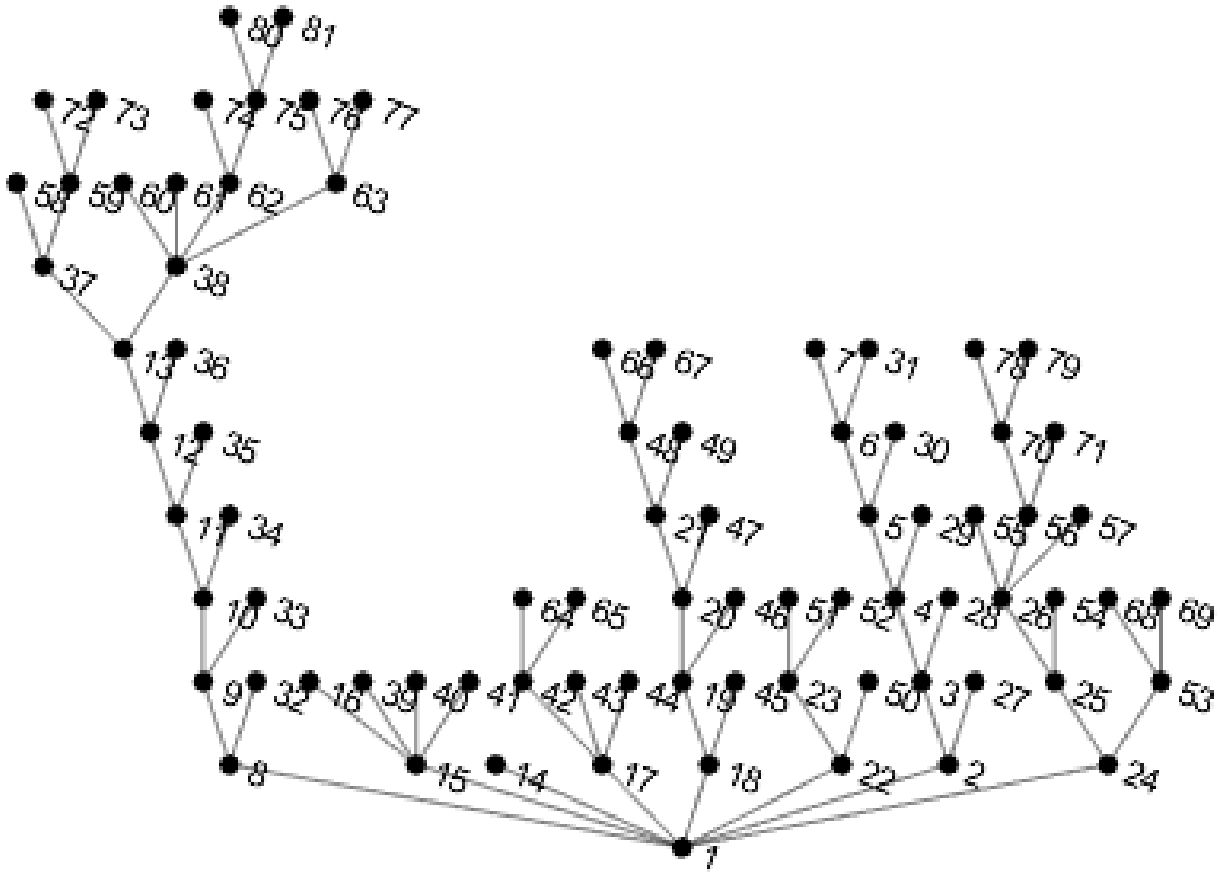

Figure 8: Node connection diagram of Gradisce location

The modeling phase was investigated under some simplifying assumptions. Reactive power is only available for some industrial/commercial customers; therefore, in other cases it must be estimated. At this stage, the model neglects reactive power flows. Protection devices are neglected (static numbers are available; therefore, separated validation and marking of possible supply interruptions is feasible from the data); transformer LV-side voltages are 1.04 per unit, similarly to the practical settings (based on measurements). Unbalanced calculations are considered with a 4-wire line representation and 3-phase transformer model based on the vector group and impedance data.

The proposed P2P local market concept requires an accurate mapping technique of the real-time grid states. The grid module uses power measurements recorded in consumer connection points and a graph-based representation of the real grid to estimate the actual state (and electrical parameters) of the grid. For validation purposes, the load-flow voltage results and the real voltage measurements are compared. Despite the extensive availability of power measurements, a limited set of voltage values were accessible. Naturally, one-phase consumers provided only one time series, and 34 pieces of 3-phase measurements are missing. This means that more than 75% of consumers are taken into the validation, which is significant in the context that an LV site is investigated. While voltage time series have a 10 min resolution, the power meters record data every 15 minutes.

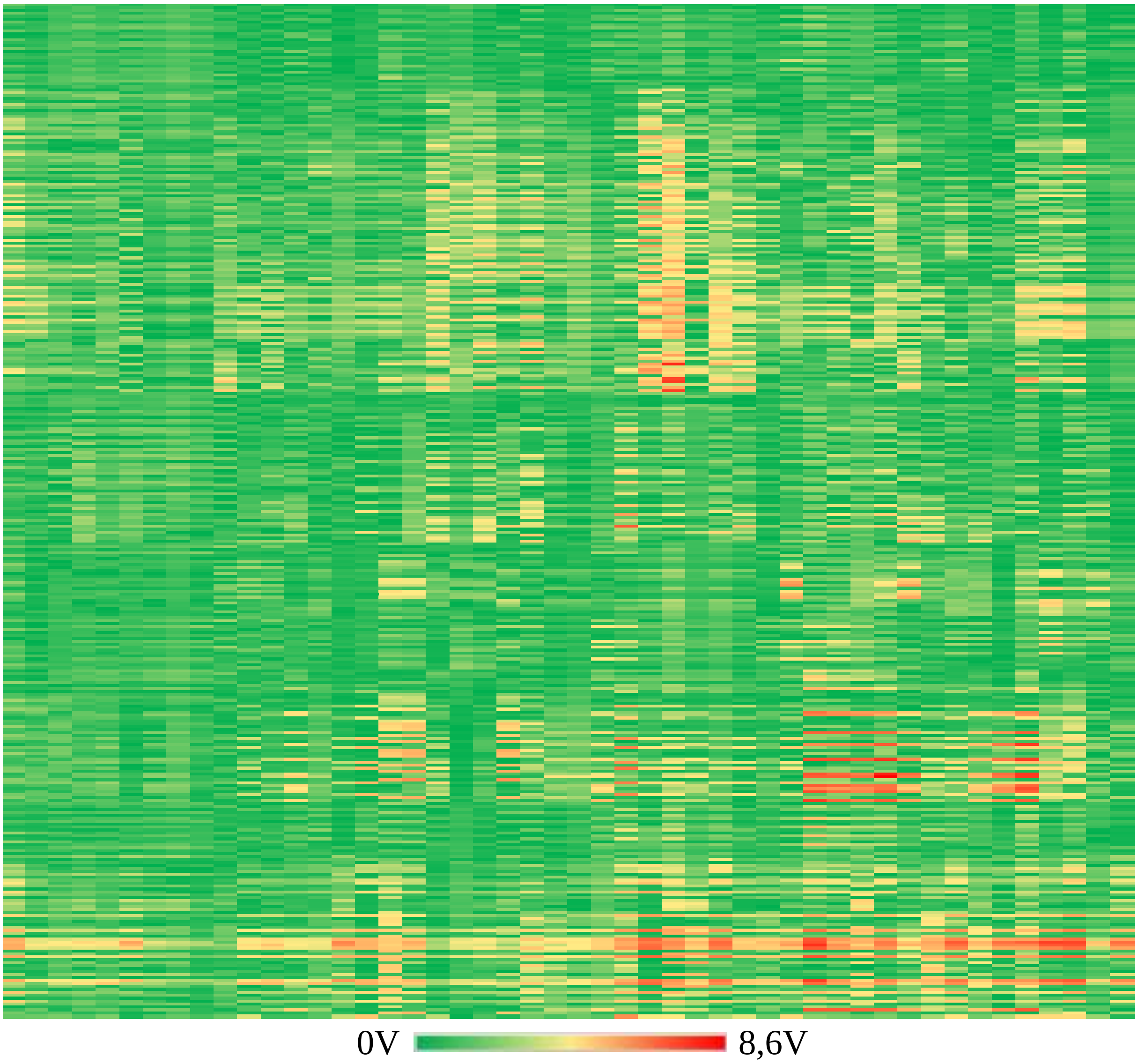

Figure 9: Heatmap of deviation between simulation and real voltage dataset; each row shows one metering point (node) and each column represents one momentum from 00:00 to 23:30 with 30 min resolution

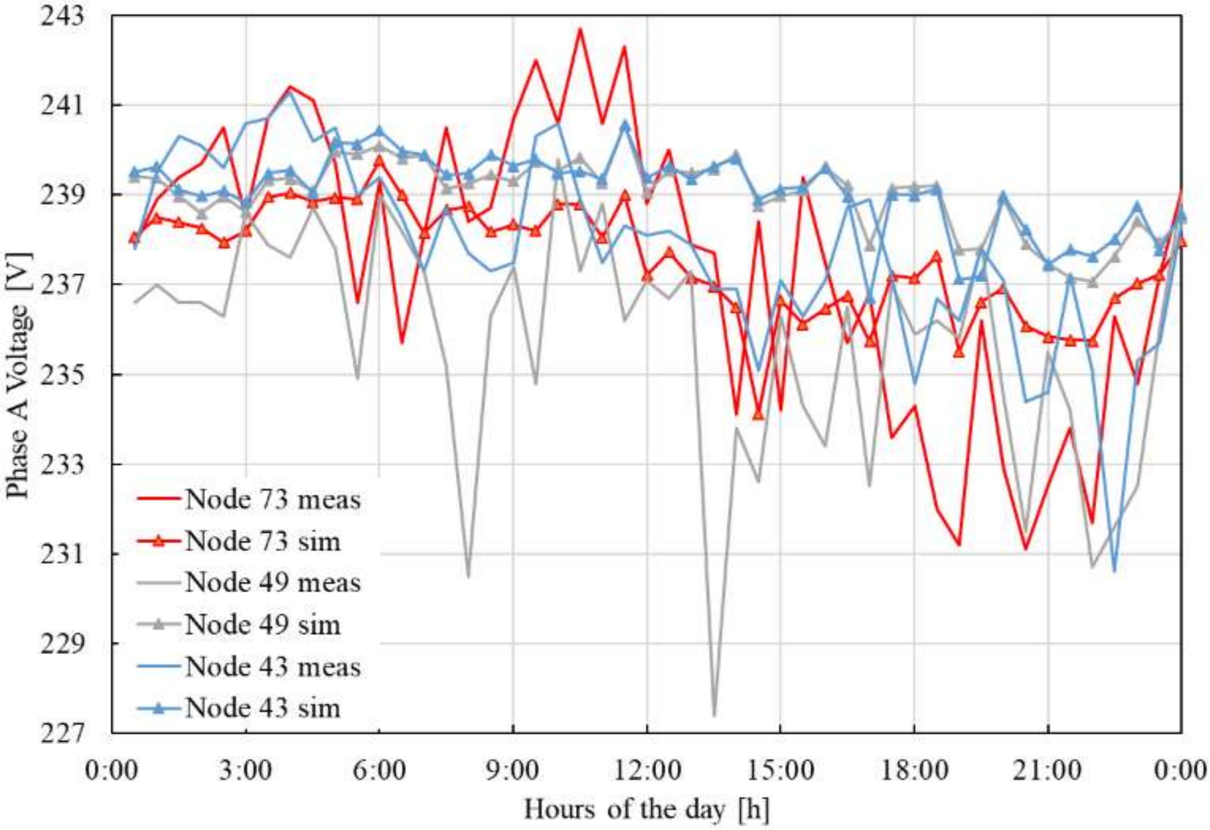

Figure 10: Metered (solid lines) and simulated (triangle markers) end node voltages in case of three circuits; the node numeration is denoted above

Since the proposed local market uses 15-minute timesteps, the validation process included 48 comparable moments in 24 hours, at the top and the bottom of every hour. The grid model accuracy compared with real-time measurement set was validated on data corresponding to the 13th of August. The deviation between real-time and simulation records are demonstrated via a heatmap in Figure 99. The rows of the heatmap represent every measurement time series. The 48 columns show the simulation accuracy at a moment with a color gradient from 0% deviation (green) to 8,6% (red), respectively. An optimistic 1% assumed sampling error means approx. 2,3 V deviation between real and metered data. Figure 9 shows that in most cases the deviation between simulation and on-site measurements is under this threshold. The performance of the grid module simulation is significant and verifies that the model maps the real grid features well. The root cause for larger deviations in the metering data is unknown, it should be considered a significant load element switch, which is hard to predict in the case of low number of LV customers.

While, Figure 9 introduces a general picture about the performance of the grid module, Figure 10 shows a comparison of 3 circuit endpoint node voltages. This reveals the voltage patterns of both simulated (triangle marked) and real measurements (solid lines). It is seen that the simulation and measured time series have a similar fluctuation, respectively.

2.3 Description of the IACMS algorithm

The Integrated Asset Condition Management System aims at the highest exploitation of the components in the physical grid and thus eliminates network constraints that would hinder the operation of and the free access to the market. At the same time, the system is avoiding unnecessary risks associated with the outages caused by ageing equipment. These goals are achieved by the consideration of various information about the assets and then informing the market about their availability and loadability.

The underlying theoretical consideration is that the nominal power or ampacity of the equipment are calculated based on worst case scenarios. Accordingly, if the weather is considered, a much more accurate seasonal ampacity can be calculated. Standardized calculations, at the same time, do not take into consideration the aging of the equipment, which would lessen their loadability.
The IACMS module is considering the differences of data stored and condition information collected by the operators of the demo sites and is therefore prepared for lack of data.
The system consists of the following modules for all types of equipment:

- Thermal behavior model applying statistical environmental data
- Asset condition module limiting excessive ageing by adjusting the thermal limits

2.3.1 Transformers

The algorithm calculates the upper loadability limit for the given time interval in case of a given forecasted ambient temperature value. The initial load ratio (K_0) is set to 500% of the nominal load value so that the iterative solution approaches the final K_i value from above, using the interval halving method. The output is the permissible transferred power for the given time interval, which is 15 mins.
The inputs of the IACMS for transformers are as follows, source are the DSO-s:

- Basic (nameplate) data: type, nominal voltages and currents, nominal power, no-load loss, short-circuit loss, weight, oil weight, location
- Operational history information: time in operation or installation date
- Condition information: visual checks, oil tests, insulation resistance tests, other diagnostic measurements

2.3.2 Overhead lines

For medium voltage power lines, the ambient adjusted line rating (AA-LR) gives an optimal solution by considering the required input data and the achievable surplus transmission capacity. For this purpose, the ambient temperature and solar radiation should be known along the power line route in real time, while the wind parameters (speed and direction) are taken into consideration as constant values. Accordingly, a surplus 10% transmission capacity in average can be achieved by the application of AA-LR calculation methodology. The output of the calculation is the real time ampacity of the OHL. This value is calculated every 15 mins.
The inputs of the IACMS for overhead lines from the DSO-s are as follows:

- Basic (nameplate) data: type, nominal voltage and current, type and data of conductor, location
- Operational history information: time in operation or installation date, planned height above ground
- Condition information: visual checks

The inputs of the IACMS for overhead lines from C&G sensors are as follows:

- LISA sensor detecting the damage of the conductor by electric field measurement
- IMOTOL sensor detecting the deformation of poles by residual strain measurement

2.3.3 Cables

In case of cables, the algorithm creates a detailed thermal model for the cable structure considering losses and thermal properties of the different layers. Using this model, plus taking into account the environmental conditions, the permissible load can be calculated for a given time interval. The output of the algorithm will be the maximum permissible rating for the day that is safe for the integrity of the cable structure.
The inputs of the IACMS for cables are as follows, source are the DSO-s:

- Basic (nameplate) data: type, nominal voltage and current, material and cross-section of conductor, resistance of conductor
- Operational history information: time in operation or installation date, installation mode/laying depth, soil type if buried
- Condition information: insulation resistance measurements, diagnostic measurements

2.3.4 Summary of IACMS results

The following table contains the total excess energy allowance throughout the demonstration periods where IACMS was active, which means a total of 7 weeks. The values equal the transmissible energy above the static limits that were made possible by the IACMS calculation, per asset type and per demonstration site. The values were calculated by the following method: the total transmissible energy based on the static load was subtracted from the total transmissible energy based on the dynamically calculated load, considering a full load, nominal voltage and a power factor of unity in both cases. At Zsombó, there were no cables in the LV demonstration area.

Table 1: Excess energy allowance (total values for 7 weeks)

	Besnica	**Zsombó**	**Bóly**
Cables	11.55 MWh	NA	40.59 MWh
Overhead lines	35.22 MWh	135.25 MWh	69.99 MWh
Transformers	8.47 MWh	67.37 MWh	66.72 MWh

2.4 Scenarios in the demonstration

In this demonstration, the operation of the market was simulated using artificial bids. Each bid was described by the following parameters:

- type of the bid (supply or demand);
- index of the trading period, for which the bid is relevant;
- volume of the bid;
- submission price of the bid.

For every considered participant, bids were generated based on the historical consumption/production data provided by the demonstrators. It is assumed that every participant submits bids to the market in two steps: First, day-ahead bids are submitted on the day before the trading period (D-1); and second, intra-day bids are submitted on the day of trading. In the case of intra-day bids, it was assumed that the prediction of consumption/production regarding the trading period is more precise than in the case of day-ahead bids.

The demonstration was performed for different scenarios, listed in Table 2. DSOs uploaded the data for the analysis, then the BC was calculated, and the bid generator provided the p2p activity. 19 different scenarios were analyzed during a year timespan. Scenario 1, 17 and 18 are the so-called base scenarios for seasons of winter, spring-autumn and summer respectively. These scenarios provide a reference for the analysis of different considerations, which can be grouped:

- Data availability – metering and synthetic load profiles are always available, while a feeder metering (Sum-meter) is only available in Scenario 2;
- DNUT elements – loss, load ability (with or without IACMS) and voltage regulation;
- Share of DNUT (Scenario 3 and 4 considers different options);

- Scenario 15 considers symmetric conditions in the modelling;
- Order types (metering based / flexibility);
- Scenario 13 and 14 analyzed a local energy storage system (only available at Zsombó site).

Table 2: Scenario schedule

Number	Start date	End date	Name (DNUT change / data availability change)
1	2021.01.04	2021.01.24	Base
2	2021.07.12	2021.07.25	Grid measurements included in the estimation
3	2021.04.26	2021.05.16	Shared DNUT
4	2021.05.17	2021.06.06	Fix DNUT for bidder, remaining for aggressor
5	2021.06.07	2021.06.20	Congestion management limit
6	2021.06.21	2021.07.11	Congestion management limit + punishment
7	2021.01.25	2021.02.21	Voltage limit in the DNUT
8	2021.02.22	2021.03.14	Voltage limit with DNUT punishment
9	2021.07.26	2021.08.15	Losses + congestion management
10	2021.03.15	2021.04.04	Losses + voltage limit
11	2021.09.06	2021.09.26	Losses + congestion management + voltage limit
12	2021.09.27	2021.10.17	Extra flexibility offers added
13	2021.10.28	2021.11.07	DSO storage use case 1
14	2021.11.08	2021.11.21	DSO storage use case 2
15	2021.11.22	2021.12.05	Asymmetry consideration test
16	2021.12.06	2021.12.19	Non-anonym bids, without automatic pairing
17	2021.04.05	2021.04.25	Base case for spring
18	2021.08.16	2021.09.05	Base case for summer
21	2022.01.03	2022.01.24	DSO congestion forecast test with increased base case flow

The following table summarizes the parameter settings for the simulations. The parameters were tuned by preliminary tests to provide practical and realistic scenarios. However, the sensitivity analysis for these opens up further possibilities for this implementation.

Table 3: Parameter settings for the simulations

Parameter name	Value	Dimension	Description
Voltage limit cost	1000	EUR/pu	The price for exceeding voltage limits, a component of DNUT, is practically unlimited and excludes orders that surpass these limits.
Current limit cost	1000	EUR/pu	The price for exceeding line loading limits, a component of DNUT, is practically unlimited and excludes orders that surpass these limits.

Transformer limit cost	1000	EUR/pu	The price for exceeding transformer limits, a component of DNUT, is practically unlimited and excludes orders that surpass these limits.
DNUT trading volume	20	pu	The unit of power transmission, for which DNUT is calculated, is equal to 2 kW.
Per unit power	100	W	Per unit of power used.
Voltage limit	0.15	pu	Voltage limit that applies in both directions and is around 35V. Going over this limit results in additional DNUT fees.
Transformer limit	5	%	Transformer loading limit. Going over this limit results in additional DNUT fees.
Overflow ratio	0.2	-	Ratio of energy transmission in the system, that is not part of the BC, but covered by local market activity.
Voltage linear cost	0.0037	EUR/pu	The cost for deviation from the reference voltage; is applicable in both directions and is assessed for voltages within the range of the reference voltage and the voltage limit.
Current linear cost	7.36E-05	EUR/pu	The cost for deviating from the BC current; is applicable in both directions and is assessed for all lines.
Loss cost	0.02	EUR/pu	Cost of total system loss caused by the transmission.
Transformer linear cost	7.36E-06	EUR/pu	The cost for deviating from the maximum transformer loading.
Retailer purchase price	0.0156	EUR/pu	Price on which the retailer purchases a unit of energy.
Retailer selling price	0.0338	Eur/pu	Price on which the retailer sells a unit of energy.
Battery scenario parameters			
Voltage deviation interval (lower bound)	1	%	Exceeding this voltage limit at the battery connection point will turn on the battery in discharge mode.

Voltage deviation interval (higher bound)	4	%	Surpassing the voltage limit at the battery connection point will activate the battery in charging mode.
Maximum battery power	160	kW	Nominal maximum power of the battery.

Table 4 summarizes the statistical attributes which were used to evaluate the different scenarios. Since the framework gives all the relevant market and grid data as an output, more descriptive attributes were created to help the participants in the analysis.

Table 4: List of the most relevant output variables

Unit of measure	Variable name
[%]	Maximum of line load in BC over all lines and periods
[%]	Maximum of line load in OLM over all lines and periods
[%]	Maximum of line load in ALM over all lines and periods
[%]	Expected shortfall (5%) of all line loads in BC (over all periods and lines)
[%]	Expected shortfall (5%) of all line loads in OLM (over all periods and lines)
[%]	Expected shortfall (5%) of all line loads in ALM (over all periods and lines)
[%]	Expected shortfall (5%) of worst case line loads (worst case over periods) in BC
[%]	Expected shortfall (5%) of worst case line loads (worst case over periods) in OLM
[%]	Expected shortfall (5%) of worst case line loads (worst case over periods) in ALM
[%]	Maximal loss per traded volume ratio (LpTVr) in BC (over trading periods)
[%]	Maximal loss per traded volume ratio (LpTVr) in OLM (over trading periods where OLM is active)
[%]	Maximal loss per traded volume ratio (LpTVr) in ALM (over trading periods)
[%]	Minimal LpTVr in BC (over trading periods)
[%]	Minimal LpTVr in OLM (over trading periods where OLM is active)
[%]	Minimal LpTVr in ALM (over trading periods)
[%]	Maximal change in LpTVr in ALM compared to BC
[%]	Minimal change in LpTVr in ALM compared to BC
[V]	Maximal voltage deviation (VD) in BC (over all prosumers and periods)
[V]	Maximal VD in OLM (over all prosumers and periods)
[V]	Maximal VD in ALM (over all prosumers and periods)
[V]	Minimal voltage deviation (VD) in BC [V] (over all prosumers and periods)
[V]	Minimal VD in ALM [V] (over all prosumers and periods)

[V]	Average voltage deviation (VD) in BC (over all prosumers and periods)
[V]	Average VD in OLM (over all prosumers and periods when LM is active)
[V]	Average VD in ALM (over all prosumers and periods)
[V]	Expected shortfall (5%) of voltage deviation (VD) in BC (over all prosumers and periods)
[V]	Expected shortfall (5%) of VD in OLM (over all prosumers and periods when LM is active)
[V]	Expected shortfall (5%) of VD in ALM (over all prosumers and periods)
[V]	Average change in VD in ALM compared to BC (over all prosumers and periods when LM is active)
[%]	Exchanged flexible power relative to maximal transmissible power

2.5 Evaluation of the complete set of demonstrations

The 4 demonstration sites provided a validation environment for the developed market and grid modelling methods. Figure 11 provides the average ratios of OLM and BC traded volumes for all 3 base cases (winter, spring and summer), and all 4 demonstration sites.

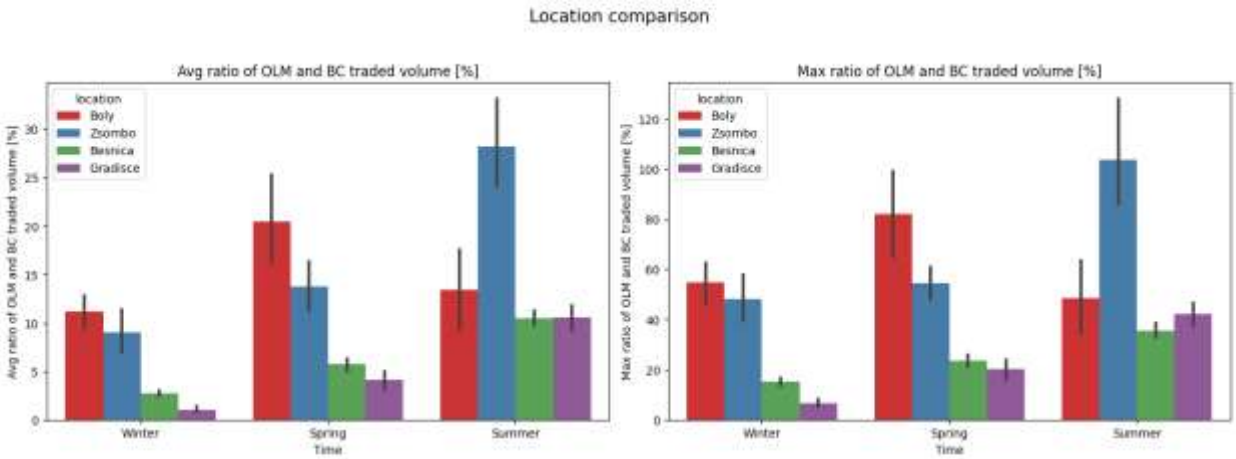

Figure 11: Average ratio of ALM and BC traded volumes in the whole demonstration – base cases

Due to the fact that the producers on the local markets are PVs, the seasonality clearly had a great effect, as in the summer the traded volume change is significantly larger. Site Bóly (marked with red) had the biggest share of local generation (this was the only site with MV model and a MV PV power plant), however in the summertime there was decreased OLM activity due to the high DNUT, because losses increased on the site greatly. Regarding the Slovenian demonstration sites, the lack of production and therefore the lack of supply bids clearly constrained the p2p trading. The traded volumes basically confirmed the viability of the p2p markets in general, and with increasing volatility, the market activities were expanded. The results clearly show that the availability of local generation is an entry barrier. The consumption also has seasonality, which also adds to the processes.

One of the most important aspects of the introduction of the DNUT is the concept of payments. 3 different approaches were analysed through the demonstrations. The basic concept was that the aggressor pays the DNUT (Scenario 1), while another solution could be a 50-50% share (Scenario 3), and the DNUT can be fixed for the bidder, and the remaining part is paid by the aggressor, the dataset is still the whole demonstration period for these scenarios (Figure 12). The trading intensifies in the summer, especially when the aggressor pays the DNUT – this means, that the available local generation is a tempting option for the local users. The fixing of the DNUT leads to the reduction of the traded volumes, which indicates further activity from p2p point of view – this means that fixing the bidder's DNUT is a possible tool for market enhancement. This predictability might encourage prosumers to access the local market.

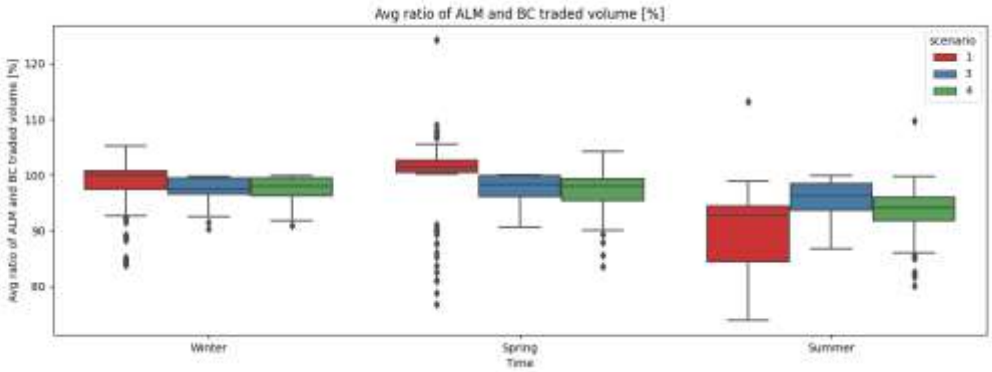

Figure 12: Different concepts for the DNUT share

Figure 13 shows the different bid acceptances throughout the demonstration of the voltage regulation options. 4 scenarios were important from this point of view:

- Scenario 1 – BC
- Scenario 7 – Voltage limit – if a transaction would lead to violation, it is not allowed
- Scenario 8 – Voltage limit with punishment fees near the limit
- Scenario 10 – Voltage limits and losses define the DNUT

The demonstration sites are generally voltage constrained, so this element has actual effects on the trading (contrary to the CM, which is described later). E.g. for the average ratio of accepted demand bids for Scenario 1 and 8, there is a clear limitation spring. However, since these results are aggregated values for the 4 sites, the location attributes cannot be considered. At different site analysis some further aspects are discussed in this report below. Another key conclusion is that the trading activities are larger in the summer, and for most of the time, the grids were not constrained by the limits.

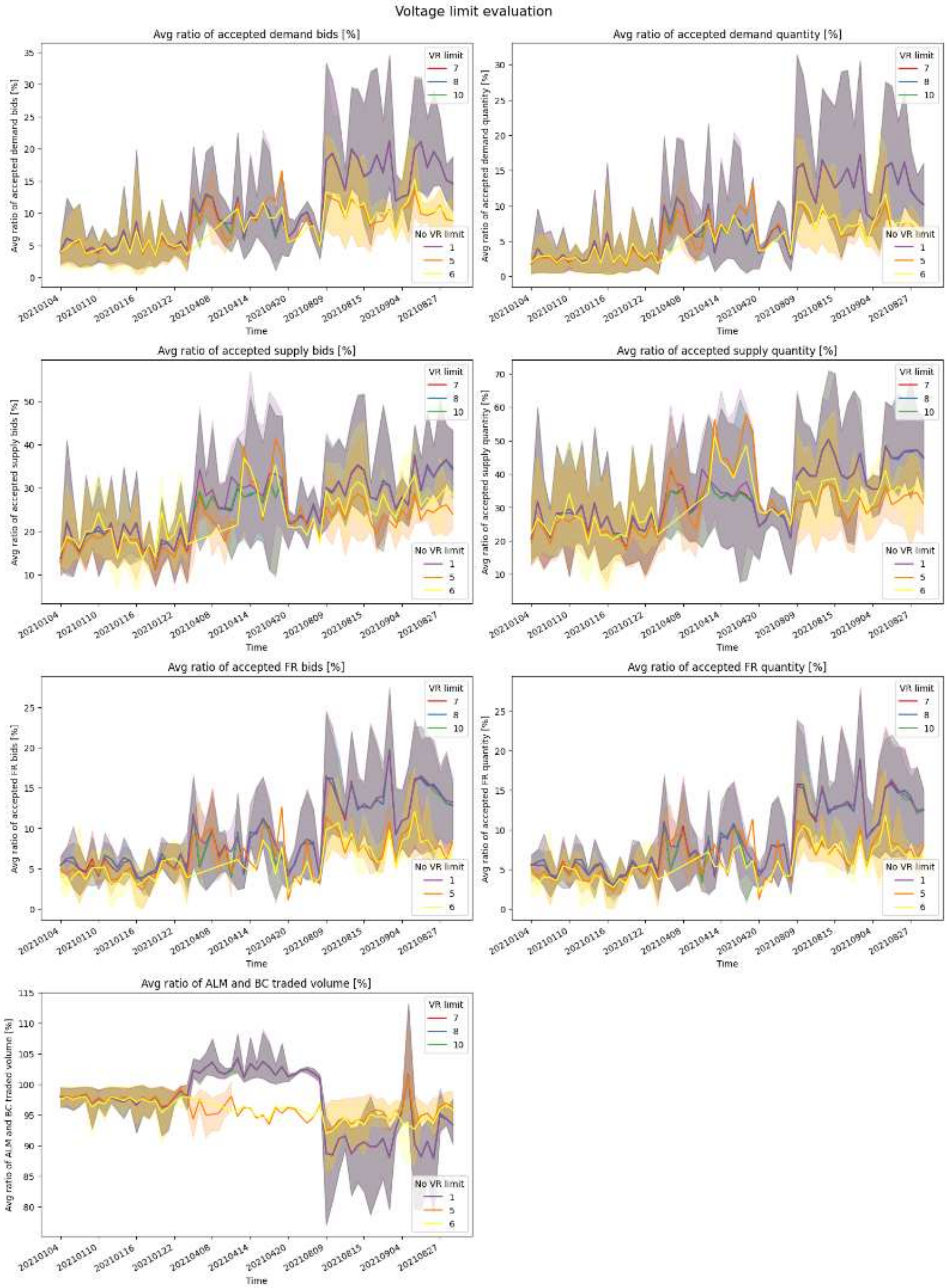

Figure 13: Voltage regulation aspects in the DNUT – effects on the bid acceptance

The next discussed parameter is the CM option. Since the static loadability of the network branches is larger than the flows, there are very few few occurrences of congestion – however some were present. In the future with more and more renewables, higher loadings are expected, which will underline this capability of the developed framework. These LV demonstration sites usually have overhead line grids – in case of cable LV grids with shorter length, loadability might be a constraining factor. Testing the framework at such sites would add further conclusions to these scenarios. In the case of Bóly, where MV level is also considered, the situation is different, and CM has a limiting effect.

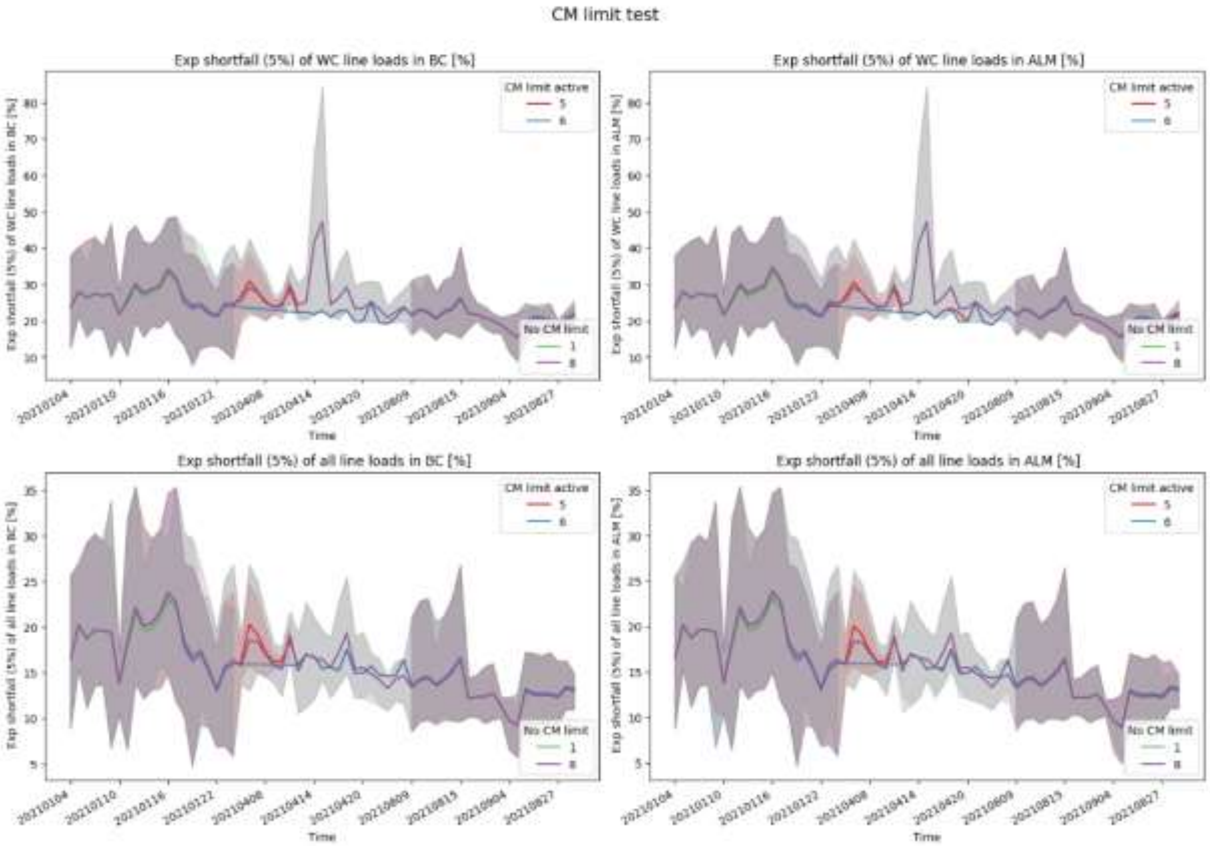

Figure 14: ES in CM scenarios

In Scenario 15, a symmetric grid representation was used, which resulted in restricted market activity. However, the phase assignment of element is not known at the DSO sites, which makes asymmetry tough to handle. The difference in the modeling approach is clear, however a practically usable asset enabled framework must be aligned with the DSO data availability. There is a clear potential in handling asymmetry properly as Figure 15 describes.

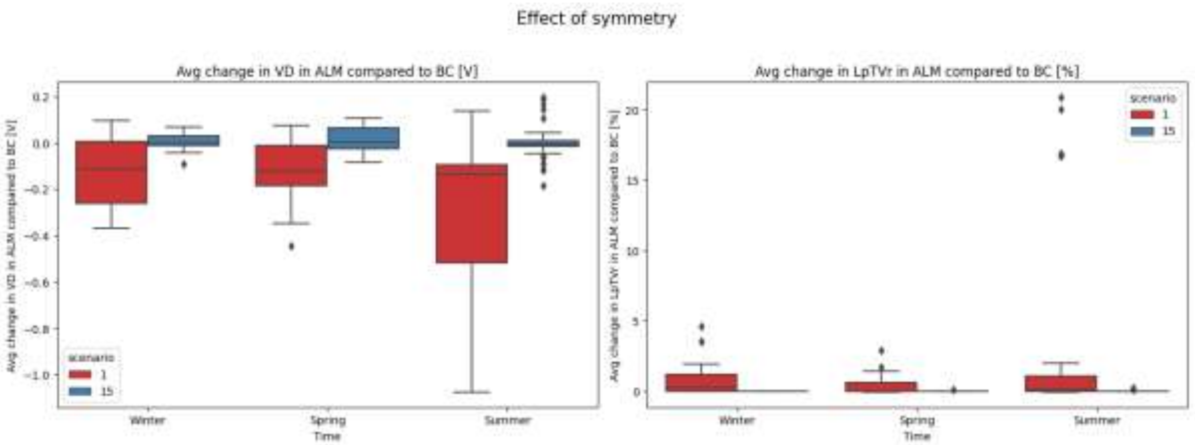

Figure 15: Symmetry – asymmetry considerations

2.6 Slovenian Pilot Site

Basic requirement for running the simulations from the DSO perspective were input data. BME as the developer of the algorithms and programs in MATLAB (licence was arranged by Elektro Ljubljana), specified which data would be needed, in what format and how and where should the data be available. Elektro Ljubljana agreed to provide all necessary data for both LV pilot sites, which comprise grid topology and the technical parameters of lines and assets.

After having a clear picture about the grid, BME also integrated the smart meters data. This means, data from the meter, which measures the total consumption and electricity quality parameters on the level of MV/LV transformer station and this is so called Sum-meter. Sum-meter measures and stores information about Voltage, current, power factor, active and reactive energy (bidirectionally) in 10-minute resolution. For calculations of the load flows and voltage levels among grid branches (lines, cables) and nodes, Elektro Ljubljana provided data from all smart meters installed on the LV grid, measuring the consumption and production of the grid users- customers- market active participants. Both selected LV grid have a common feature, that all grid user's connection points are equipped with the smart meters. 15 min data of active power and energy have been collected, for more than two years. Simulations were using real smart meters data. Every Monday, for the past 7 days 15 min smart meters data were collected and stored on server where authorized participants had access to perform analysis.

2.6.1 Preliminary proof-of-concept simulations for Gradisce

Market simulations are carried out for two scenarios for the same day of operation:

- Scenario A: the original LV network in Gradišče is used, which only contains two prosumers that inject power to the grid throughout the day.
- Scenario B: two additional, randomly selected nodes are replaced by prosumers, while the energy production profiles of existing ones were used.

In both scenarios, a base case (generation and load) is defined based on measurements, which represents the estimated state of the network without the influence of the local market. In this article, we focus on two of the grid-related aspects of the market results, namely phase voltage deviations and changes in network loss. Therefore, prosumer prices, calculated DNUT, social welfare, and other economic measures are not discussed. The sum of network losses in a given quarter-hour is divided by the total traded volume to ensure comparability between the base case, and local market results. The total traded volume is defined as the sum of generation and consumption in the system.

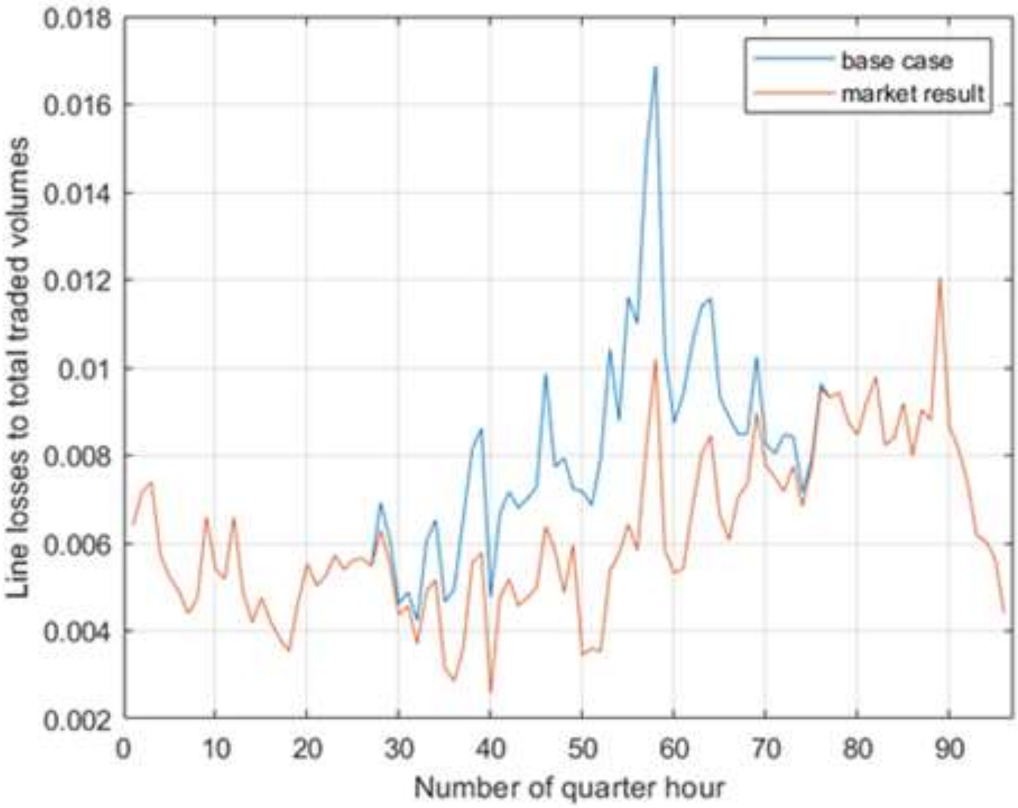

Figure 16: Comparison of relative losses for the base case and local market results in scenario 1

Figure 16 summarizes the relative losses (MWh/MWh) in Scenario A. In this case, the local generation is rather low, most of the consumption is covered by the external grid. Therefore, the loss relative to consumed energy is less favourable, as the flows follow the conventional route from the medium voltage grid through the transformer to the customers. Compared to that, the introduction of the local market provides information on the grid state for participants, thus showing a possibility to bid for the local generation. These added transactions lower the relative losses as the generation is physically closer to the consumption.

Figure 17 depicts the highest and lowest voltage phase RMS values for both the base case and the local market results, calculated in 15 min time steps for the whole day. Despite the additional trading, the voltage values remain in a tight zone. Although the applied dynamic tariff practically forbids voltage limit violations, this result is rather due to the lack of supply bids (which come from only 2 generators). The number of supply orders is raised by connecting two more producers to the network in Scenario B.

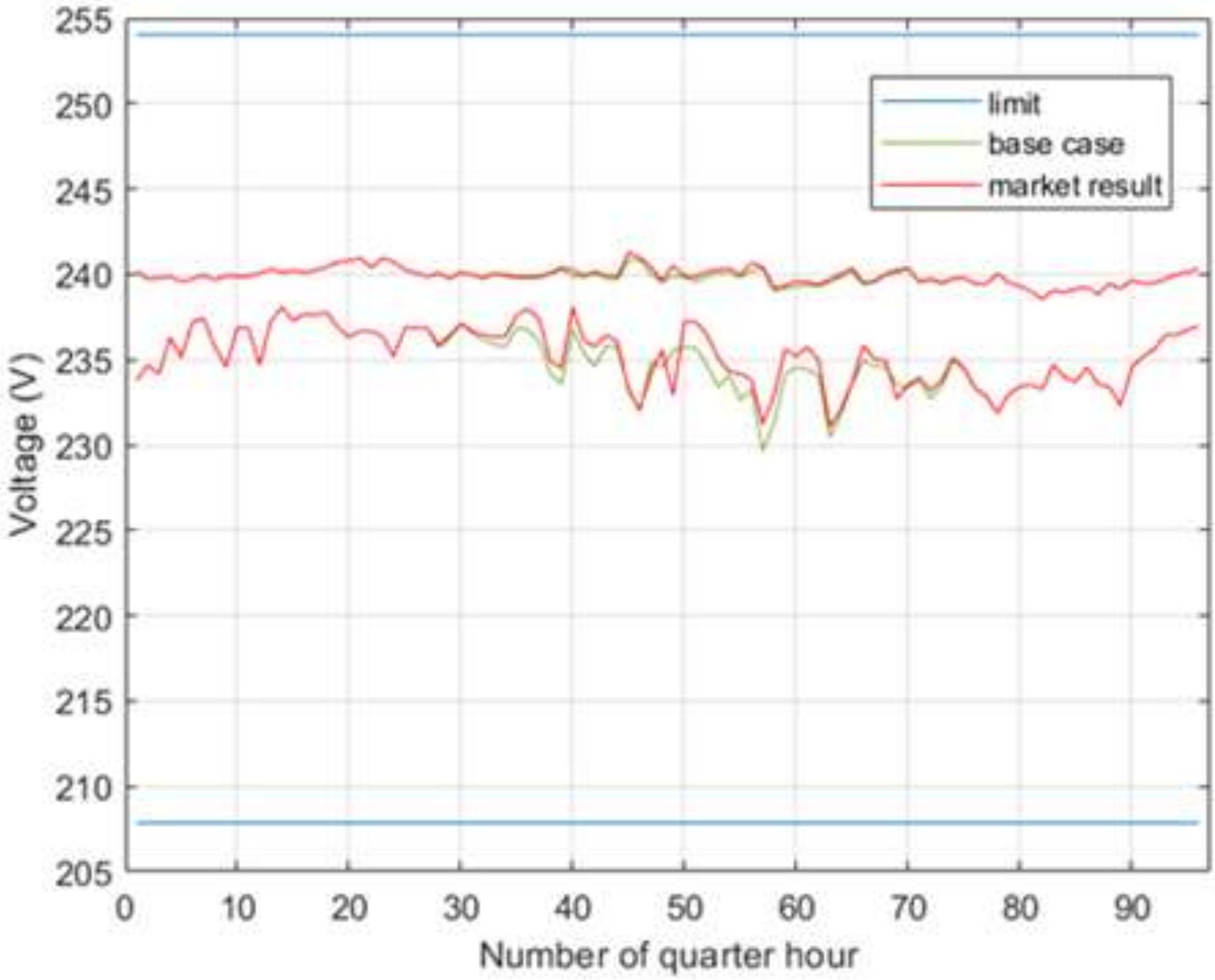

Figure 17: Comparison of minimum and maximum phase voltages for the base case and local market results in Scenario A

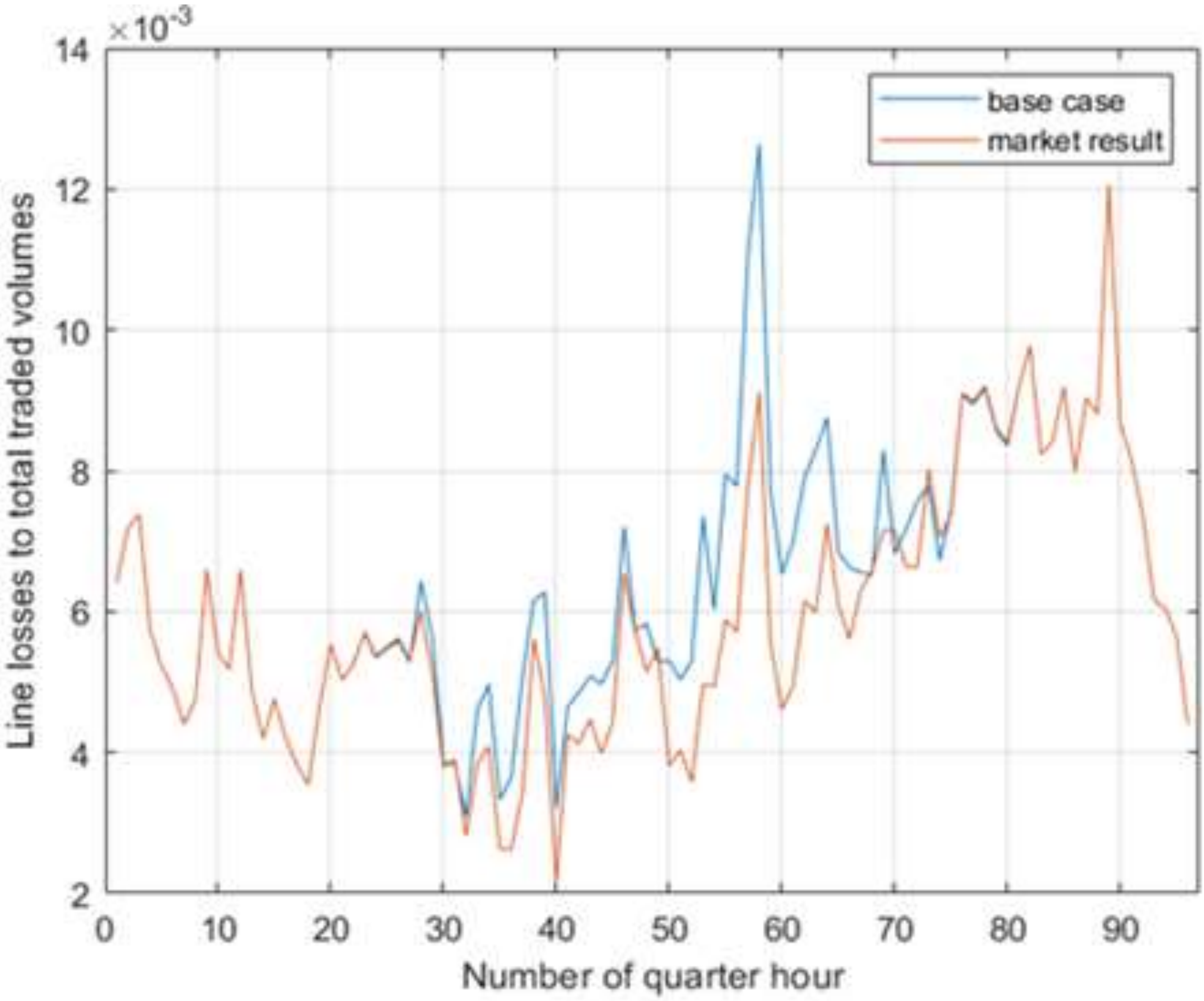

Figure 18: Comparison of relative losses for the base case and local market results in Scenario B

In this scenario the relative losses (Figure 18) in the base case are already lower compared to Scenario A due to the increased number of local generators, which imply less loaded network branches. This loss ratio is further improved by the local market.

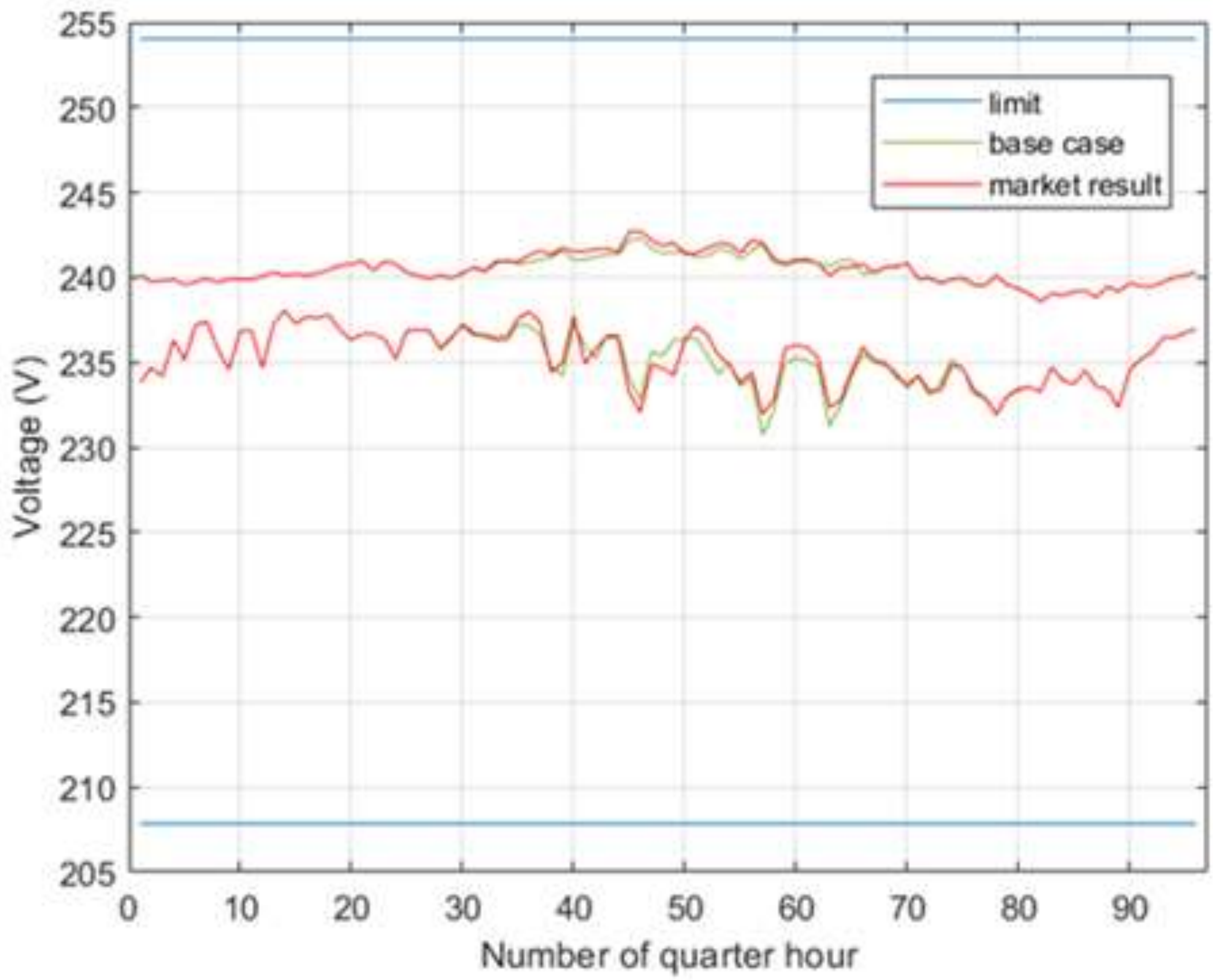

Figure 19: Comparison of minimum and maximum phase voltages for base case and local market results in Scenario B

Figure 19 shows that there is still only a slight rise in voltage RMS values, meaning that the constraints defined by the operation standards are not violated.

2.6.2 Demonstration of use cases

Regarding the Slovenian demo sites, if we rely strictly on the original data, no trading emerged in the local market because of the lack of production, no generation was present. To overcome this issue, 3 fictive producers were added to each site (based on historical PV data) to the following nodes:

Simulations for different scenarios were run on one week time frame according to Table 2, thus the results were provided for the same period.

The results were uploaded on a weekly basis (the name of the directory includes the date of the last day of the week), the output files were available in .xlsx and in .mat format (MATLAB) as well.

The system performs a post-processing of the results as well, and calculates indicators, which may be of interest during the evaluation process.

The basic idea of the pre-processing was to provide integrative descriptive values, based on which the whole evaluation may be carried out, but if needed any more detail, values-results were available even on the level of single line loads or voltage levels in a single period during the simulation.

In the stats out files, the so called 'expected shortfall value'- ES had been calculated, which is a very simple coherent measure of risk: it stands for the expected value of the worst 5%. For example, if we have 100 lines, and the normalized load value (between 0 and 1, where 1 stands for the maximal load) is given, then the ES is calculated this way: we take the ascending (non-descending) ordering of these values and take the average of the last 5.ES may be useful, because traditional statistical values (like the average or the maximum) are not always very representative, the whole distribution is on the other hand a too large data set to analyse.

In this document, the visualization of the results is specific, that for each demo site, results had been calculated only for specific time frames and this is evident also from the graphs.

Slovenia provided topologies for two LV networks, Gradisce and Besnica. Both grids are from the perspective of geographical location not close to each other. Slovenian pilot locations have also different number of loads (mainly households), that is why the results are presented on separate figures. From the DSO perspective, we observed also other results; especially interesting were the results of settlement, for specific scenarios.

In the case of ELJ, the following scenarios were performed:

- Base case, base case summer (Scenario 1, 18)
- DNUT fix for bidder, remainder paid by aggressor (Scenario 4)
- Congestion limit + punishment test (Scenario 6)
- Voltage limit + punishment test (Scenario 8)
- DNUT contains loss, congestion and voltage limit values (Scenario 11)
- Extra flexibility orders (Scenario 12)

Results of the simulations were given mainly for months of January, February, rarely for months in Spring and then again for all scenarios, results were available again for the Autumn period, as the scenario schedule describes (Table 2).

2.6.3 Congestion management

Figures 20 and 21 demonstrate the effect of the congestion management mechanism built into the DNUT. The plots show the comparison between the line loads with and without the congestion management mechanism in place.

The results suggest that the congestion management mechanism built into the DNUT does not have a significant impact on the line loads in the current demonstration on the LV level. The line loads remain low with only minimal fluctuations throughout the simulation (except for Besnica site where an outlier value can be observed), indicating that the congestion management does not significantly affect the overall loading. This is due to the fact that congestion is extremely rare in such LV networks as line loading rarely approaches the permitted line loading limit. This holds for both demo sites and across all simulation periods. Line loading in the winter period tends to be larger as this time is characterized by higher consumption without solar power to balance it out.

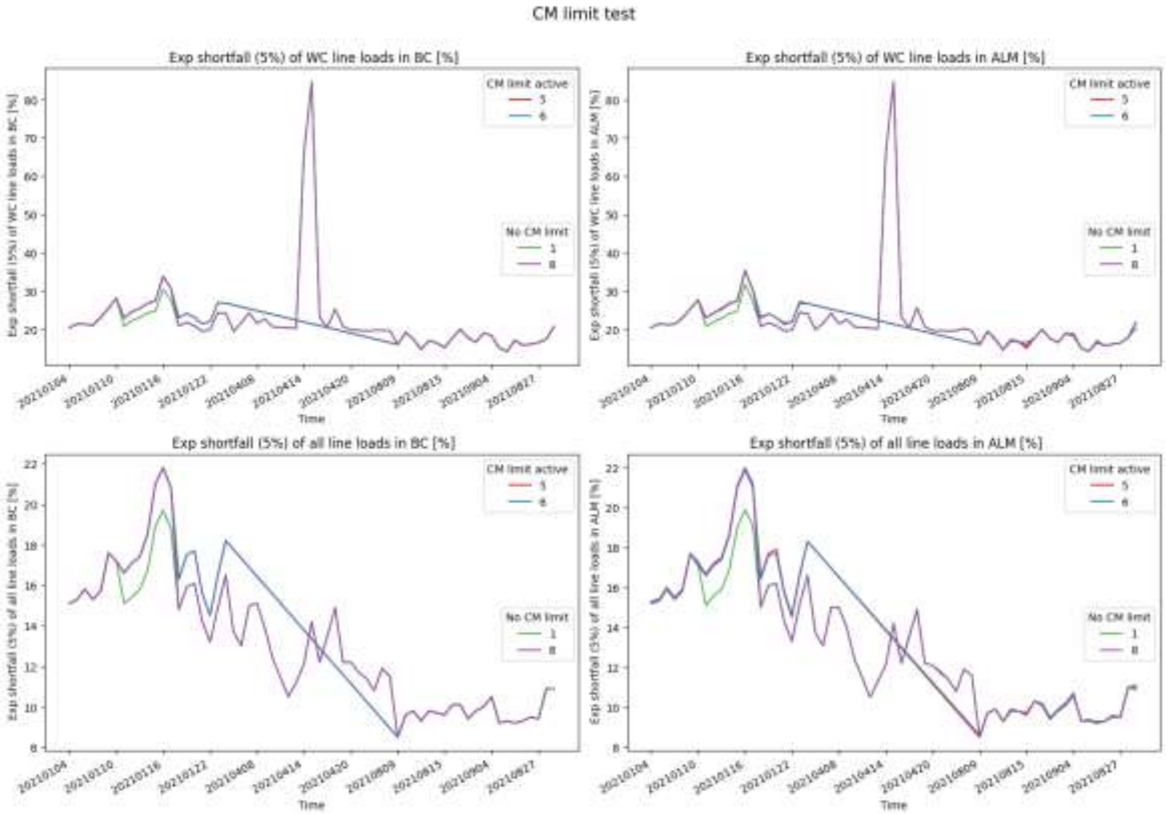

Figure 20: Besnica line loads with and without congestion management built into the DNUT.

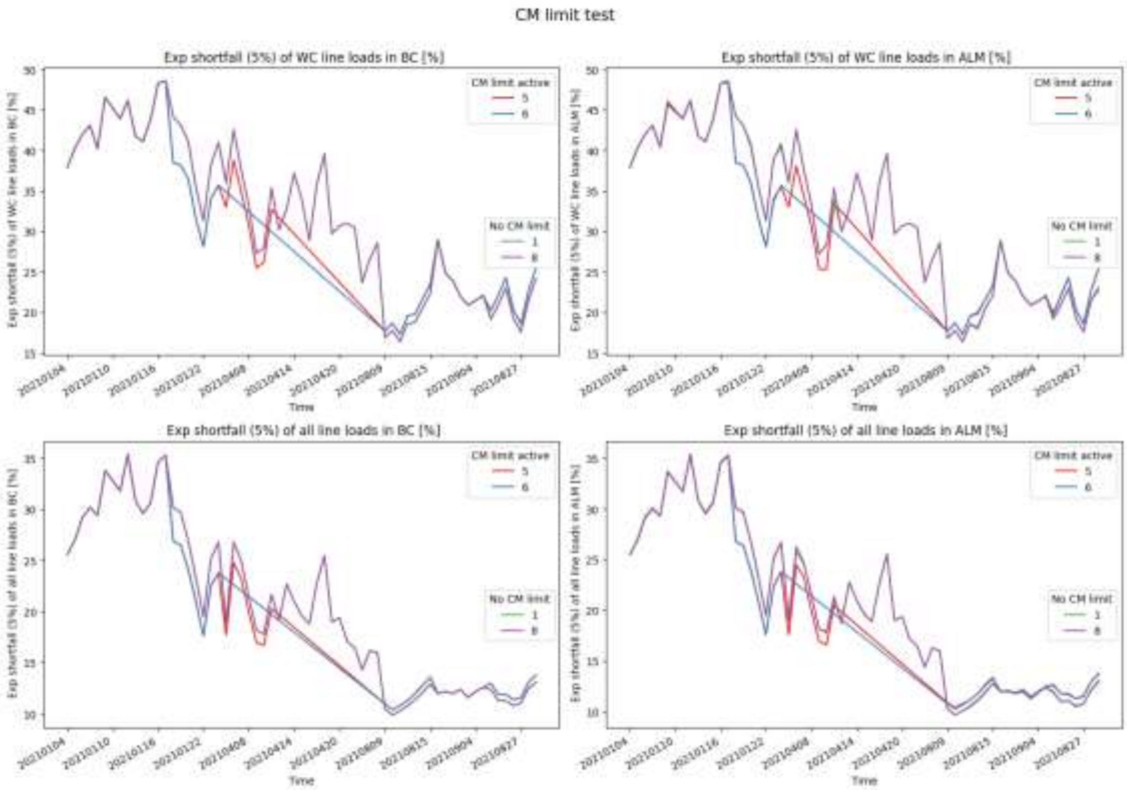

Figure 21: Gradisce line loads with and without congestion management built into the DNUT.

2.6.4 Impact of Loss in the DNUT Calculation

Figures 22, 23 show different levels of penalization for loss in the DNUT calculation and the corresponding loss per traded volume (LpTV) values. Scenarios 7, 8 show the LpTV values without considering loss in the DNUT calculation, while scenarios 1, 10 show the LpTV values with loss penalization in the DNUT calculation.

While the LpTV values do change slightly when loss is considered in the DNUT calculation, the changes are not significant and the overall pattern of the LpTV values remains the same. The reason for this is that the DNUT calculation without loss penalization already accounts for certain aspects of loss (e.g., scenarios 7 and 8 penalize voltage limit violations that strongly correlate with loss as well), so the additional penalization for loss does not result in a significant change in the overall LpTV values. However, there are small changes in the LpTV values when considering loss in the DNUT calculation, and this effect might be emphasized with more significant penalization of loss.

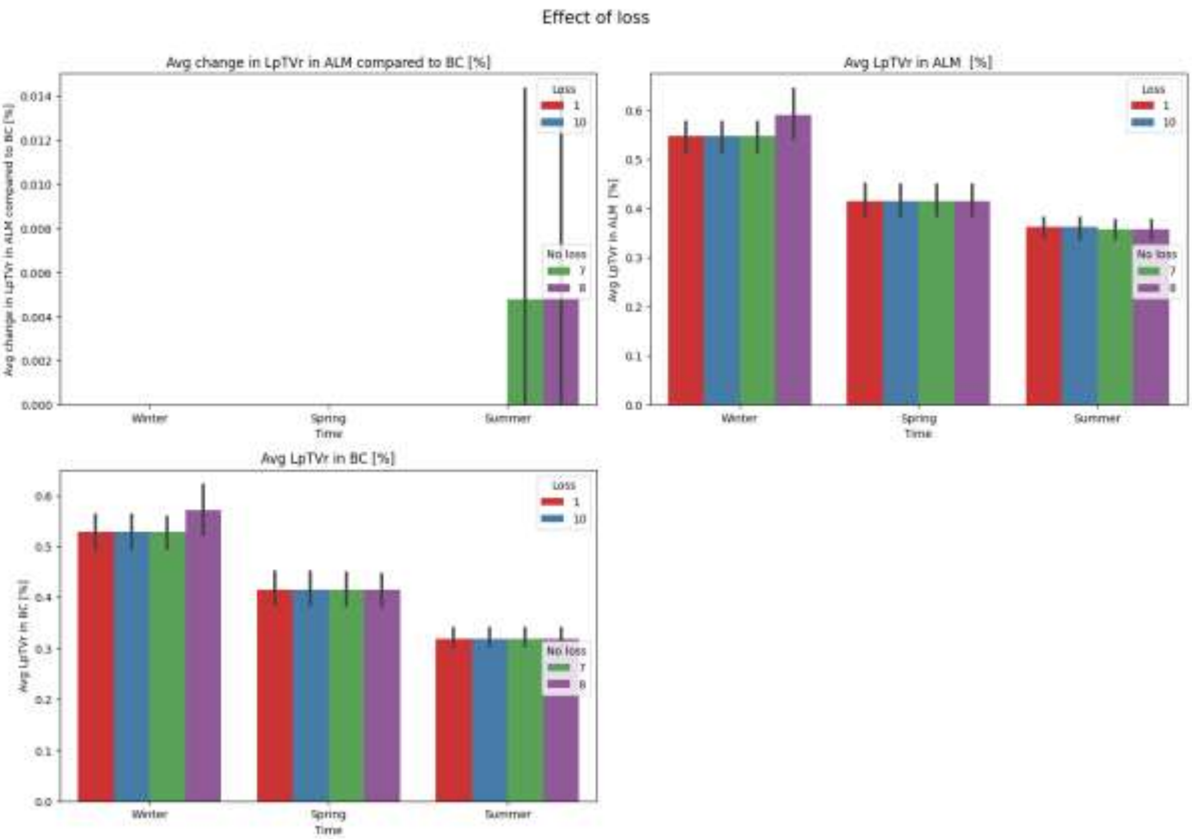

Figure 22: Besnica Loss per Traded Volume (LpTV) values with and without loss built into the DNUT.

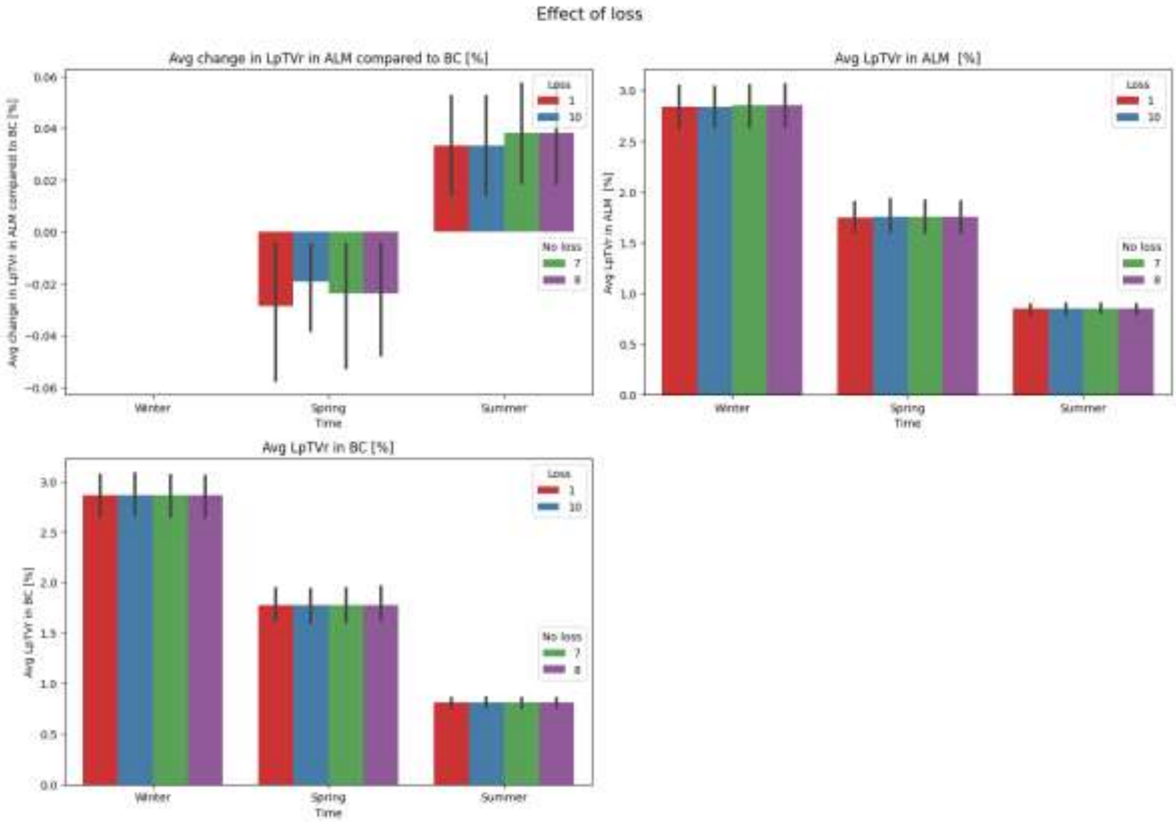

Figure 23: Gradisce Loss per Traded Volume (LpTV) values with and without loss built into the DNUT.

2.6.5 Effect of Voltage Regulation in the DNUT on local market activity

Figures 24 and 25 show scenarios representing different types of voltage regulation in the DNUT and its effect of local market activity.

The figures demonstrate that when a voltage regulation element is built into the DNUT (scenarios 7, 8, 10), there is no significant impact on local market activity compared to the baseline scenario (scenario 1) or compared to other scenarios without voltage regulation (scenarios 5, 6). However, when congestion management is introduced into the DNUT (scenarios 5 and 6), there is a small but noticeable reduction in local market activity, which is due to the limited variability of orders in terms of congestion management compared to order variability in terms of voltage deviation. These effects are based on the settings of DNUT cost elements, as linear costs for current and voltage changes were introduced.

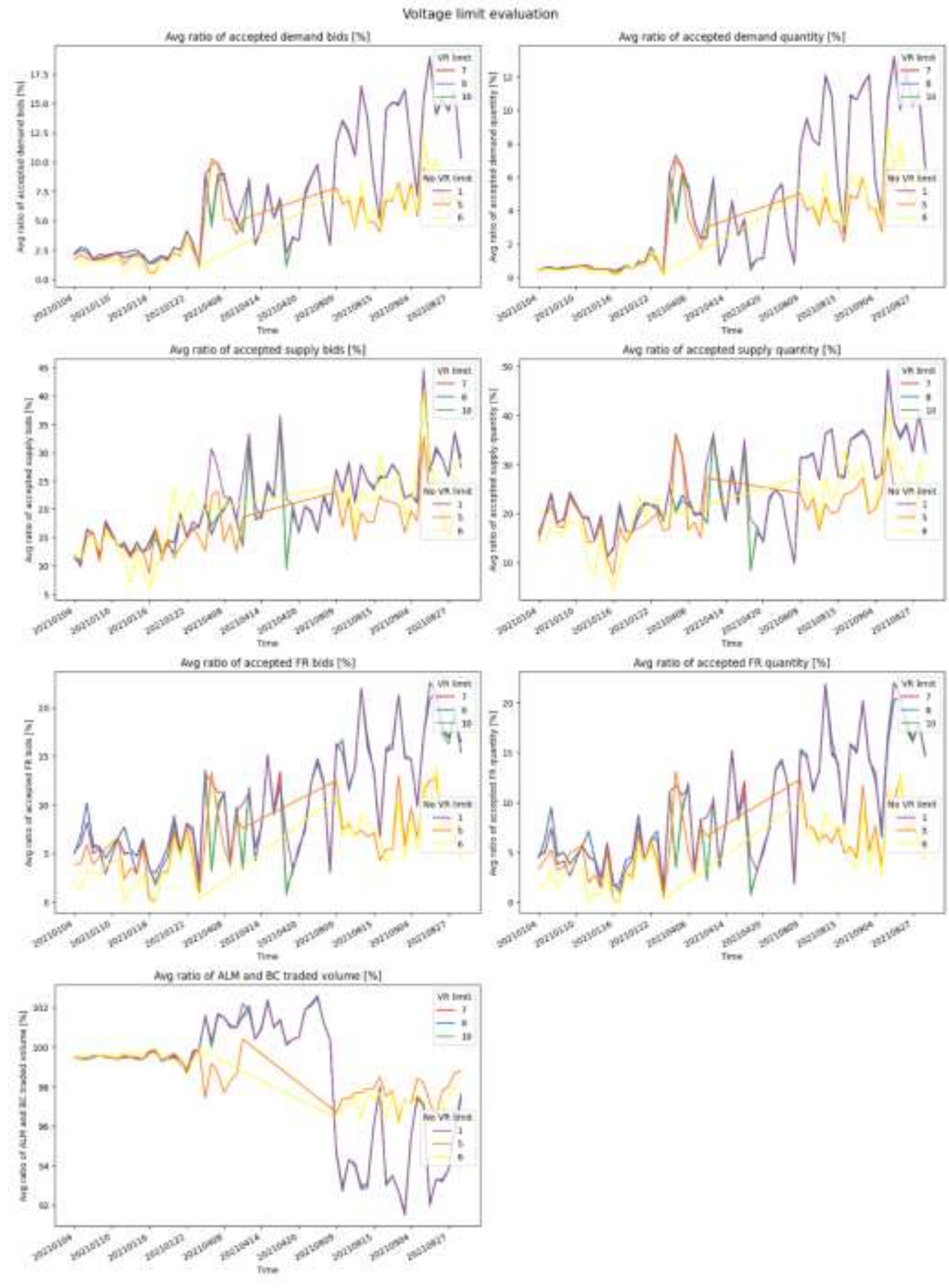

Figure 24: Besnica effect of active voltage regulation element built into the DNUT in terms of local market activity.

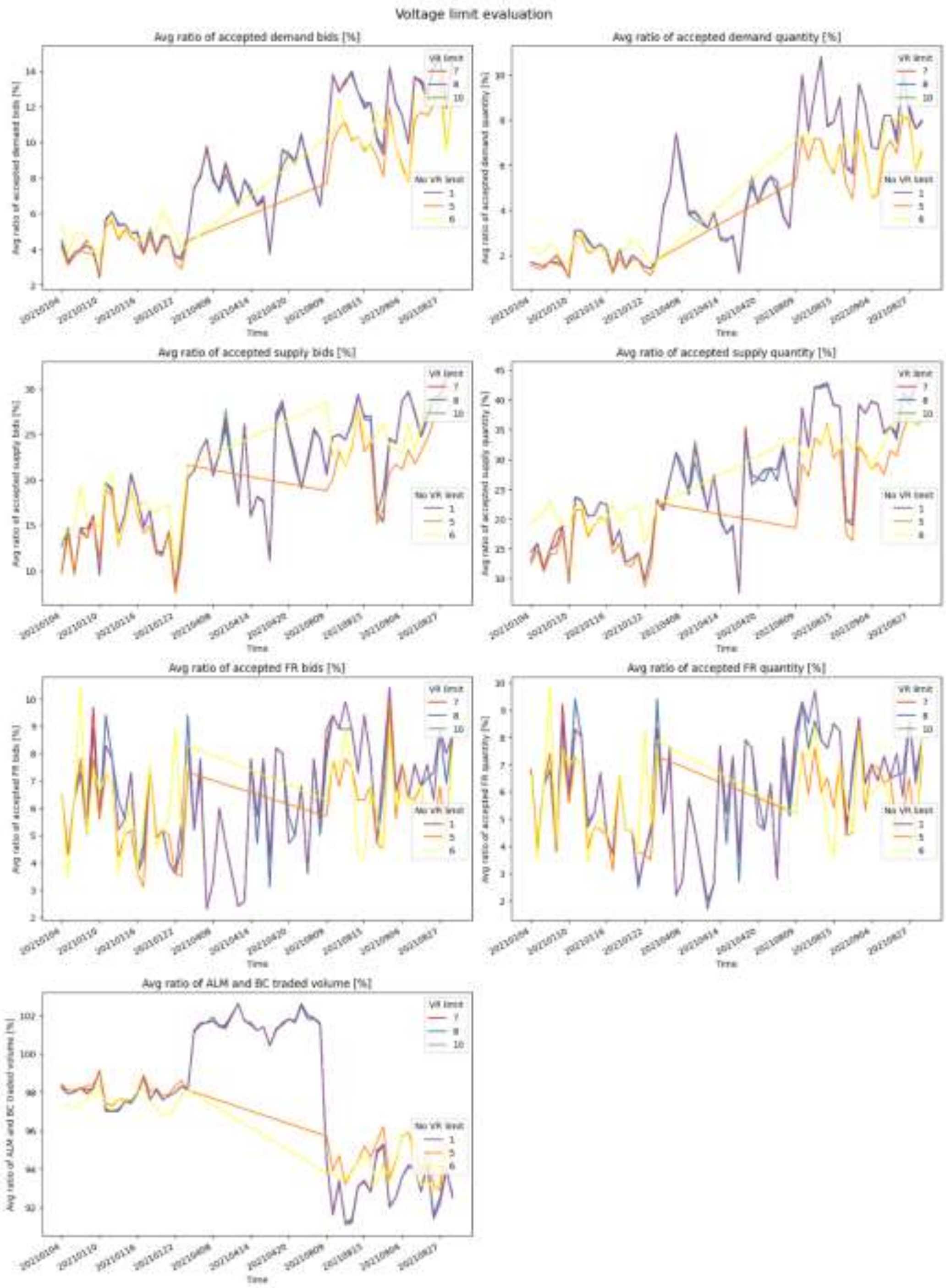

Figure 25: Gradisce: effect of active voltage regulation element built into the DNUT in terms of local market activity.

2.6.6 IACMS effect evaluation

The objective of IACMS was to allow increased energy flow through the assets, so as to not limit the operation of the local market.

The following tables summarize the inputs and outputs of IACMS for one demonstration week (4-10 January 2021) in the Besnica demo site.

Table 5: Input weahter parameters of the IACMS for the weeek beginning 4 January 2021

Weather Parameter	Average value for 7 days of the week	Min value for 7 days of the week	Max value for 7 days of the week
Ambient temperature (°C)	1.757	-0.6	4.6
Wind speed (m/s)	0.433	0.11	1.22
Wind direction (degree, most significant)	58.494	-	-
Solar radiation intensity (W/m^2)	150	150	150
Precipitation intensity (mm/h)	0	0	0
Relative humidity (%)	98.077	94.87	100
Rain	0	-	-
Snow	0	-	-

Table 6: Results of IACMS calculation on the transformer

Transformer	Value
Average rated load (kVA)	50
Average permissible load (kVA)	66.3636
Min permissible load (kVA)	65.1
Max permissible load (kVA)	67.4
Total excess energy over static load (kWh)	2749.08

Table 7: Aggregated results of IACMS calculation on cables

Cable	Value
Average rated load (A)	178.25
Average permissible load (A)	185.5553
Total excess energy over static load (kWh)	3401.16

Table 8: Aggregated results of IACMS calculation on overhead lines

OHL	Value
Static line rating (A)	160.5
Ambient adjusted line rating (A)	235.9971
Total excess energy over static load (kWh)	17574.80

Figures 26, 27 compare local market activity in Besnica and Gradisce for scenarios with and without IACMS active.

Figures 26, 27. show that the expected shortfall of line loading decreases in the Slovenian sites when IACMS is active meaning that line loadability in these cases is higher (with some exceptions including scenario 4 that has a very high market activity due to the DNUT sharing protocols). This highlights the benefits of using the IACMS tool, as it incentivizes safer network usage by providing more information about line loading and increasing market activity, making IACMS an essential tool for grid management.

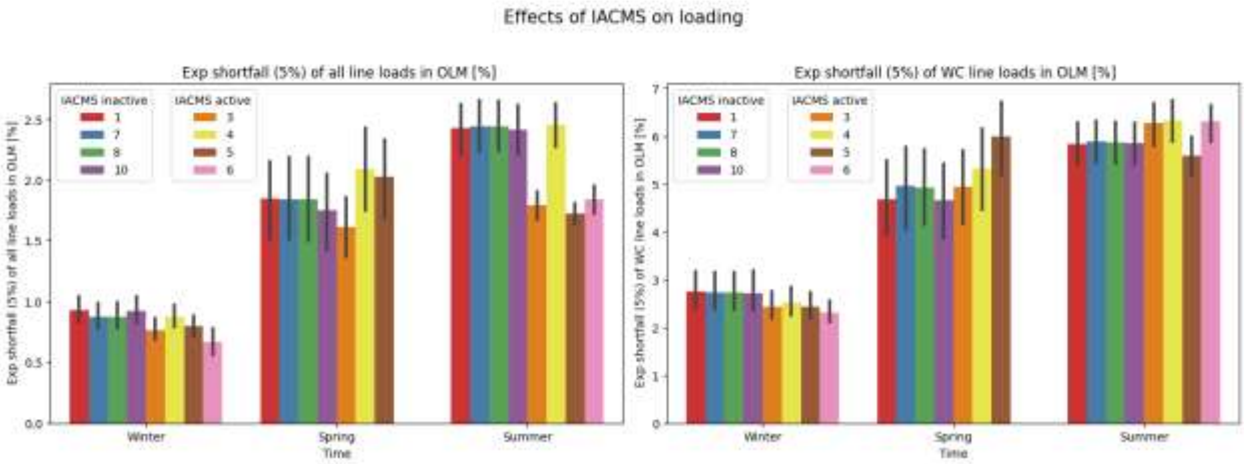

Figure 26: Gradisce: local market activity according to IACMS activity status demonstrated by the expected shortfall of line loading.

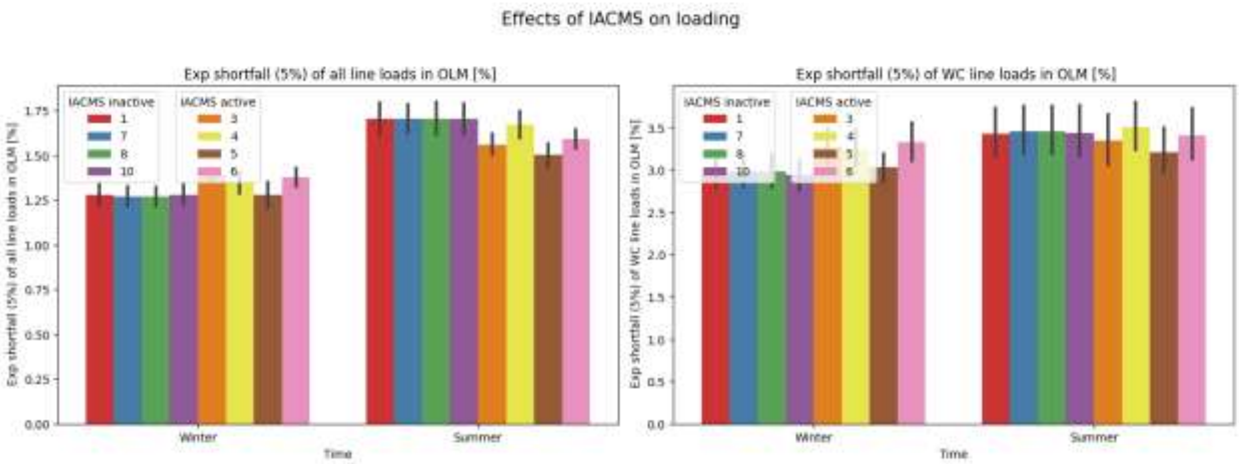

Figure 27: Besnica: local market activity according to IACMS activity status demonstrated by the expected shortfall of line loading.

2.7 Hungarian Pilot Sites

2.7.1 Congestion management

Figures 28 and 29 demonstrate the effect of the congestion management mechanism built into the DNUT at the Hungarian sites. The plots show the comparison between the line loads with (scenarios 5, 6) and without (scenarios 1, 8) the congestion management mechanism in place.

The results suggest that the congestion management mechanism built into the DNUT has a significant impact on the line loads only for Bóly demo site, as only this site had MV level model. However, for both sites, the line loads remain low throughout the analysis. This demonstrates that congestion management does not affect the overall loading when loading is already well under the limit.

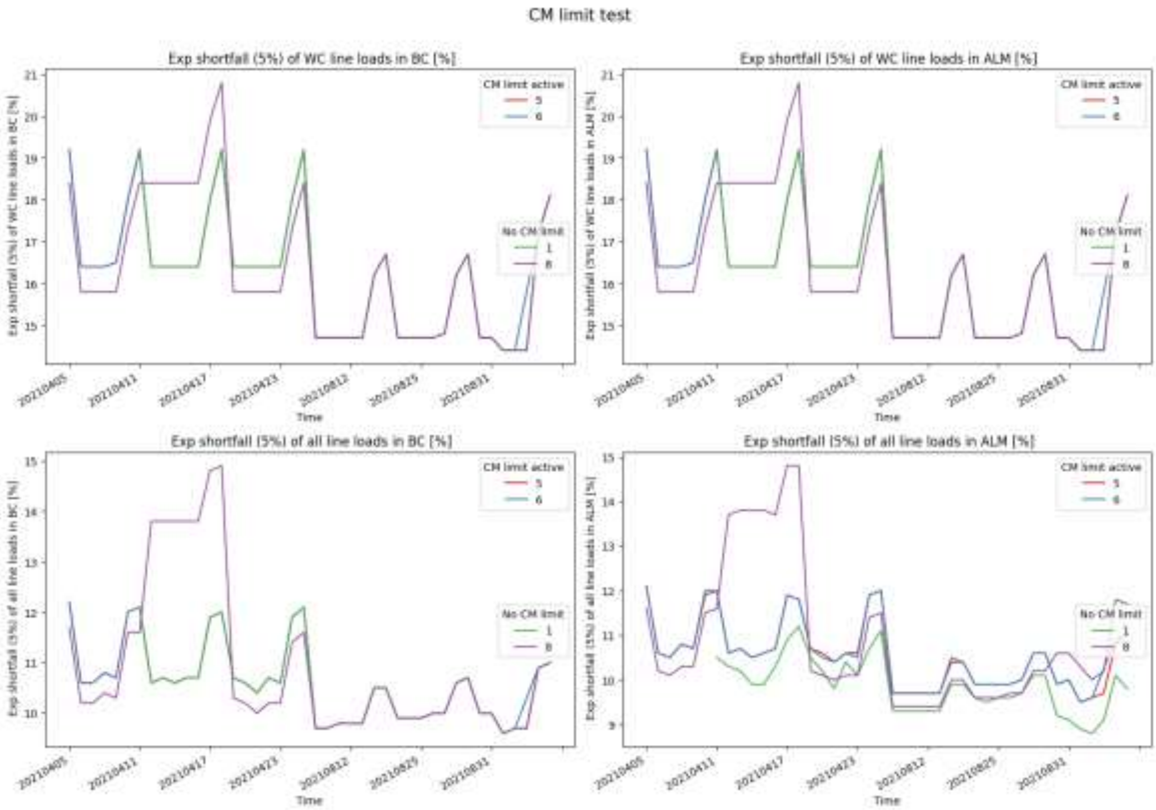

Figure 28: Bóly: line loads with and without congestion management built into the DNUT.

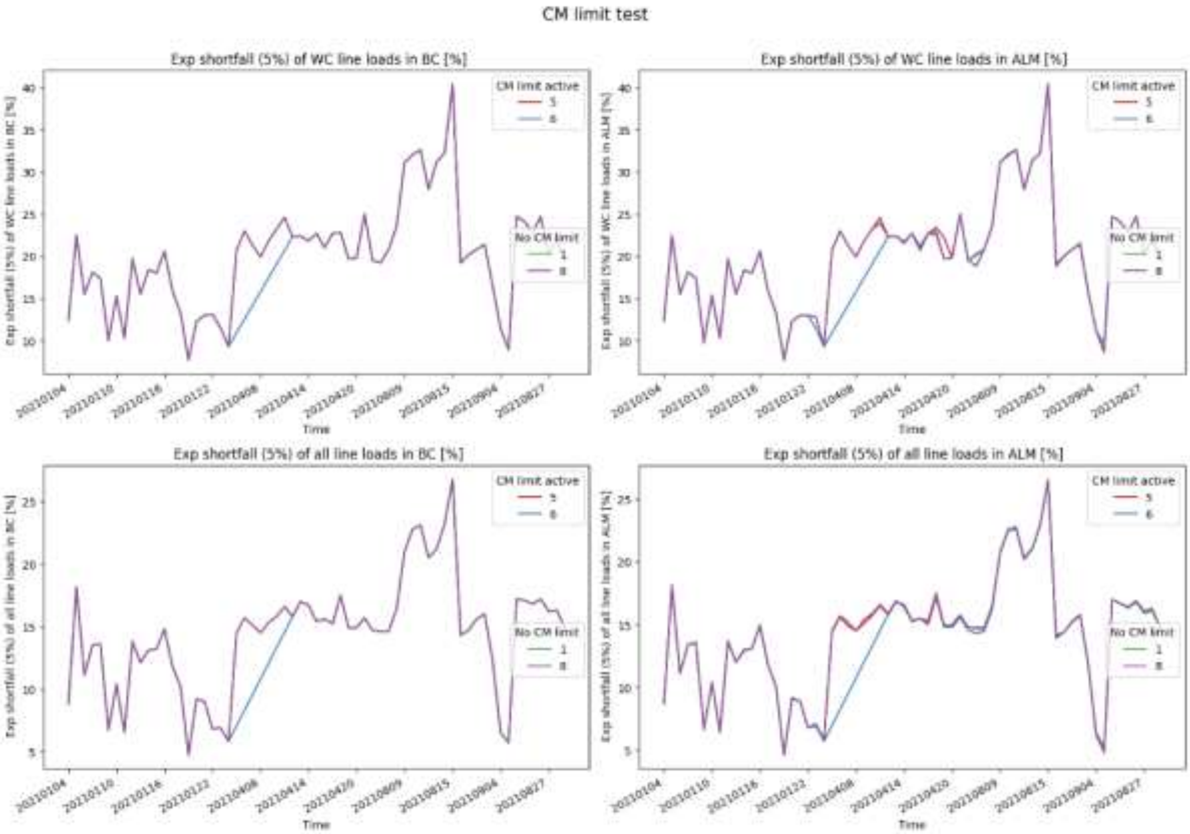

Figure 29: Zsombó: line loads with and without congestion management built into the DNUT.

2.7.2 Impact of Loss in the DNUT Calculation

Figures 30, 31 show different levels of penalization for loss in the DNUT calculation and the corresponding loss per traded volume (LpTV) values for the Hungarian sites. Scenarios 7, 8 show the LpTV values without considering loss in the DNUT calculation, while scenarios 1, 10 show the LpTV values with loss penalization in the DNUT calculation.

For the Zsombó site (Figure 30.), slight changes in LpTV values occur when loss is included in the DNUT calculation, but the overall pattern remains unchanged. This may be because the DNUT calculation without loss penalization already includes elements that correlate with loss (e.g. scenarios 7 and 8 penalize voltage limit violations), so adding more penalization for loss does not significantly alter the LpTV values.

For the Bóly site, LpTV increases with the loss of consideration in the DNUT. This paradox finding suggests that voltage limit regulation is a more effective tool for loss minimization when it comes to local market operation than directly penalizing estimated loss.

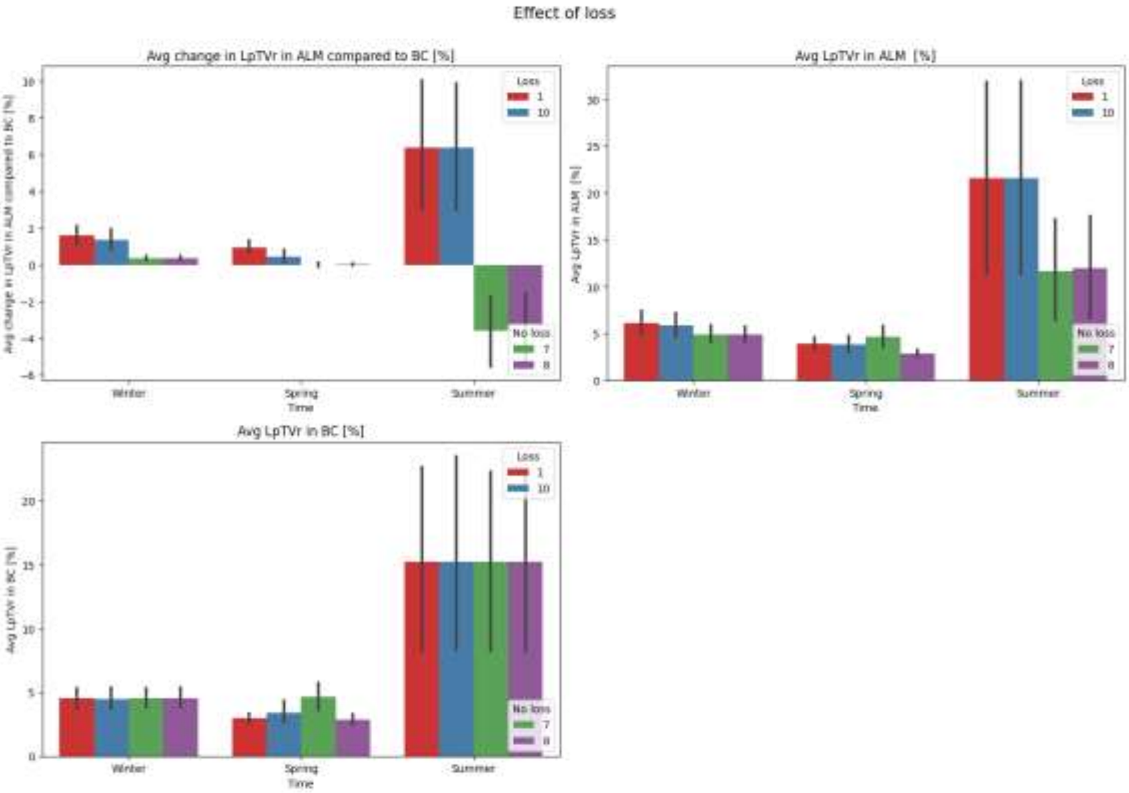

Figure 30: Bóly: Loss per Traded Volume (LpTV) values with and without loss built into the DNUT.

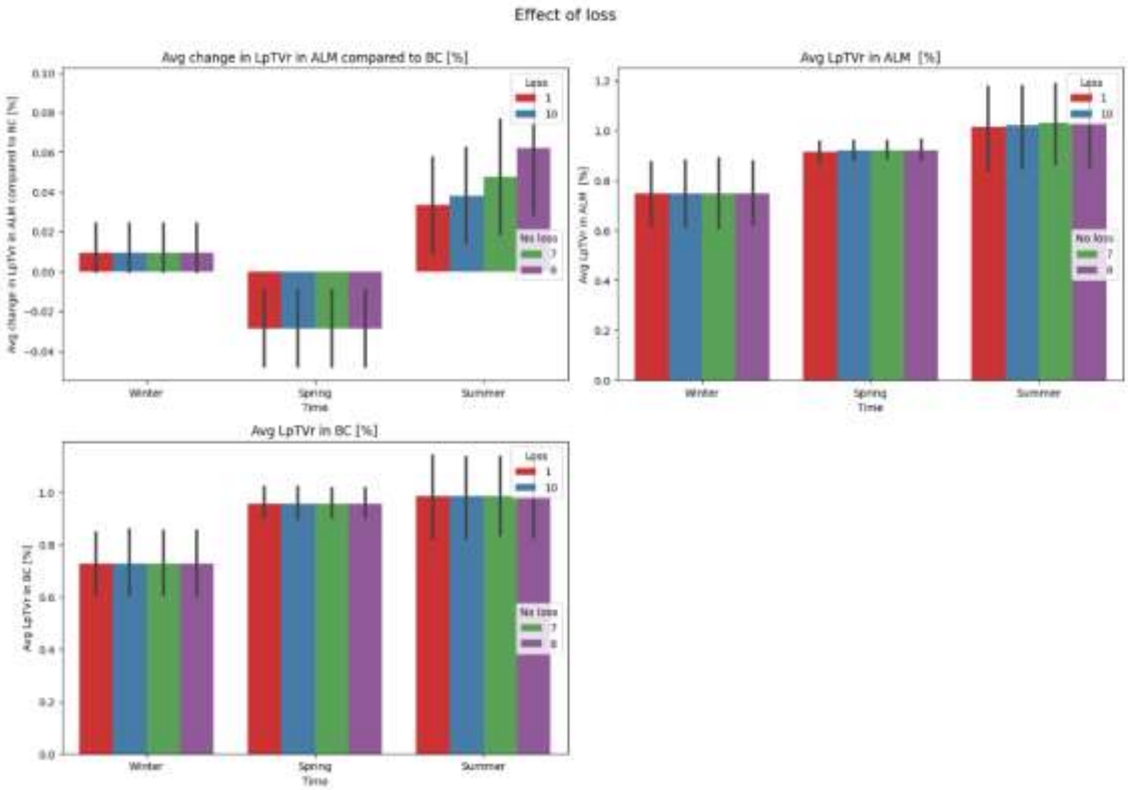

Figure 31: Zsombó: Loss per Traded Volume (LpTV) values with and without loss built into the DNUT.

2.7.3 Effect of Voltage Regulation in the DNUT on local market activity

Figures 32, 33 depict various voltage regulation scenarios in the DNUT and their effect on local market activity in Hungarian sites. The results indicate that when voltage regulation is incorporated into the DNUT (scenarios 7, 8, 10), there is no significant change in local market activity compared to the baseline scenario (scenario 1). However, scenarios without voltage regulation (scenarios 5, 6) that involve congestion management in the DNUT, lead to a noticeable decrease in local market activity, due to the price assigned to current increase. This highlights that congestion management results in less order variability compared to voltage deviation. This effect is more pronounced at the Bóly site due to its unique system characteristics, like Bóly's MV network part, where congestions are more incident resulting in the local market activity.

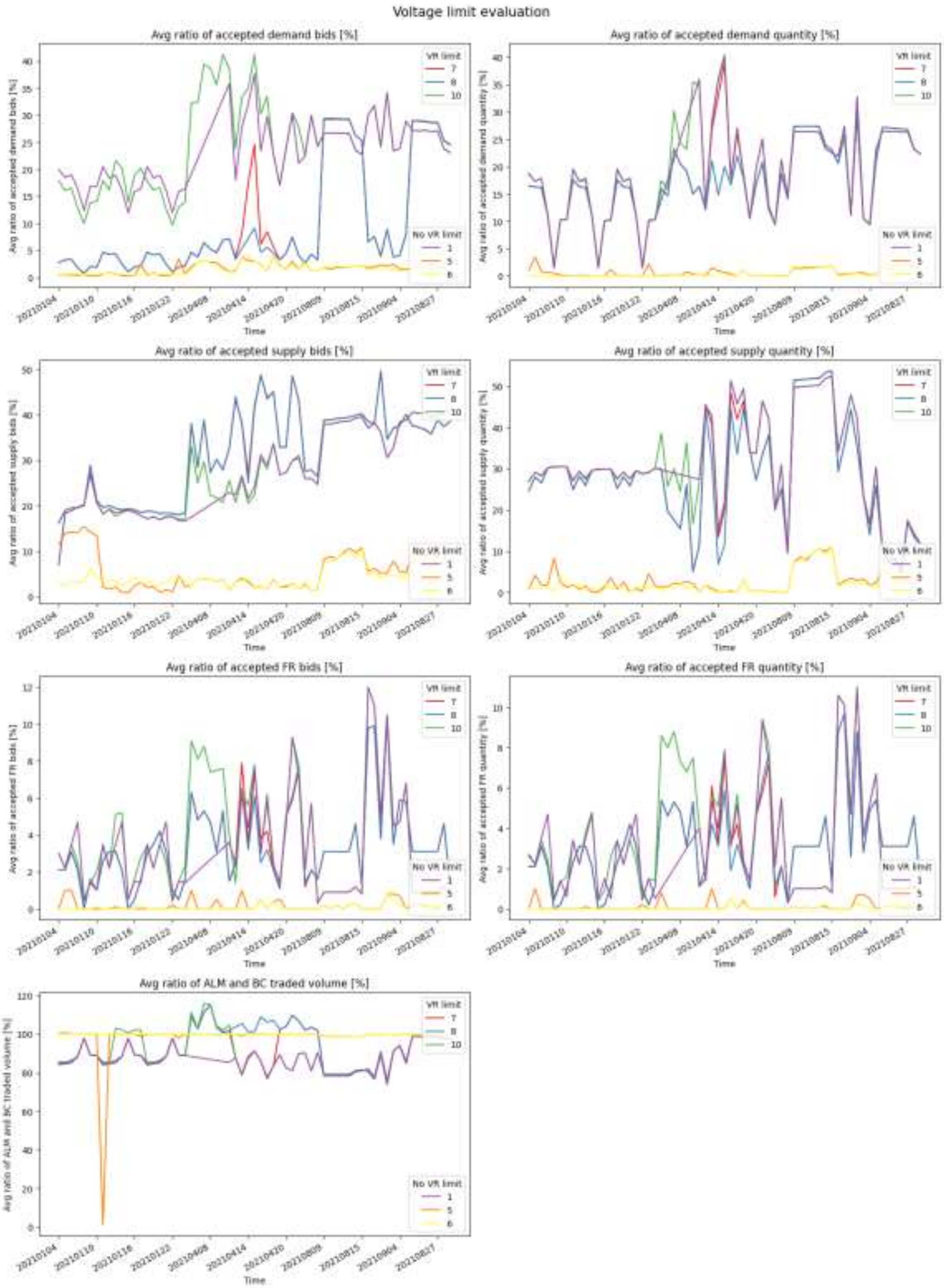

Figure 32: Bóly: effect of active voltage regulation element built into the DNUT in terms of local market activity.

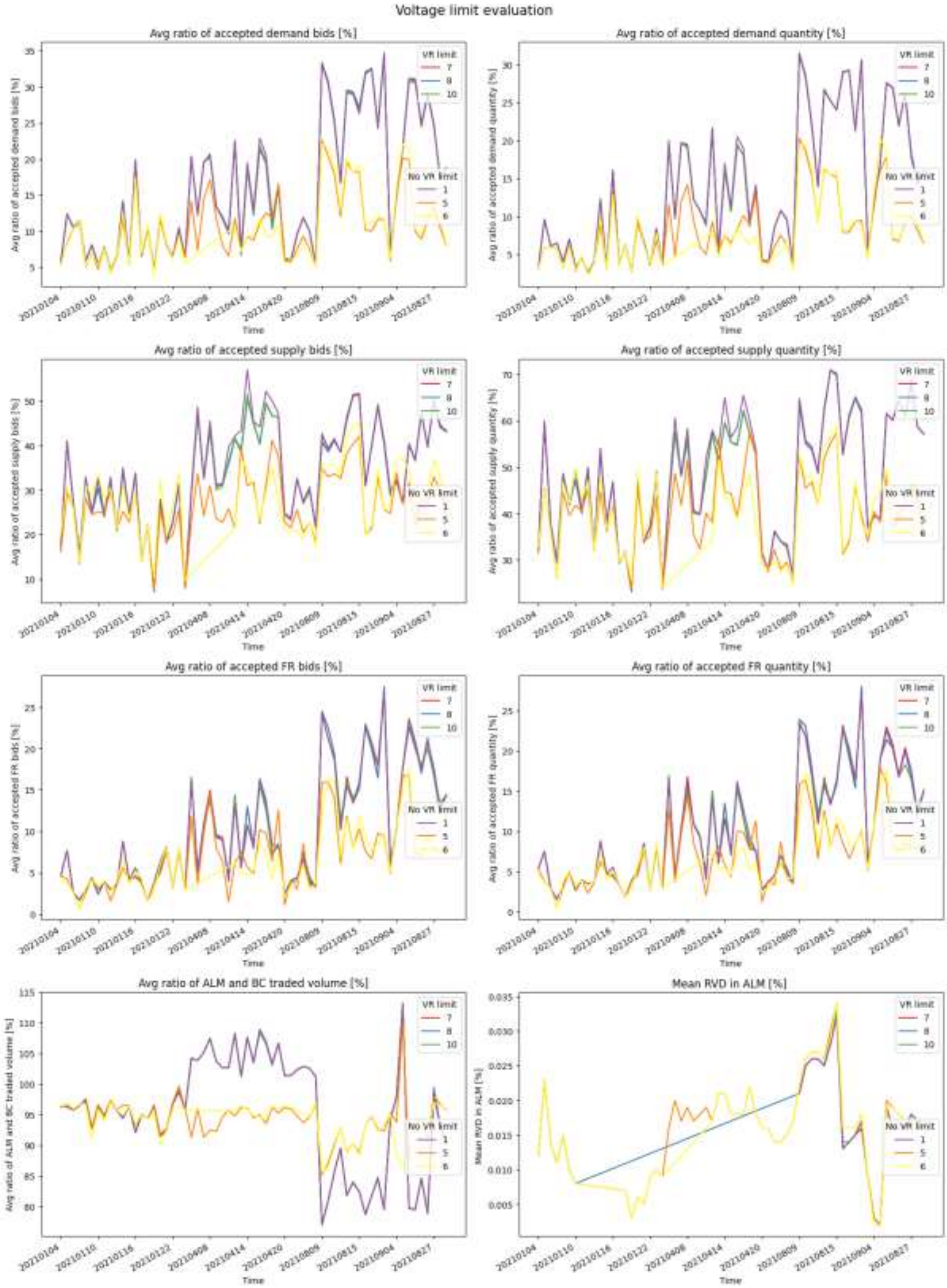

Figure 33: Zsombó: effect of active voltage regulation element built into the DNUT in terms of local market activity.

2.7.4 Battery operation at Zsombó site

The site Zsombó offered a unique testing possibility with a DSO owned battery energy storage system. Figure 34 shows the results from the scenario where the storage system operates as a market facilitator, providing bids on the local market. It increased the level of demand bid acceptance, while a bit altering the voltage in some cases.

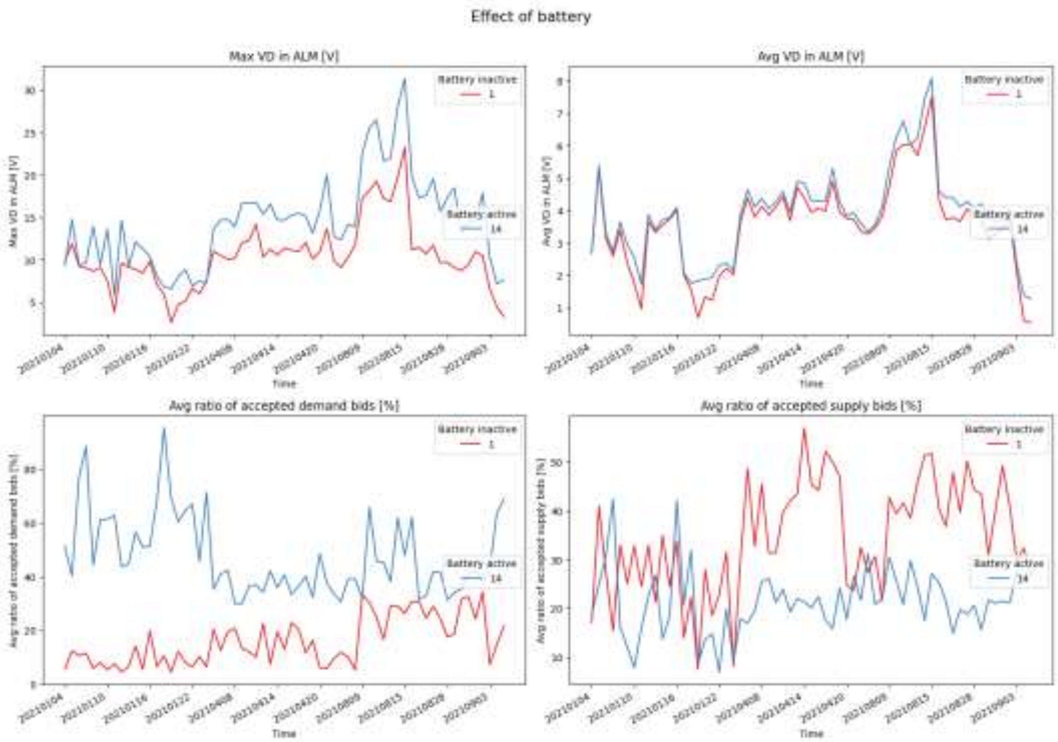

Figure 34: Battery as market facilitator at site Zsombó.

2.7.5 Effect of IACMS operation on local market activity

The objective of IACMS was to allow increased energy flow through the assets, so as to not limit the operation of the local market.

The tables below summarize the inputs and outputs of IACMS for one demonstration week (4-10 January 2021) in the Zsombó and Bóly demo sites. The Zsombó site features one transformer and only overhead lines, while the Bóly site features underground cables, as well.

Table 9: IACMS weather inputs at the Zsombó demo site, 4-10 January, 2021

Weather Parameter	Average value for 7 days of the week	Min value for 7 days of the week	Max value for 7 days of the week
Ambient temperature (°C)	4.971	-1.1	8.4
Wind speed (m/s)	1.079	0.44	1.97

Wind direction (degree, most significant)	52.554	42.12	74.88
Solar radiation intensity (W/m²)	150.000	150	150
Precipitation intensity (mm/h)	0.000	0	0
Relative humidity (%)	98.579	96.04	99.9
Rain	0.000	0	0
Snow	0.000	0	0

Table 10: Transformer IACMS calculation results at the Zsombó demo site

Transformer	**Value**
Average rated load (kVA)	400
Average permissible load (kVA)	505.95
Min permissible load (kVA)	494.88
Max permissible load (kVA)	525.32
Total excess energy over static load (kWh)	17800.32

Table 11: Overhead line IACMS calculation results at the Zsombó demo site

OHL	**Value**
Static line rating (A)	400
Ambient adjusted line rating (A)	498.355
Total excess energy over static load (kWh)	61138.01

Table 12: IACMS weather inputs at the Bóly demo site, 4-10 January, 2021

Weather Parameter	**Average value for 7 days of the week**	**Min value for 7 days of the week**	**Max value for 7 days of the week**
Ambient temperature (°C)	4.800	-0.5	9.3
Wind speed (m/s)	1.027	1	1.19
Wind direction (degree, most significant)	36.600	-	-
Solar radiation intensity (W/m²)	150.000	150	150
Precipitation intensity (mm/h)	0.000	0	0
Relative humidity (%)	97.316	95.19	99.06
Rain	0.000	0	0
Snow	0.000	0	0

Table 13: Transformer IACMS calculation results at the Bóly demo site

Transformer	Value
Average rated load (kVA)	400
Average permissible load (kVA)	506.51
Min permissible load (kVA)	491.92
Max permissible load (kVA)	523.44
Total excess energy over static load (kWh)	17894.4

Table 14: Cable IACMS calculation results at the Bóly demo site

Cable	Value
Average rated load (A)	230.75
Average permissible load (A)	309.25
Total excess energy over static load (kWh)	1827382.88

Table 15: Overhead line IACMS calculation results at the Bóly demo site

OHL	Value
Static line rating (A)	289.67
Ambient adjusted line rating (A)	444.71
Total excess energy over static load (kWh)	338242.42

The effect of the IACMS on the trading activity can be followed on the following figures.
Figures 35, 36 show the operation of IACMS at Hungarian sites, demonstrating how it decreases the expected shortfall of line loadings by increasing dynamic loadability. This is due to IACMS providing crucial information to enhance market and network management, making it an essential tool for ensuring the stability and safety of the electrical grid. The only exception is scenario 4 where DNUT sharing protocol permits transactions even with high line loading. Summer is the busiest season for the market due to a high number of photovoltaics.

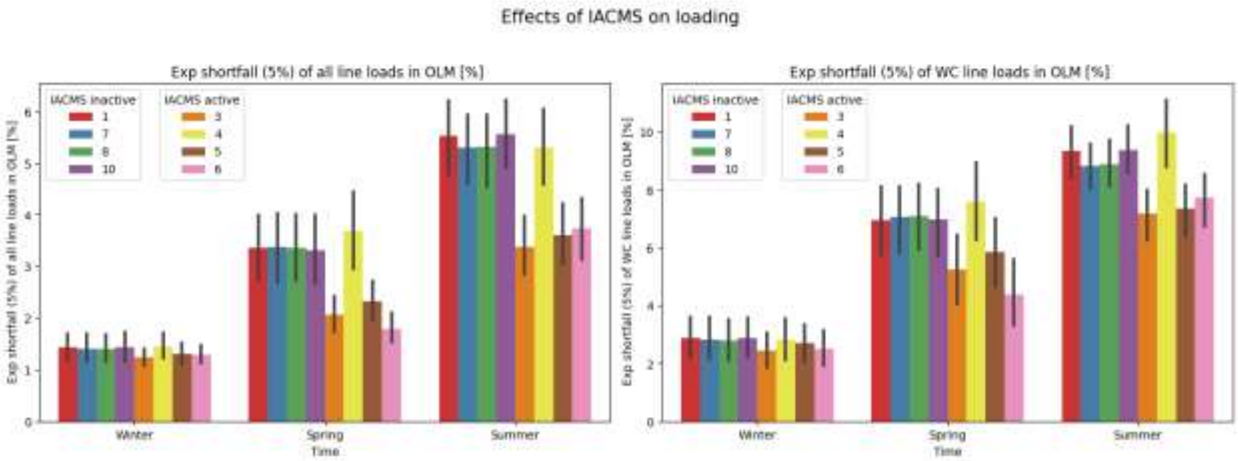

Figure 35: Zsombo: local market activity according to IACMS activity status demonstrated by the expected shortfall of dynamic line loading.

Figure 36 illustrates the impact of IACMS information on market activity at the Bóly site. For Bóly, analysis was carried out only for the spring and summer periods. The IACMS's market enhancing effect is also noticeable at the Bóly site. This site, due to its specific system characteristics, such as the higher frequency of congestions in the medium voltage network, can benefit from more accurate information on line loadability as demonstrated below.

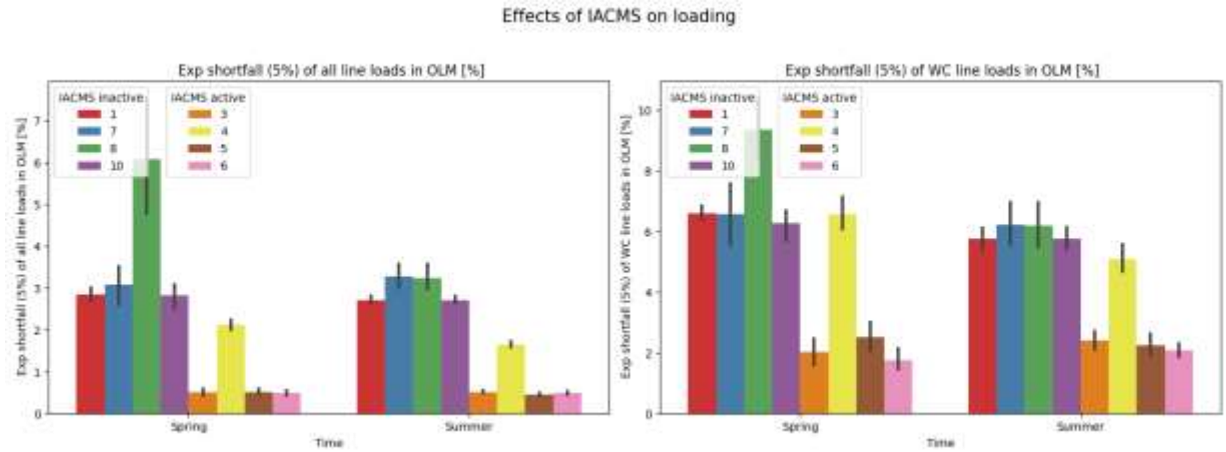

Figure 36: Boly: local market activity according to IACMS activity status demonstrated by the expected shortfall of dynamic line loading.

2.8 Summary of the P2P market result, relevant for all pilot sites

The integration challenges of renewable energy transform the entire value chain of the power sector. The future market model can be differentiated on several levels: it could be dependent on the amount of energy, transmission distances, the number of participants, etc., but the decentralization is inevitable. Local energy generation is becoming widespread nowadays, not only for economic reasons, but also as a representation of independency and decent behavior. Peer-to-peer (P2P) markets aim to provide trading opportunities between a large number of market players, even when buyers and sellers are fragmented. Also, auctions on P2P markets are a flexible solution, allowing prices to respond to market conditions. This local market structure is appropriate to enhance the customer's access to new energy-related market activities, which therefore could play a part in the energy transition. The players on this marketplace shall submit their bids (if they are buyers) or asks (if they are sellers). These shall include information on the quantity of electricity and the network connection point where the exchange will take place. Consumers may buy electricity from sources different than their local retailer and can also offer their household generation for sale. The introduction of this market structure is feasible in parallel with the conventional one. There is a possibility to handle services through such P2P markets. If the trading is not done between two consumers, but between a consumer and a DSO, the DSO can create a group of bids and asks, thus creating means of flexibility. Such flexibilities can either be used by the DSO for grid services or aggregated/forwarded to the TSO, depending on the wholesale TSO-DSO coordination scheme. The DSO and the TSO also participate in the market, and they can both behave as bidders: by specifying and pricing their flexibility needs (and the price they are willing to pay for it), they can enhance the utilisation of local sources. This latter aspect is also necessitated by the merging of traditional DSO and TSO operations, which converge previously separated tasks, thus the demonstration could provide a way for testing this aspect as well.

This marketplace is based on the P2P concept and provides the possibility to create local energy transactions by simulating the behaviour of market participants in line with different bidding strategies from previous research. The load and generation datasets are derived from DSO databases to create realistic reference situations. Then the effects of the different bidding strategies can be analysed. The demonstration aims to examine the cooperative use of these two elements of the toolset. 3 DSOs are involved, 2 from Hungary and 1 from Slovenia. The DSOs offered unanimous measurement data about the demonstration locations and provided inputs to create a new dynamic network usage tariff (DNUT). The concept of dynamic tariff based on forecasting the constraints by network calculation is not widely implemented in practice. Integrating such solution with the P2P concept is generating new ideas as frameworks are being developed. In these demonstrations, prosumers can buy and sell electricity either from this local market (P2P context) or from the retailer in the already existing framework. In addition to the P2P context, the project proposed a novel dynamic network usage tariff scheme (DNUT). The grid fees for each transaction are calculated by the actual effect on the infrastructure (losses, voltage limits, overload, asymmetry effects considered). To calculate such, the project developed a modelling approach tailored for medium voltage (MV) and low voltage (LV) networks, which is appropriate for steady-state analysis. Since P2P markets have a large number of expected bids, and the calculation must pair a DNUT (grid effect) to each bid, a sensitivity-factor based simplification is proposed instead of running a large number of load flows. With these tools, end users can behave as “market participants”, dynamic pricing can be used efficiently, and the effects of network asset constraints can also be taken into consideration. Data used for the demonstration will be provided by affected DSOs, while the behaviour of consumers is to be examined by the involvement of consumers in the affected DSO service areas. The demonstration focuses on upscaling the role of customers and creating new services and market rules within the local marketplace. These tools will be part of the Interoperable pan-European Grid Services Architecture (IEGSA); thus, their collaborative operation could be demonstrated, and mutual benefits could be exploited. The IEGSA has to provide an interface for consumer participation, an access for DSOs, and a pool for asset condition data.

Most of the output variables have not shown any sign of change, depending on the characteristics of each scenario, and even those, that did, further investigation would be needed.

Presented variables give significant information (loss, voltage deviation, etc.) about how the network would respond to each trading scenario, but as it is presented in the previous chapters – a minor of them had shown any signs of changes during the aforementioned scenarios. This leads to a conclusion, that the trading does not have any significant impact on the network, which is very possible, because the number of local RES is low.

The results presenting voltage deviations need further analysis, because results of both grids and also the results of scenarios give unexpected values.

2.8.1 Transparency in data and communication

During the demonstration the sensor usability was ensured in IACMS module. The IEGSA platform connection via interfaces were effectively developed and implemented. The beforehand mentioned and detailed running results proving the business rationality of the P2P local market concept. This complex and international cooperation seemed to be a success story in spite of difficulties.

2.8.2 Scalability

The approach of asset-enabled local market platform is demonstrated to be an effective tool for various, differently designed DSO operational environments, and distribution grid sections. The applied methodology can be thus used in any, non-looped, tree-like distribution network, to solve various grid service requirements. The ease of use of the energy product based bidding can deliver benefits for multiple stakeholders, system operators, individual and aggregated grid users, and can further provide an entry point for higher level (system balancing) of local flexibility aggregation. This approach is recommended for further usage as a single solution can be of use for a multitude of scenarios, local specialties, with single aimed, or combined use cases.

2.8.3 Use cases for participants

Different use cases were tested, and can be further included, on the basis of energy product biding.

- DSO congestion management – as a distributed marketplace helping congestion alleviation
- Settlement platform for energy communities, with usage tariff markups providing a single channel for multiple incentives
- Providing local balancing
- Peer-to-peer trading with grid tariff incentive
- Incentivizing self-reliance of network areas – moving towards autonomous microgrids

2.8.4 Conclusions

This demonstration described a P2P local market concept which is applicable for distribution networks. The opportunities with the proliferation of such local P2P markets were described. The INTERRFACE simulation framework was introduced from the viewpoint of demonstration analysis. The basic concept of the market operation and DNUT was presented. Thanks to the dynamic network usage tariff (DNUT) facilitating transactions which result in desired flows according to the actual state of the distribution grid, several measures describing the efficiency of operation are expected to improve during the simulated operation of the local market. The loss compared to total trading volume is expected to be reduced. Line congestions and near-overload of system components (e.g., transformers) are expected to be alleviated, in an ideal case, the load of the network will be more balanced. Voltage regulation measures are expected to improve (in the case of the corresponding DNUT calculation – the DNUT does not always include elements related to voltage stability). The results showed that the framework is capable of providing data for evaluation of the local P2P market. However, in the first scenarios, there are not large differences due to the bidding strategies. Further analysis with increased activity could show the potential of the developed tool. The proposed local energy market provides an opportunity for participants to translate their flexibility potential to local transactions financially beneficial for them. If a consumer participant is ready to reschedule some of its peak load, and energy is available at the local market at an appropriate price, the peak-shaving of overall consumption patterns may be realized via the result of such transactions.

3 Blockchain-based TSO DSO flexibility (T6.2) - Evaluation of the results of the demonstration

3.1 Scope

An objective of this demo is to create an intelligent flexibility platform (EFLEX) with Blockchain-based technology, which is scalable to be applicable in the whole of Europe, allowing trading of flexibility services among prosumers TSO and DSO. Blockchain technology was adopted as a means for secure, reliable and transparent cooperating agreements and information sharing exploiting its decentralized approach. Within this task a common structure of rules will be set in coordination with WP4, based on Balancing network code, the Capacity Allocation and Congestion Management (CACM) guideline. This demo tested a prototype, developed by EMAX, for the TSO-DSO flexibility market with Blockchain based, smart contracts and smart billing.

A 3-phase approach was pursued to enhance a prototype for flexibility market with Blockchain based, smart contract and smart billing, as follows:

- development of a custom prototype where basic use cases can be simulated and where market players are invited to test,
- evolution to a Minimal Viable Product (MVP), capturing the fundamental functions and architecture of the platform and,
- initiation of a continuous growth cycle by checking the use cases of the different players (Prosumers, TSO and DSO), the transparency in data and control and by validating the correctness of transactions (in the market/procurement process) and the transaction capacity, automatic level and speeds of market/procurement process.

Sub-tasks include setting-up technical requirements and flexibility market arrangements for the test case, enhancing a prototype for flexibility market with Blockchain, including proof of concept, and demonstrating TSO-DSO procurement for flexibility.

With the vision to demonstrate a blockchain-based flexibility market platform where flexibility services are traded amongst TSOs, DSOs, and prosumers, there are four main tasks for the EFLEX platform:

- Evolution from Minimal Viable Product (MVP) deployment to public test network.
- Preparation for demonstration in test sites.
- Initiation of a continuous growth cycle.
- Testing and verification.

The outcome of the EFLEX should be as follows:

- A reliable platform, where TSOs, DSOs, and market players come together and trade flexibility services in a transparent and cost-effective manner.
- The platform is scalable and replicable.

3.2 Focus

This demo demonstrates a flexibility marketplace under T6.2 in Bulgaria and Romania supporting:

- Congestion Management:
    - Provide solutions to reduce network overload.
    - Reduce investment in costly hardware/network upgrades.
    - Enable participation of flexibility assets on the distribution grid level to ensure system stability.

- TSO-DSO Coordination:
  - Validate the viability of data transfer between TSO and DSO.
  - Avoid double activation of flexibility asset through sound coordination and effective signaling.

3.3 Current market scenario

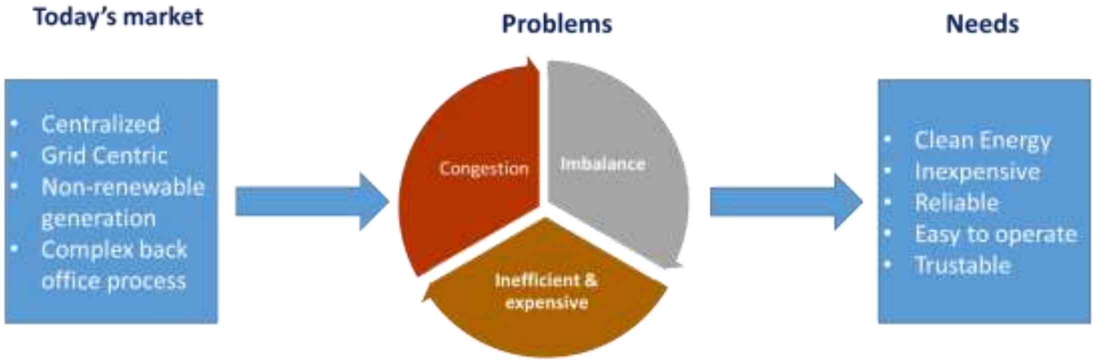

Figure 37: Current market scenario

As shown in the above Figure 37, the current electricity market is centralized which relies on non-renewable energy generation, multiple entities and complex processes. This inefficiency leads to not just increased price and time but heavy impact on climate too. With this approach the electricity market faces congestion and imbalance related issues.

3.3.1 Problems of System Operators

Below are few points that outlines the problems mainly faced by the system operators,

- Difficult to hold system security and need flexibility services for network operation.
- Conflict while procuring flexibility services from DSO connected resources.
- No framework to sell where they can maximize gaining.
- Traffic light system for DSO was introduced but not evident in reality.

3.3.2 Solution

The solution is decentralized market and a platform to support change from 'Grid centric' to 'Customer Centric'. With this approach energy can be utilized from renewable sources providing opportunity to the prosumers engaging them in clean energy production and earn revenue too. An additional benefit is not necessary to install expensive infrastructure to support clean energy generation.

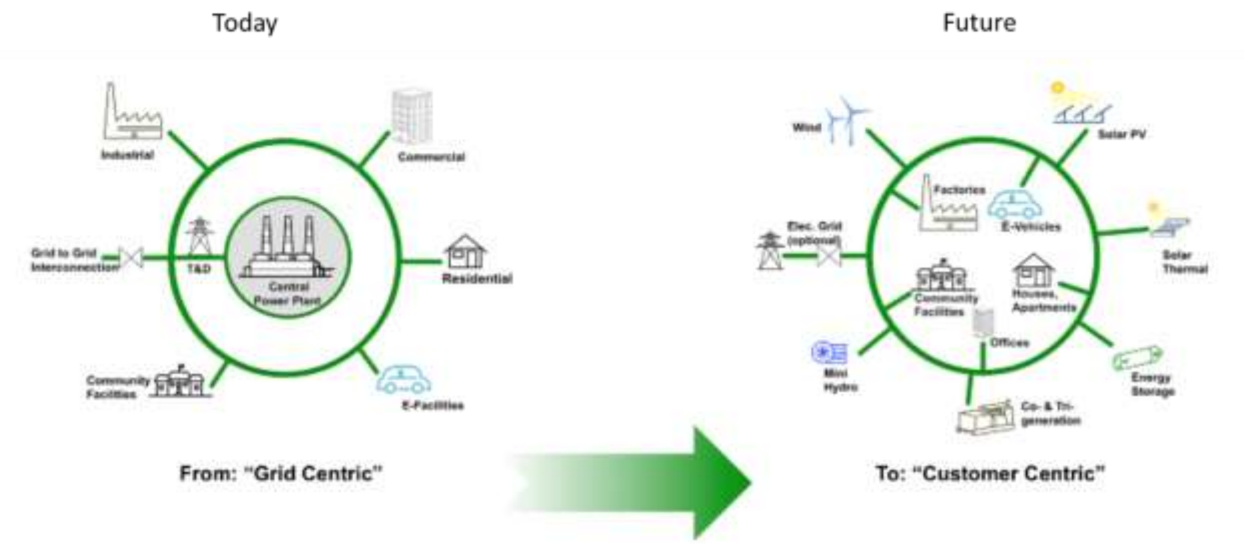

Figure 38: Grid vs Customer centric

3.3.3 Methodology

Decentralized market which promotes clean energy, direct trading and coordination between the stakeholders can be achieved using innovative technologies like blockchain and IoT.

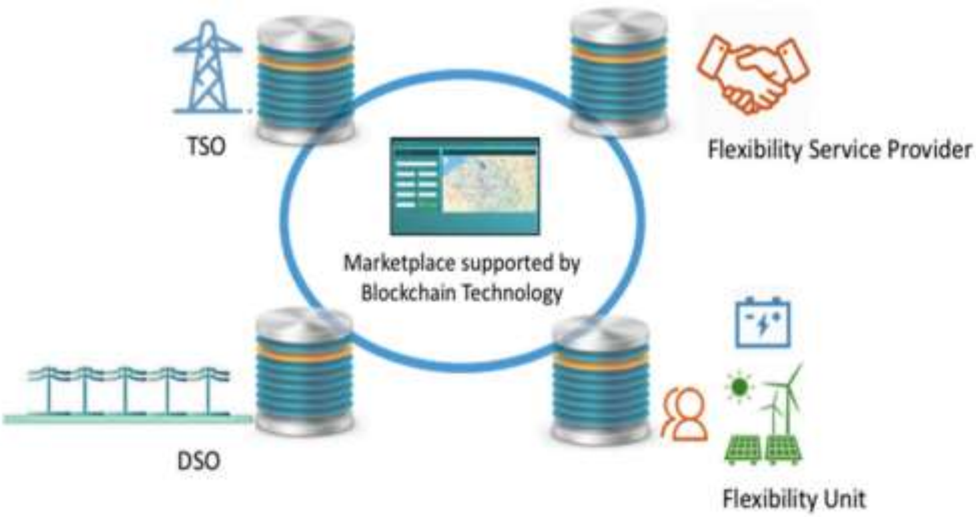

Figure 39: Energy Marketplace with blockchain technology

3.3.4 Why blockchain?

Blockchain is public and accessible to all, it is scalable, it is secure since data is encrypted and the transaction settlement happens faster in seconds. Additionally, it:

- Optimizes processes and thus lowers energy bills for consumers
- Brings greater market transparency
- Creates local value and strengthen prosumers
- Enables simpler transactions and brings automation

- Enables enhanced security and data integrity

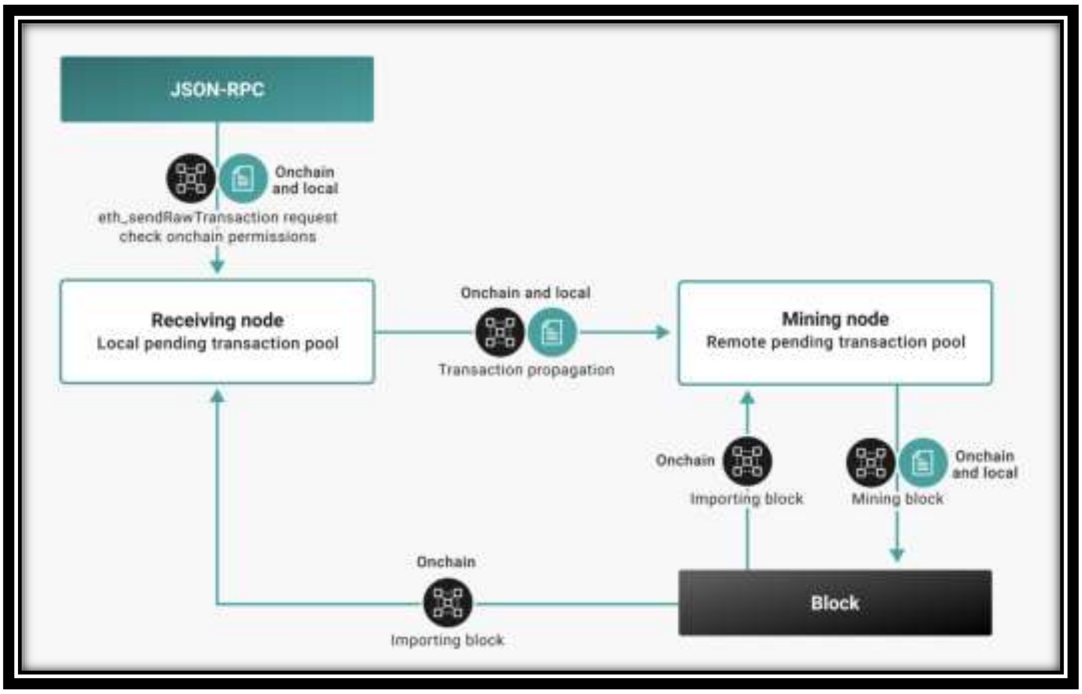

Figure 40: Blockchain network architecture

3.3.5 EFLEX architecture incorporating blockchain

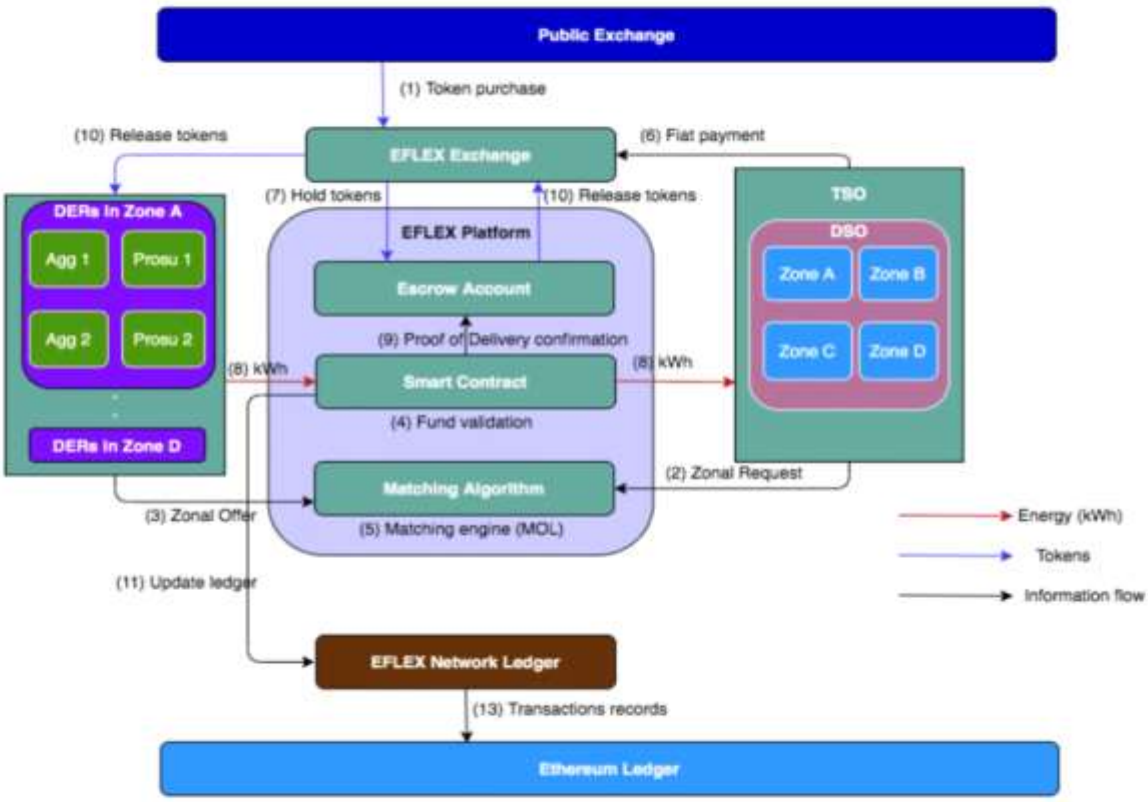

Figure 41: Eflex architecture incorporating blockchain

The Eflex architecture incorporated with blockchain and IoT is safe, secure and easy to use. The architecture is designed to avoid double activation with the help of smart contracts and distributed ledger technologies. The entire system is transparent yet secure with authentication and role-based access mechanism. It is designed to support automatic matching with the help of in-house matching algorithms.

3.4 Blockchain and Transaction Evaluation Metrics

Blockchain metrics are used to measure the quality, performance and scalability of blockchain applications.

The following are common metrics,

3.4.1 Blocks Per Hour, Blocks Per Day

These metrics measure the speed at which records are submitted and stored on the blockchain network and how fast the network can carry out its consensus algorithm. Because the capacity of a block is fixed, the quantity of blocks processed can be calculated accordingly.

Every block that is created has a timestamp. The timestamp in the blockchain system can measure how many blocks are created and added during specified time periods, such as per hour or per day. The results of these measurements help assess the performance and scalability of the blockchain system.

3.4.2 Transactions Per Second

This metric is used to measure the quantity of records or transaction records submitted and stored per second. It is used to assess the volume of processing a blockchain network that is undergoing and to judge its scalability requirements.

3.4.3 Transaction Latency

This metric is used to measure the time from which a transaction is submitted to the network until the time that the transaction has been written to the ledger (or rejected). This metric is measured by checking the timestamp of transactions and comparing the time they were submitted to the time they were validated and stored. This metric can also provide insight as to how fast consensus algorithms are being carried out.

3.4.4 Transaction Throughput

This metric is used to measure the time it takes for valid records to be appended to blocks. The total number of committed and validated records is divided by the total amount of time (in seconds) it takes to commit (validate and store) those records.

3.4.5 Full Node/Partial Node Ratio

This metric is used to measure the quantity of active full nodes and partial nodes on a blockchain network. This measurement is important because if a blockchain network ends up having no active full nodes, it can lose the historical data in the full copy of the distributed ledger. Because of the critical importance of maintaining sufficient redundant copies of the distributed ledger, this measurement is closely tracked.

3.4.6 Energy Efficiency

Though not directly a network performance indicator, energy efficiency plays a crucial role considering the scarcity of energy across the globe and how consensus around saving it is rising worldwide. A blockchain requires a certain amount of energy to function, basically to validate, process and store transactions. The amount of energy consumed here depends, to a great extent on the consensus mechanism employed.

While most major blockchains use Proof of Work (PoW), a high-energy consuming model, various newer blockchains rely on more advanced and low-energy consuming Proof of -Stake (PoS) or Proof of Authority (PoA) models.

Table 16: Comparison of blockchain technologies based on metrics

Metrics	**Bitcoin**	**Ethereum**	**Hyperledger Fabric**
Blocks per day (avg)	~144	~20,000	~20,000
Transactions per second	~7	~100,000	~3000
Transaction latency	~10 minutes	~12 seconds	~12 to 14 seconds
Energy efficiency	PoW (high energy)	PoS (99.95% less energy)	PoS (99.95% less energy)

Based on the above comparison metrics it is evident that Ethereum 2.0 is better than other blockchain platforms. In addition to that, the language/platform support to develop applications on top of the platform is much better in Ethereum.

After thorough research, EFLEX platform is developed on the Goerli Testnet (Ethereum 2.0) which is scalable, secure and processes transactions much faster, making it suitable for peer-to-peer energy trading.

3.5 Activities of demonstrator

3.5.1 Authentication

Flexibility service providers (FSPs) / DSOs / TSOs install Metamask wallet extension to their browser (Chrome or Firefox) and acquire test tokens for transactions. This step enables simple and smart token-based micropayments thereby reducing the intrinsic market entry barriers for distributed generators and other flexibility assets (electrical loads, storage, EVs) and increasing overall market efficiency. Once wallet extension is added users can register themselves on EFLEX marketplace and configure their needs and submit requests / offers.

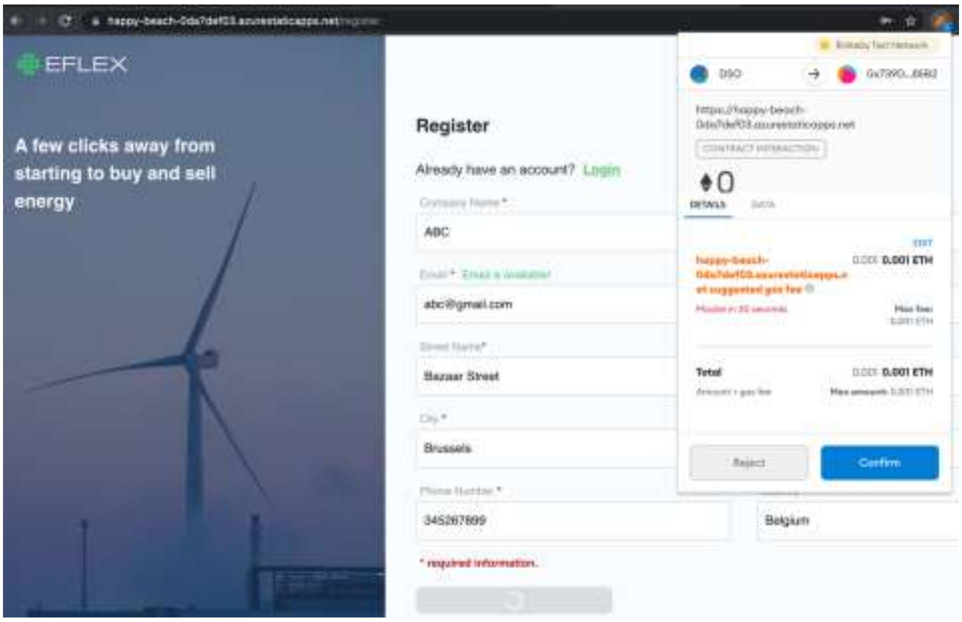

Figure 42: Registration page

The Dashboard displays the current market information of requests and offers, the flexibility market information with the volume and the price of requests and offers.

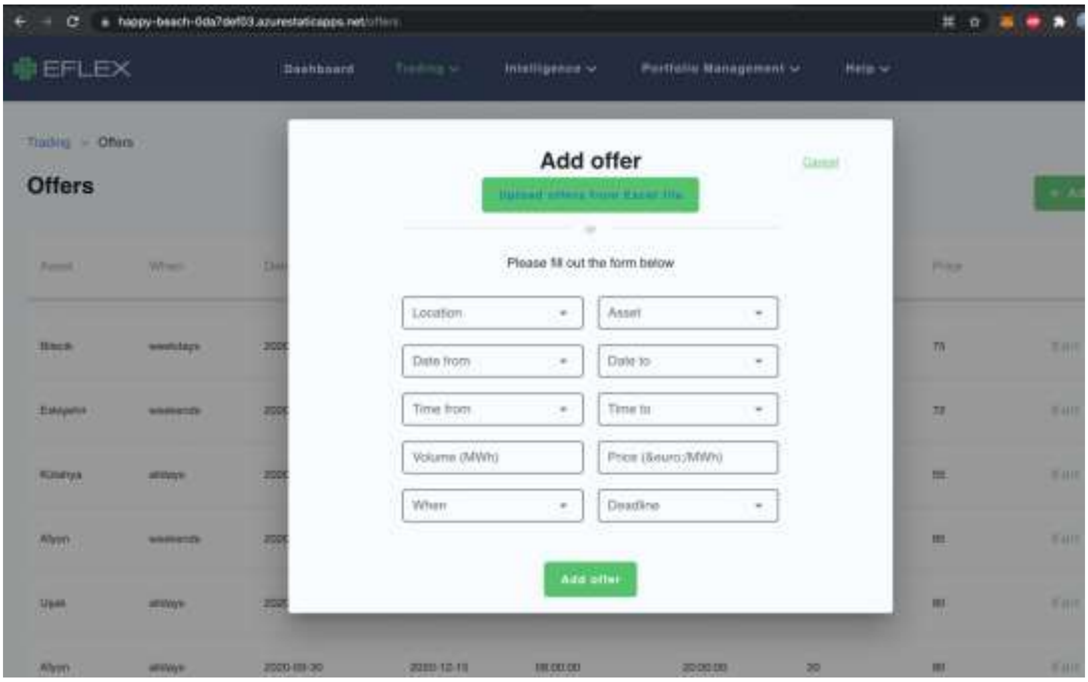

Figure 43: Add offer page

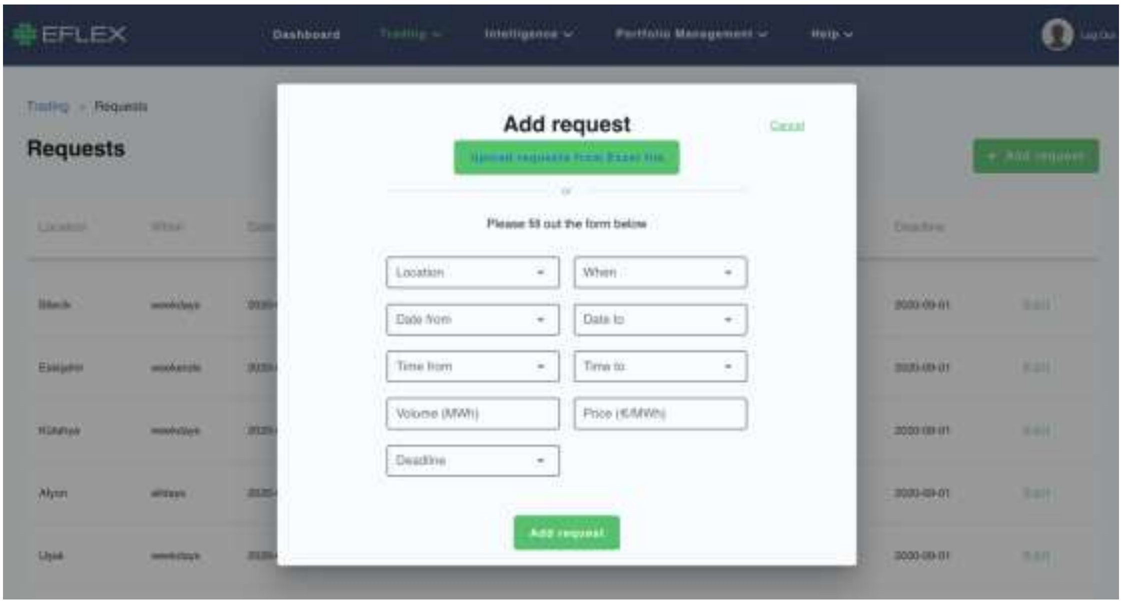

Figure 44: Add request page

3.5.2 Visibility

Once registration is complete, we make it possible for flexibility service providers and asset owners to visualize the evolution of congestion as well as for TSOs/DSOs to visualize the availability of flexibility assets in Bulgaria and Romania.

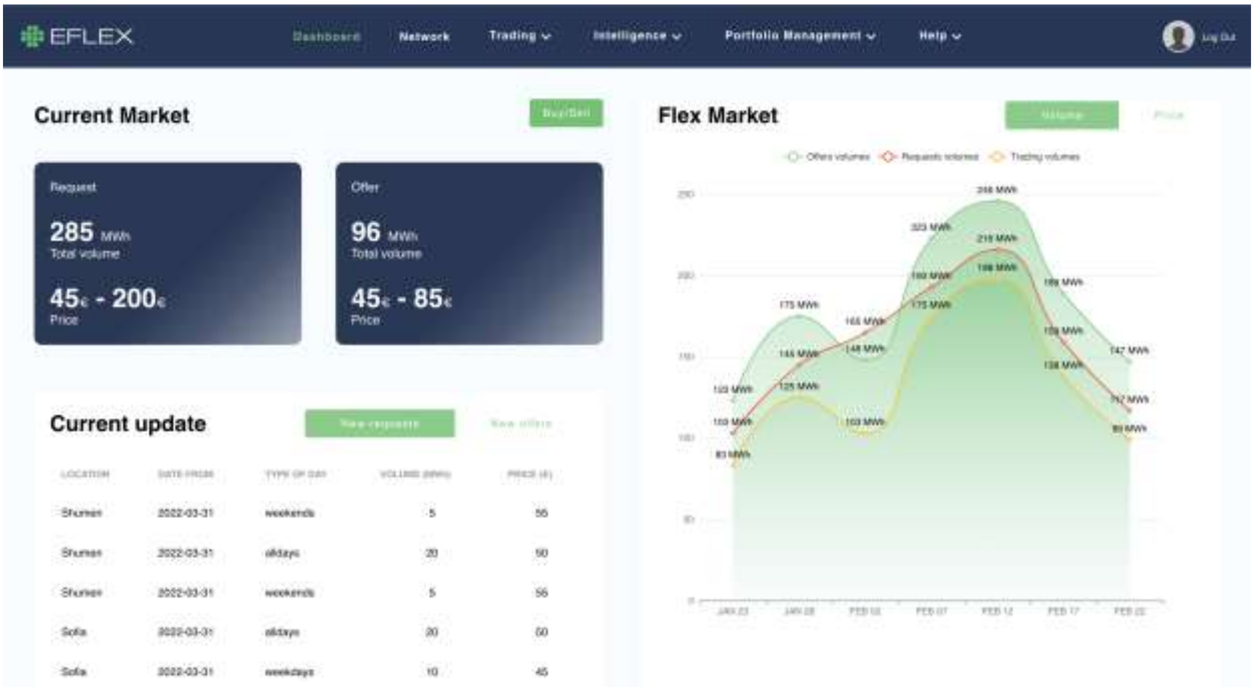

Figure 45: Dashboard

This Dashboard also displays the wholesale market information with the day ahead and intraday data from the ENTSO-E Transparent Platform via API Endpoints.

Figure 46: Day-ahead and Intraday data

3.5.3 Matching

The DSOs/TSOs can select or filter available offers on the market and proceed to manually purchase these offers or we have developed matching algorithms that filter offers based on the request. Multiple offers can be selected from both manual and automatic matching.

3.5.4 Trading

The DSOs/TSOs can proceed to buying after selecting offers through manual or automatic matching. The cost for procurement is initially sent to the escrow account. After the settlement process where the cost is determined based on the flexibility offered the cost will be deducted or sent fully to the flexibility service provider from the escrow account.

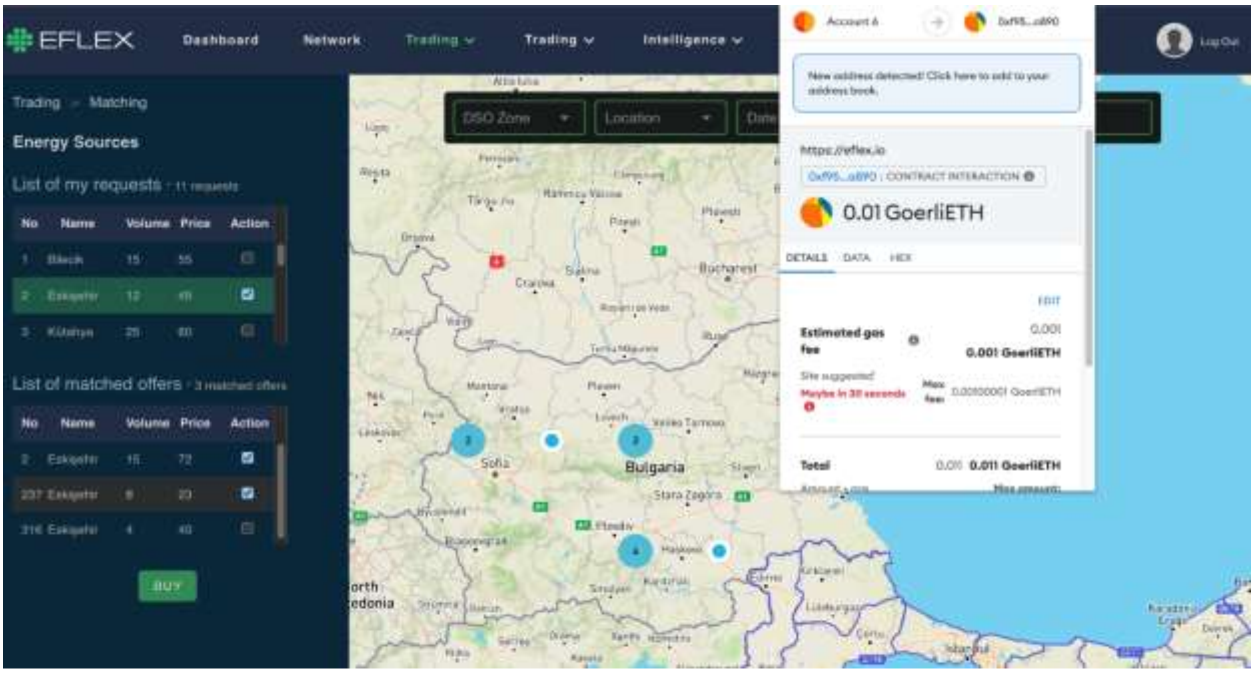

Figure 47: Automatic matching page

3.5.5 Settlement

There is no longer a need to clear the transaction centrally (as both sides have pre-trade transparency that their counterpart will meet the terms of the transaction, and settlement happens almost instantly). Business processes no longer need to synchronize directly with each other, but rather via an adapter from the EFLEX platform that maps process states and data onto the Blockchain as a transport container. The financial settlement of flexibility reservation and activation is carried out through the EFLEX trading platform based on predefined contracts and agreed to prices.

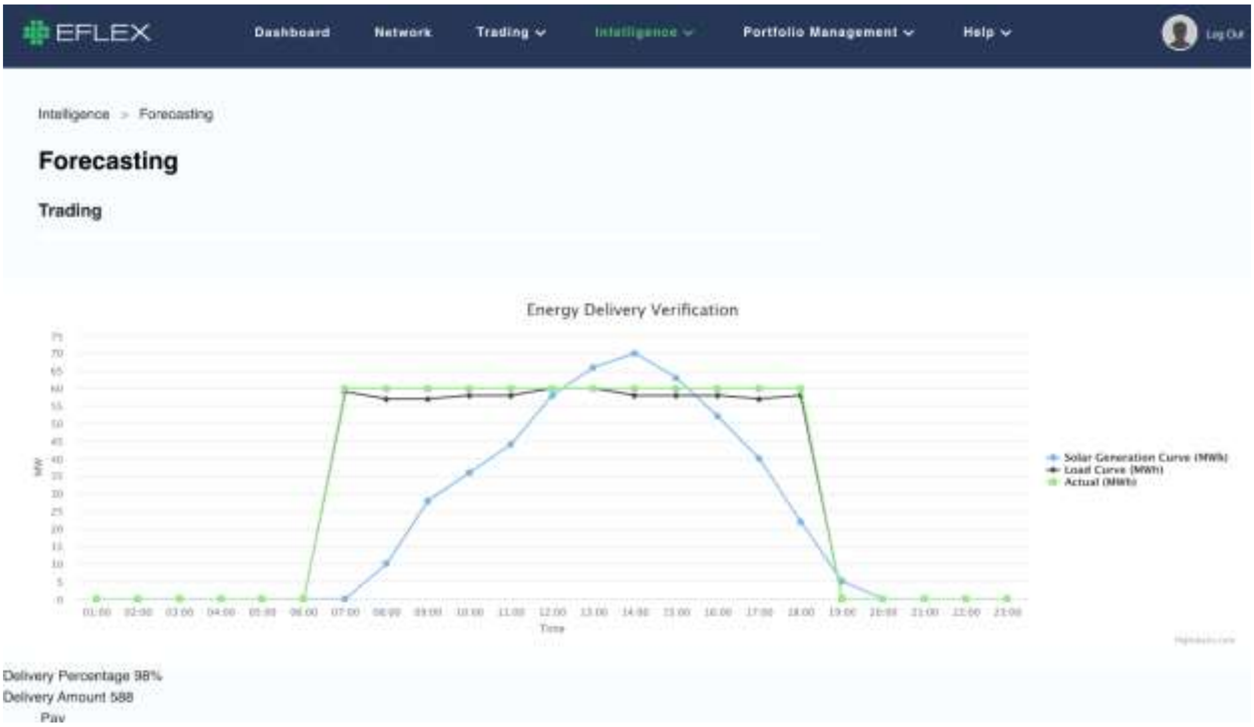

Figure 48: Settlement page

3.6 Demonstration in test sites

The demonstrations were performed in the two test sites from May 2022 to August 2022. The following activities were included:

- create 20 profiles per test site.
- run the trading twice per week
- report performance of the platform back to the partners
- introduce the platform to other stakeholders in Slovenia, Bulgaria and Romania

3.6.1 Visualization of the network layers

The network layers visualize the substations and the lines from the high voltage to the medium voltage and the low voltage based on the data from ENTSO-E. These layers also display the assets connected to the lines.

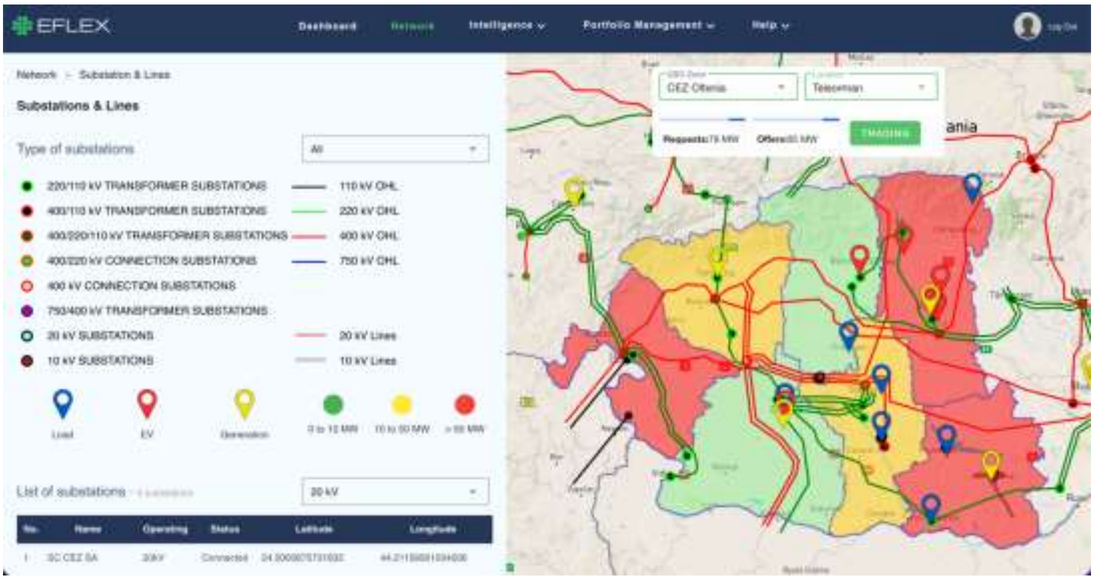

Figure 49: Network information of Partner DSO region, Romania

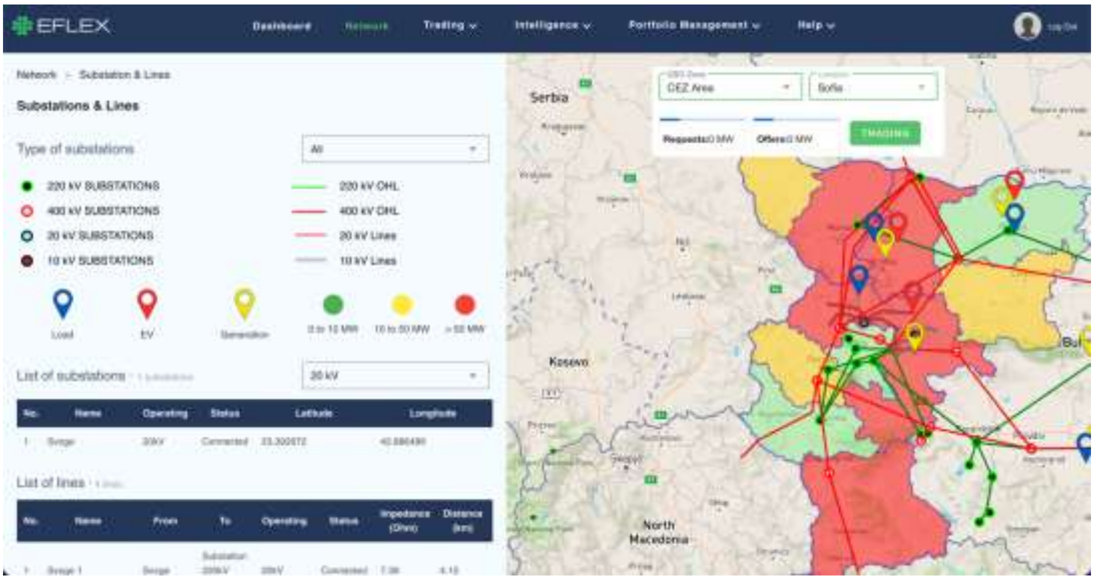

Figure 50: Network information of Sofia region, Bulgaria

Matching function to support the trading

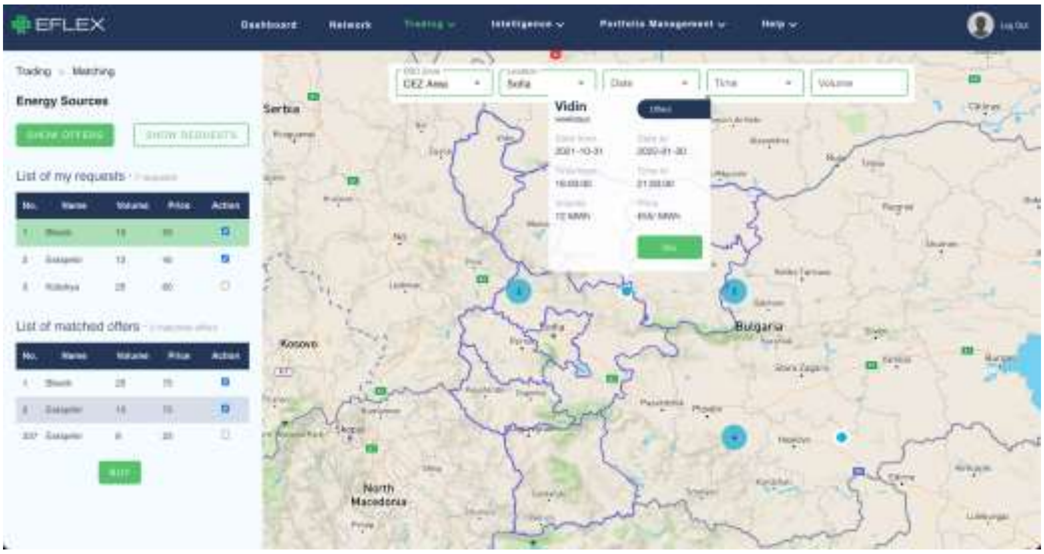

Figure 51: Manual matching

Summary and Pricing Intelligence

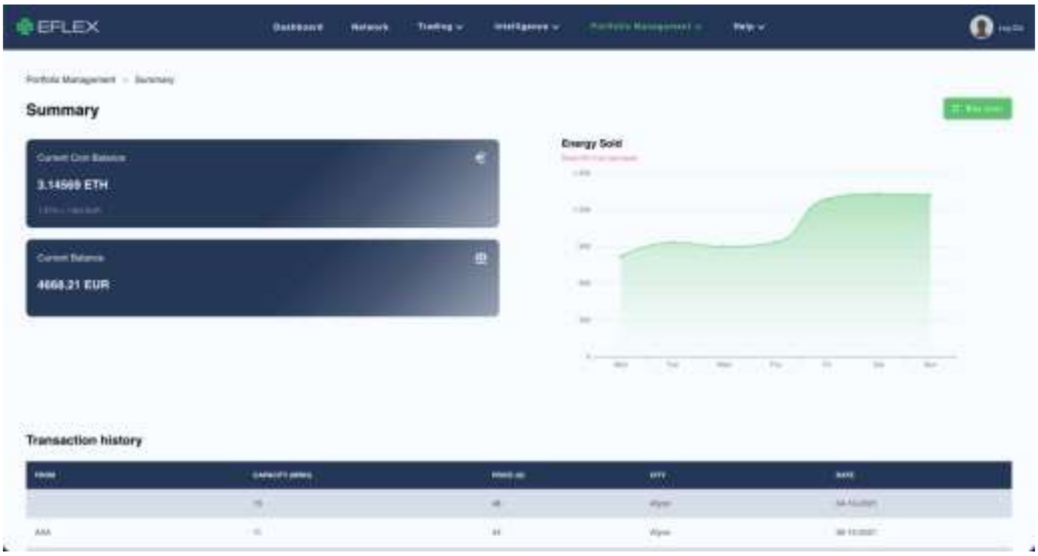

Figure 52: Summary and Price Intelligence

3.6.2 Results of the demonstration

The below presented table and graph showcases the number of offers, requests, trading and the total volume of offers, requests and trading performed during May to August 2022 in the partner DSO testing site, Romania.

Table 17: Number of offers, requests and trading in Romania

	Offers volumes (MWh)	Requests volumes (MWh)	Trading volumes (MWh)
May 2022	2384	2106	1793
Jun 2022	2195	1963	1608
Jul 2022	1956	1785	1592
Aug 2022	2480	2624	2136

Figure 53: Number of offers, requests and trading in Romania

The below presented table and graph showcases the number of offers, requests, trading and the total volume of offers, requests and trading performed during May to August 2022 in the partner DSO testing site Sofia, Bulgaria.

Table 18: Number of offers, requests and trading in Bulgaria

	Offers volumes (MWh)	Requests volumes (MWh)	Trading volumes (MWh)
May 2022	2340	2164	1937
Jun 2022	2324	2072	1962
Jul 2022	2154	1846	1534
Aug 2022	2387	2558	1942

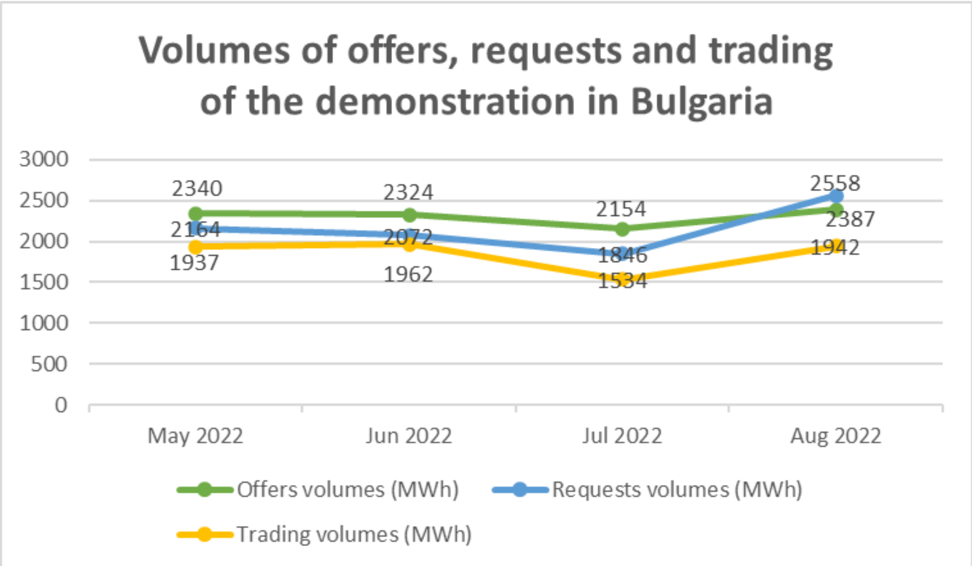

Figure 54: Number of offers, requests and trading in Bulgaria

3.7 Platform Evaluation

3.7.1 Transparency in data communication

Blockchain can be defined as an incremental, unchanging, transparent record distributed based on consensus. This system allows the user to add data – a new block – but does not modify or delete previous data, forming instead a type of data currency. To achieve this, it uses a mechanism that creates consensus between actors, which are distributed and do not require mutual trust, but rather must simply trust the mechanism used to reach the consensus. Accordingly, no actor could consistently act alone to control the network and force it to accept something that the others reject. Basically, blockchain is a technology capable of maintaining records and their updates in a way that makes fraud or changes after the creation of the record practically impossible.

The activity validation rules vary based on the blockchain, but the basic concept is that any transaction needs to be validated by most of the network, impeding fraud and attacks from hackers. The strength and reliability of the system increase with the amount of processing power from the computers connected to the network. With this security, agreements that before were entrusted to third parties and agents can be replaced by this "digital truth validation."

One of the most appealing aspects of blockchain technology is the degree of transparency that it can provide. Blockchain has the potential to enable responsible consumption, and enhance democratic governance, through traceability of information as a means of ensuring that nothing is unduly modified. The level of transparency that blockchain affords adds a degree of accountability that has not existed to date. At the same time, one of the most appealing aspects of blockchain technology is the degree of privacy that it can provide. How could blockchain safeguard the rights to privacy and control over our data, whilst promoting data transparency?

Enabling transparency of information is one of the biggest promises of blockchain technology, which provides a fully auditable and valid ledger of transactions. Blockchain is supposed to be a transparency machine in which anyone can join the network and, as a result, view all information on that network. Through the necessary encryption and control mechanisms, blockchain safeguards transparency by storing information in such a way that it cannot be altered without recording the changes made. Thanks to the ability of the technology to prove – in a cryptographic way – to third parties that data is immutable, it has the potential to make payments more transparent and systems more accountable. The terms of every transaction remain irrevocable and are open for inspection to everyone or to authorized auditors in ways never witnessed before. The transparency of blockchain offers users an opportunity to look through the history of all transactions. The transparency and accountability that blockchain technologies afford could play a role in limiting undue online surveillance, censorship, and human rights abuses. For instance, in the case of an entirely public blockchain, all information becomes public: anyone can see all data stored as they are supposed to be both accessible for everyone and transparent, to prevent data manipulation. As transparency is fundamentally concerned with the quality of being clear, obvious, and understandable without doubt or ambiguity, improving accountability through blockchain will help us build an inclusive, transparent, and accountable platform.

3.7.2 Scalability

EFLEX was initially designed to work on a private ethereum network setup with 3 nodes. When the network was tested to process hundreds of transactions in a simulated environment it took a long time and sometimes stopped working. One solution was to add more nodes to the network to mitigate the scalability issue. The problem with this approach is in the complexity of setting up the node and configuring it to work as peers with the other nodes. On the other hand, it was expensive to maintain these nodes since data was accumulating every second and thus storage space needed to be added at additional cost. The second solution was to opt for a public test net where there is no need to maintain the network and these networks processed more transactions without halting compared to the private network. EFLEX currently works on the Rinkeby test network which might change in the future to Goerli network due to the ethereum network upgrade.

3.8 Use cases for participants

Under the current system, energy is produced in centralized generation facilities and delivered to industrial and domestic users via the distribution networks operated by energy companies. Traders buy and sell energy on the exchanges and banks act as payment service providers, handling the transactions made by the parties involved. Blockchain-based energy processes would no longer require energy companies, traders or banks (for payments). Instead, a decentralized energy-transaction and supply system would emerge, under which blockchain based smart contract applications empower consumers to manage their own electricity supply contracts and consumption data. A platform developed with this technology will benefit various actors in the energy sector in multiple ways. EFLEX is a reliable platform, where network operators, market players, and prosumers come together and trade flexibility services in a transparent and cost-effective manner.

3.8.1 Prosumers:

Eflex platform powered by Blockchain technology strengthens the market role of individual consumers and producers. It enables prosumers, i.e., households that not only consume but also produce energy, to buy and sell energy directly, with a high degree of autonomy. It is an opportunity for prosumers to not just sell flexibility for a fixed fee but to market it individually. The platform helps the customers with just a single solar panel to participate in the end user market.
Main roles of individual prosumers,

a. Manage assets
    - Add new asset
    - Edit asset
    - List assets

b. Manage offers
    - Add new offers
    - Edit offers
    - List offers

Prosumers use the blockchain-based platform to learn about different sellers' and purchasers' energy usage patterns, to regulate their individual energy consumption using domestic demand response schemes, and then trade with each other among the local community that is able to maintain the supply and demand in a balanced way.

3.8.2 TSO & DSO:

With the arrival of renewables, smart metering and smart grid technologies, the role of system operators has changed considerably. They are burdened with various new responsibilities. First, they should, for example, handle the data received from smart meters, and manage and utilize them for the purpose of forecasting, risk management, scheduling and planning of distribution systems. Second, managing local markets at the distribution systems level is one of the new responsibilities of the system operators and they should simultaneously ensure that the system constraints are not violated. As a result, the system operators need more services in order to provide infrastructure for renewables-based distributed generation and meet the demand.
Main roles for SO's,

c. Manage requests
    - Add new requests
    - Edit requests
    - List requests

d. Procure flexibility
    - Matching
    - Payment
    - Settlement

Currently, the platform provides visualizations for the SOs where they can see the evolution of their local energy grids congestion and availability of local flexibility assets. In this way, the platform aims to help them to plan in advance how to ensure the stability of the grid and find out where they can buy flexibility services to balance energy demand on their networks. Moreover, we have created a full onboarding experience for SOs to register on the platform and indicate their specific needs for grid flexibility. To match this demand, flexibility service providers, such as renewable energy generators and prosumers, can set up their profiles on the platform to submit their offers to system operators.

Once the market players indicate their needs and offering, Eflex allows them to trade flexibility services with each other. These transactions are based on blockchain, providing smart contract and smart billing solutions. Transactions are communicated to the market players in real-time with the help of blockchain ledger. This helps the system operators to immediately see how the local grid reacts to the trading and how it affects the grid congestion.

4 Monitoring of Key Performance Indicators

4.1 KPI selection & monitoring

The following table represents the KPI definition, the domain it belongs, the stakeholders relevant to the defined indicator, the method of assessment such as if its suitable for local energy market and finally if it's assessed by demonstration and simulation.

Table 19: Identified KPI's

Domain	KPI	Relevant stakeholders	Method of assessment		
			Suitable for local energy market	Assessed by demonstration	Assessed by simulation
Tech	Delivered/requested flexibility ratio	DSO, Market operator	Yes	Yes	Yes
Tech	Delivered flexibility ratio	DSO, Market operator	Yes	Yes	Yes
Tech	Penetration levels of distributed renewable energy resources	TSO, DSO	Yes	Yes	
Tech	Congestion management	DSO, End-user	Yes	Yes	
Tech	Scalability		Yes	Yes	Yes
Economic	Self-sufficiency of the market	DSO	Yes	Yes	
Economic	Average trading rate				Yes
Economic	Total gross marketplace volume				Yes
Techno-economic	Benefit for DSO and FSP	DSO, aggregator, end-user	Yes	Yes	

Table 20: KPIs of the WP6

WP - Activities	Performance Indicator	Framework for Metrics	Target Values	Progress
	6-1 Number of involved MV or LV operating prosumers	6-1-1 Number of total consumers involved actively on the demo area	>30 (pc)	Completed
	6-2 Exchanged flexible power / max.	6-2-1 Power in kW	100	Completed

WP6 – Pilot Deployment, Demonstration and Evaluation – Demo Area 2 (Peer-to-Peer trading)	possible transmitted power of the grid			
	6-3 Trading might influence on the voltage, power flows	6-3-1 Max allowed voltage change, power flow	20	Completed
	6-4 Successfully set up asset-enabled local markets platform	6-4-1 Number of transactions per month	100	Completed
	6-5 Successfully set up the Blockchain-based TSO-DSO flexibility platform	6-5-1 Number of transactions per month	100	Completed
	6-6 Use cases of the different players (Prosumers, TSO and DSO)	6-6-1 Number of Use cases	4	Completed
	6-7 Correctness of transactions (in the market/procurement process)	6-7-1 Level of Correctness of transactions	90%	Completed
	6-8 Transaction capacity, automatic level	6-8-1 Speed of market/procurement process	15´	Completed

4.2 Assessment of achieved KPI values

a. Delivered/requested flexibility ratio:

   This metric is used to identify the ratio of the amount of successfully delivered flexibility to the amount of requested flexibility during each occasion by the DSO

b. Delivered flexibility ratio:

   An indicator to identify if the amount of requested flexibility is offered

c. Penetration levels of distributed renewable energy resources:

   This indicates the participation level and revenue stream of aggregators and end users

d. Congestion management:

   Indicates the number of congestion situations avoided

e. Scalability:

   This identifies how many transactions the platform can manage

f. Self-sufficiency of the market:

   To identify how in the local market the energy consumption is fulfilled without using any external sources

g. Average trading rate:

Indicator to identify the number of matching and procurement that happened between the buyer and seller

h. Total gross marketplace volume:

Indicates the overall trading volume

i. Benefit for DSO and FSP:

Indicator to measure the profit made by buyer and seller using the marketplace platform

5 Socio-economic analysis

5.1 TSO-DSO coordination

In recent years the energy system has undergone critical changes as a result of the increasing need for renewable energy resources. On the other hand, the incorporation of renewable energy into the power system poses several challenges to transmission and distribution system operators. The transition to clean energy is welcoming but concerns about the quality, voltage and frequency of such systems have been raised. The main objective however is to be able to use renewable energy sources guaranteeing efficient congestion management, reduction in operational cost and increased flexibility. To facilitate the integration of renewable sources into the energy system the interaction between TSO and DSO that are responsible for balancing the demand and supply should be improved. Through increased cooperation, DSOs and TSOs can better align their network expansion plans and identify synergies that could result in significant cost savings on large infrastructure. Further, an increased TSO-DSO coordination also enables effective utilization of distributed energy resources in congestion management, thus the service operators can defer investment in grid infrastructure. To further facilitate the integration of renewable energy and customer connections, the service operators should regularly exchange and publish information on available network capacity.

Thus, we have developed a marketplace that validates the viability of data transfer between TSO and DSO and optimizes the processes and actions through effective signalling and sound coordination by scheduling visibility, increasing transparency and interoperability. This has been achieved with the support of Blockchain-based smart contracts and distributed ledger technology by automatically synchronizing the data between multiple nodes (ledgers), managing distributed commits across those nodes in real-time and automatic recovery in case of failure. Through Blockchain-based shared database we broadcast relevant information such as offer assignment, time-schedule, settlement info etc. to all authorized participants in a traceable and unchangeable manner. We also document the request and offers in a comprehensible, confidential and unchangeable manner.

5.2 EFLEX Flexibility Trading Platform

5.2.1 Flexibility Trading Platform value chain

The traditional value chain of the energy industry ran linearly from generation over transmission and distribution to the end customer, according to the actual flow of electricity. Figure 55 shows the value chain, where the physical electricity flow is managed by the grid operators, which are regulated by the province.

However, the energy market has changed considerably, particularly as a result of the decentralization of generation by fluctuating renewable energies. Increased digitalization can help to enhance the degree of process automation. Automation can help to deal with increased complexity – whether it is the compilation of billing reports or short-term trading in the intraday market. With respect to that, Eflex platform has several steps involved in getting electricity to the end user. It is typically broken up into four steps, as follows:

i. Generation,

ii. Transmission, and

iii. Distribution

iv. Sales

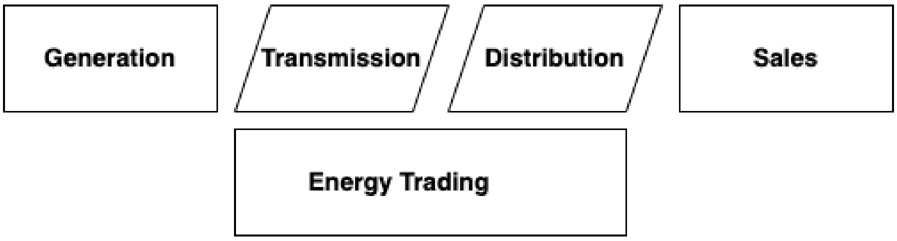

Figure 55: Eflex energy value chain

Generation:

Energy producers, typically start the flow along the electricity value chain. These are then delivered to the power plants, where they are converted into electricity during the generation process or converted differently in case of the prosumers. Since electricity has a low storage value, it must be transmitted to its point of use. It can be used personally or the excess can be traded for additional cost. The earnings of entities in electricity production are based on input costs and electricity demand.

Transmission:

Electricity transmission is the bulk or micro transfer of power over a long/short distance at a high voltage. Electricity is delivered from generating stations to substations near population and industrial centers through the transmission network.

Distribution and Energy Trading:

The distribution network takes over once electricity has reached a broad area where it will be used. The distribution task is to distribute electricity to various users, whether residential, commercial, or industrial.

The distribution segment is compensated for its services by its customers. This is where power trading enters the picture. Power trading connects the generation and distribution components of the power sector value chain, allowing for more competitive trade, reducing wastage and shortages. The practice of power trading allows surplus generation from one region to flow to another region with a power shortfall. Power trading is a transaction in which the price of power is negotiable, and there are options as to who to trade with and for what amount.

Sales:

Once the flexibility is procured the final step in the value chain is settlement where the amount of flexibility delivered is verified and the cost for each unit delivered is determined and paid.

5.2.2 Impact on service providers and asset owners

In the traditional model of centralized power generation, the flow of electricity is unidirectional, that is from power plants to end consumers through power transmission and distribution networks. Traditionally, the TSO has been responsible for operating the electricity transmission network and transporting electricity from centralized generation facilities to regional/local distribution networks to meet the demand of various DSOs. They are in turn responsible for delivering reliable and secure power to end users within specified constraints of voltage and frequency. The deployment of renewable generation technologies connected to the distribution network has resulted in the bi-directional flow of electricity through the network. In this new context, with the deployment of distributed energy resources the role of DSO needs to expand to harness the flexibility offered by these new technologies on the distribution system.

The roles and interaction processes between the service operators needed to be redefined to increase the integration of distributed energy resources within the energy system. There is a necessity for the congestion and balance on the network to be managed in an optimal way. Efficient cooperation between

DSO and TSO is critical for the participation of distributed renewable energy resources in the electricity market. The DSO should also act or enable a data exchange platform between TSO and asset owners providing visibility to the TSO on the type and availability of energy sources. The Eflex platform has been developed to provide better visibility on the availability of flexibility aiding the actors in the system.

As the number of distributed renewable energy resources are expected to increase with more connected devices, such as EVs, PVs and heat pumps, the TSOs lack of visibility over these resources can lead to load and generation forecasting errors, which can affect the reliability of the system. Each system operator, TSO and DSO are responsible for the operational security and quality of supply in the network and should therefore be entrusted to monitor and interact with its respective grid users. In the case of DSOs, they should interact with the stakeholders connected to the grid and gather data collected via smart meters. By channeling the data and sharing it, the TSO will have increased visibility of resources at any time and be able to use it.

With the help of Eflex platform the service providers can share the balancing responsibility. Flexibility from the distribution grid is reserved exclusively for DSO to fulfil their responsibility with respect to local grid constraints and local grid balancing. DSO autonomously provides balancing services and congestion management for local grid based on predefined exchange schedule between DSO and TSO. Since most of the functions are automated in the platform such as matching and settlement with the help of modern technologies it helps the asset owners and service providers to deal with the increasing need of clean energy and integration of distributed energy resources in the system.

5.2.3 Impact on the power system and society at large

As the energy sector witnesses the rise of energy communities and a more decentralized market with the release of intelligent trading platforms like Eflex, large number of homeowners and companies have the option to invest in their own production and storage capabilities to become less reliant on traditional energy suppliers. The core concept of developing and releasing flexibility trading platforms and motivating energy communities is to bring supply and demand closer together. Ideally everyone involved will benefit from each other without an intermediary or a central wholesale market.

Peer to peer energy platforms enable people to take control of where and how they want to buy electricity. The idea is to remove as much complexity as possible and enable formerly passive consumers to become an active part of energy community. Demand and consumption profiles can be matched and the needs of different actors can be aggregated through the platform. This setup can solve problems like demand response for small entities and also help deal with such problems on a larger scale. Energy communities can solve problems like grid balance by forming alliance over distributed assets based on data, automated processes and smart contracts. Decentralized markets and energy communities gains traction since the financial benefits are shared between the members. As energy markets change with the advent of peer-to-peer trading platforms, they are an important part in tackling problems such as demand response and grid balance, and help bridge the gap when transitioning from fossil to renewable energy.

6 Conclusions

6.1 Exploitable results

For T6.1:

The local market trading has been demonstrated at four sites, the necessary data provision also. Results of simulations were analyzed just to teach the DSOs on how they will be provided in whole testing period. From the DSO's perspective, the most important is, that the pilot proves, that market participants would trade between each other without causing local peaks; the participants are in a way flexible, because they do not cause peaks or even unpleasant post peak effect, which can cause even higher local congestions.

The LV market platform is proved to be operable parallel to a working traditional retail system. The proposed DNUT structure fully considers the network state and energy flows resulting from the transactions on the local market and the estimated base case of the retail market. Furthermore, through DNUTs the platform is able to handle potential changes in the behavior of prosumers (e.g. transitioning a part of their power consumption from retail to the local market platform).

Instead of blocking unfavorable transactions or punishing participants for burdening trades during the settlement process, the platform incentivizes participants before entering the transaction. The market is not only competitive per se, but the DNUTs also promote network-friendly transactions for a prosumer by being lower for bids placed at favorable (e.g. neighboring) nodes.

The local market platform developed and tested during T6.1 is a potential trading and settlement platform for any local markets where grid friendly transactions can be incentivized through the different optional DNUT elements. Thus, transactions reducing the network loss, moderating voltage problems, congestions and overloading can be encouraged. The proposed market platform could also be adequate for energy communities where possible further incentives might be examined – e.g. to better incentivize the local usage of local production, reducing infeed at the settlement point of an energy community. In this case the bid price levels and the default supplier tariff levels have even greater importance. The advantage for energy communities lies not only in solving demand and supply matching with settlement but also in conveying demand/supply needs in the community and price incentives to react realizing demand response. Similarly, the market platform in 6.1 could be also used in a microgrid for trading.

The demonstrations have proved that the DNUT concept can reduce network loss, voltage problems and congestions. The effectiveness of the different incentives is very dependent on the punishing tariffs set for loss, congestions, or voltage limit violation, if applied. The platform can exclude trades that would cause any congestion or overvoltage. These two latter make this platform especially suitable for energy communities to solve local trading and ensure trades that are supporting the DSO in voltage regulation and congestion management at once. This is important because energy communities try to ask for grid usage tariff reductions from the DSO for the reason that they reduce loss with higher proportion of self-supply and reduced inverse flows caused by local PV production. However, these reasons are not ensured otherwise. Moreover, the local market platform of T6.1 could provide a tool for the DSO to operate a local market where he could ensure such trades if regulation allows DSO operation of energy communities.

During this project, a DSO flexibility market has been approached from the local trading point of view, facilitating trades in favor of the DSO with the option and possibility to exclude trades violating voltage, line, or transformer limits. The concept has been further developed and has become a base for testing another idea – the system operator incentivizing and activating flexibility through the traffic light concept currently being investigated in another Horizon 2020 project named Onenet.

The PV and distributed renewable integration is also supported through incentives built-in the trading platform. On the one hand, trades that are violating voltage and line limits can be excluded. On the other hand, trades helping to lead to nominal voltage and reducing loading are favored and reactions for grid supporting trades are encouraged by lower bid prices.

For T6.2:

Shared Economy:

P2P energy trading simplifies the process of allowing prosumers to be part of the electricity market and trade electricity with their neighbors. This concept of trading is similar to shared economy models such as Uber and Airbnb.

Revenue Stream:

P2P energy trading could permit prosumers to exploit the gap between selling electricity at wholesale prices and buying electricity from the grid by enabling them to make profit by setting prices below market. Consumers would also see bill savings when participating in P2P transactions by reducing payments to intermediaries such as energy utilities and electricity network operators.

Clean energy:

This model not just benefits individual prosumers but makes renewable energy more accessible and helps to keep the community resilient to power outages during emergencies. It helps to increase the use of green energy, improve energy security and reduce carbon emissions.

Supports main grid:

P2P trading platform enables better management of decentralized generators by matching local electricity demand and supply at all times. It helps decrease peak load, reduce investments related to the generation capacity and transmission infrastructure needed to meet peak demand.

Faster real-time settlement:

Settlement happens almost instantly without any need for centralized authority to clear transactions. It is possible because of the predefined rules accepted by buyers and sellers defined on smart contracts. With the help of IoT infrastructure and smart contracts the energy delivered is verified automatically and transactions are settled within seconds with the additional benefit of reduced transaction cost.

6.2 Lessons Learnt

The following are main lessons learned out of T6.1 pilot demonstrator:

- The provision of data, particularly network data is fundamental for system operators to control and coordinate their actions. At European level, it is conceived that in the future, several local P2P markets will be established and therefore, system operators (TSOs and DSOs) will require a single interface (IEGSA) for the optimal exchange of grid information, and towards other market parties as well. Network data exchanges not only for the efficient allocation of market exchanges but also related to topological changes in the grid, should automatically be handled by IEGSA.
- Currently, several DSOs have their own “sign-in” web-based solutions. This helps to the effective communication between grid users and local DSOs. Simulated P2P market also employs user interface where the local market platform acknowledges or refuses user registration. Registered users are recognized through their grid connection point and other data. The verification process is based on a database provided by the DSO as part of the initialization step listing grid users with connection points and other parameters stored in the flexibility register of the IEGSA platform. On a larger scale, flexibility register should be capable to handle significant amount of grid users with sufficient efficiency and security levels.
- Distribution system operator will also share metering data through IEGSA within which historical metering data should remain available for post-operational evaluation. In addition, market results

shall also be forwarded to IEGSA, and stored in the flexibility register for the settlement process as well.

There should be a level of communication of real-time data implemented by IACMS between IEGSA towards relevant distribution system operators. This to ensure the automatic a proper representation of the network condition in the marketplace.

And the main lessons learned out of T6.2 pilot demonstrator are:

- With the increasing climate risk and higher electricity cost people are transitioning to renewables and clean local energy. To meet the demand for renewable energy there is a need to accommodate decentralized energy system which comprises the energy produced from DER's. To support such a system and improve the coordination between the actors involved, a platform like EFLEX plays a crucial part in helping achieve this transition.
- Flexibility marketplace like EFLEX digitizes the procurement process to make it easier for aggregators and flexibility providers to view the local opportunities and to participate in the procurement process.
- P2P trading is expected to give multiple benefits to the grid in minimizing the peak load demand, energy consumption costs, and eliminating network losses. However, installing P2P energy trading on a broader level in electrical-based networks presents a number of modeling problems in physical and virtual network layers.
- To achieve an integrated European market, and to reduce market-entry barriers for suppliers, aggregators, prosumers and SOs, the platform should integrate interoperability both regarding data formats and functionalities.
- With the arrival of renewables and smart grid technologies additional functionalities are added to DSO's role. First, they have to manage local markets in the distribution system level and second, handle the data received from smart meters and utilize them for the purpose of forecasting, risk management, scheduling and planning of distribution systems. DSO's will benefit with the successful deployment of EFLEX interface which encompasses the above-mentioned features.
- Coordination between SO's is necessary to efficiently deal with the interaction between different use options for flexibility, to ensure the optimal utilization of flexibility services and to avoid counterproductive behavior.
- The technology platforms need to be updated regularly with every new change or release. It is necessary to keep up with the rolling changes since they come up with performance improvements and bug fixes. EFLEX has multiple modules with its own technology stack and the modular approach helps for seamless upgrades. The modular architecture not just helps with efficient updates but plays a major role in scaling.
- On a larger scale, when there are more users and thousands of transactions happen, the platform should be capable of handling significant amount of grid users with sufficient efficiency and security levels.
- For a P2P platform to be successful, it is crucial that people must be educated and given awareness about new technologies and provided incentives to accommodate devices such as smart meters.

6.3 Final thoughts

Regarding T6.1,
Demo areas and input parameters data are defined and finalized. The progress is significant, namely the information scheme is completed; all result of the market operation is available to all DSOs involved in this pilot. Operators have also made the evaluations of the results. As described above, the aim of this

demo is to create an asset-enabled local electricity market which considers distribution grid's state during the trading process and facilitates transactions beneficial for the reliability and security of supply. To this end, a simulated local Peer-to-Peer (p2p) market operating on real metering and grid data enables consumers to buy electricity from other local parties regardless their local utilities/supplier. Also supporting the exchange of energy of grid users having small RES-production units with other parties in their local network. Local market aims at minimizing undesired effects of local grid transactions by the application of Dynamic Network Usage Tariff (DNUT). Congestion management through DNUT reduces tariff on local transactions to solve congestions locally in benefit of network flows.
In addition, pilot uses additional grid information from an Integrated Asset Condition Management System (IACMS) which constantly monitors critical network elements and provide real-time estimations about their actual loading levels. This approach helps both solving congestions and reducing network losses while contributing to the voltage stability of the distribution grid.

Regarding T6.2,
I. As power flows become more intermittent and more unpredictable, networks will have to tackle congestion related issues such as feeder overload management and voltage management. If 100 MW of balancing power is requested today, it might be distributed across 5-10 medium-sized generators. If the same volume will be requested in 5 years´ time, it might be distributed across 100-1000 small generators, including batteries operated by households. **With flexibility control in hand of multiple owners, documentation, transparency and automation are of crucial importance**. Here, Blockchain-based TSO-DSO congestion management at the grid level **supports the complex communication and cooperation of many stakeholders or assets avoiding bottlenecks** at the distribution grid level.

ii. There is a strong need to empower small and medium players to participate in the marketplace through the provision of flexibility services. Here, the automated storage of transactions on Blockchain enables simple billing, which otherwise would be complex to achieve manually. Payment to small/medium sized generators or load centers for their services in the form of tokens increases overall market efficiency. Tokens stimulate behavior beneficial to the grid in the form of flexibility and allows it to be quantified and billed at the same time. **Additionally, the involvement of prosumers opens up the value of their assets, thus reducing intrinsic market entry barriers.**

iii. Finally, the marketplace (EFLEX) **digitizes the procurement process** to make it easier for aggregators and flexibility providers to view the **local opportunities** and to participate in the procurement process. There are several aspects of trading process that brings efficiency (e.g., asset registration, validating assets' metering data and settling the associated financial operations is performed end to end using Blockchain based smart contracts and distributed ledger technology)
So far, the EMAX platform is a prototype, which means that the project partners operate in a testing and simulation environment. The first results from the testing indicate that the solution is working well and that it is a useful tool for the DSOs to manage the congestion and voltage constraints of the grid in a smart and efficient way. It also allows flexibility providers to join the energy market as an active player.