# D5.5: Energy Trading Market Demonstration

## Deployment of the +Trondheim Energy Trading Solution

+CityxChange | Work Package 5, Task 5.9
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| **Authors** | Stein Danielsen (Volue); Ola Hendseth (Volue); Klaus Livik (Volue); Bjørn Ove Berthelsen (TK); Gleb Sizov (TE) |
| **Contributors** | Boris Tistan (Volue); Bernhard Kvaal (TE); Mette Rostad (TE); Ella-Lovise Hammervold Rørvik (TE); Erik Næss Guldbrandsøy (NTNU) |

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# List of Acronyms

| | |
|---|---|
| **AlgoTrade** | Automated trade executed by algorithms |
| **AMS** | Advanced Metering System |
| **API** | Application Programming Interface |
| **Bid** | Buy and/or sales offer |
| **BCV** | Bold City Vision |
| **BMS** | Building Management System |
| **CIM** | Common Information Model |
| **CSO** | Community System Operator |
| **DER** | Distributed Energy Resources |
| **DPEB** | Distributed Positive Energy Block |
| **DoA** | Description of Action |
| **DSO** | Distribution System Operator |
| **ETP** | Energy Trading Platform |
| **EV** | Electric Vehicle |
| **GA** | Grant Agreement (with the EU Commision) |
| **GIS** | Geographical Information System |
| **LEM/LFM** | Local Energy Market / Local Flexibility Market |
| **LHC** | Lighthouse City |
| **LV** | Low voltage |
| **NIS** | Network Information System |
| **OPTIMAX®** | On site energy management system (ABB) |
| **PEB/PED** | Positive Energy Block/District |
| **PV** | Photovoltaic |
| **Python** | Programming Language |
| **RES** | Renewable Energy Sources |
| **SCADA** | Supervisory Control And Data Acquisition |

| | |
|---|---|
| **TE** | Trønderenergi |
| **TSO** | Transmission System Operator |
| **V2G** | Vehicle-to-grid |
| **VOL** | Volue (formerly Powel/POW) |

# Executive summary

This delivery D5.5 in the +CityxChange project describes and details the planning for and deployment of the software solution serving the local energy market which will be demonstrated in Trondheim. The software for market access and trade is developed by Volue (former Powel) and specially customised and innovated to serve the +CityxChange project through the T2.5 task *Development of a platform for local trade of energy and flexibility*, a work described in the preparatory report D2.7 *Local dPEB trading market demonstration tool*[1]. However, for the purpose of setting up a live local energy market, the following building blocks are integrated and included in the solution deployed:

- **ABB** OPTIMAX® for asset operation.
- **Volue** Algotrader for market participation.
- **Volue** Digital Marketplace for market operation.
- **IOTA** for secure third party data verification to ensure consistency between executed trades and the following settlement.
- **TE** Operator software for forecasting, flexibility optimization and settlement.

The project's approach and solutions for establishing local Positive Energy Blocks (PEBs) are more than just obtaining balance between local energy consumption and production. In the Trondheim demonstration project this is in fact more a matter of optimising available and viable local renewable energy sources in order to scale local PEBs to district level, with a roadmap for 2050 of obtaining balance between green, local renewable production and optimised utilisation of green energy sources - and energy consumption.

In the demonstration area where the local energy market solution is deployed, a substantial part of the energy available locally is not utilised, and substantial shares of this energy are available within short time windows only and will be available as a traded product on the local energy market. A scalable and efficient PEB is thus - as Trondheim sees it - dependent on systems and solutions being able to utilise this flexibility in order to obtain balance between local production/utilisation of renewables and local energy consumption.

The solution is deployed and digitally integrated to become the local energy market system as planned. In addition it is focused on the process of onboarding customers/assets. This includes training, asset identification and registration - and last, but not least: Agreements between customers and the market operator.

For LHC Trondheim a well functioning local energy and flexibility market developed, owned and operated by energy company Trønderenergi (TE), based on the Volue Energy Trading Platform (ETP), full integration of all market participants through a Distributed Energy

[1] https://cityxchange.eu/knowledge-base/d2-7-local-dpeb-trading-market-demonstration-tool/

Resource Management System/DERMS (ABB Optimax ®), and secure verification of all trades through IOTA Tangle, makes up a crucial and integral part of the scalable PEB solution to be deployed.

The Volue ETP, local market solution, and full impact of the market side of the solution is based on open P2P trade of energy resources and products. This is not (yet) allowed today according to national legislation[2] and central parts of the prevailing concession regulations. Further work on the regulatory aspects is described in a separate report D5.9: *Playbook of regulatory recommendations for enabling new energy systems*.[3] +CityxChange has therefore applied to national regulatory body RME[4] for temporary dispensations from national legislation in order to demonstrate the solutions in Trondheim.

[2] Energiloven: https://lovdata.no/dokument/NL/lov/1990-06-29-50

[3] https://cityxchange.eu/knowledge-base/d5-9-playbook-of-regulatory-recommendations-for-enabling-new-energy-systems/

[4] https://www.nve.no/reguleringsmyndigheten/

# 1 Introduction

*Note: +CityxChange official beneficiary Powel (POW) has during the course of the project gone through a change of brand. The new brand being Volue. The prevailing report thus consequently denotes this partner VOL.*

The present report describes the work performed within the +CityxChange Task 5.9, *Deployment of the Energy Trading Platform*, with Volue (VOL) as Task Lead. The Energy Trading Platform was developed in Task 2.5 - *Development of a platform for local trade of energy and flexibility*, described in +CityxChange deliverable *D2.7 Local dPEB trading market demonstration tool* [3], delivered 27.01.2021. Some of its technical details are repeated in this report as they remain valid.

In accordance with TE and TK, the local flexibility market and the local energy market are to be operated on the same Energy Trading Platform, developed in Task 2.5 by VOL. *Deployment of the trading platform* (Task 5.9) is the prerequisite for the operation of both the local energy market and the local flexibility market. TE will be the operator of both markets during the demonstration (Task 5.10, *Local Flexibility Market*).

Details on the relation with other tasks within the project are described in Section 1.2.

## 1.1 Background and objectives

Within the +CityxChange project, the overall scope is to fuel the process of city blocks and city districts from being energy negative to becoming energy positive. This process includes establishing and demonstrating how different incentives for setting market driven value of flexibility and other local renewable resources will support and strengthen this process. By designing, developing, and deploying a fully digital operated local market, an arena is established to enable a demonstration within the project scope and plan. Based on the in-detail designed market (D2.7 - Local dPEB trading market demonstration tool)[5] the trade platform is developed to demonstrate within the overall PEB as shown in figure 2.1- a software solution for market participation and operation - including a local marketplace designed for the purpose of a Common Energy Market operation.

[5] https://cityxchange.eu/knowledge-base/d2-7-local-dpeb-trading-market-demonstration-tool/

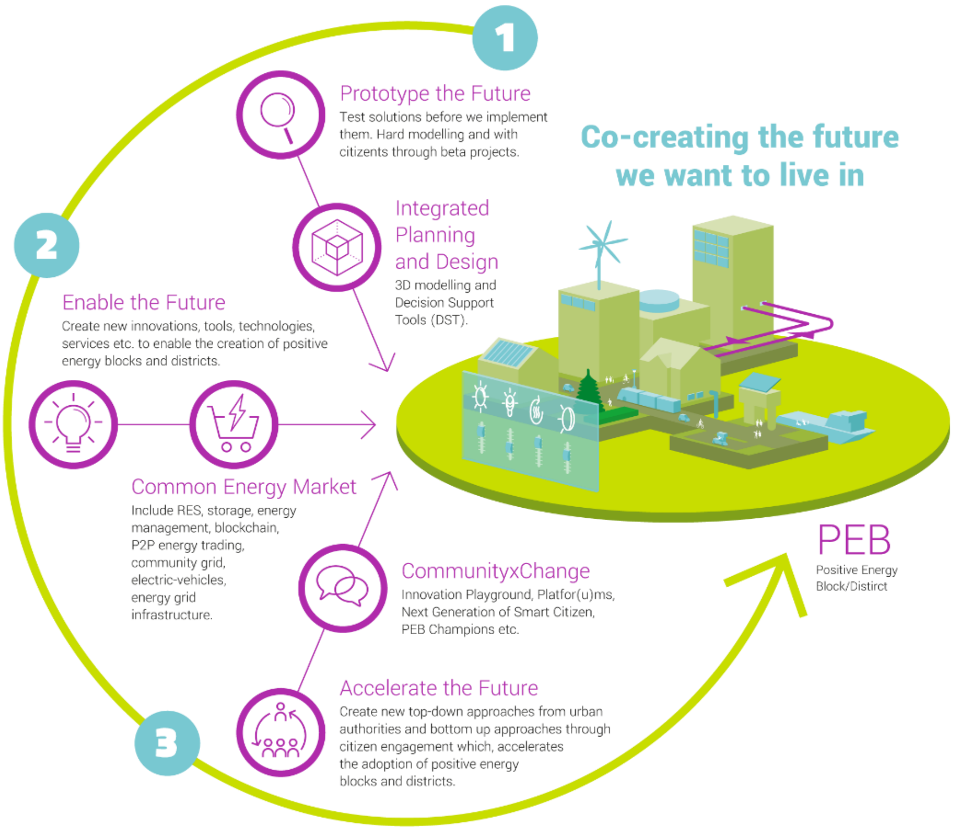


*Figure 1.1 The Common Energy Market within +CityxChange project processes from prototypes of technology and systems to enabling the DPEB (positive energy block/district). Source: +CityxChange project.*

The operation of the local energy market in +CityxChange is inspired by the model and roles of the well proven Nordic and European power market implementations. The Nordic power market has acted as a model for market development internationally for years. An important basis for the operation of the Nordic power market is clear roles with defined mandates and responsibilities. The approach for deploying the local energy market was to adopt relevant elements from the general market and make them fit in a local energy environment. This basic reference to the existing Nordic and European power market [5] is in detail discussed and analysed in +CityxChange project deliveries[1], [3] in Work Package 2 (WP2).

The traditional end-customer is given the ability to be an active market participant by providing both locally generated power and flexibility by utilising available flexibility in the consumption. As a market participant, the customer - as a consumer or producer - described in figure 2.2 will manage energy assets that are active with bids of sale or buy in the marketplace. The market design gives the customers' assets market access to local resources - independent of size.

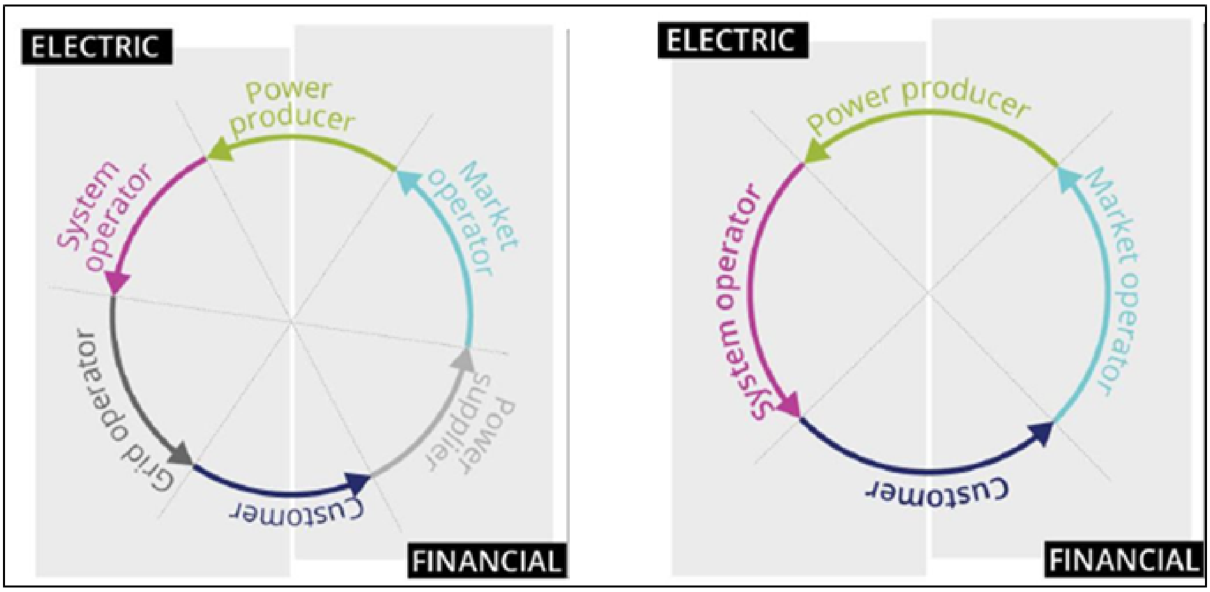


*Figure 1.2 The global (wholesale) market includes 6 different major roles, while the local market is designed with 4 major roles. Ref:* D2.1: Report on enabling regulatory mechanisms to trial innovation in cities [1].

The objective of this deliverable is to support the ongoing green energy transition by deploying software for operation of and participation in local energy and flexibility markets. Providing market access for any energy asset regardless of size, will make the investment in energy assets more profitable and hence increase motivation for investing.

The green energy transition is a big change for achieving a sustainable future. In essence it can be characterised by the 4 Ds: Decarbonisation, Decentralisation, Digitalisation and Democratisation. Increasing the motivation for players within a local community to invest in energy assets, will contribute to both decarbonisation and decentralisation; increase in new emission free production capacity, increase in energy awareness through market participation to reduce peak demand, and decentralised production capacity in combination with flexibility to reduce the need for transmission capacity. Highly digitised solutions enabling a high degree of automation is a prerequisite for end-customers becoming active market participants, and together with adaptations in rules and regulations lays the foundation for democratisation of the energy system.

A functional and fully automated local energy and flexibility market is by itself an important delivery and innovation within the +CityxChange project. In addition, local trade of energy and flexibility is an important part of the +CityxChange PEB solutions in LHC Trondheim as a contributor to obtaining PEBs. Also, utilisation and exploitation of local flexibility is an important means to optimise city level energy resources to obtain Positive Energy Blocks and Positive Energy Districts. This will result in improved energy efficiency and extensive RES interventions.

## 1.2 Task dependencies within the project

With the Deployment of Energy Trading Platform task 5.9 in centre, the dependencies between +CityxChange project tasks are mapped and presented in Figure 2.3. The foundation for Task 5.9 is Task 2.5 and the report D2.7 - *Local dPEB trading market demonstration tool*[6] In addition, the deliverable D5.9 - *Playbook of regulatory recommendations for enabling new energy systems* (Energy regulatory framework, Task 5.4) [4] is a vital set of guidelines for how local energy markets are allowed to be set up, in addition to necessary dispensations from the national regulatory body for energy (RME) for setting up local energy markets.

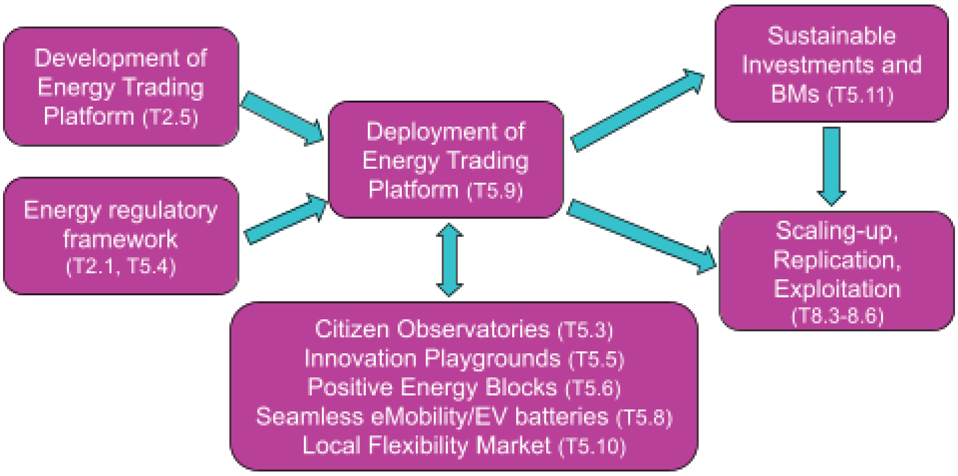


*Figure 1.3. Task dependencies between Task 5.9 (Deployment of the Energy Trading Platform) and other +CityxChange tasks.*

There are strong dependencies towards other tasks within the demonstration projects in LHC Trondheim, especially the tasks on *Seamless eMobility* including EV batteries as market participants through V2G EV charging and the interaction with the Positive Energy Blocks (PEBs), where solutions for connecting assets to the market will be deployed, and *Local Flexibility Market* where the demonstration of the market will be performed.

In the +CityxChange project the work and interactions are performed within 3 tasks where the core partners have been working tightly together on a weekly basis during - especially - the last 1.5 years: Task 5.6 - *PEB deployment* (asset and system integration - ABB), Task 5.9 - *ETP deployment* (VOL), and Task 5.10 - *LEM/LFM deployment* (TE) and asset/system selection for the LEM/LFM integration and inclusion of additional buildings into the local markets (ABB).

[6] https://cityxchange.eu/knowledge-base/d2-7-local-dpeb-trading-market-demonstration-tool/

Results and outcomes from the demonstration of the local energy platform and market will perform important input to *Sustainable Investments and Business Models* (Task 5.11); both concerning potential future business value for VOL and TE and for further scaling-up, replication, and exploitation. The concept and solution for the Energy Trading Platform is widely used for dissemination and communication as a core solution within +CityxChange at the *Citizen Observatories* (Task 5.3), and in the *Innovation Playgrounds* and innovation labs (Task 5.5).

## 1.3 Adaptations to and deviations from Grant Agreement

During the project period it is clarified and realised some internal changes in progress and priorities compared with the original plan. These deviations from the Grant Agreement are presented in table 2.1.

*Table 1.1. Deviations from (D) and adaptations to (A) the original plan (GA / DoA).*

| Grant Agreement (DoA) | D/A | Adaptation to/ Deviation from DoA |
|---|---|---|
| CSO and TSO as actors participating in the trades | A | The model with an independent local CSO is not being deployed in Trondheim. TE will fill the role as local market owner and operator.<br>The TSO will not be involved in the local trades as the market solution will not be set up for aggregating flexibility in order to trade larger capacity volumes with the TSO. The local grid owner/system operator is allowed access to the market as a participant to acquire flexibility when needed. |
| "The deliverable describes the phased deployment of the energy market where Phase 1 includes 8 buildings at Sluppen and 3 buildings at Brattøra, and Phase 2 where the market is extending to the remaining buildings in the demo areas of Sluppen and Brattøra, and integrates Campus Gløshaugen for physical and virtual trade" | D | Phase 1 (into full operation by 30.04.22 at the latest): 4 (actually 5) buildings at Sluppen - due to revised PEB Sluppen set-up and building selection - and an increased numbers of 13 buildings at Brattøra are included, a total of 17 (18) buildings included.<br>Phase 2 is not possible to implement within the project period (31.10.23). The Brattøra Phase 1 is, however, scaled up substantially, and thus provides a broad and large scale demonstrator for a wide variety of types of market actors. However, the Brattøra area has already been scaled up regarding |

| | | |
|---|---|---|
| | | flexibility integration beyond original phase 1 plans (see details in future D5.11 Trondheim DPEB Demonstration).<br>TK will together with partners search for opportunities to extend and scale the markets to additional buildings post 2023. This is well in accordance with TK energy and climate goals for 2030, and further work within the scope and ambitions for the LHC Trondheim Bold City Vision and Guidelines (D5.7) |
| DoA describes a dashboard solution for the ETP displaying the trades, trade volumes, etc. | A | A dashboard solution itself with real-time displaying of the trades and trade volumes is not fulfilling concerning the needs for both displaying, reporting, showcasing, and benchmarking the trades in the two LEMs/LFMs. A report tool will be available, being a full substitute for a dashboard. |
| Onboard new actors/participants for the LEMs/LFMs through the citizen observatories (Task 5.3) and innovation playgrounds/labs (Task 5.5) | D | Direct onboarding of participants through other channels and means - such as 1-1 meets proved the only viable way of onboarding, given strong needs for detailed technical, legal, and business discussions. Observatories were used in the sense of the main TK project office. Details on the developed process for onboarding are found in Section 5.. |
| D5.5 deliverable was according to Grant Agreement due M26 (31.12.20) | D | Extended to January 2022 due to the need for and the increased value of including preliminary results from operation of the local energy and flexibility markets and the strong integration and co-dependency of the two market types. |

# 2 Energy market software architecture and features

The trade platform developed for demonstrating local energy trading in a PEB consists of the following software building blocks included by partner providers:

- **ABB** OPTIMAX® for asset operation (physical connection of building-integrated or separate assets and connection to online/cloud backend and sending signals to the assets or their controllers).[7]
- **Volue** Algotrader for market participation (software for set-up and implementation of assets trade strategies and preferences).[3]
- **Volue** Digital Marketplace for market operation (receive asks and bids from Algotrader and settle trades).[3]
- **IOTA** for secure third party data verification to ensure consistency between executed trades and the following settlement.[3]
- **TE** Operator software for forecasting, flexibility optimization and settlement (software that supports strategy set-up for each asset to be implemented in Algotrader).

Each building block is an individual and independent software developed to serve a specific purpose. Data is exchanged through standardised APIs and stored in a common database. The prediction and optimisation are done on asset level and are exchanged as time series which are read into algorithms defined in the Algotrader. The asset owner is the responsible party for both the predictions, optimisations, and defining of the algorithms. However, in the project TE has provided these tasks as a service for the asset owners. The algorithms in the Algotrader ensures the assets' automated participation in the local market as described in figure 2.1. The Digital Marketplace matches corresponding bids and offers to enable automated trades, and the OPTIMAX® executes the dispatch accordingly. Information about the trades as well as the execution is stored in the IOTA Tangle[7] to ensure immutable data verification for settlements and invoicing.

[7] https://www.investopedia.com/terms/t/tangle-cryptocurrency.asp

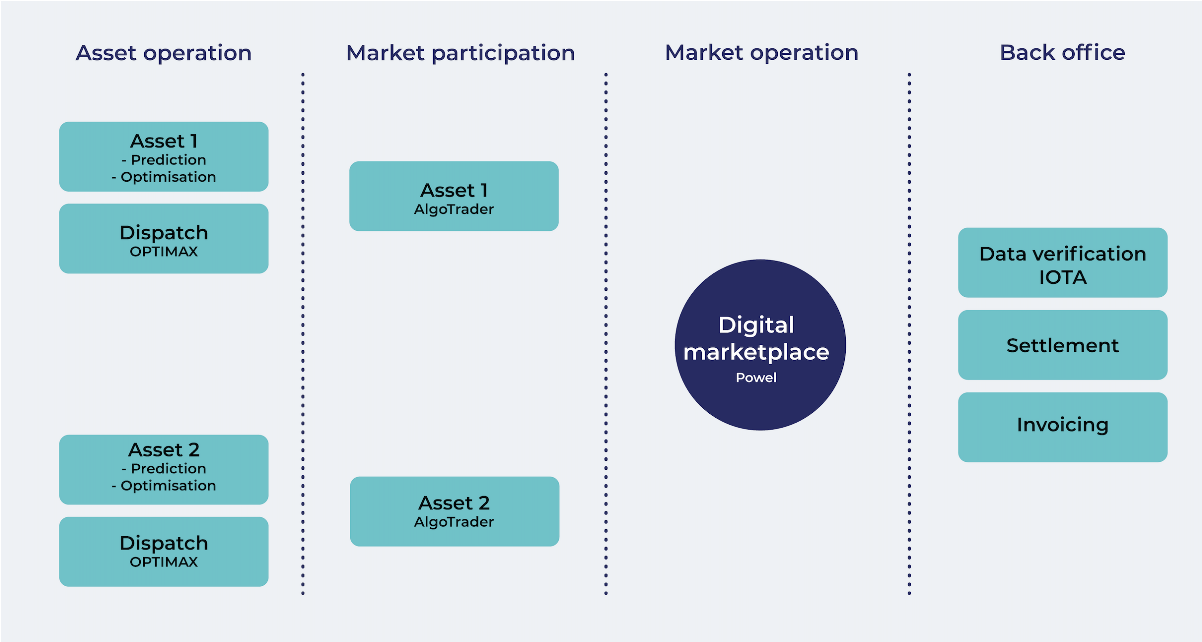


*Figure 2.1 The relation between the building blocks to enable local market operation. From Dahlen et al. (2020) - D2.7 Local dPEB trading market demonstration tool [2].*

With complex interactions that are happening in the local market setting, there is a need to orchestrate the flows between forecasting, grid calculation, problem detection and trading in the local market. This is served by a rule-based customised system for each asset and deployment and takes care of executing the tasks based on the evaluation of the rule conditions. The rule-based customised system is outlined and executed as a predefined strategy for each asset modelled in AlgoTrader [3] (D2.7 *Local dPEB trading market demonstration tool*).

## 2.1 Software architecture

The deployed trade platform has an IT architecture as described in figure 2.2. The software architecture is characterised by a central database exchanging information with functions and parties. The database is operated by Volue, with ABB and TE having additional supporting systems, all connected by APIs. The portfolio of functions include data management, predictions, grid calculations, and trading. Of these it is only data management (Database + API) and Local Market (Trade Platform, Algotrader and ledger integration) that are included for this deployment. These are facilitating the main functions of the trade platform, data ingestion and market transactions.

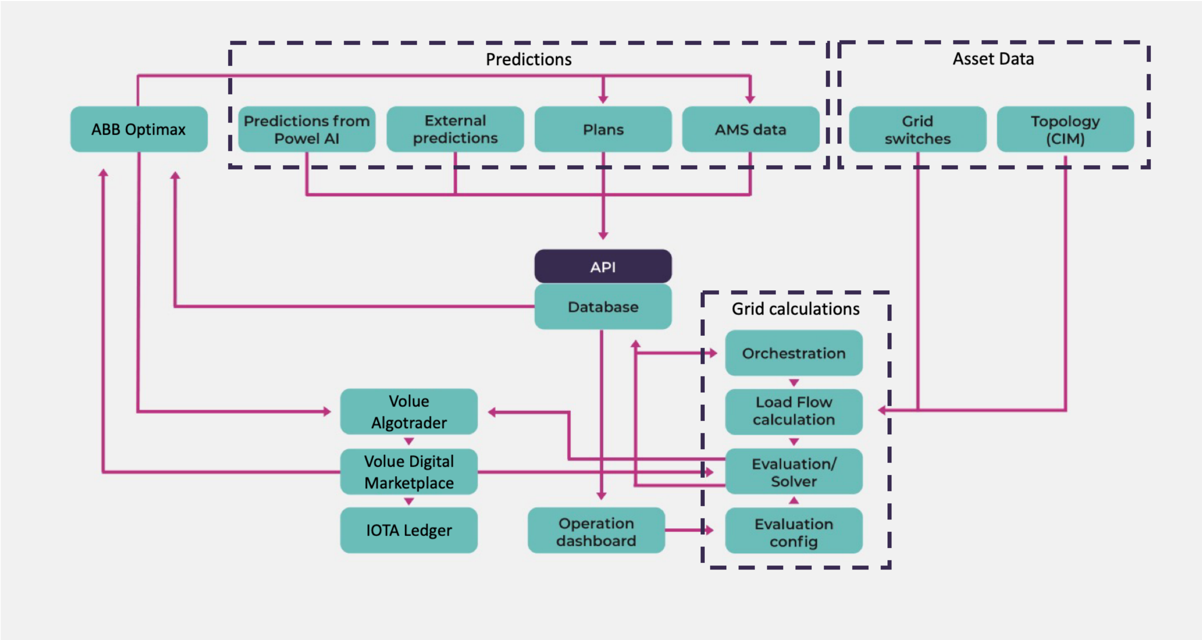


*Figure 2.2 IT-architecture of the deployed Energy Trade Platform, including grid calculation.*

Central database serves as the main way of exchanging time series data for different parties (VOL, TE, ABB, etc.). The central database is based on TimescaleDB technology with FastAPI. This database is deployed alongside a well documented, simple Data API based on FastAPI technology, allowing read/write privileges to authenticated users, enabling exchange of time series data. [8]

## 2.2 Software features

### 2.2.1 Predictions

Asset data is needed for proper planning, forecasting, and operation of local market and PEB systems. This includes AMS meter readings, switch positions, and asset configuration, plans and measurements from 3rd parties, and similar types of time series data.

For ideal operation of the local market, all assets need consumption and/or production predictions. These can come from various partners, but they all are read/written through Data API, the same as any other time series. This also includes weather and market predictions, which are also further used in planning and trading processes. The predictions can be provided by various partners, but they are all read/written through Data API, similar to any other time series.

The prediction service consists of small microservices, written in Python, and running on Kubernetes orchestrated clusters in the cloud and is flexible and easy to scale for each individual PEB.

### 2.2.2 Local grid calculations and asset data

When asset localisation and connection points to the local grid are defined, it is possible to update with the actual grid topology as developed in the report D2.2 *Toolbox for design of DPEB including e-mobility and distributed energy resources (DER)* (Dahlen et al., 2020) [2]. The toolbox makes it possible to simulate how renewables in detail will contribute to a PEB/PED with regards to capacity, energy and cost. The tool includes a feature for making grid and load flow calculations in a local grid topology. The topology is exported from DSO's GIS or NIS system by using the standard CIM model and stored in an object store, which allows easy storage and fast read/write speed of data when such cloud based calculations are required. The load flow analyses for a local grid are shown in figure 2.3 as a service using a common database and external topology data. The load flow analysis will support the understanding of local system services demands - and how to set a market based value of contracted and activated resources dependent on location, volume, and time. The calculations are available on a daily basis or on request.

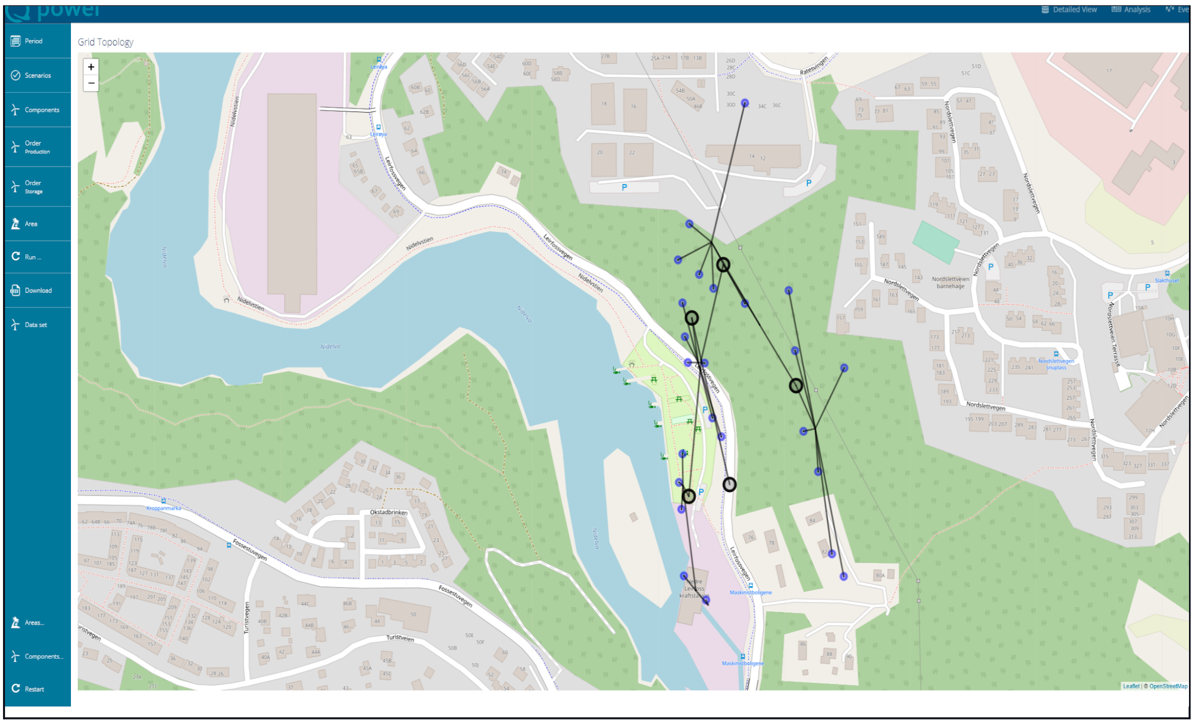


*Figure 2.3 Local grid area and topology in Trondheim close to the Sluppen PEB area with assets mapped. From "D2.2 Toolbox for design of PEB including e-mobility and distributed energy resources. +CityxChange Deliverable".*

Figure 2.3 shows the local grid topology imported by using the CIM import model between GIS/NIS to TrønderEnergy/DSO and to the grid calculation model. The connection points (black circle) and the consumption points/meters are shown as blue points. The topology shows the electricity connections - not the real coordinates for the cables. The available grid calculation tool is a collection of individual services, written in C# that are integrated through APIs. All services run in the cloud and all except the load flow calculations are cloud native applications. The services run on Microsoft's Azure cloud platform. This approach means that every service can be exchanged with third party solutions where feasible.

### 2.2.3 Market participation through Algotrader

The algorithms in the Algotrader are in essence a way to model in detail the market preferences for each asset or market participant.

Figure 2.4 presents a detailed view of how the strategy preferences are modelled and edited. A white box approach is applied in order to create a robust, open-source architecture, allowing customisation for customer-specific strategies. The solutions offer both standard algorithms for trading strategies and the flexibility to build and test new market strategies in Python with the help of the dedicated microframework for easy coding.

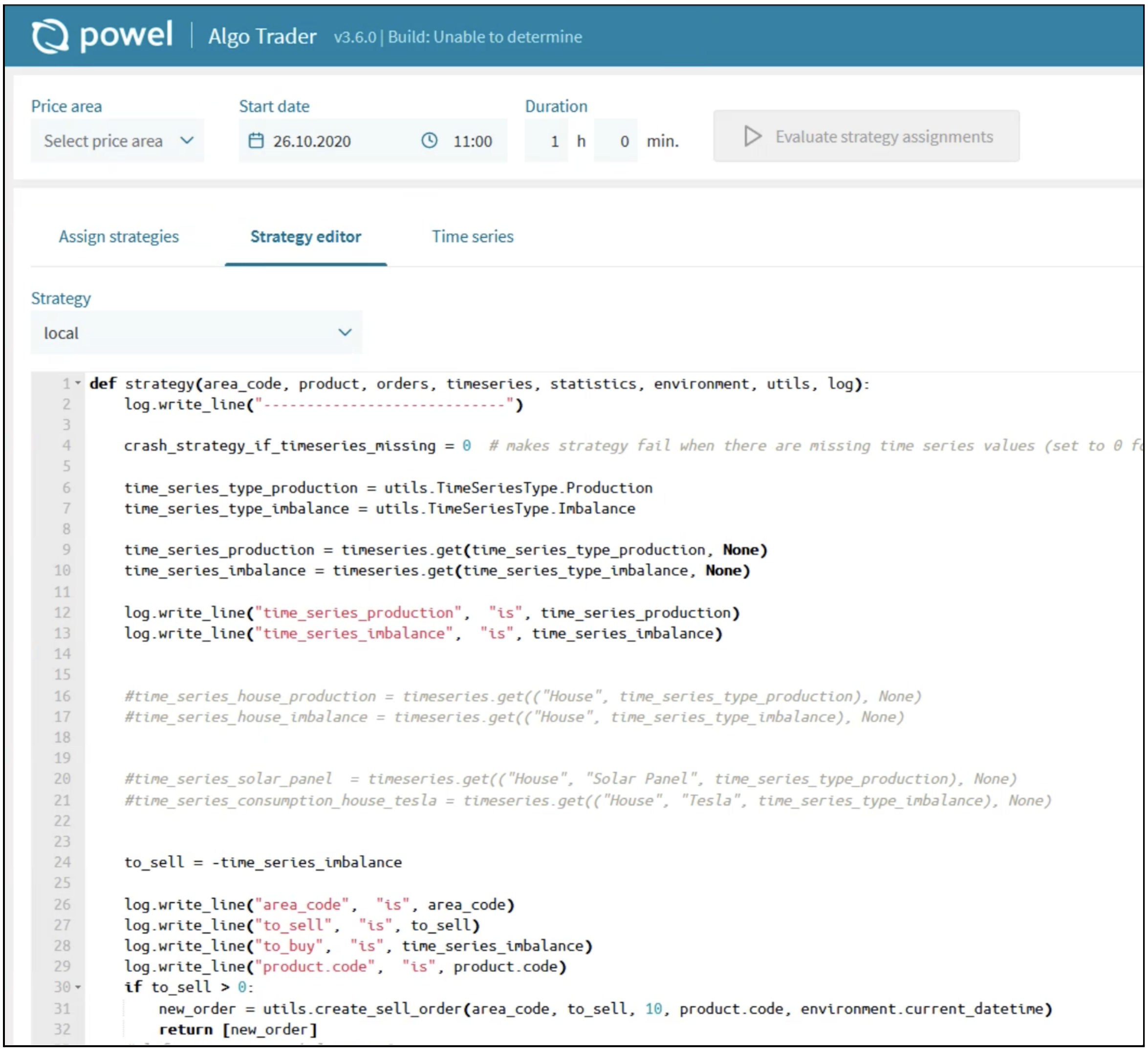


*Figure 2.4 Strategy editor for setting up the assets' local trade preferences.*

In the Strategy editor, asset owners can develop new strategies and edit existing ones at any time keeping track of all the code changes. The strategy editor allows the asset owner who codes the strategy to input descriptions and generate parameters with descriptions that can be seen and changed through a dynamic user interface while launching the strategy. This allows the actors with no coding experience to use the solution efficiently. The strategy editor also includes a number of predefined strategies that the actor can test, set live and use as a starting point, or modify in accordance and in line with their own logic. The strategy editor offers an easy-to-code interface, and supports the coding process with a dedicated microframework. This is important in order to lessen the code that has to be written by offering whatever an actor trading in a local market needs as ready functions.

When launching the trading strategies, the market participant chooses for which time each strategy should be active, as shown in figure 2.5. An actual strategy can be assigned for a given period of time and is running until a time limit or when manually revoked.

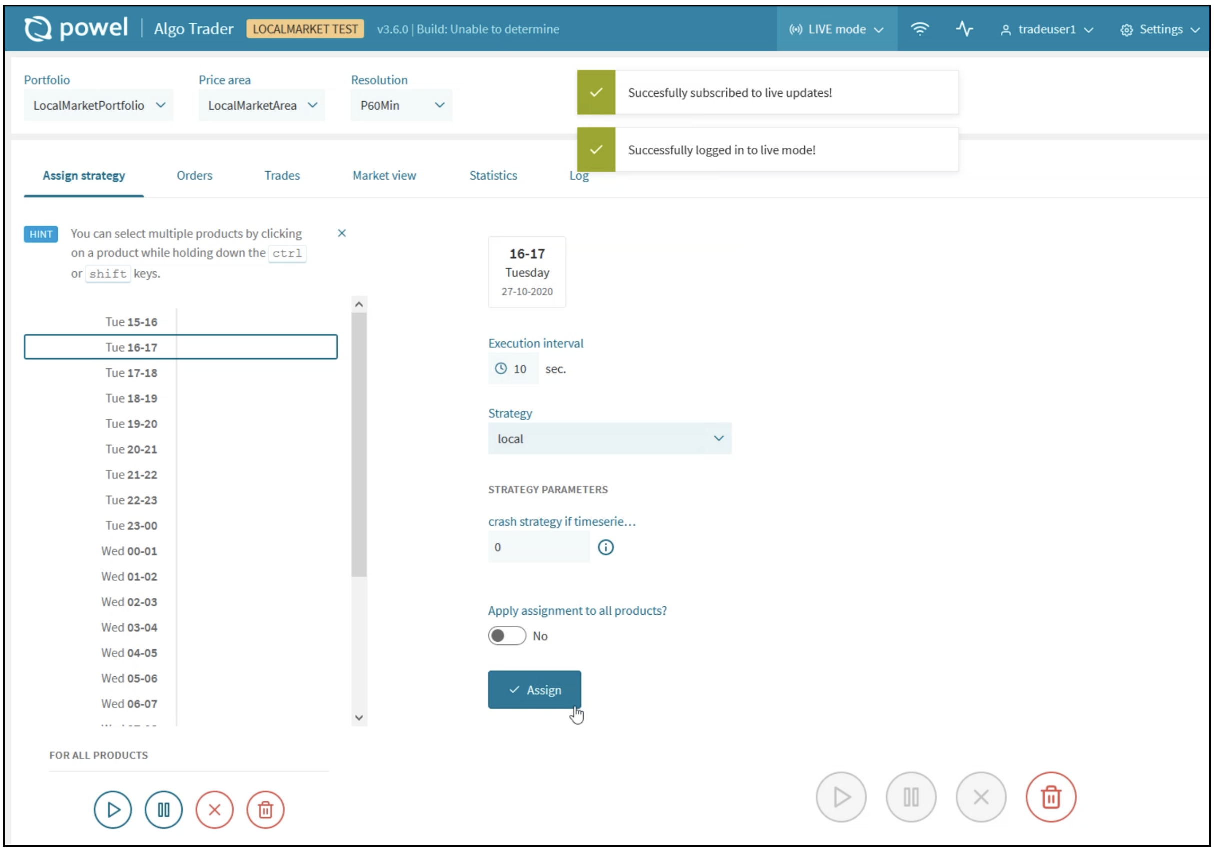


*Figure 2.5 User interface for how to choose trading strategies for a specific period.*

The actual data flow to enable automated local trading is described in figure 2.6**.** The most important data is metered kWh/h. These data are used for both calculating predicted kWh/h to be used for establishing bids and offers, and for settlement purposes. The algorithms defined in Algotrader transform predicted kWh/h together with specific preferences per asset into bids describing how much energy the asset wants to produce/consume at what price for each timestep. Several bids/offers can be made at each timestep as long as the price varies. Details about price setting for the trades are in detail described in [3].

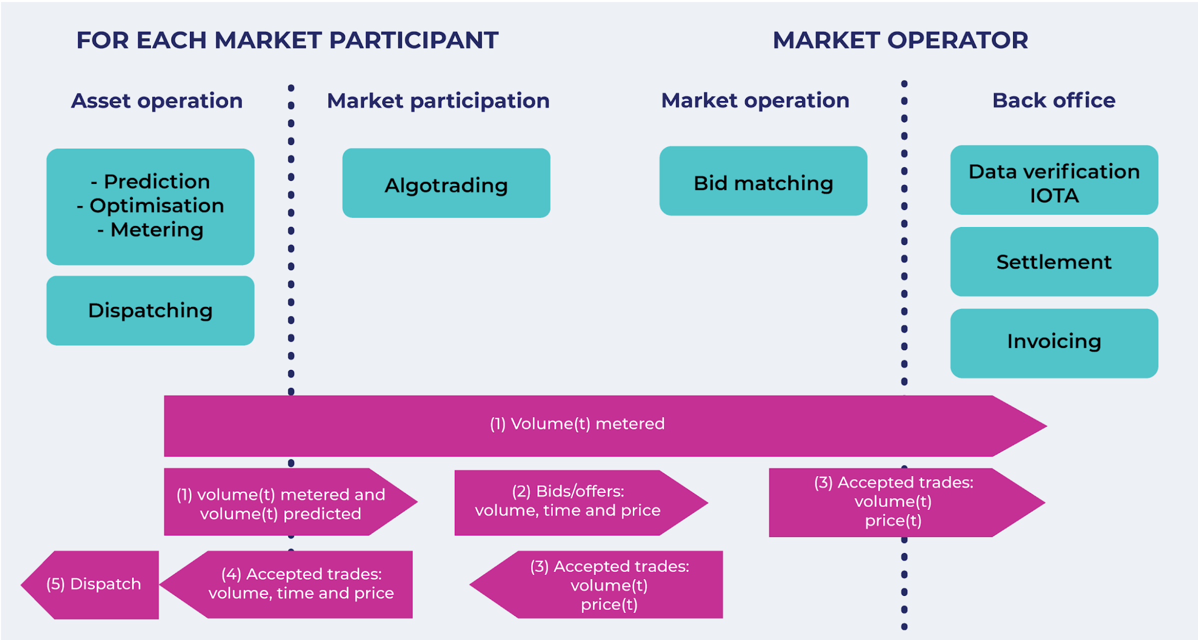


*Figure 2.6 Trade process local power market - from bid to invoicing.*

## 2.2.4 Market operation through Digital Marketplace

The Digital marketplace as described in figure 2.1 ensures matching of all corresponding bids and offers available at the local energy market based on their bid/ask price and order they received. The matching algorithms matches top-most orders based on the following sorting rules:

- Open Bid Orders: Price Descending, Time Ascending
- Open Ask Orders: Price Ascending, Time Ascending

Because the local market is mirroring the logic in the continuous intraday power markets in Europe, price is not being set in advance, but only based on the current bid/ask balance, and willingness of actors to buy/sell energy for a given price.

To access the market, assets are not integrating directly with the market API. They are instead interfaced through the algorithmic trading solution, Volue Algotrader. This software takes care of combining asset preferences, forecasts and plans and depending on the trading strategy selected, creates buy/sell orders in the local market.

The backbone of the Digital Marketplace can operate on a time resolution suitable for also covering system services like reserve markets and ancillary services. This will be adapted in due time for the market to start up, meaning the GUI will have 15 minutes resolution.

### 2.2.5 Asset operation

The deployed energy trading platform, as described in figure 2.6, operates the local energy assets through utilising the extensive interfaces and flexible setup of the ABB OPTIMAX® technology. It has various setups adapted to the individual assets, where it will be run as an on-premise or cloud solution. The assets that will be interfaced are very different in design, operation and capability, and the deployed asset operation and management technology is developed to work for all types of assets, from PV panels to snow melting facilities.

The local controller includes the possibility to make some predictions for the purpose of controlling the assets in line with the individual market strategies as implemented in the deployed algorithmic trading solution. It also includes load dispatch based on signals about accepted trades coming from the trade platform after bid matching.

Assets connected and controlled through a building automation system that is running in a local network will be integrated by installing a physical or virtual machine that runs the local OPTIMAX® in the same network as the building management/automation system (BMS). The enabled machine is then granted access to operate the asset(s) by communication via the building automation system. Some aspects of this have been described for the Gløshaugen case in D5.3: *Campus Microgrid Model Prototype* and details for the PEB deployment will be described in the future D5.11: *Trondheim DPEB Demonstration*.

### 2.2.6 Back office process

The back office processes are about ensuring correct settlement between buyer and seller in the local market, and invoice accordingly. In a local market, one of the main objectives is to remove barriers for market participation so that everyone can participate, regardless of size. Enabling a high amount of micro transactions will be key to succeed with a local market. This means that cost per transaction needs to be close to zero. To enable secure micro transactions with low cost, IOTA verification service is deployed to ensure immutable information shared between all market players. The verification service developed by IOTA guarantees the integrity of data used in the trade platform. In particular, matched trades generated by the market operation as well as assets data, generated by assets operations (such as ABB OPTIMAX®) need to be verified by the market back office before a settlement and invoicing is triggered. The infrastructure makes use of a Distributed Ledger, which provides an immutable data store, and makes it impossible to alter stored information undetected. When data or its copy is shared on this immutable infrastructure, its integrity can be guaranteed. A comprehensive description of the IOTA verification service can be found in the report D2.7: *Local DPEB trading market demonstration tool [3]*.

The information used by the market operator to perform invoicing consists of all bids to the market (volume, price and time), accepted trades (volume, price and time) and metered volume [kWh/h], produced and consumed. Based on this information, the market operator derives how much of the produced/consumed energy is traded locally, which then creates the foundation for invoicing.

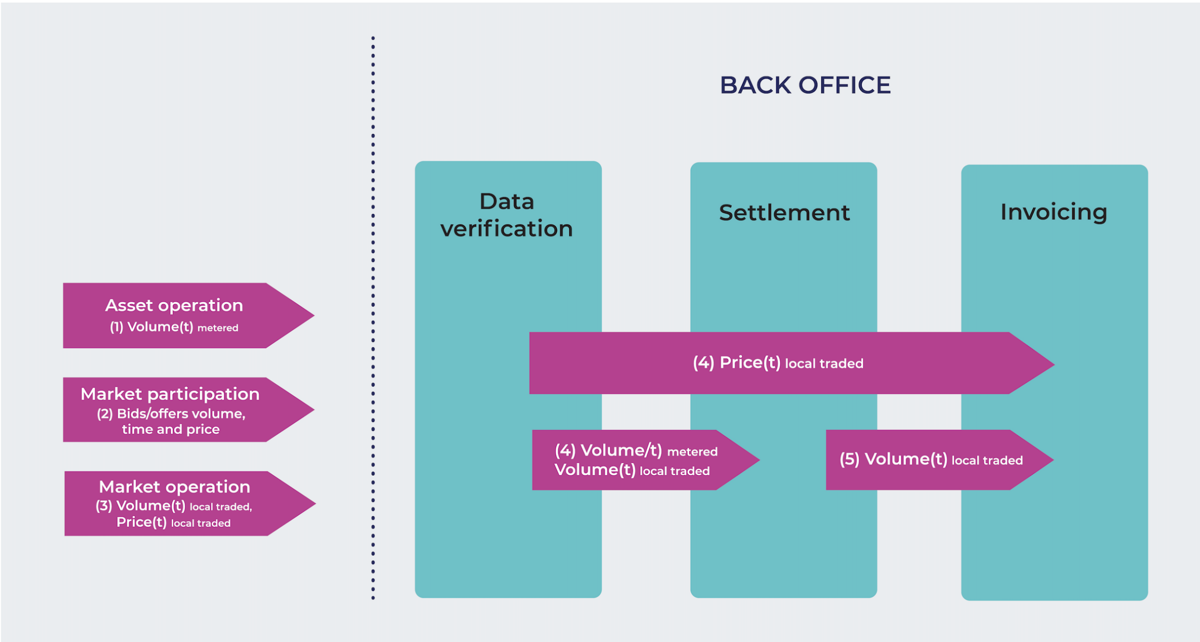


*Figure 2.7 The invoicing process for local power trade - a stepwise description.*

The project has deployed the IOTA verification service, currently in a parallel way, to be consistent with overall needs and local regulations. Some assessments on this are also found in *D1.3: Report and catalogue on the ICT data integration and interoperability* [9].

Systems used for settlement and invoicing are existing solutions used by TE in their market activities, hence have not been deployed as part of the project.

# 3 Deployment of the local energy market

The deployment of the Local Energy Market in the Trondheim case consist of two separate tasks:

A. Deployment of the software as a cloud based solution, including all necessary building blocks.
B. Deployment of the market operation, including onboarding of all the physical energy assets within the PEB, configuration of market participation, and dispatching.

The deployment includes that assets are connected physically and digitally to the market trade platform. Ready for being demonstrated in the actual case in Trondheim. It is important to underline that the deployment is scalable and replicable when it comes to technical requirements and types of installations. This first deployment will act with lessons learned and procedures for how to further use this deployed solution in the +CityxChange project.

## 3.1 Project deployment timeline and milestones

The activities in realising a live local energy market over a total deployment period of 12 months has several milestones as described in figure 3.1, in the form of a playbook and guide. This is a general timeline for deployment and replication of the market based on the work presented here. Internal project deadlines differ, as they include development phases as well.

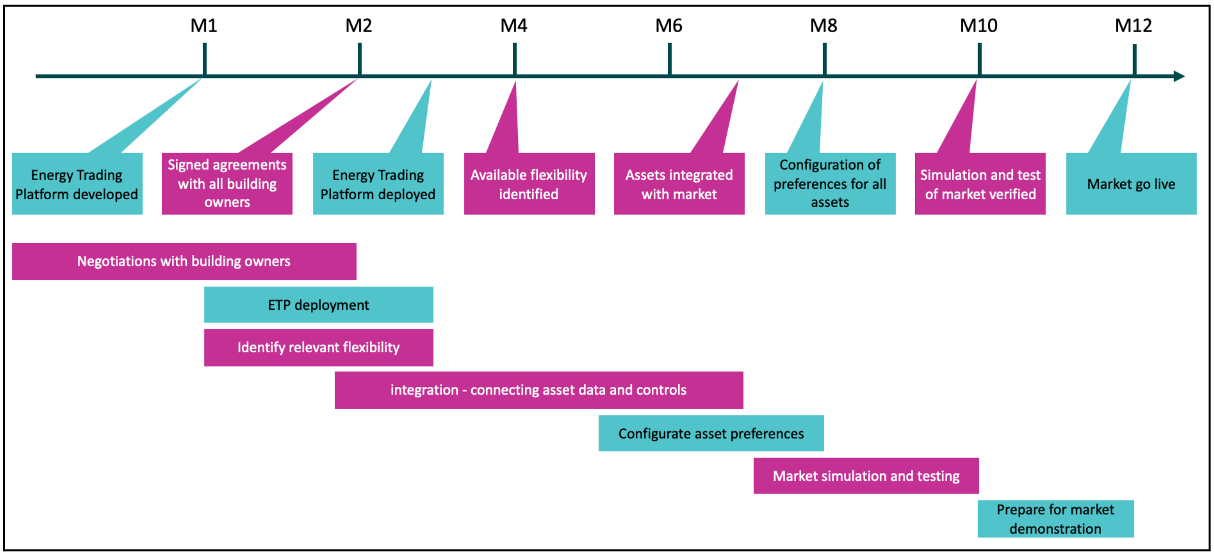


*Figure 3.1 Deployment milestones in the process of establishing a live local energy market.*

The different deployment sub-processes described in figure 3.1 in establishing the local market are experienced as the following six steps with related milestones:

1. Establish bilateral agreements/contracts with building owners and/or owners of actual flexible local assets.
2. Identify and define all available flexibility with regards to energy [kWh] and demand [kW].
3. The software required to operate the local market is installed and deployed giving all local players/participants access to the marketplace..
4. Asset - market integration; connect each asset to the market so that they can be controlled based on a confirmed trade.
5. Each asset with their identified available energy resources[kWh and kW] are configured in line with individual preferences for the local trade platform.
6. Market set-up and operation is tested and simulated for all assets. The complete local market solutions including the contracted flexibilities are approved.
7. Local market operational kick-off! Involve all participants. Explain market operations with the purpose of building trust and interest. Develop market reporting to participants.

The project has a defined timeline with a time frame of one year, including intermediate milestones for the whole process starting with a developed Energy Trading Platform (ETP) as milestone for Month 1. This may not be valid in general, it will vary depending on a variety of factors - many of them highly local. Experiences so far from LHC Trondheim shows that some of the subtasks are complex and time consuming. This is especially applicable to identification of and decision on viable sources of flexibility, *de facto* integration of assets on the local energy market, and defining and configuring the preferences and presets for all assets. Indicative timeline and intermediate milestones are presented in table 3.1.

*Table 3.1 Timeline for deployment of the project's local market in Trondheim.*

| Month | Milestone |
|---|---|
| M1 | Energy Trading Platform developed |
| M2 | Signed agreements with building owners / ETP deployed |
| M3 | Energy Trading Platform deployed |
| M4 | Available flexibility identified |
| M7 | Assets integrated with market |
| M8 | Configuration of preferences for all assets |
| M10 | Simulation and test of market verified |
| M12 | Market goes live |

The operation of the primarily automated local, disaggregated flexibility market will probably face different so far not known challenges of technical character.

## 3.2 Deployment of the local energy market software

The Energy Trading Platform (ETP) with its building blocks was developed in Task 2.5 and described in the deliverable D2.7 *Local DPEB trading market demonstration tool* [3]. The connection to wider systems of the project is further explored in *D1.2: Report on the Architecture for the ICT Ecosystem* and the respective WP2 reports. The deployment of the software was done using managed Azure Kubernetes Service (AKS). This allowed us to create an instance of ETP on the Volue.AI production cluster, under Volue's Azure subscription specific for the +CityxChange project. Originally there were plans to use a common, dedicated +CityxChange Azure subscription, to track all the costs regarding deployment of various solutions from all project participants (ABB, TE, Volue, IOTA), but this plan was put on hold for practical and cost reasons. Using an already prepared set-up enabled a faster deployment without the need for additional licence and set-up costs.

### 3.2.1 Approvement of deployed software

The software is deployed by VOL and operated by TE. For the purpose of the project, a Proof of Concept architecture (POC) as described in figure 3.2 is established for how to approve the software deployment.

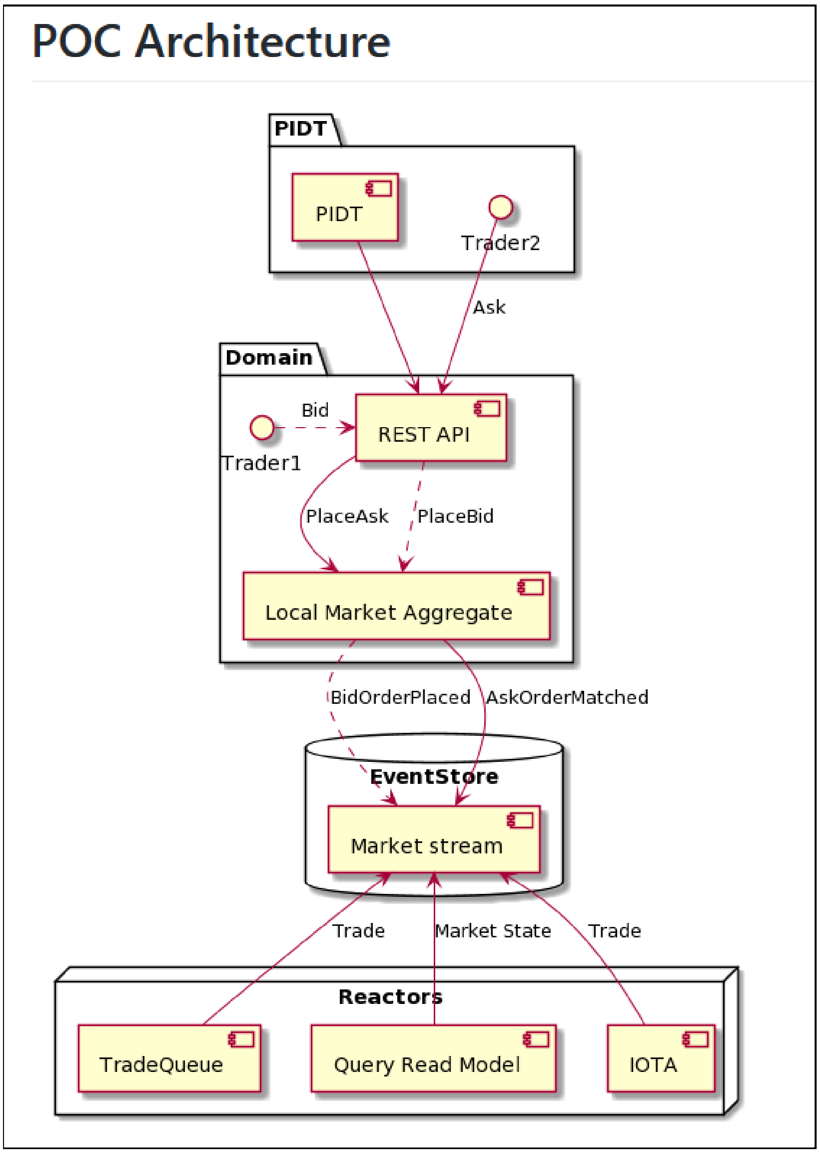


*Figure 3.2 POC architecture for the software approval procedures.*

The main endpoints affecting the local market operation which are deployed are the data API endpoint, trade initialisation, and operation interfaces and Digital Marketplace (denoted PIDT in fig 3.2).

Using Azure Kubernetes Service allows us to set proper hardware limitations and requirements for the solution, isolate all components from the rest of applications running on the same cluster, and assure a high level of reliability. Volue will be monitoring, securing and updating the Kubernetes cluster while the services are being deployed and used by the project.

There are 4 modules within the Digital Marketplace deployment:

**Volue Algotrader and Volue Intraday Trading** module takes care of the manual and algorithmic interface to the local market, and is deployed as a single container within Volue Azure AKS, with appropriate APIs and interfaces to access the Digital Marketplace. TE as a Market operator has access to these via defined users.

**Central Database** is a single instance of Volue TS database, which is deployed as a container within Volue AKS, with a FastAPI as an interface for both read and write operations. TE and ABB are provided with access credentials to allow for asset and trading data to be exchanged and used further in Market Access and Digital Marketplace. Link to the Volue API documentation is attached in References [8].

**Digital Marketplace and Event Store**

Local Market backend, which takes care of storing and matching orders in the Digital Marketplace, is deployed as two containers: Market backend and Event Store. The former takes care of accepting orders from Market Access and places them in the Event Store database, which takes care of archiving and storing complete history of all the orders as they happened, for audit and verification purposes. Project participants don't have direct access to Market backend, but TE as market operator has access to Event Store, therefore can audit and track all the orders and transactions.

**Data Verification Service (IOTA)**

This service is deployed alongside the Digital Marketplace backend, within the same deployment container, and serves a purpose of duplication of all matched orders into IOTA ledger. This then allows for integrity checks of the trades, and ensures that data in the Event Store is not a single source of truth regarding the market transactions.

### 3.2.2 Data API Endpoint for database read and write

The Data API endpoint allows read and write to the central database. All participants who need to use and exchange data need to integrate with this endpoint. Complete documentation, list of allowed calls and examples how to integrate can be located at link in references.

### 3.2.3 User interface to access and edit own trade strategies

This user interface allows users, after authenticating with username and password, to access the user interface of Volue Algotrader, the algorithmic trading application applied for connection of trade strategies to the local market. This allows users to define, run and test trading strategies for the local market. Figure 3.4 presents the deployed software interface for editing the assets strategies as set in figure 2.4 to be used by the algorithmic trade. In the deployed solution in the +CityxChange project it is the partner TE, acting as the local market operator, that operates and supports the market participants in setting up their priorities and strategies for market trade.

The deployment includes an interface for the user to define and store many strategies for each asset. Then it is crucial that the operator on behalf of the user can change strategy if the market situation or asset owners priorities changes. The deployed solution includes a user interface as described in figure 3.3 making it easy and trustworthy to update strategic priorities. This change of priority may be for part of or the whole portfolio for a special time of the day or other specific events. Examples may be renewed highest buy price for a specific period of time as shown in figure 3.4.

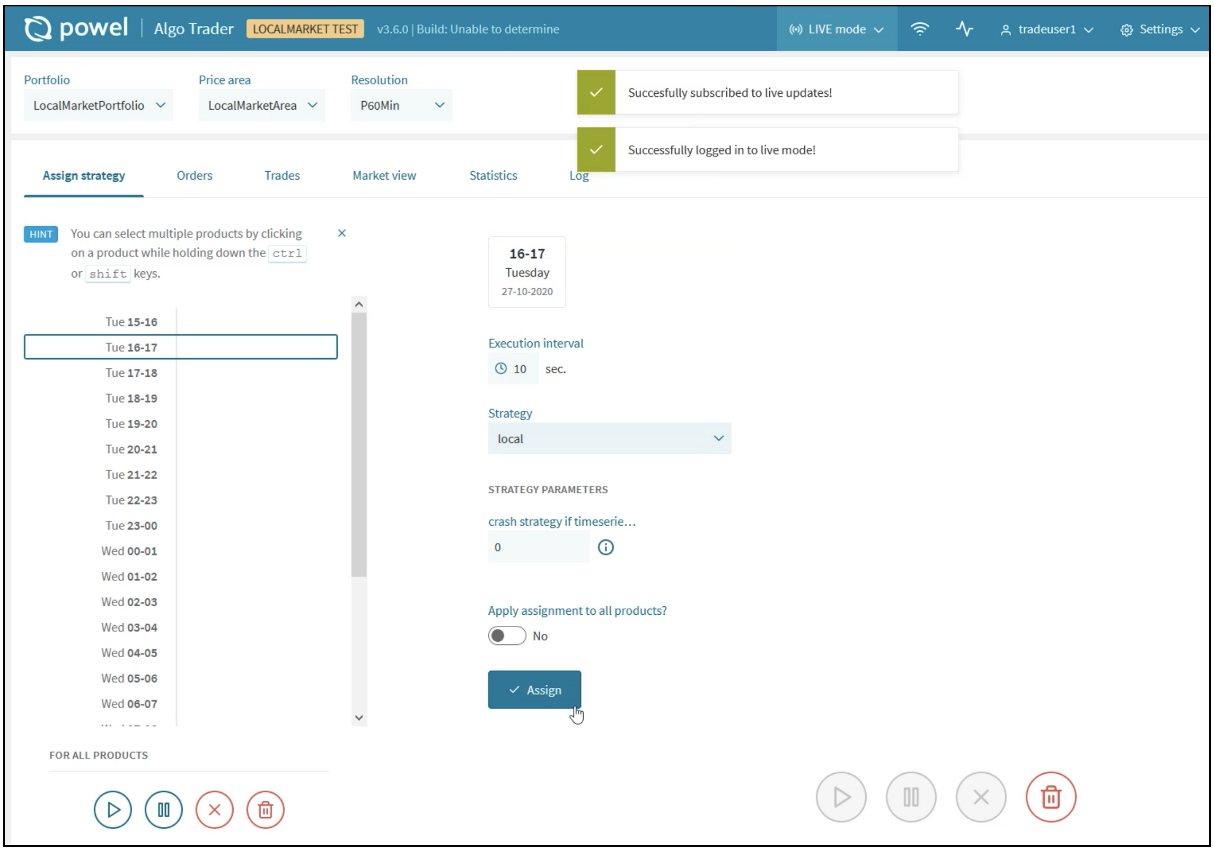


*Figure 3.3 Deployed strategy editors interface for how to prioritise among defined and stored trading strategies for a specific period.*

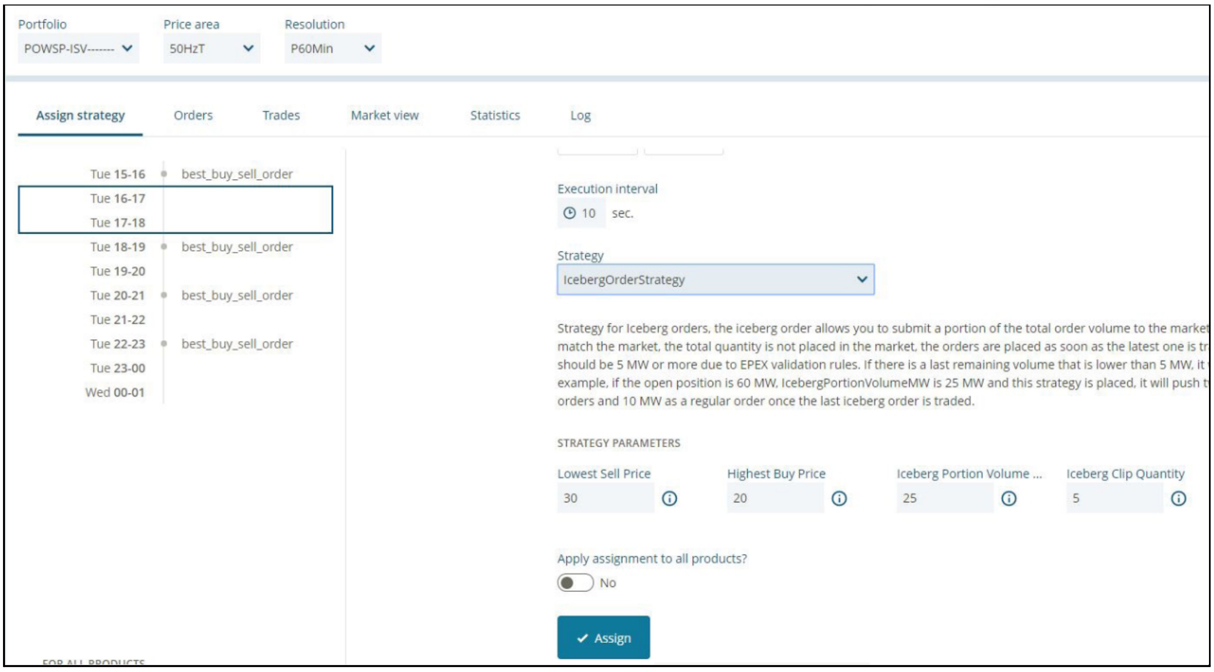


*Figure 3.4 User interface for showing the assigned trade strategy for a specific product at a specific period of time.*

### 3.2.4 User interface for digital monitoring of the marketplace

This endpoint interface allows market participants and market operators to monitor and gain an overview about open orders in the market and judge its state. While it is possible to create and manage trade orders, it is, however, deployed in a highly automated trade environment in the local market. Still it is asked for the possibility to monitor ongoing automated trades as presented in figure 3.5.

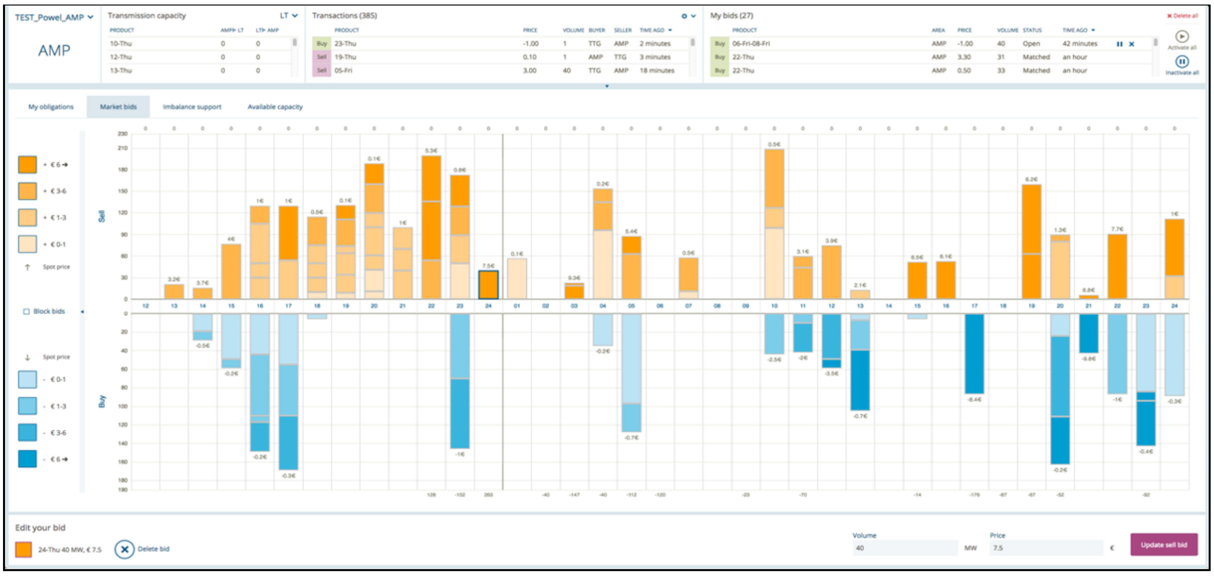


*Figure 3.5 Interface that monitors and presents an overview of ongoing trades in the local market.*

### 3.2.5 Connecting assets with the local energy market

ABB OPTIMAX® [7] is deployed as an energy management system to ensure connection with the actual assets that participate and the market. ABB OPTIMAX® sends information about current state to the common database and reads information about trades so that new setpoints can be executed with the control system. One instance of ABB OPTIMAX® is deployed for each participating asset.

### 3.2.6 Data verification between trade- and setpoint execution

To ensure correct settlement and invoicing, information about accepted trades (volume and price) and metered volume (kWh/h) is sent to the IOTA tangle as an immutable data storage. Volue is syncing all the matched orders into the tangle, so this information can be paired with metered data from ABB and other asset owners.

## 3.3 Deployment of the market operation

All available energy resources for the local energy market and its deployed solutions are located in the energy blocks in Trondheim as described in +CxC task T2.1 [1] and realised in +CxC task T5.6 and the upcoming *D5.11: Trondheim DPEB Demonstration*. In this task it is installed energy resources including technical instrumentation for market access purposes. The task includes mapping of energy resources, flexibility, digital connections and the overall +CityxChange scope of realising and demonstrating positive energy blocks.

### 3.3.1 Establish agreements between market operator and asset owners

As a first step before deployment, the system operator TE formulates and signs a comprehensive agreement with the asset owners that addresses how the energy resources shall be actively used and clarifies responsibilities. The agreement should be in line with actual GDPR and national legislation.

The agreement provides security for both parties (building owners and relevant partners in the +CityxChange project). Due to the fact that the project is an innovation project, the agreement details had to be developed in close dialogue with asset owners/building owners. As a result, the agreements were developed with a level of detail that served a selling purpose and a purpose of setting up trade priorities for the available tradeable energy resources. Seeing that, the Cooperation Agreement indicates that up to four additional agreements or attachments must be signed to complete all aspects linked to the operation of the local energy market.

In the first part, collaboration agreements have been established or will be established in the project with all building owners or owners of smart meters - actors. The agreements are general, meaning they are made regardless of whether they are participants in +CityxChange or not. The collaboration agreement is complementary, explaining the project with purpose and scope. The agreement includes common topics like duration, termination, liability and obligations, rights, ownership of results, guarantees, limitation of mutual financial responsibility and Force Majeure. Confidentiality and HSE are also described.

The agreement is followed by four additional agreements that bring more detailed descriptions. One will ensure that the building owner's BMS is available for ABB. Another provides a detailed agreement for the use of energy and flexibility resources. The third is an agreement on how measurement and settlement will occur and be handled. Finally, an agreement on sector coupling electric - thermal sector with district heating company and +CityxChange official partner Statkraft Varme (SV) will be included if applicable.

The Cooperation Agreement states that building/asset owners will not experience increased costs as a result of their participation in the local energy and flexibility market, but rather benefit from smarter use of energy and flexibility. It does not provide a guarantee on concrete cost reductions or increased revenue as a result of their market participation.

### 3.3.2 Identify local energy resources and flexibility for the local market

There are three main groups of participants considered when identifying resources for the local flexibility market; flexible participants, inflexible participants, and production participants (a building can be a combination of participant groups). The three groups are based on their possible contribution to the market. Intuitively, flexible consumers contribute with flexibility to the market by shifting, reducing or increasing power consumption, while inflexible participants can not contribute to the market in the same way. However, some inflexible consumers may cause high power consumption peaks for the overall system which should be accounted for in the local flexibility market. Such participants could potentially buy flexibility from flexible assets or production units to decrease the overall power peak. Generally, production participants will not be considered flexible, as it is preferred to maximise utilisation of local energy production rather than curtailment of it.

Although these three groups have the potential to contribute to the market somehow, their potential depends on several variables and characteristics linked to asset specifications and possibilities for communicating with the asset. Among those characteristics, the system operator experienced the following to be most significant:

- Assets specifications
    - Capacity/size (kW)
    - Potential of shifting demand/production
    - Time periods that can be managed by the market (daily, weekly...)
    - Response time of asset (time)
    - Energy source (electric, gas, heat etc.)
- Assets communication
    - Remote control - controllable from a central system
    - Demand response - respond to external signals

The asset's specifications are essential for the flexibility potential and its impact on the local market. First, the capacity (kW) and the potential of shifting demand/production is crucial for an asset to provide a certain amount of flexibility into the market. Additionally, when and for how long an asset can shift demand/production must be considered. Second, communication with the asset has to be in place or installed. Access to remote control is particularly important for flexible assets. Without this communication, it will not be possible for an asset to send bids or receive bids from the market platform, thus not providing any flexibility through the market.

### 3.3.3 Configure and register participant's market preferences

When all participating energy resources were identified, the next step was to register all resources and their identified variables in the deployed market trade software system. This registration includes the set-up of each asset's controls and trade strategies as exemplified in the figures 3.1, 3.2 and 3.3.

This registration and configuration are in line with signed agreements for the actual resources. This is done in a dialogue with asset owners. Market operator, TrønderEnergi (TE), deploys trading strategies on behalf of the asset owner accommodating their preferences. The trading strategies for the three kinds of market participants (production, flexibility, inflexibility) as illustrated in figure 3.6 run automatically and don't require manual involvement from asset owners. However, asset owners have the possibility to control the strategies through Algotrader UI, e.g. enabling or disabling strategies for specific time periods and adjusting parameters such as the amount of flexibility available and price premiums for local production.

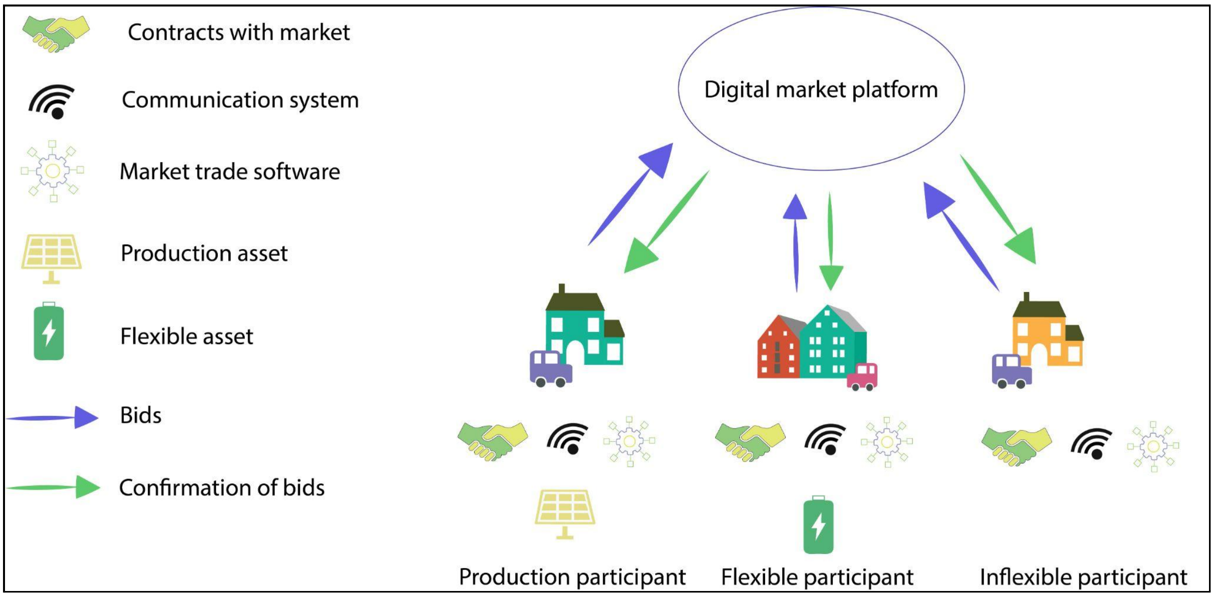


*Figure 3.6 Illustration of examples of three types of market participants, and the requirements for contributing in the local market.*

In addition to trading strategies, asset control schemes are configured to reflect owners' preferences and requirements for how different assets and their components are controlled to prevent asset degradation and provide sufficient comfort level to the asset users. As a rule, SCADA systems should be configured to override control signals from the market when technical limits or comfort levels are violated.

### 3.3.4 Market simulation

Flexible assets can use their flexibility to reduce their peak load, whereas non-flexible assets don't have that ability. Through a local flexibility market where both flexible and non-flexible assets are participating, one can achieve cooperation between assets, such that flexible assets can sell their flexibility to non-flexible assets. The local market opens in general for matching local consumers and producers and thereby hopefully reducing the import/export from/to the local grid. The assets should collaborate such that they together achieve the goals of the +CityxChange-project. The effectiveness of the collaboration depends on the dynamics between each asset's bidding strategies and the market mechanism of the local market. To test the dynamics of the market mechanism and bidding strategies, the system operator TE developed a simulator of a simplified local flexibility. This work is still in progress, and will be further presented in the future D5.6: *Trondheim Flexibility Market Deployment Report*.

The simulator consists of two main parts:

- Simulation of assets
- Simulation of market

In the simulator, each asset creates bids based on its available flexibility. The bids consist of price-volume pairs for the next delivery period. The local market mechanism matches the assets bids and sends the contracts back to each asset for the next delivery hour. If an asset doesn't match the demanded/necessary volume in the local market, it buys or sells this volume in the global market. The flow of the simulator is visualised in figure 3.7.

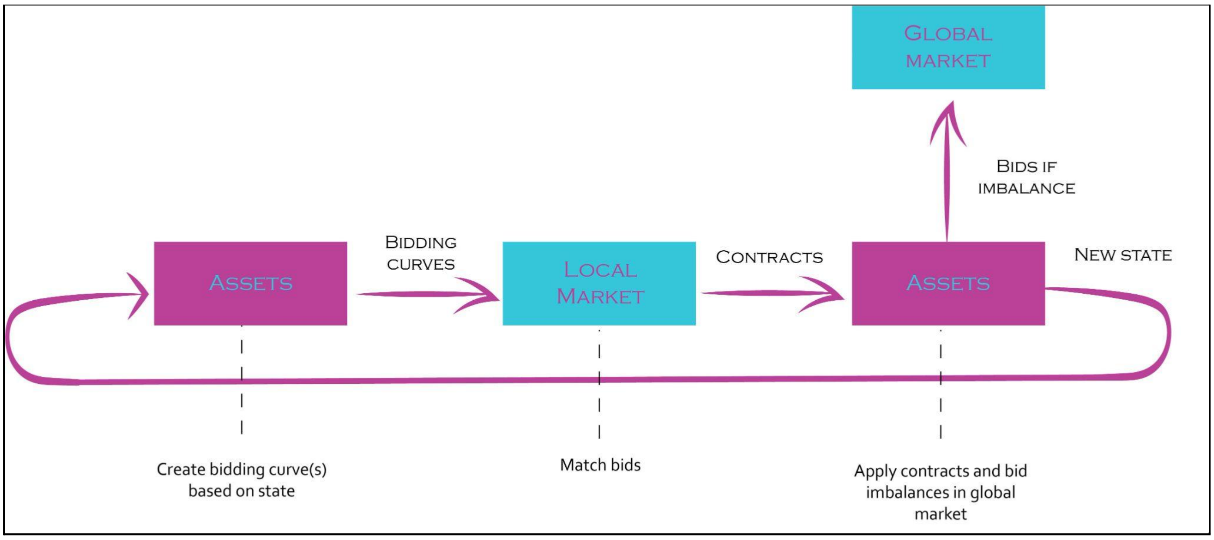


*Figure 3.7 Flow diagram of the market simulator.*

The simulated market mechanism is a uniform auction market mechanism, the same as in Nord Pool's Day-ahead market (Nord Pool, 2020)[5]. However, unlike the day-ahead market where the bids are submitted for the next day, LFM auctions are organised for the upcoming several hours with a time resolution down to 15 min periods similar to the intraday market. Each participant submits multiple price/volume pairs that form a bidding curve. After settlement time, a clearing price and volume are found, based on maximising the total surplus, meaning maximising the measure of the total wellbeing which is  digitally modelled and implemented in algorithm as the trade strategy for each asset that participates in the local market. Compared to the real-time markets, in a uniform market, the buyers and sellers are less affected (both negative and positively) by the volatility of the bids. A uniform market mechanism also achieves the same results as sketched up in D2.7 [3].

The bidding curves consist of both volumes connected to necessary demand/production and volumes connected to flexibility, as explained in D2.7 (Livik et al., 2021). The price of the flexibility is calculated based on the deviation in profit/cost an asset has for selling its flexibility.

The simulator has been tested on a simulated local flexibility market at Rye in Norway (a small village in the municipality of Trondheim, project site operated by TrønderEnergi) [6] consisting of:

- A barn: A non-flexible consumers
- A household: A non-flexible producers
- A windmill: A non-flexible producer
- A solar panel: A non-flexible producer
- A battery: A flexible consumer and producer

The LFM simulator has been tested with the five participants listed above for 24 consecutive hours in June 2021. On this day the barn and the household are in total consuming more than the windmill and solar panel are producing until 06:00, as seen in figure 3.8. After 06:00, the windmill and the solar panel are in total producing more than the main apartment and barn can in total consume. The aggregated volumes sold and bought both in the local flexibility market and the global market are visualised in figure 3.9. From this figure, one can notice that before 06:00 volumes are imported from the global grid to the local grid. After 06:00, excess power is exported from the local to the global grid.

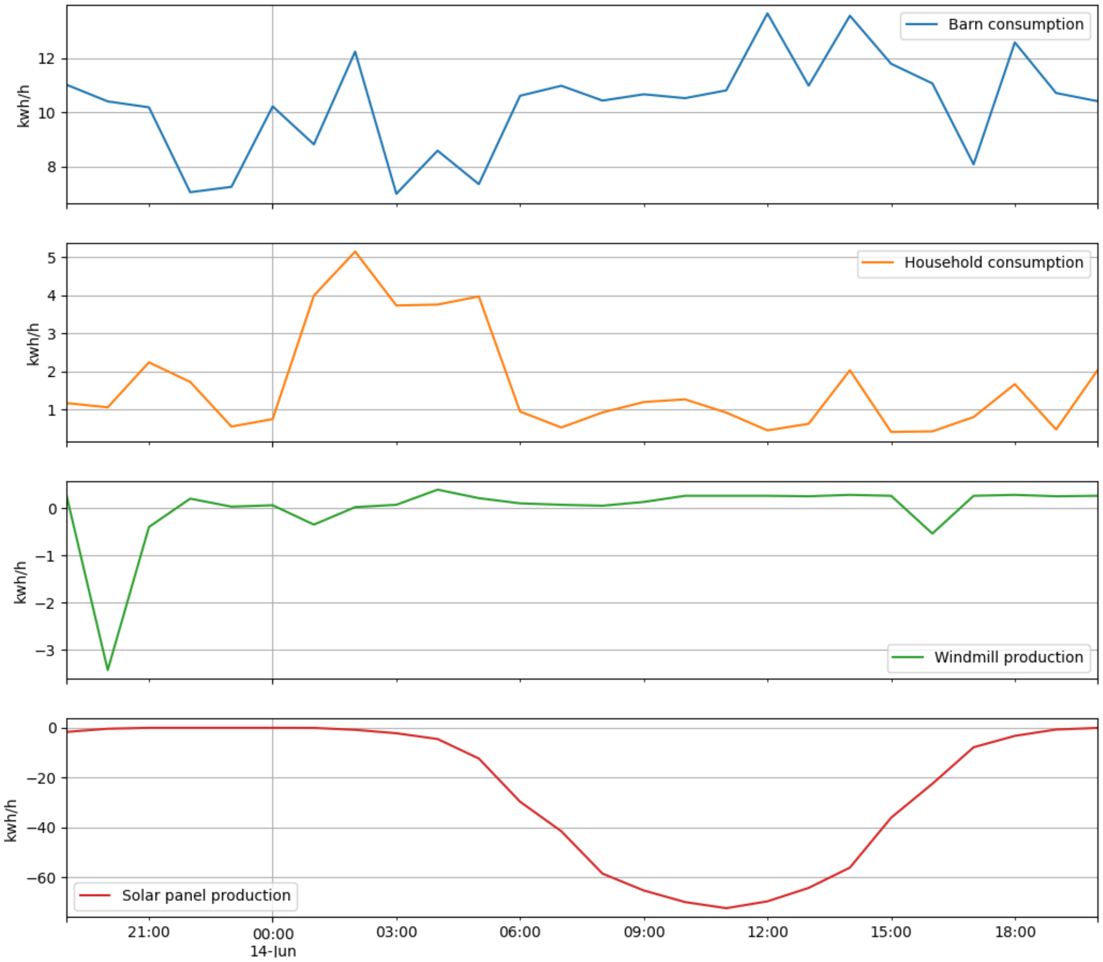


*Figure 3.8 Consumption and production of the non-flexible assets over the simulation time. Production is given by negative values, whereas consumption by positive values.*

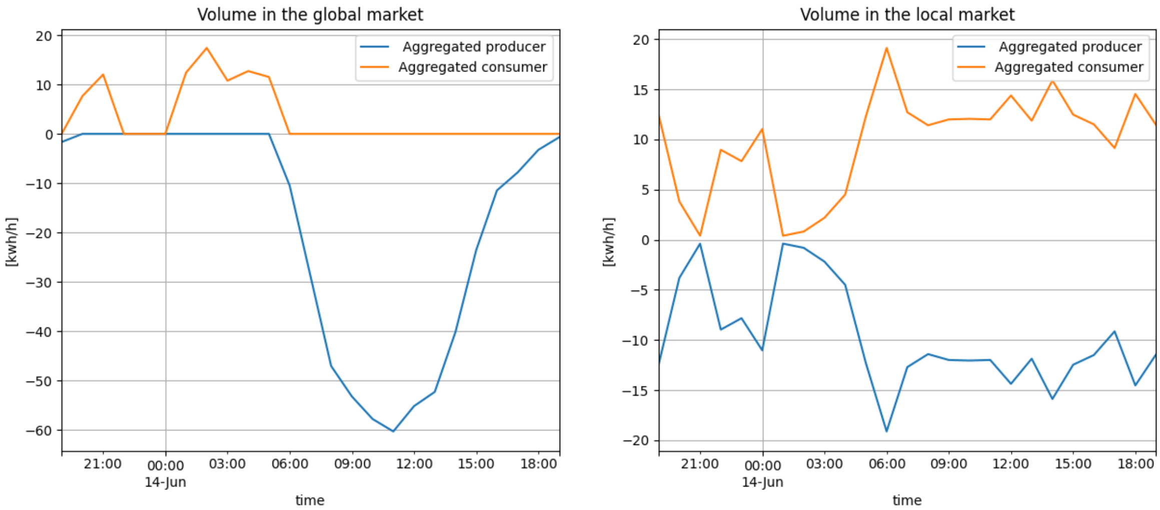


*Figure 3.9 Volume aggregated volume traded in the global and local market, for the five assets. Production (volumes sold) is given by negative values, and consumption (volumes bought) is given by positive values. The volume sold in the local market is the mirror of the volume bought, due to balance in the local market. This is not the case for the global market, due to only aggregating for the five assets of this example.*

Figure 3.10 shows the individual assets traded volumes. The battery (as a flexible asset) is participating quite a lot in the local market. In some cases the battery sells power in hours with lower production than consumption from non-flexible assets, e.g. cl. 00:00, and buying power in hours with higher production than consumption from non-flexible assets, e.g. cl. 07:00. These actions help reduce the imbalance in the local grid.

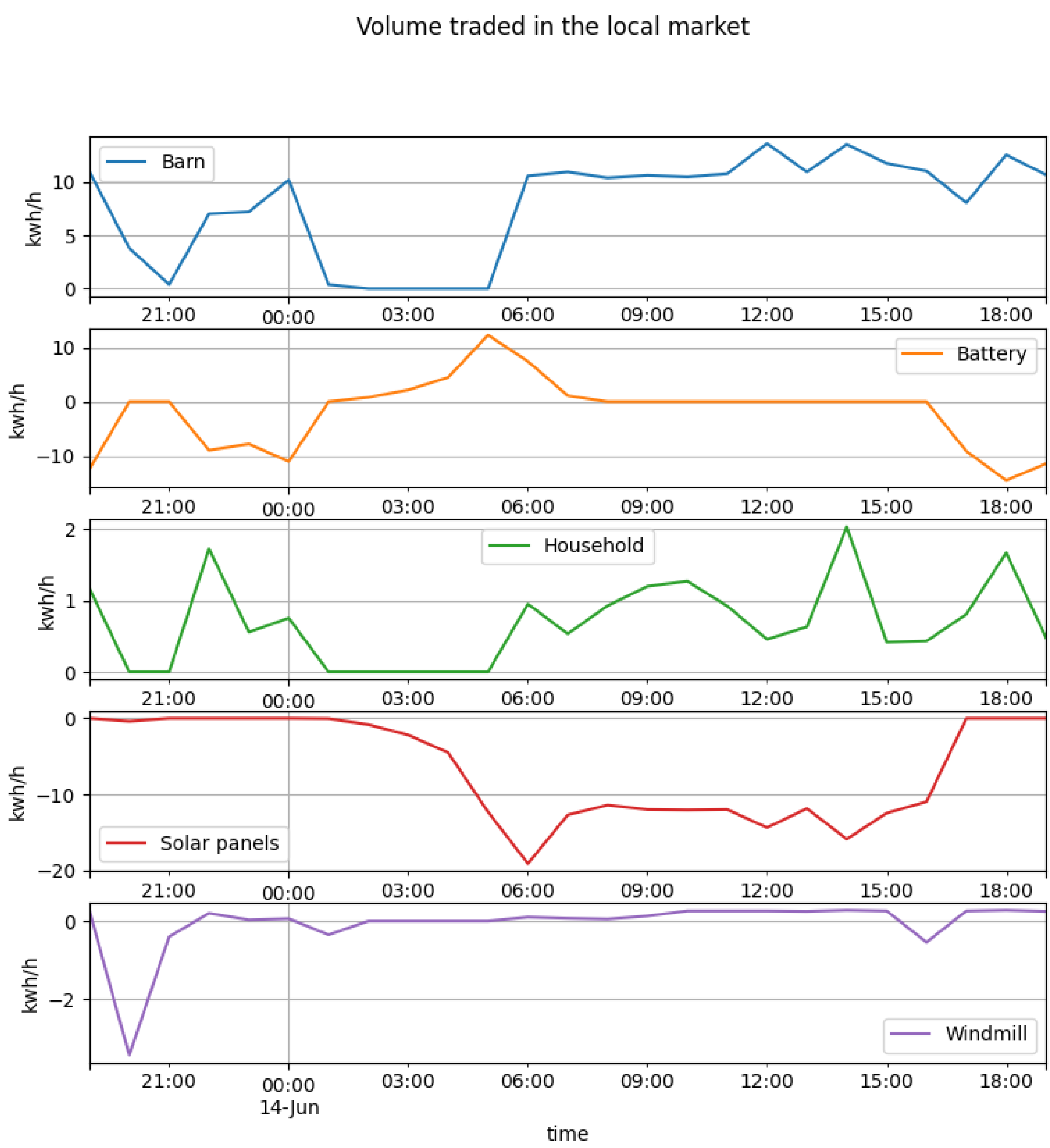


*Figure 3.10 Volume traded in the local market per asset. Production (volumes sold) is given by negative values, and consumption (volumes bought) is given by positive values.*

In the simulated period, at least 40% of the participants traded at each delivery period, as seen in figure 3.11. The maximum number of participants trading was 100%. The number of assets trading would depend on the available volume and price of the bids.

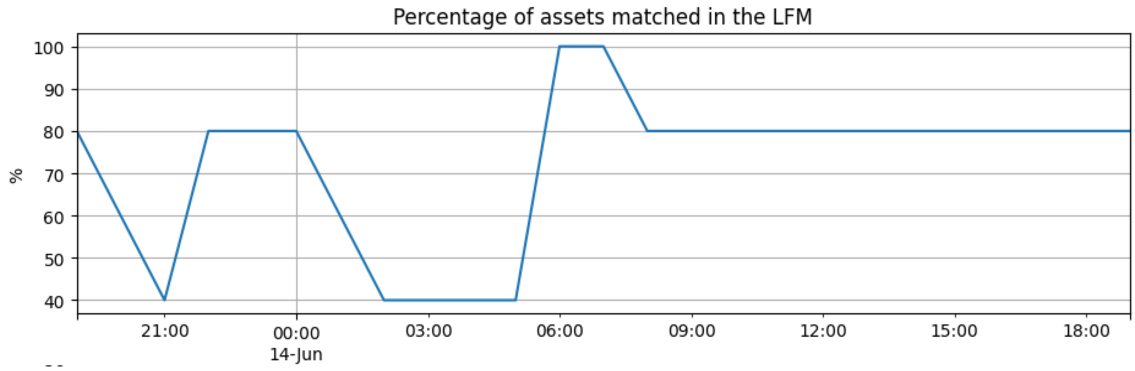


*Figure 3.11 Percentage of assets trading in the local market for each delivery period.*

Figure 3.12 plots the volume imported/exported to/from the local grid, with and without local flexibility market. The figure shows that by adding the LFM, the load exported and imported was reduced in the simulated period.

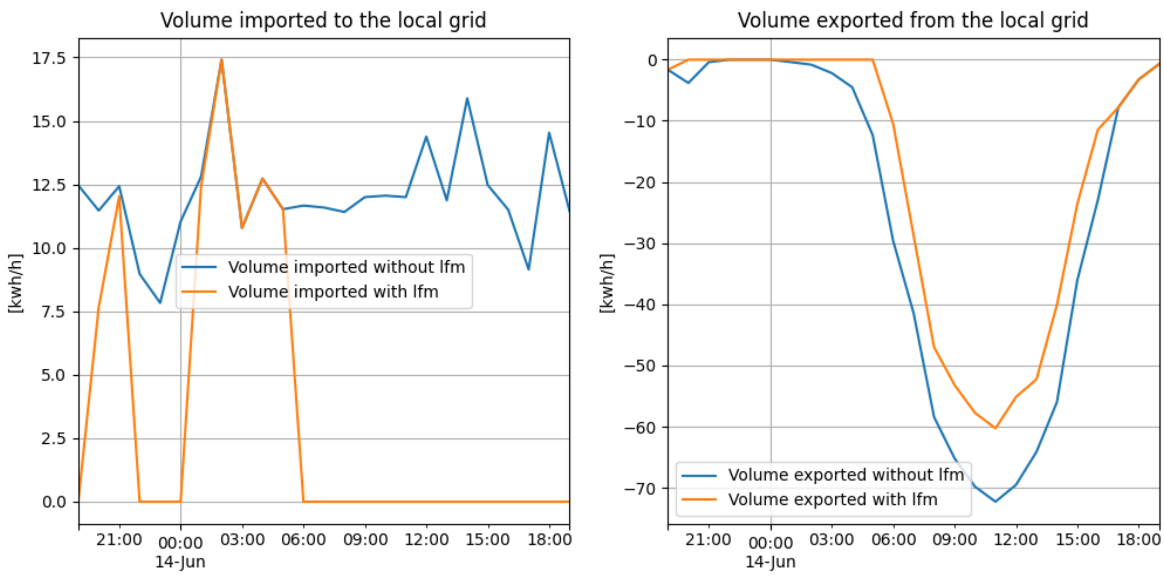


*Figure 3.12 Aggregated volume imported (bought) to the local grid and aggregated volume exported (sold) from the local grid, with and without a local flexibility market, at each delivery period. Production (volumes sold) is given by negative values, and consumption (volumes bought) is given by positive volumes.*

### 3.3.5 Go live with automated trade in the local energy market

Deployment of the local energy market in Trondheim is work in progress and more details will be presented in D5.6 linked with the flexibility market work, while *D5.11: Trondheim DPEB Demonstration* will present the overall PEB work. This section describes tasks that need to be completed to operationalize the market.

**Task 1: Setting up dataflow for assets**

The market operator TE should be able to receive data from assets (temperature, $CO_2$ level, consumption, battery charge, etc.) and send control signals that would change assets' load for a specific time frame. To enable this dataflow, ABB is setting up connections to assets' SCADA systems to send and receive data to/from Volue Data API, which is accessible to TE. This is a critical task for market deployment. It is also a complex task with a lot of uncertainty because it involves connecting multiple hardware and software systems that were not designed for this kind of integration.

Currently, ABB is working with partners at connecting physical assets to the market. Historical data has been acquired for several assets and buildings at Brattøra and the live data will be available early 2022. For the Sluppen area, the process of connecting assets and acquiring data is ongoing.

After integration is completed, tests will be performed by sending control signals and monitoring demand response in the asset data.

**Task 2: Modelling asset flexibility**

Trading strategies rely on asset flexibility models to predict the amount of flexibility available. Flexibility models are identified and calibrated based on data from the assets. This requires running an automatic procedure where varied control signals are sent to assets and asset data is collected to capture changes in asset state and load. The data is then used for model identification, calibration and testing.

**Task 3: Deployment of trading strategies**

Trading strategies will be calibrated to achieve the desired market dynamics. This can be accomplished using the market simulator described in section 3.2.4 and flexibility models from task t.2. In addition, the strategies will be adjusted to accommodate preferences from market participants as described in 3.2.3

Components of the trading strategies including dynamics and optimization models, will be deployed in TE cloud infrastructure. Data API and Algotrader will be used to submit bids to the marketplace.

**Task 4: Testing of the market**

With assets connected to the market, trading strategies and the market platform deployed, the market will be tested in a series of experiments lasting from several hours to days. The data from these experiments will be collected and analysed to verify the dataflow, demand response and market mechanisms on physical assets.

Two types of tests will be conducted, with and without bids from DSO, to confirm the functionality of the market with respect to its goals of utilising local production and flexibility and providing services to DSO.

**Task 5: Deployment of settlement mechanism**

Settlement mechanisms will be developed and deployed to provide financial settlement for the owners. The mechanism combines energy data from assets, trades from the market platform and data fingerprints from IOTA to calculate the amount of energy traded and delivered inside the LFM and generate a corresponding settlement.

The trade solution is technically made for being automated. The Powel Digital marketplace is operated by the market operator and receives bids (bid includes buy and sales offers) from all market participants. Registered local assets are participating at the Digital marketplace by utilising the Powel Algotrader software. Data is received from the ABB OPTIMAX® units which are installed at each market asset site. Integrity of data about executed trades is guaranteed by the IOTA tangle and data is exported to the billing responsible part which in the project demonstration will be the market operator. Dispatch of agreed trade of flexibility is executed from OPTIMAX® directly to the asset or as a signal to the building energy management system for the dispatch action. TE functions as the market operator and is responsible for onboarding assets through dialogue with asset owners and modelling the assets using Powel Algotrader.

Volue has conducted introductory meetings with key personnel from TE and ABB in order to facilitate their use of the Energy Trading Platform. Basics concerning deployment, access credentials, and documentation were the main topic of these meetings. This has allowed ABB to integrate the data feed from their OPTIMAX solution, allowing data to be shared and used in the Local Market and by other parties. This was the first test of the deployment of the Trading Platform, conducted in December 2020.

We have conducted two such workshops with TE, not focusing only on data feed integration, but also on dynamics surrounding Algotrader and the local market. TE is now testing the environment and developing their trading strategies. Powel is assisting with any questions and concerns that arise in the process.

# 4 Guidelines to deploy local energy markets

A well functioning trade solution for local energy markets claims a tight collaboration, interaction, and integration of the technical building blocks included in the total market solution. The total process is a chain of actions with different parties involved operating partly in parallel. Deployment management must be responsible for the overall progress and scopes. However, this overall process is possible to define in some guidelines based on the deployment process experienced in the Trondheim case of +CityxChange project. The experienced guidelines are presented in the following summary.

## 4.1 Clarify roles, responsibilities and opportunities

The core actors/roles in the marketplace are: 1) ETP and automated trade solution provider, 2) system/asset integrator, 3) market owner/operator, 4) trade verification system/actor. When roles and activities are defined and agreed it is a main lesson learned that tight cooperation in the complete deployment phase is crucial to achieve expected results with a well functioning local energy market. More specifically guidelines for main steps are presented in the following.

When roles are clarified it is required that the involved possibilities to participate in the local market is understood. Especially when it comes to the role of local system operator and its understanding of the possibility to purchase local resources as a system service option either from market operator or bilaterally.

It is experienced that energy framework regulations must be understood with regards to the local energy system and its new approach to sustainable supply of energy. In Europe the energy framework of regulations are not in favour of local energy markets operation including local system operation. The conclusion is that dispensations from some regulations are required before the market is put into operation. Dialogue with the regulatory body is important to start in an early phase of the deployment phase - or even in the phase when the innovative process of defining the local market set-up is worked out.

## 4.2 Involve asset owners and customers - early

Local energy markets are literally speaking renewable power to the people. It is however in a stage of being considered as an energy innovation concept - and is experiencing a need to be treated like this. The reality is that the power market in general and flexibility market more specifically has a tradition of being a low interest topic among people. This understanding is crucial for the more detailed discussion and steps in setting up agreements between assets and the local market.

Experiences show that the understanding of basic market operation principles is a prerequisite among the involved parties.
When this understanding is settled, it is the correct moment to describe in more detail how the local energy resources should establish their market behaviour. This dialogue is then proposed to be basic for setting up each asset's strategy for how the automatic trading is executed on intradaily basis. The first phase and rounds on establishing the first set of market rules is done in close collaboration and discussions between building owner tech personnel and TE personnel that performs the actual coding of the presets into the Volue Algotrader. This will be a trial&error task and prone to iterations and more advanced asset management in the time to come as we obtain experiences and results. The need for realizing as much flexibility as possible based on experiences from operation of the different assets must be balanced against the asset performance and factors such as maintaining adequate indoor temperature and air quality. What actor/type of actor to be the best for “owning”, facilitating, and coordinating such learning and knowledge exchange in the future, is still an open question. However, for an accelerated green energy shift and necessary further digitalization of the energy systems and markets, such competence and capacity building is highly important.

## 4.3 Deploy and test market operation software

The local market trade software including market operation is the hub for a well functioning local market. Towards this goal, the technical deployment is not the most critical phase. The critical issue is to establish the local market digital infrastructure and test it for all actual local energy resources/assets/flexibilities.

The trade system architecture includes digital integration with ABB OPTIMAX ® and further to the market assets itself. APIs and protocols required for these purposes must be defined in detail and implemented. It should be agreed upon using as standardised protocols and apis as possible. In this process it is crucial that it is the local market solution’s prerequisites that has the role of being the master. If not, the consequence is experienced to be a kind of “anarchy” with proprietary protocols and sub optimising on asset level instead of striving for an overall well functioning local energy market - fully automated. This is crucial for the market set-up.

## 4.4 Train asset owners

To be able to fully exploit the flexibility of local energy resources and loads it is required that the owners and customers have a basic understanding of how their potential participation should be organised and digitalised in individual strategies.

For the local market demonstration it is a limited number of assets to be implemented. Experiences from the deployment is that the following stepwise chart for developing a frame for motivated asset owners is important to consider:

- Practical and economic collaboration with existing actors and arenas.
- Decide if there is a need for contracts.
- Need or presence of technical equipment.
- Description of the physical content and premises present or needed within the CO.
- Accessibility, office space, meeting rooms, workshop-space, showroom, studio and other things.

This list does not fit all local market set-ups, but need to be customised dependent on resources, regulatory framework, digital infrastructure and traded products/services.

## 4.5 Establish a digital infrastructure that fit trade rules

The success of a local energy market requires that all local energy assets are given market access independent of size. A digital infrastructure that includes connection between all resources and the market trade software acts as the basic cobweb for market operation.

Smart meters are installed and connected to all actual resources in the demonstrated local market in Trondheim as described in figure 4.7. This is done as a part of the grid owners responsibilities due to national smart meter rollout schemes which are completed already in 2019. For additional resources, included flexible loads, digitally connected meters that make it possible to identify tradeable flexibility. It is crucial that the identified, modelled and metered tradable energy and demand are equipped with meters certified for the local market settlement.

The responsibility party for meter data collection and meter data management must be clarified and agreed in an early phase of the market set-up and deployment phase. In the actual demonstration the responsibilities are specified and agreed among the local grid operator, national meter data company and local market operator.

# 5 Conclusions and lessons learned

A main conclusion from the deployment of the local energy market is that it is innovation in its nature in 2021. This understanding triggered and initiated the development of new cooperation processes between building owners/energy resource owners, project technology partners ( ABB, Volue, and IOTA) for the main purpose of deploying and testing the local trade solution fully automated and operated by the partner TE. This process in establishing an energy system included signed agreements that turned out to become the cornerstone for the local market to be demonstrated and operated.

The local energy market software for trade purposes itself and its features had to be approached as integrated building blocks integrated in a digitalised local energy market system that can be automatically operated - for all local assets independent of size. This approach included the defining of detailed market strategies, with the consequences that the value of local assets had to be understood and digitalised as market preferences at the different periods of time down to each 15 minutes resolution. This was possible to realise because the basic principles copied from the existing wholesale power market in Europe were applied in the local set-up.

It was in the deployment that we learned that all energy assets, independent of size, can participate in local markets. This is possible thanks to the basic market rules defined in addition to the realised digitalisation of all market operations. Meters that communicate digitally with the market operator's platform are - based on experiences and learning in Trondheim - considered to be the back-bone and important infrastructure to ensure close to real-time trades. This is in turn a prerequisite to ensure local system operation based on local system services.

The Powel/Volue Energy Trading Platform (ETP) developed for the +CityxChange project, and specifically designed for local trade of flexibility, energy, capacity, and system services, comprises two main modules: Algotrader, and the Digital Marketplace.

- The Algotrader software is deployed and tested and ensures the market participants' (assets') automated participation in the local market.
- Digital Marketplace software is deployed and matches corresponding bids and offers to enable automated trades.

The Volue energy trade platform (ETP) and Local Flexibility Market solution (now being developed and soon to be operated by Trønderenergi - TE) is based on automated trades, and making different assets for the individual market participants. The assets may cover a wide range of sources of energy/flexibility. Examples include PV plants, EV batteries, snowmelt systems/heat cables, heat pumps, and HVAC systems. The fully deployed solution is experienced to fulfil main requirements for local energy market set-up and operation.

For a full scale local market to function with an operation that add for the participants it is clearly experienced that the following features must be realised:

- Integration of all market participants onto one single management system - Distributed Energy Resource Management System, DERMS, also ensuring data feeds and -exchange in real-time
- A local market solution and operator system and software for forecasting, flexibility optimisation and settlement.
- A software based system for ensuring secure third party verification of all trades and to ensure consistency between executed trades and the following settlement.

Within the +CityxChange project, ABB OPTIMAX ® fills the role of the DERMS. Optimax is a HW/SW based solution which is highly flexible and easy to tailor to local needs and set-ups. This has proven important in the LHC Trondheim - and will be in general - as the DERMS needs to connect to and exchange data with a vast array of BMS etc from a huge variety of providers. The energy/flexibility market preference set-up solution developed by TE is coded inside the Volue Algotrader, and will interact directly with dynamics of the ETP.

For secure verification of trades +CityxChange uses IOTA Tangle, especially set up for serving the crucial backoffice role of the local market. With over time tens of thousands of trades between a larger number of participants, the verification is extremely important. From a commercial point of view, IOTA Tangle is also important for the LHC Trondheim case, since it provides a verification solution at low/zero costs per transaction.
For the full market solution to be set up correctly and fully functional, tight collaboration between these 4 actors is necessary. The collaboration started off in the development phase and needs to extend past the time of implementation - until the operational testing phase and tuning/fixing of the full system is completed.

The Volue ETP is designed for trades down to a 15 minute time resolution. This is important in order to enable capturing of flexibility, often available within narrow timeframes - far less than one hour, and thereby being able to increase the utilisation of available local user flexibility. Through designing, setting up, and piloting local energy and flexibility markets for such a granularity, LHC Trondheim and the local partners will also obtain highly valuable experience and knowledge building prior to the implementation of 15 minute Market Time Unit (MTU) for the intraday and balancing markets within the Nordic DSOs by Q2 2023.

The trade platform has an IT architecture which is characterised by a central database exchanging information with functions and parties. The functions include predictions, grid calculations, and trade. Data exchanges include smart meter data, forecasts, and other information represented as time series. The main conclusion is that with those major tasks realised with the partners' basic building blocks deployed and integrated in an energy market system - with a prerequisite that the market set-up and operation is within regulatory framework - the local energy market including flexibilities and storage will add value and reduce emissions.

It is important to include preliminary results from the operation of the local energy and flexibility markets before an energy trading solution of this type is fully implemented. The energy market solution and the energy trading platform need to work seamlessly together. This may lead to some necessary changes as well as tuning of the ETP. The outcomes and results from the full implementation of ETP will be included in the +CityxChange deliverables and reports D5.6 - *+Trondheim Flexibility Market Demonstration Report*, and D5.11 - *+Trondheim dPEB Demonstration*. A brief roadmap for this is shown below, for the period January until the end of April 2022, if no further delays occur. All subtasks excluding tuning of ETP started during 2021.

- Asset/Market actor integration into ABB OPTIMAX for PEB and LFM (Jan. - Apr.)
- LFM Simulator development, including testing on synthetic and real data (Jan. - Mar.)
- Coding of LFM modules and testing (Jan. - Apr.)
- Tuning of ETP based on early experiences from LFM Simulator and LFM (Febr. - Apr.)
- Deployment of LFM (Apr.)

There may be needs for additional tuning of ETP at later stages of operation, due to causes and incidents not known at the delivery of the prevailing report.

Experiences show that the understanding of basic market operation principles is a prerequisite among the involved parties. This may include, but is not limited to, building owners, housing associations, DSOs, and local market operators. This is important - even a precondition - to describe in more detail how the local energy resources should establish their market behaviour. This dialogue is then proposed to be basic for setting up each asset's strategy for how the automatic trading is executed on intradaily basis. There is a need for development work in order to establish what type of actor to facilitate and run such learning and competence exchange processes.

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