D2.7: Local DPEB trading market demonstration tool

+CityxChange | Work Package 2, Task 2.5

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01-09-2020	v.01	Klaus Livik (POW) Boris Tistan (POW) Stein Danielsen (POW)	Initial version built from working documents and software
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10-01-2021	v.03	Klaus Livik (POW) Stein Danielsen (POW]	Fixed minor errors and updated chapters 1-5

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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
CGS	Community Grid System
CIM	Common Information Model
DER	Distributed Energy Resources
DLT	Distributed Ledger Technology
DPEB	Distributed Positive Energy Block
DSO	Distribution System Operator
EAF	Enterprise Architecture Framework
eMaas	E-mobility as a service
EV	Electric Vehicle
FC	Follower City
GIS	Geographical Information System
GUI	Graphical User Interface
JSON	Programming Language
LHC	Lighthouse City
LV	Low voltage
NIS	Network Information System
OPTIMAX®	On site energy management system
PEB/PED	Positive Energy Block/District
PV	Photovoltaic
Python	Programming Language
RES	Renewable Energy Sources
SCADA	Supervisory Control And Data Acquisition
V2G	Vehicle-to-grid

Executive Summary

This report, deliverable D2.7 of the +CityxChange project Task 2.5, describes a market design for the local market that shall be demonstrated. It also describes the software trade platform which is developed for the purpose of large scale operation of the local market. The demonstration includes trade operations with local energy resources like PV, EV chargers (V2G), batteries, heat, flexible load and others. The trade solution - inclusive the back-office routines - is based on a complete digitized chain of data flow and dispatch actions and opens up for a wide range of asset types and is scalable and replicable.

The delivery has a distinct innovative approach to local market design and operation. This is due to that the market access and operation are fully digitalised including the asset preferences, clearing and settlement. The D2.3: Report on Flexibility Market [8] describes in detail technical and intentions of a local flexibility market. This learning is the basis for the design of a local energy market as described and made ready for demonstration of a trade platform in this report.

The software solution is in its kernel operating the local market similar to how trade is executed in the energy wholesale market. The solution is scalable when it comes to number and size of assets. It is also possible to configure the solution to manage multiple local markets. Sector coupling for local market trade of energy is made possible to be demonstrated because all actual energy assets are metered with smart meters and the heat resources are presented in the local marketplace as a flexible resource/product.

The trade solution is technically made for being automated operated. 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 utilizing 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.

The local energy market trade solution is going to be implemented and demonstrated in Trondheim as a Lighthouse City within the +CityxChange project.

1 Introduction

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 a fully digital operated local market it is established an arena which makes this possible to demonstrate within the project scope and plan. Based on the in-detail designed market the trade platform is developed as a software solution for market participation and operation - including a local marketplace designed for the purpose of a Common Energy Market operation.

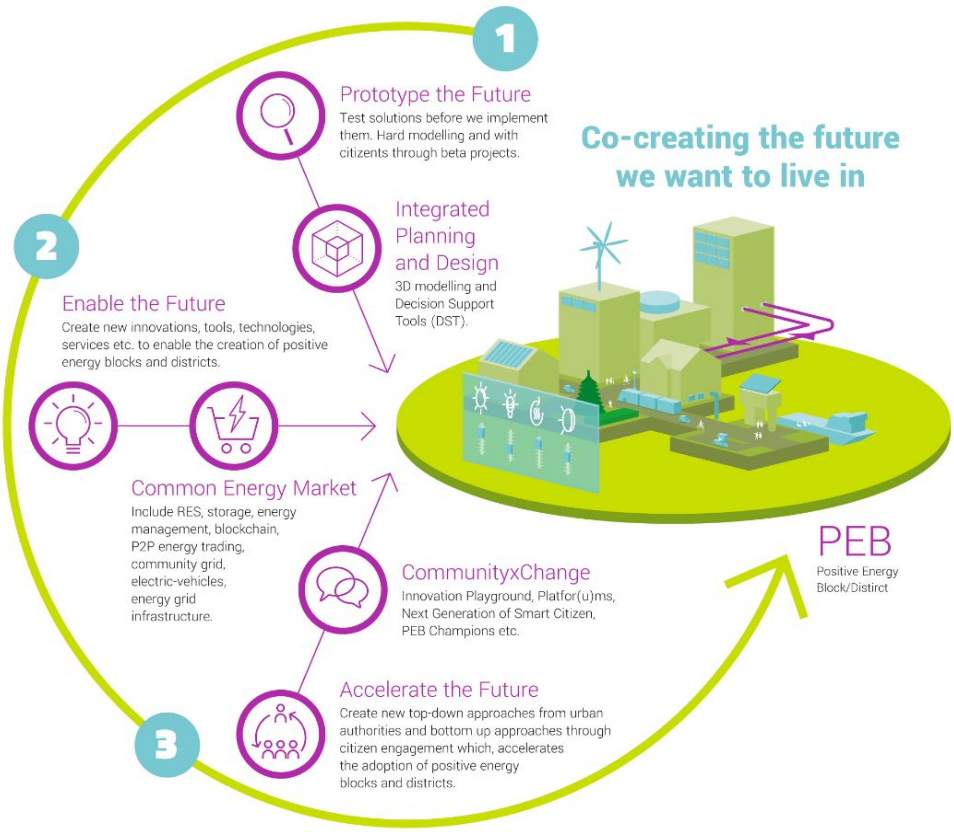


Figure 1.1 The Common Energy Market within +CityxChange project processes from prototypes of technology and systems to enabling the DPEB (positive energy block/district).

The design 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 mandate and responsibility. The approach for designing the local power market was to adopt relevant elements from the general market and make them fit in a local energy environment. A description of the Nordic market is presented in [5].

The traditional way is that the electrical power flows from the power producer, via system operator and grid operator to the consumer. The money flows in the opposite direction – from the consumer, via power supplier and the market and ends up with the producer.

For the local market, there are a couple of obvious deviations: the consumer can also be a producer and vice versa, and system operations can be simplified by dealing with fewer voltage levels. But one of the main reasons for establishing a local energy market is to allow for market access for participants that are usually disqualified from the general market due to size or other matters. In a local market, that means the traditional power supplier is obsolete because everyone can have direct market access instead.

A fundamental prerequisite for the market design is the gap analyses, recommendations and conclusions given in the project delivery report D2.1: Report on enabling regulatory mechanisms to trial innovation in cities.

The traditional system for how electrical power is produced, transported and consumed has been from large centralized power plants via grid on different voltage levels to the end-customers which has consumed whatever he wants whenever he wants it. By the introduction of new digital technology and distributed renewables and storage, this hierarchy now might be subject to change. It is a paradox that this promotes local systems that will demand flexibility and locally supported system services. However, it gives incentives to innovation in market design, market operation, dispatch management and real-time operation of even the smallest power resource.

The traditional end-customer will be given the ability to be an active market participant by providing both locally generated power and flexibility by utilizing available flexibility in the consumption. As a market participant, the customer - as a consumer or producer - described in figure 1.2 will manage energy assets that are active with bids of sale or buy in the marketplace. The market design will give the customers' assets market access for local resources - independent of size.

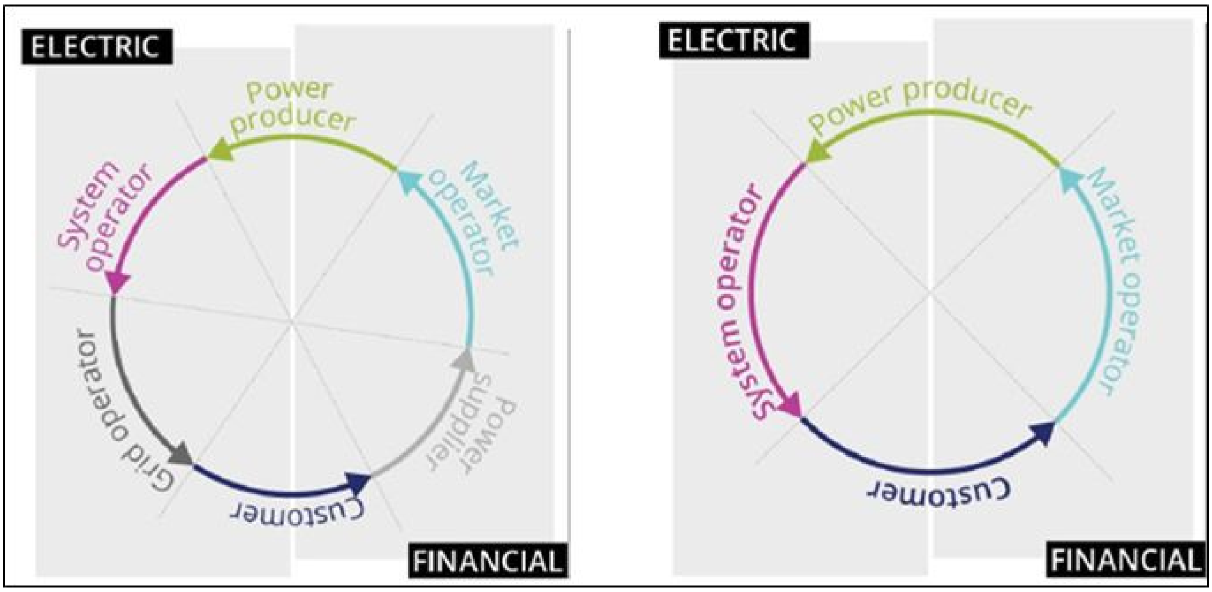


Figure 1.2 The global (wholesale) market includes 6 different major roles, while the local market is designed with 4 major roles. Ref: D2.1: Report on enabling regulatory mechanisms to trial innovation in cities [1].

Main lesson learned is that the local market is possible to design with only four basic roles. The market design is defined and detailed within this framework.

The goal of the delivery is to establish a market design and market operation software prototype which includes the roles as defined in figure 1.2. The implementation for demonstration purposes will be an important step in the process towards DPEB. The D2.7 Delivery goal is to demonstrate a local energy market which:

- Provide market access for local energy assets - regardless of size.
- Make local energy assets profitable for the owner - and motivate for investments.
- Make local energy resources valuable for the total energy system.
- Reduce needs for grid investment and system services.

By making it profitable for the asset owner to provide energy and flexibility to the local market, it will motivate them to invest in energy resources which will help achieve DPEBs. In addition, making flexibility available will improve system operation and secondly it will support new business models and new entrants within the overall scope of fueling the green shift.

This document describes how to set up a local market and technical systems and platforms, allowing for market access for every energy resource, regardless of size, location and owner. It touches upon questions of how to set up a local energy and flexibility market, how to enable participation and how to operate the market, including back office functions.

The solution for the local energy market to be demonstrated is based on project background from the contributing partners. The innovative step within the project delivery "D2.7: Local DPEB trading market demonstration tool" is based on partners' domain skills and experience in the power industry regarding market design, trade solution, settlement, blockchain and digitalisation.

The development is characterised by the following add-ons and deltas from the documented project background:

- Detailed description of a digitalised local energy market - enabling all assets to participate.
- ICT architecture which makes the value chain from dispatch to invoiced trade smooth and verified.
- Trade solution developed and tailored to be operated in line with actual market design.
- APIs for asset data with the purpose of market access and trade.
- Model for defining asset strategies and preferences for trade.
- IOTA DLT tailored for verification of local trades and dispatch by using technology from project partner ABB.
- Solution for local algo trade including an innovation which makes it possible to be applied for local marketplace operation.
- A trade solution made flexible when it comes to time resolution and product types.
- A complete trade platform for being demonstrated in the LHC of Trondheim, but ready for being scaled and duplicated.

A substantial part of the innovation is the close cooperation within the project tasks which have resulted in overall +CityxChange deliveries of ICT architecture, system design and detailed flexibility market descriptions. Thanks to this cooperation between project partners it has been possible to define the local market - and to establish an innovative technology for how to make it operative and ready for large scale demonstration.

2 Design of the local power market

2.1 Main principle and characteristics

Market design is in this context to be understood as a practical methodology for creation of the local power market to be demonstrated. The design is in the project based on the design and operation of the Nordic and European power market [5], more specifically the NordPool intraday continuous trading market [6]. The proposed design of the local market challenges and inspires the project to accelerate digitalisation and to rethink long standing fundamentals of how the power market shall face the future. A basic reference for the design process is the D2.1 report [1].

The local power market is designed as a market for continuous trading where bids and offers are matched automatically when they are registered in the digital marketplace. The market will be operated as a first-come-first-served market, meaning that the one who first responds to a bid/offer, gets the trade. The main ambition for the market design is to allow for market access for any participants, regardless of size, type and owner of the asset. The key market design principle is to introduce a local market operator. This means that all bids and offers are done at the local marketplace, and the local market operator is the real counterpart for all trades, unlike peer-to-peer trading. Figure 2.1 presents an overview of the main elements that characterize the local power market demonstrated in the project.

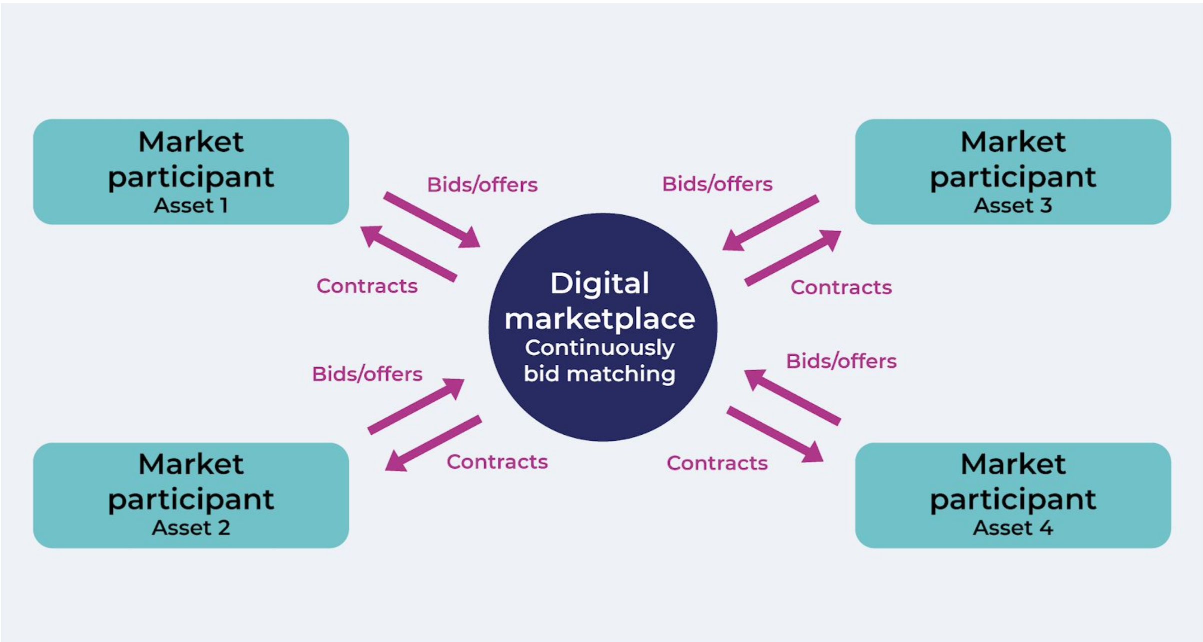


Figure 2.1 Continuous bid matching at the marketplace, where all participants trade energy.

The product traded in the market is kilowatts [kW]. Bids can be placed for any period of time during trading hours. One bid is for one time step. If the market participant wants to make a bid for several time steps, several bids need to be placed. One bid consists of volume [kW], time [hh:mm] and price [€/kWh] for the actual timestep. Bids and offers are automatically matched by the digital marketplace when one buyer wants to buy at least the volume which a seller has put up for sale, for at least the price the seller has set for the volume and at the time period the volume is available. A contract is established on the basis of the trade, where the volume, time and price is in accordance with the bids and creates an obligation for the bidder for a physical delivery in terms of production or consumption. The price for the specified volume will then be calculated for each trade separately as where the price of the seller and buyer meets. The bidder bids in expected production or consumption for each time step to the market, with a corresponding price.

Market participants sovereignly decide how much, when and at what price they want to buy or sell to the market. Any volume that is produced or consumed that is not traded in the local market will be settled against the power supplier outside the local market which the buyer or seller has an agreement with. If the amount of energy produced is less than what's sold or the energy consumed is less than what's bought, the market participant is not compliant with its obligation, and will experience a minor penalty from the market operator.

Type of energy asset in this respect means any kind of asset that either consumes or produces energy, and can be metered individually. In order to achieve an efficient and liquide market, which in essence will provide an optimisation across all assets within the PEB, it is beneficial to regard each asset as an individual market participant.

If one office building consists of PV power production, battery storage and flexible consumption, these should act as three individual market participants with separate meters.

2.2 Set-up of the local power market

Main market principles and characteristics are general prerequisites for a market design that supports the local market to serve processes to reach the goal of DPEBs. Next step is then to design the market based on these fundamentals. The market will then open up so that local energy resources defined as assets - regardless of size - have access to the marketplace. The main characteristics of the design of the local market are as follows:

- The moving horizon of the local trade will be for the period the spot price is calculated and available.
- Gate closure is 15 minutes before time of delivery, with the ambition to move closer to the time of delivery once we get experience from the operation and when applied digital solutions prove that they can handle these challenges.
- Time resolution in the market is 15 minutes, with the ambition to develop towards minute resolution.
- The Powel Algotrader, adapted for the local market, translates predictions and preferences into bids and offers and interacts with the local marketplace as a continuous and automated process. It is running as a cloud service, connected to the local energy assets and the DSO grid.

- The local marketplace is established by the use of Powel Digital marketplace. A trade agreement is reached and a contract established, once a bid is matched to a corresponding offer, which is done on the marketplace managed by the market operator.
- Once a trade agreement is executed, a digital signal is sent using a common API to OPTIMAX® (gateway between trade platform and asset) – or a third party device with load control functionality – for dispatching of the actual asset.
- Trade data is sent to the IOTA tangle to secure an independent storing of contract information and verification.The IOTA Verification Service has been developed in order to guarantee the integrity of data used in the trade process.
- Comparing data from the meters and the contracts creates the basis for settlement and invoicing.

This list of requirements and characteristics are specified to help understand how the local energy market is dependent on a range of details, both technically and design wise. To ensure that all required market characteristics are possible to fulfill, it is established a complete IT-infrastructure that includes the chain from meters, communication, dispatch equipment, optimisation of asset bids/offers, transparent and trustful trade, trade verification and back office routines ending up with accepted bills. In figure 2.2 it is given an overview of the building blocks in the overall solution demonstrated.

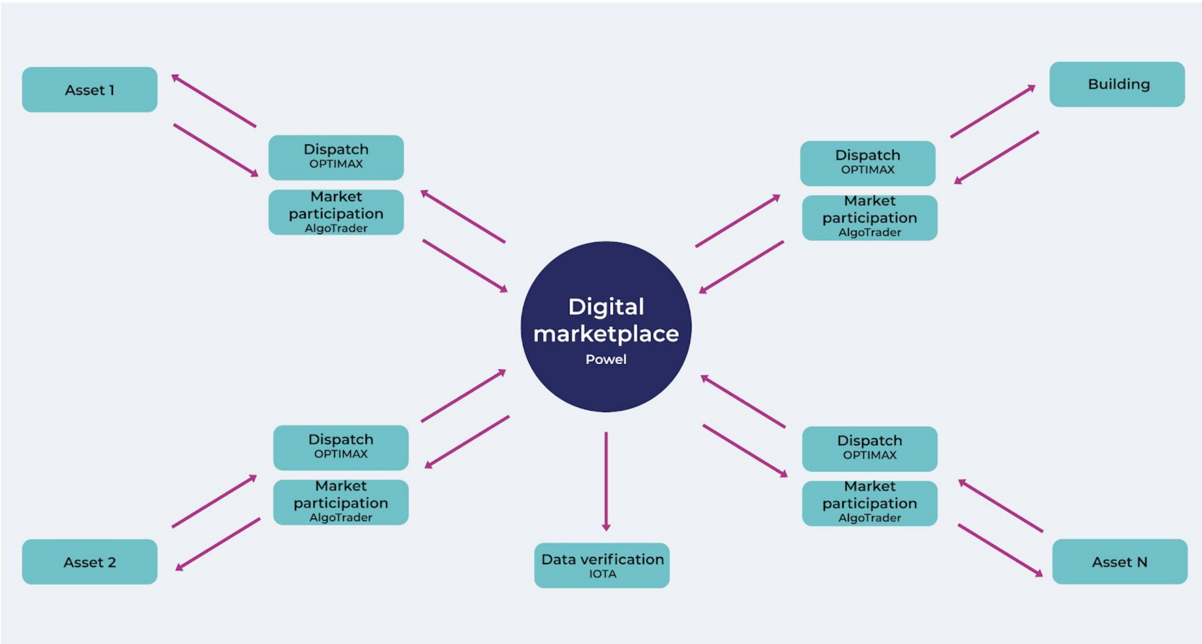


Figure 2.2 Building "blocks" in the solution that operates the local power market.

In figure 2.2 Asset 1 could be for example a PV power producer, Asset 2 a battery and Asset N the local system operator. The trade platform is scalable when it comes to the number of assets/buildings and is possible to operate when the local markets evolve from PEB to PED and further to city levels. The trade platform software is cloud based and is designed and developed to easily be replicated for new markets and cities.

2.3 Local market roles and players

For the established market design, four market roles have been defined: Market operator, System operator, Power producer and customer. Each with important and clear defined tasks and responsibilities. The roles and the connection between them is illustrated in figure 2.3 it is given an overview of main principles to apply for the market design and operation.

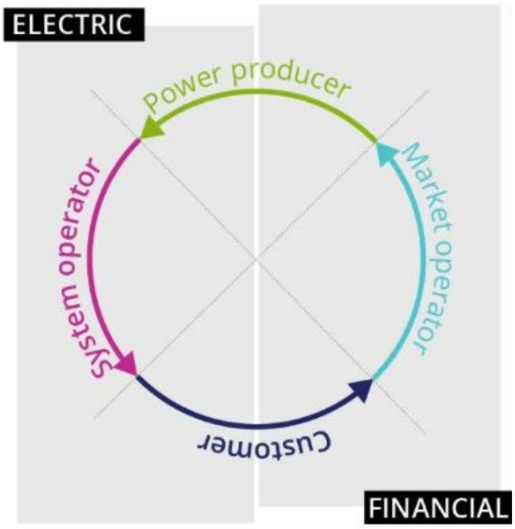


Figure 2.3 Local market roles and responsibilities. (From D2.1: Report on Enabling Regulatory Mechanism to Trial Innovation in Cities [1]).

The roles are to be regarded more in terms of functions that need to be covered rather than legal identity. Most of the tasks and functions will be operated fully digitised and automated. This approach promotes disaggregation rather than aggregation of energy assets.

2.3.1 Market operator

The market operator is responsible for allowing market participation, efficient market operation and fair payment of energy bought and sold within the local energy market.

More precisely the market operator shall:

- Be independent.
- Conduct market surveillance and auditing.
- Be the counterpart for all local trades.
- Ensure correct settlement.
- Ensure correct invoicing.
- Be the link to the global market including the day-ahead spot price.

2.3.2 Customer

A market customer is an energy consumer for a given time if he consumes energy from the market. A customer can be a power producer when it provides energy or flexibility to the market. Examples are heating/cooling, bus-charger and batteries.

2.3.3 Power producer

A market participant acts as a power producer when providing power/energy to the market. A battery is a power producer when it discharges. A consumer is a power producer when it sells energy and/or capacity back to the market. Examples are PV production and batteries.

2.3.4 System operator

The main responsibility for the system operator is to ensure quality and security of supply of electric energy. The system operator monitors that the local grid is being operated within its physical limits. For this, predictions for both local production and consumption is vital. If the predictions tell that there will be challenges ahead in time, measures need to be taken to secure the supply. In the local market, the system operator will benefit from volumes available in the digital marketplace to acquire needed capacity to secure the running operation, and by that take the role as a market participant.

2.4 Metering and settlement procedures

The local market demonstrated in the +CityxChange project is linked to the existing wholesale market through the DSO grid. This is a situation which is addressed in the settlement process. Basic principles for the metering are:

- All market participants have one or more certified smart meters in operation.
- Local market participants are free to have a main supplier from the global market.
- All local producers are free to sell either to the local or global market.
- The marketplace has access to all metered data from all participating assets.

For the settlement process it is crucial that data applied are verified in line with the actual trade when it comes to volume and time. For this purpose the dispatch procedure and actual “disconnection” and traded flexibility are developed to give precise data for the billing process.

Due to that the common local market is linked to the global market when it comes to additional supply and grid connection it is developed a principle for how to secure correct billing between local actors and multiple suppliers - local and global. This is also discussed in innovation projects addressing local market designs in the international arena. An interesting example for a situation with more than one supplier in one metering point is discussed by Elecon in the UK [2]. The situation is described and evaluated, but not implemented and demonstrated so far.

However, when a customer purchases its supply partly from the local market and partly from the global market it is important to have routines for how to split the supply invoices between local traded supply and purchase from global supplier. Figure 2.4 presents an example with a situation where one customer (with one smart meter) buys power supply from multiple providers.

Figure 2.4 Example of enabling customers to buy power from multiple providers.

The Customer in figure 2.4 has a metered consumption of 50 kWh/h. In the local market the consumer purchases 20 kWh/h from a local PV actor. In addition the customer has access to a V2G resource which for the actual hour sells to the customer 10 kWh/h. That means that the default supplier in the global market in the actual hour[h] is responsible for a supply of:

Global market supply = Consumption(50) - PV purchase(20) - V2G purchase(10)= 20 kWh/h.

With only one meter and two three different suppliers, the global suppliers invoice shall be for 20 kWh/h only. That means that the bill will be a calculated share of total consumption - not the total consumption as read from customers certified meters. The calculation of the actual share is either done by the global market supplier or the local market operator. In the demonstration of the local market this principle will be tested in dialogue with involved suppliers.

The global market interacts with the local market through the meter installed at the assets. For this market a “Harmonised electricity market Role Model (HRM)” is developed by ENTSO-E, EFET and ebix [11]. The necessity for such a role model arises from possibilities that a single actor may assume multiple roles - including that metered data must be managed to cover settlement and billing procedures in local markets. This is especially important when metered consumption or local generation is purchased or sold to multiple parties.

With multiple power providers it is a prerequisite that all settled supply trades are verified with details about volume, time and prices. In the trade platform's digital marketplace all such data is stored and made possible to be applied for correct invoices of the supply for all involved local providers. The residual will be the metered global market supply. This residual is presented as time series with volume, time and price elements used for global suppliers bill calculation. The calculations may be executed by market the operator, metered data responsible, DSO or the global supplier. Agreements about how to make the invoicing procedures must be settled between involved parties. In Norway the ELHUB [10] could be a third party given this responsibility.

In chapter 3 it is described how the settlement process with multiple providers will be handled for the local markets in Trondheim in the +CityxChange-project.

3 Powel trade platform for local markets

The platform for local trade of energy is developed to enable efficient operation and participation in a local market. The platform consists of solutions to enable asset operation, market participation, market operation and back office operation.

The local market operation is a chain of several steps closely and trustworthy linked together. In figure 3.1 the market steps are presented as a "chain" ending up with invoicing and payments to all buyers and sellers of settled trades in the actual period.

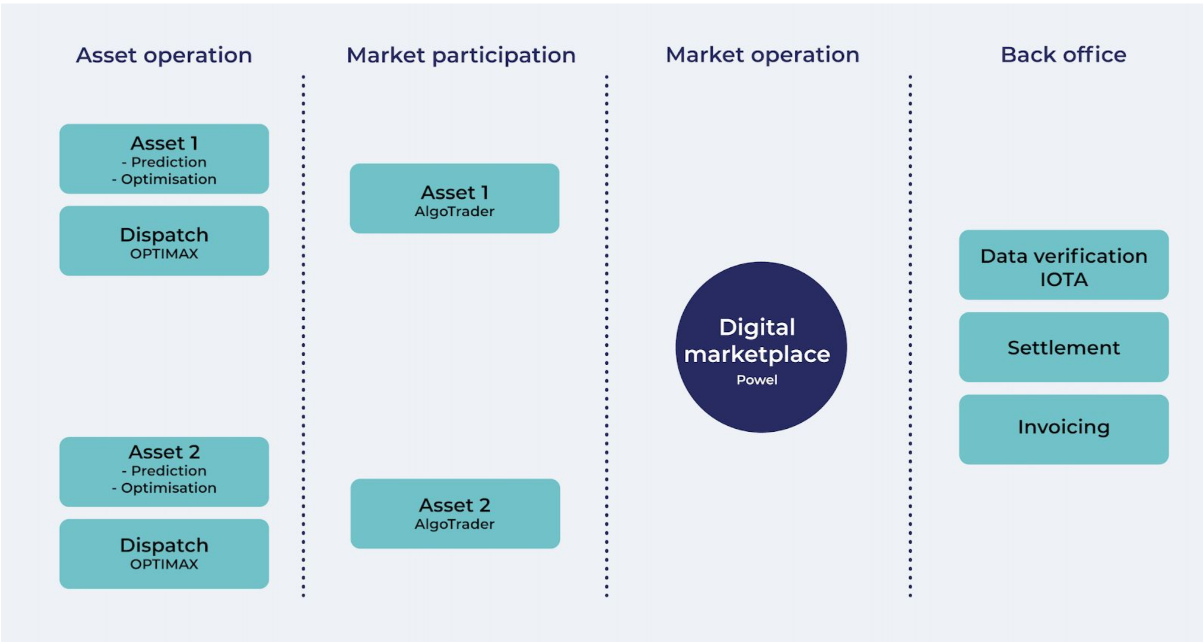


Figure 3.1 Overview of the steps from asset operation to invoicing in the demonstrated trade process.

3.1 Asset operation - optimal utilization of energy resources

Asset operation refers to the part of the process which includes how a given asset is expected to be operated prior to a trade and how it is actually operated based on a trade. It concerns the customer behaviour and preferences and it consists mainly of three parts: predictions, preferences and dispatch.

Predictions describes how the different energy assets are expected to be operated, and are a vital part of asset operation for the following reasons:

- Predictions for how much each asset is expected to consume or produce every minute is key to decide how much should be bid to the market
- Continuously updated predictions ensure possibility to always bid to the market the expected and the wanted behaviour of each asset

- Accurate and detailed predictions for production and consumption are valuable for the local system operator to decide how to operate the grid, identify potential challenges and consider acquisition of flexibility from the local market.

Preferences describes how individual energy assets might be operated based on external factors. It takes into account the prefered operation of the asset as well as willingness to pay that the asset owner has to deviate from the expected behaviour. An example for consumption preferences for a cooling storage: The preference is to keep continuously -20 degrees celsius. But the preference can be extended to also allow for -18 degrees celsius for 4 hours or -15 degrees celsius for 1 hour if the cost reduction weighs up for the disadvantages. Specifying these preferences in terms of wanted behaviour and the willingness to deviate from the wanted behaviour, both associated with a price, creates the foundation for how to model the wanted market behaviour for each asset.

Dispatch is the execution of a confirmed trade. For the cooling storage, the preference is to keep -20 degrees celsius. The cooling storage example: To maintain the correct temperature, there is a need for 100 kWh/h, which has been bought already for 10 €/kWh. Increasing the temperature to -18 degrees celsius for 1 hour means no consumption for one hour. For this, the cooling storage has made an offer to sell the 100 kWh which is already bought for that hour, for a price of 12 €/kWh. This means that 100 kWh has been bought for 10 €, and then re-sold for 12 €. But for this trade to take effect, the consumption needs to be reduced accordingly. The execution of this trade is the dispatch part, which in the project is executed by ABB OPTIMAX® based on a signal from the digital marketplace through a standard API

3.2 Market participation - trade energy locally

Market participation means to be an active part in the local energy market by selling or buying energy at a specified price in the digital marketplace. Market participation is a highly automated process, which will be executed digitally based on predictions and preferences defined by each asset. In essence, the market participants are obliged to deliver on their obligations made in the local market. The volume bought must be consumed and the volume sold must be produced. The market participants are free to use more than what is bought or produce more than what is sold, but this excess volume will then be settled against an outside power supplier as described in section 2.4. All local producing assets have their own smart meter installed. This meter registers production as time series and the market operator will calculate what is sold outside the local market as a residual compared with total local trade for a given period of time. The residual will then be settled as sales to the global market. The global market will in such situations either be the global supplier or the global marketplace (i.e. NordPool).

Market participation is understood as follows:

- For each time step, place bids at the marketplace for how much energy you want to buy or sell at a given price. One bid consists of the wanted amount of kW for one specific price for the given timestep [(time)hh:mm, (amount)kWh/h, (price)€/kWh]. A participant can place as many bids he wants for each timestep, at different prices.

The bids can be placed at the frequency you want, however placed before the defined cate closure time.

- Take a bid placed by another participant. The market works as first-come-first-served.
- If someone takes the bid you have placed, or you take a bid someone else has placed, a contract is automatically established.
- If you want to change your position, you can at any time do re-bidding for the timesteps you want. For instance if your updated forecast tells you that you will produce less power from the PV-panels than what you have already sold, you can place a new buy-bid to manage the predicted unbalance.

Example:
At 10:00, a consumer predicts a need for 100 kWh between 12:00 and 13:00. For this, he wants to pay €10, resulting in a rate of €0,100/kWh. But he is willing to pay €10,5 for 110 kWh, which means a rate of €0,095/kWh. And similarly, if the price is €0,105/kWh he only wants to buy 90 kWh, paying €9,5. This will represent the following 3 bids at the marketplace:

1. 12:00 - 13:00: -90 kWh/h @ €9,5 (€0,105/kWh)
2. 12:00 - 13:00: additional -10 kWh/h @ €0,5 (total -100 kWh for €0,100/kWh)
3. 12:00 - 13:00: additional -10 kWh/h @ €0,5 (total -110 kWh for €0,095/kwh)

At the same time, a local producer predicts he can produce 150 kWh/h at 12:00, and for this he wants €16,5 (€0,11/kWh). But he is willing to sell 100 kWh/h for €10 (€0,01/kWh) and 50 kWh for €4,5 (€0,09/kWh). This will represent 3 bids at the marketplace:

1. 12:00 - 13:00: +50 kWh/h @ €4,5 (€0,09/kWh)
2. 12:00 - 13:00: additional +50 kWh/h @ €5,5 (total +100 kWh for €0,100/kWh)
3. 12:00 - 13:00: additional +50 kWh/h @ €6,5 (total +150 kWh for €0,110/kWh)

At the Digital Marketplace, the bids and offers will be visualized as shown in figure 3.2.

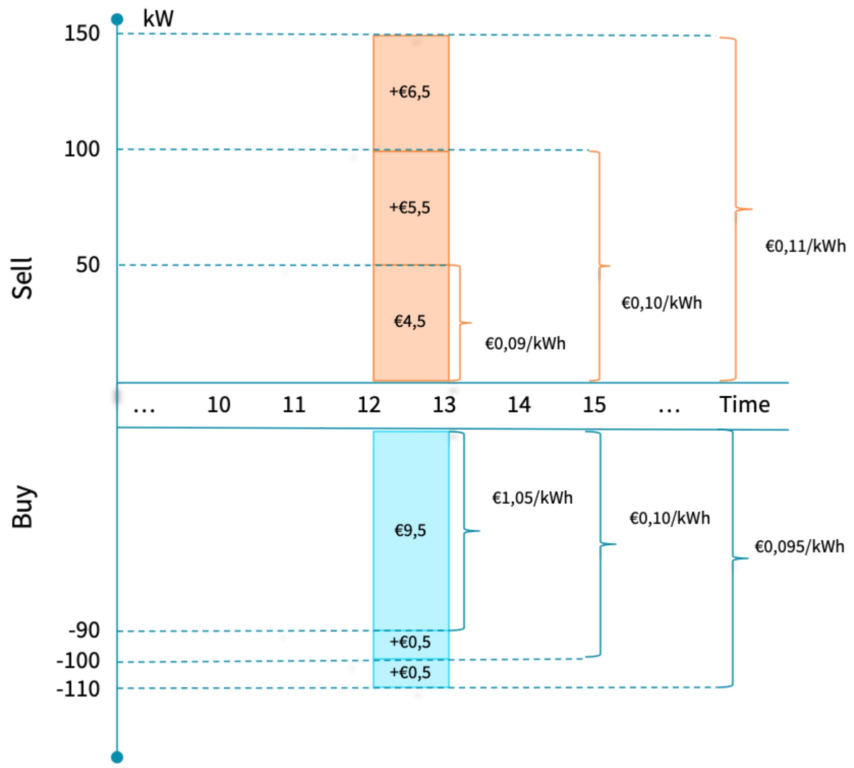


Figure 3.2 Illustration of the Bids (Buy) and Offers (Sell) at the marketplace.

In this example, an agreement is reached, resulting in the seller selling 50 kWh for €4,5 plus 50 kWh for €5,5 which means a total of 100 kWh for €10, giving a rate of €0,1/kWh. He now has an obligation to deliver 100 kWh/h between 12:00 and 13:00, and the buyer has an obligation to consume 100 kWh/h between 12:00 and 13:00.

Now the buyer can place additional offers which correspond to his other 2 bids:

1. 12:00 - 13:00: +10 kWh/h @ €1,05 (€0,105/kWh)
2. 12:00 - 13:00: -10 kWh/h @ €0,95 (€0,095/kWh)

This re-bidding based on accepted trades are visualised in figure 3.3.

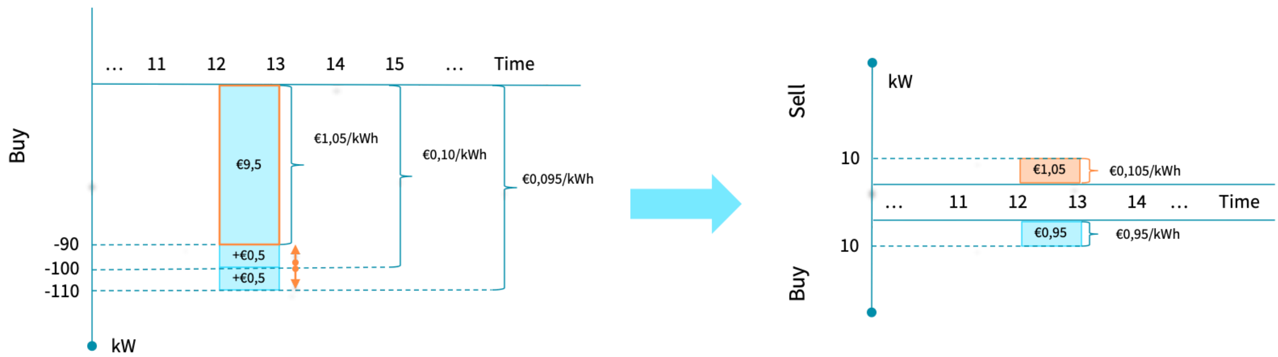


Figure 3.3 Re-bidding based on accepted trades

If then at 11:00, the seller realizes he can only deliver 90 kWh/h, he needs to buy 10 kWh/h from the market to cover his obligations to deliver 100 kWh/h. An additional agreement between the same two market participants could then be reached, where the original buyer becomes the seller and the original seller becomes the buyer. The new contract is 10 kWh/h for €1,05 between 12:00 and 13:00 resulting in a rate of €0,105/kWh.

The resulting trades between these two market participants will be 90 kWh for €8,95, meaning a rate of €0,099/kWh, and can be summed up as presented in figure 3.4.

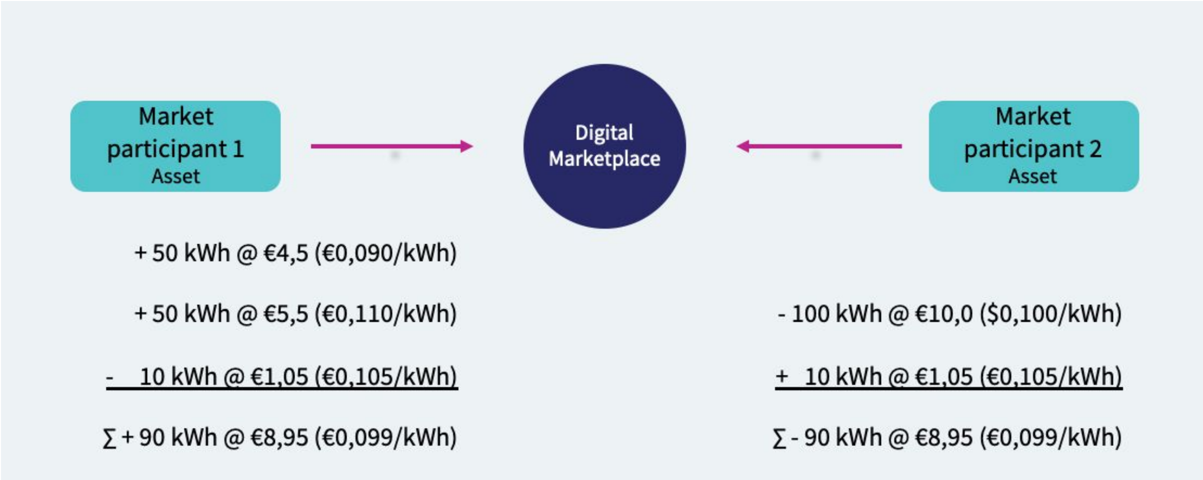


Figure 3.4 Example of transactions between two participants, trading and re-trading.

For the market participation, an algorithmic trading solution for local markets which integrates with Powel Digital Marketplace is developed. It takes into account the predictions for each asset and the preferred strategies for how to operate, and gives the actual market participation on behalf of the assets in a fully automated way. The Digital Marketplace ensures that information about executed trades will be sent to the relevant control systems for dispatch.

3.3 Local market operation

The main tasks for local market operation are to provide market access for everyone, and to ensure matching of buyers and sellers of energy. In addition, the market operator serves vital tasks like establishing the market rules and the players' compliance with the rules, to serve as a counterpart for all trades and to ensure correct settlement for all trades.

The matching of buyers and sellers means to provide a transparent digital marketplace where everyone who wants to buy or sell energy can meet. The marketplace needs to allow for placing bids and offers at any time during trading hours, where bids consist of volume [kW], time [hh:mm] and price [€/kWh]. The matching of bids and offers happens continuously and automatically by a first-come-first-served principle. The first market participant to respond on an available offer gets the contract on that specific volume, and the price is set as pay-as-bid. If a seller offers 100 kW for €10 (€0,1/kWh) and a buyer responds to that, the buyer buys 100 kW at a rate of €0,1/kWh, for a cost of €10 regardless of if another buyer later is willing to pay €50 (€0,5/kWh) for the same amount of energy.

The data for all executed trades are managed and stored in the trade platform. This is data which is used for the back-office routines.

3.4 Back-office routines in local market operation

Back-office routines in the market operation refers to the part of the process which concerns verification of trades, data settlement to ensure consistency between executed trades and executed dispatch and invoicing based on deliveries.

The Powel trade platform integrates with the IOTA distributed ledger to allow data immutability and data verification. This is done by copying data related to matched bids (buyer, seller, volume, price, time, etc.) to IOTA distributed ledger after a match between two orders have been made. This is only exposing relevant data regarding the trade, and not exposing all the orders that remained unmatched, therefore keeping trading strategies private for all parties. On the same distributed ledger, data about delivered (metered) energy is stored by an entity that has access to metered data (ABB in this case).

Settlement and invoicing are performed in 3rd party applications based on data from IOTA and Powel solution. These 3rd party applications then access both data about the matched orders, and metered data to perform settlement and invoicing calculation, and also verify that agreed upon exchanges of energy actually happened the way they were matched in the market.

A crucial part of the back-office operation is to ensure that market participants get paid for what they have sold and/or purchased. There needs to be a distinction between what is traded locally and what is purchased or sold via traditional channels. The way this is solved is to have a detailed and accurate overview of the actual local trades and metered values from each market participant about what is actually consumed or produced.

The invoicing for the local market participants will be:
$\text{Volume}(t)_{\text{local traded}} * \text{Price}(t)_{\text{local traded}}$

To ensure that Volume(t)local traded is correct, the settlement routine will be as follows:

If
$\text{Volume}(t)_{\text{metered}} - \text{Volume}(t)_{\text{local traded}} \geqq 0$
Then settlement is based on registered trades
If
$\text{Volume}(t)_{\text{metered}} - \text{Volume}(t)_{\text{local trade}} < 0$
Then handle exceptions

This means that as long as the total metered consumption in one timestep is higher than what is bought in the local market, the registered local trade is correct and is invoiced accordingly. The excess consumption is invoiced via the power supplier outside the local market. The same procedures goes for production, where excess production, additional to what is traded locally, is settled with the regular power supplier.

The challenge is when this is not the case. In those cases the market participants have not covered their obligations, and have in practice imposed an additional cost on another party, which he has to answer to. How to deal with these exceptions needs to be established as part of the market rules.

Example - combination of local market and regular power supplier:
A buyer has agreed to buy 100 kWh for €10 (a rate at €0,1/kWh) at the local market for one specific hour, which means that a seller has agreed to sell 100 kWh for €10 (€0,1/kWh) for the same hour. The counterpart for both is the local market operator. If the buyer consumes 150 kWh in that hour, he pays €10 for 100 kWh to the local market operator and pays for the remaining 50 kWh to the regular power supplier for the price agreed with the supplier.

This example shows that a consumer can buy energy both at the local market place, and at the same time have an agreement with a regular power supplier.

The total invoicing will be:
Invoicing local market = $\text{Volume}(t)_{\text{local traded}} * \text{Price}(t)_{\text{local traded}}$
Invoicing power supplier = $(\text{Volume}(t)_{\text{metered}} - \text{Volume}(t)_{\text{local traded}}) * \text{Price}(t)_{\text{power supplier}}$

Example of this principle is presented in chapter 2.4.

If, on the other hand, the metered volume reports a consumption of only 50 kWh for the same hour, the local market operator has bought 100 kWh for €0,1/kWh and paid €10 to the local producer. But he only gets paid €5 for 50 kWh from the buyer. The market operator needs to establish clear and transparent rules for how to deal with these exceptions to ensure that the party that causes the unbalance is the one who is penalized. If is the market operator that acts as a market maker and will always ensure that there is volume available in the market, and the settlement for these cases may result in that the part which does not cover its obligations is forced to buy the unbalance in the market at the best price available. For the example above, this could mean that there is a buy offer for 50kWh for €6 (€0,12/kWh), which the consumer then will be settled against. The total settlement will then be:

- Consumer:
    - Buy 100 kWh @ €10 (€0,10/kWh)
    - Sell 50 kWh @ €4 (€0,08/kWh)
    - Total invoicing: €10 - €4 = €6 in cost for 50 kWh (€0,12/kWh)
- Producer:
    - Sell 100 kWh @ €10 (€0,10/kWh)
    - Total invoicing: €10 in income for 100 kWh (€0,10/kWh)

4 Technical description of trade platform

The trade platform to be applied in the demonstration area in Trondheim is a part of the overall ICT architecture of the +CityxChange project as presented in figure 4.1. The executed service includes the whole range architecture levels from assets in a physical infrastructure which could be meters. Then through the Technology and Data Space levels. If data is coming from a meter connected to a V2G charger, the data is sent to the eMaas platform before sent to the trade platform as presented in the Business layer. Ending up with the contracted trade that helps to enable the process towards a PEB.

4.1 The trade platform in the overall ICT architecture

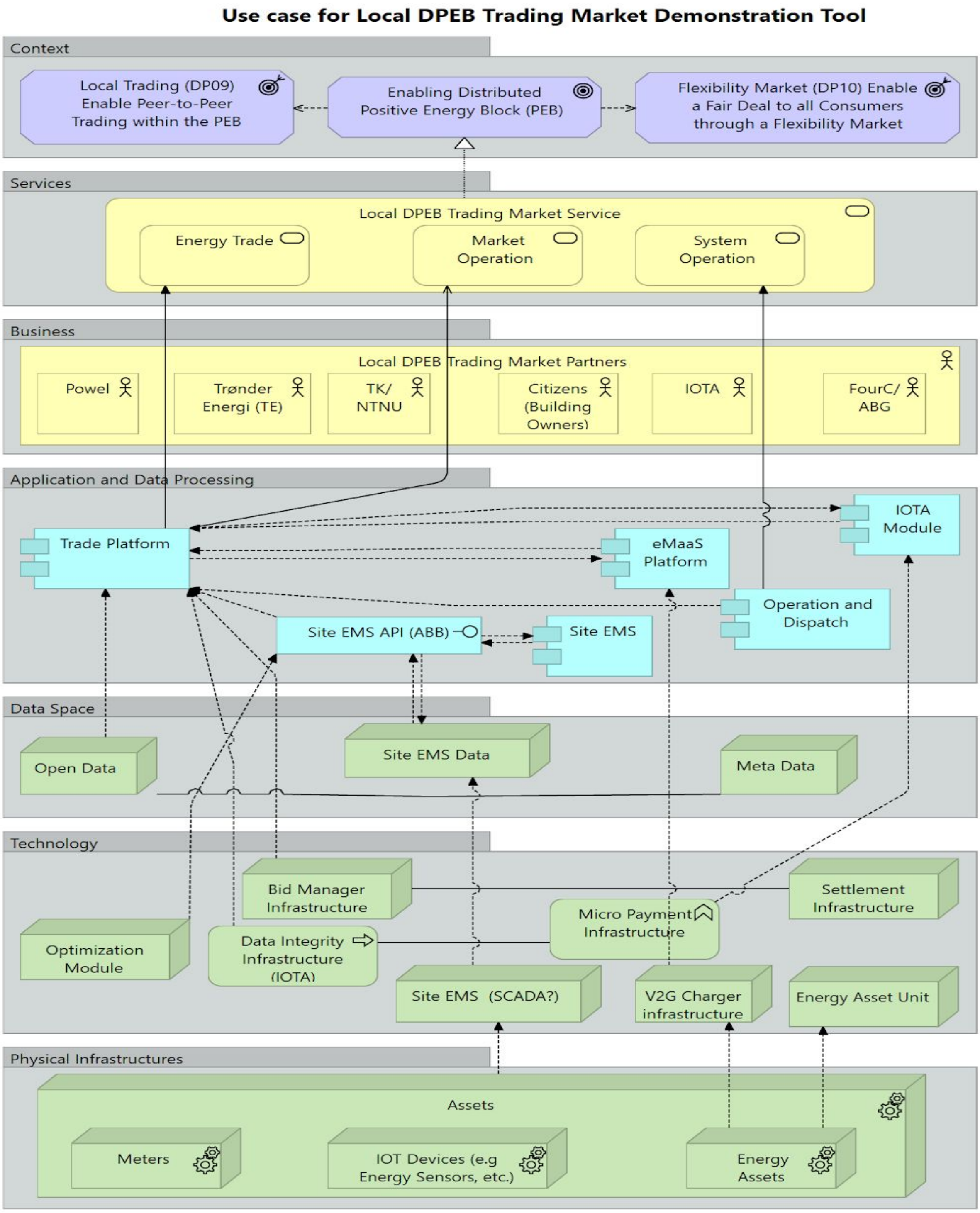


Figure 4.1 Use case for local DPEB trading market demonstration tool in the project's ICT enterprise architecture framework. (Source: +CityxChange D1.2)

The trade platform developed for the purpose of demonstrating a local power market as a service within the +CityxChange project is linked with the overall project ICT architecture as developed in D1.2 as presented in figure 4.1.

It depicts the use case for the local DPEB trading market demonstration tool developed in the +CityxChange Enterprise Architecture Framework (EAF) as seen in D1.2 Report on the Architecture for the ICT Ecosystem (Petersen et al., 2020). The use case for the local DPEB trading market demonstration tool modelled in the developed EAF comprises seven layers (see D1.2 for more details). The trade platform is captured in the Application and Data Processing layer. It is integrated with Site EMS (ABB OPTIMAX®) for data exchange and dispatch purposes. The Site EMS represents the link with actual asset data for the market operation purposes as described in the Technology layer. The business layer addresses the roles and actors that operate the market in the project's demonstration phase.

The trade platform uses data from Open data sources (such as Geographical Data, Calendar Data, and Weather data MET Norway (temperature, wind, cloudiness, fog) (www.met.no)), metadata and also utilizes data from the Site EMS via the Site EMS API owned by +CityxChange partner ABB. Information describing the ABB OPTIMAX® (Site EMS in figure 4.1) API by ABB is presented in D1.3: Report and catalogue on the ICT data integration and interoperability.

Additionally, the trade platform provides and receives data as regards to EVs deployed in the city by connecting to the eMaaS platform owned by +CityxChange partner FourC. As seen in figure 4.1 the trade platform sends and receives data from the IOTA module which ensures data integrity provided by +CityxChange partner IOTA. Additionally, the operation and dispatch module is connected to the trade platform which aims to support Local DPEB trading market service for energy trading, market operation, and system operation.

4.2 The trade platform architecture

The trade platform developed for demonstrating local energy trading in a PEB consist of mainly these individual building blocks:

- **ABB** OPTIMAX® for asset operation.
- **Powel** Algotrader for market participation.
- **Powel** Digital Marketplace for market operation.
- **IOTA** for data verification.

In figure 4.2 the trade process from asset operation to back office is described.

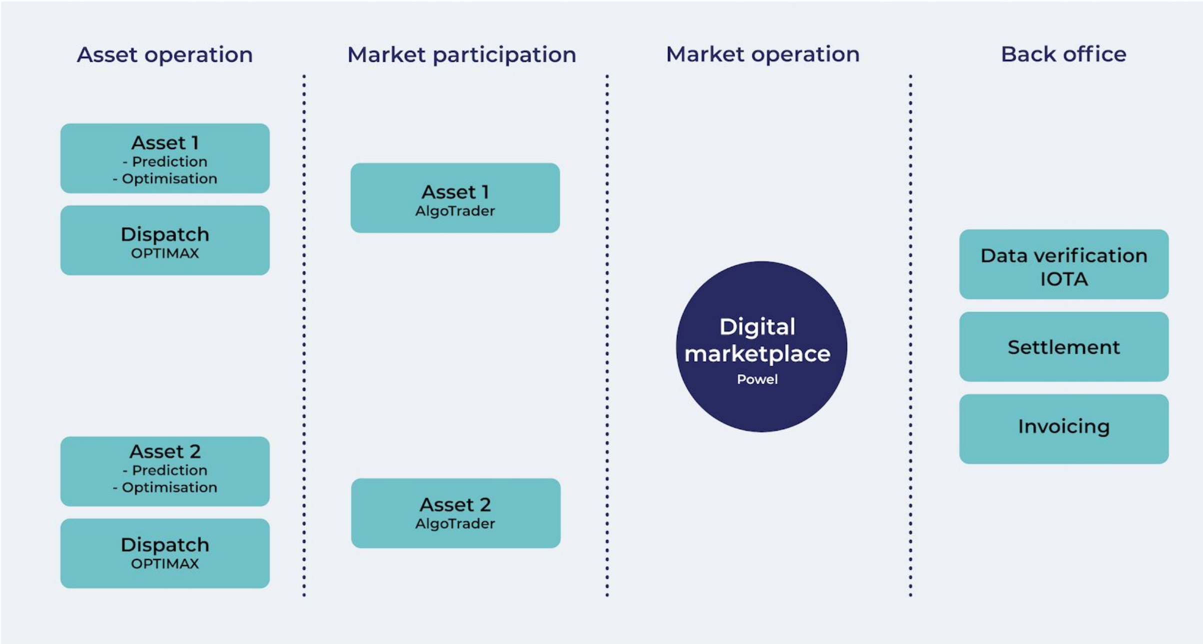


Figure 4.2 Trade process local power market - from bid to invoicing.

The trade platform has an IT architecture as described in figure 4.3. The architecture is characterised by a central database exchanging information with functions and parties. The functions include predictions, grid calculations and trade. Data exchanges include AMS data (smart meters), forecasts and other information represented as time series.

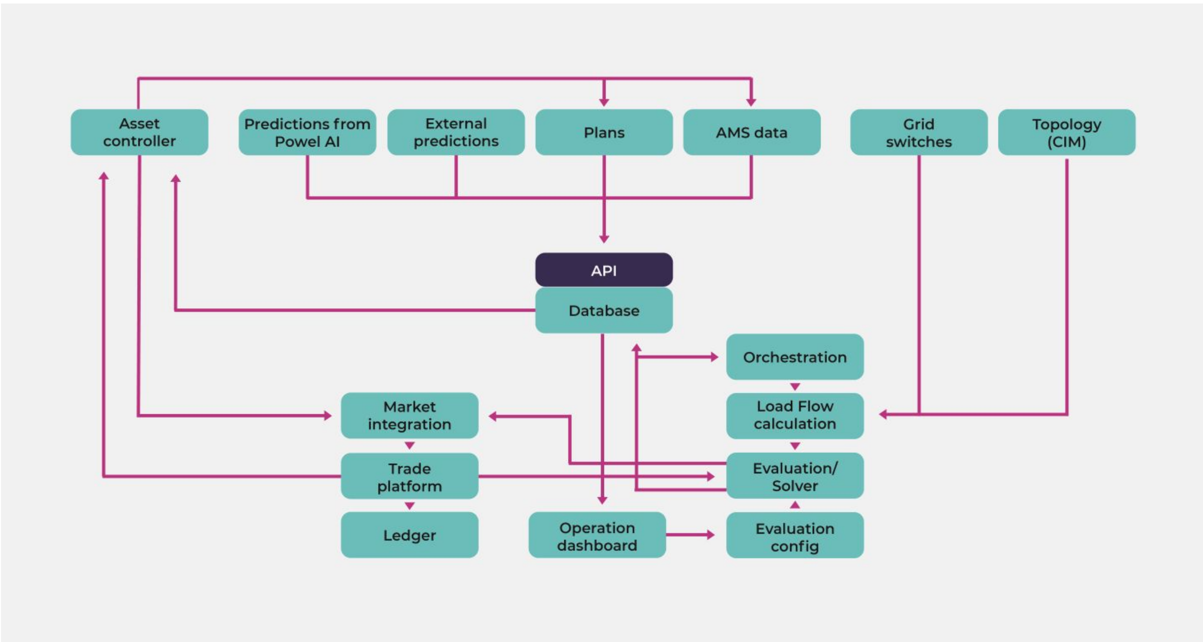


Figure 4.3 IT-architecture of the Powel trade solution.

4.2.1 Database and API

Central database serves as the main way of exchanging time series data for different parties (POW, TE, ABB, etc.). It's 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. Examples of such signals are listed below.

4.2.2 Predictions

For ideal functioning of the local market, all assets need consumption and production predictions. These can come from various partners, but they all are read/written through Data API, same as any other time series. This also includes weather and market predictions, which are also further used in planning and trading processes. In the Appendix, chapter 7.3 describes models for prediction of consumption and production. In practice, these can be provided by various partners, but they all are read/written through Data API, same as any other time series. This also includes weather and market predictions, which are also further used in planning and trading processes.

4.2.3 Asset data, plans and switch position

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.

4.2.4 Grid calculations - load flow analyses

When assets localisation and connection points to the local grid is defined, it is updated with the topology as developed in the delivery report D2.2 Toolbox for design of DPEB including e-mobility and distributed energy resources(DER) [7]. 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 are as shown in figure 4.3 as a service using 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 may be executed on a daily basis or on request.

4.2.5 Orchestration and grid calculation

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 system that can be customized for each deployment and takes care of executing the tasks based on the evaluation of the rule conditions.

4.2.6 Market integration

To access the market, assets are not integrating directly with the market API. They are instead interfaced through the algorithmic trading solution, Powel 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.

4.3 Input of data

The input data to serve the trade solution is primarily of two categories. These are:

- Data required to model and implement the asset as a market participant - once.
    - Detailed preferences (every time step, day, week...) of how the asset prefere to apply its resources into the market.
    - Price caps for each time step for when their bids shall be accepted.
    - Specifications of data sources like meters, weather forecasts.
    - Restrictions.
- Metered data and forecasts from each asset - continuously.
    - Data from smart meters/AMS sent to the trade solution.
    - Prediction for next day sent to the trade solution.
    - Restrictions.

Input data is independent of kind of asset. The fundamental prerequisite is that the actual assets are fully digitised when it comes to initiate the strategies and the data stream that serve market operation in the trade platform.

4.4 Powel Algotrader with actors' preferences and strategies

The trade platform offers a complete algorithmic trading solution that enables rapid design, testing with historical market data, deployment and refinement of automated strategies. The software solution provides an operational environment for the local market participants giving them the possibility to manage local market products with intraday trading strategies. With the solution connected directly to the local market, strategies and preferences can be implemented and the portfolio can be monitored in real-time. This gives the asset owner the control of the decisions with a user-friendly user interface for fast interaction. The solution includes pre-defined strategies that asset owners can modify or use just as it is covering position closing of local market traded products - independent of type of asset

The market preferences for the assets is in detail modelled as a part of the trade solution. These modelled preferences make the background for the bidding procedure which is automated for the purpose of algorithm based trading. In figure 4.4 it is presented a detailed view of how the strategy preferences are modelled and edited. It is applied a white box approach 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.

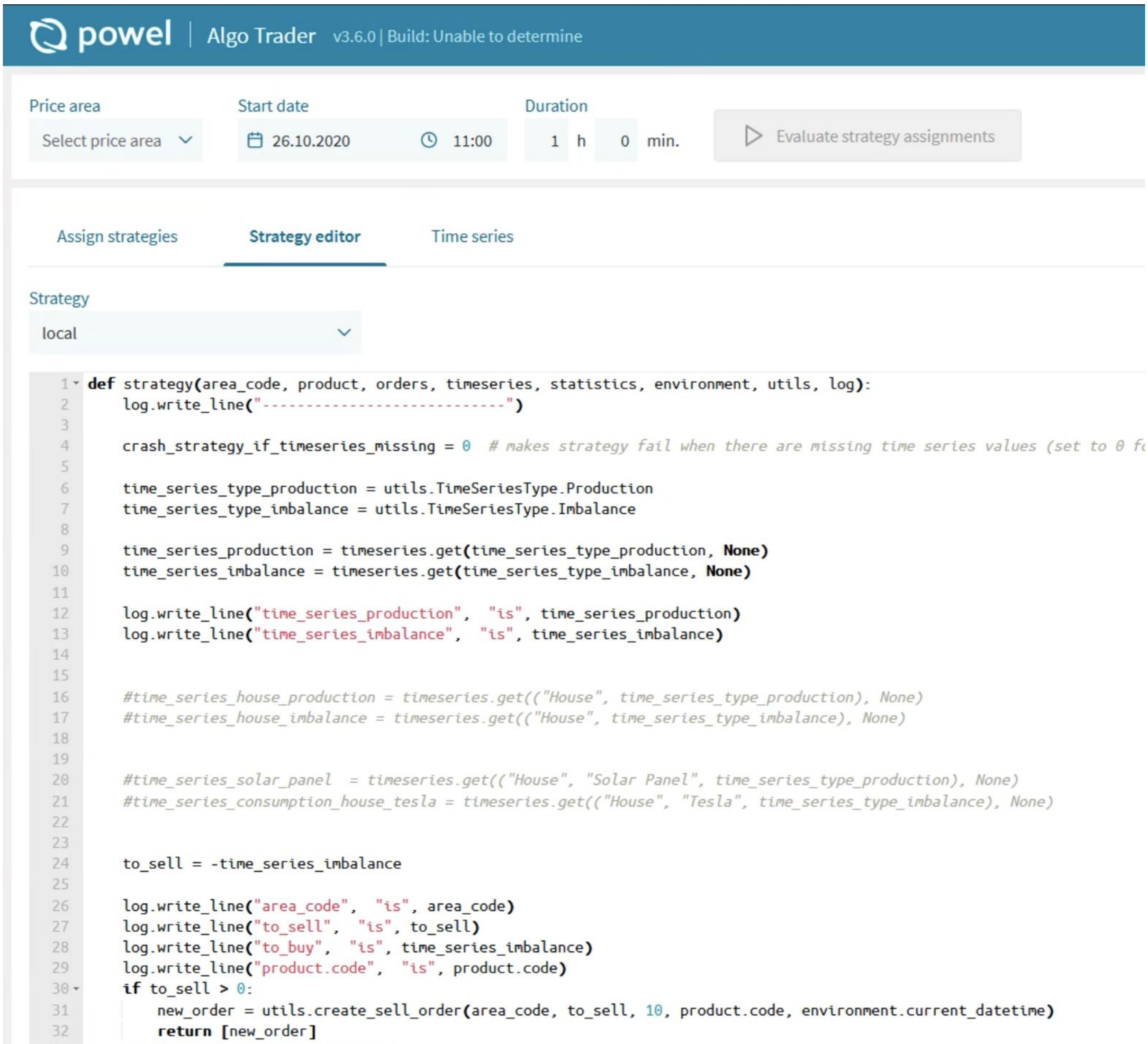


Figure 4.4 Strategy editor for setting up the assets local trade preferences.

In the Strategy editor, assets can develop new strategies and edit existing ones at any time keeping track of all the code changes. Strategy editor allows the asset owner who codes the strategy to put in 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. Strategy editor also includes a number of pre-defined strategies that the actor can test, set live and use as a starting point or modify for their own logic. Strategy editor offers an easy to code interface and supports the coding process with a dedicated microframework 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 4.5.

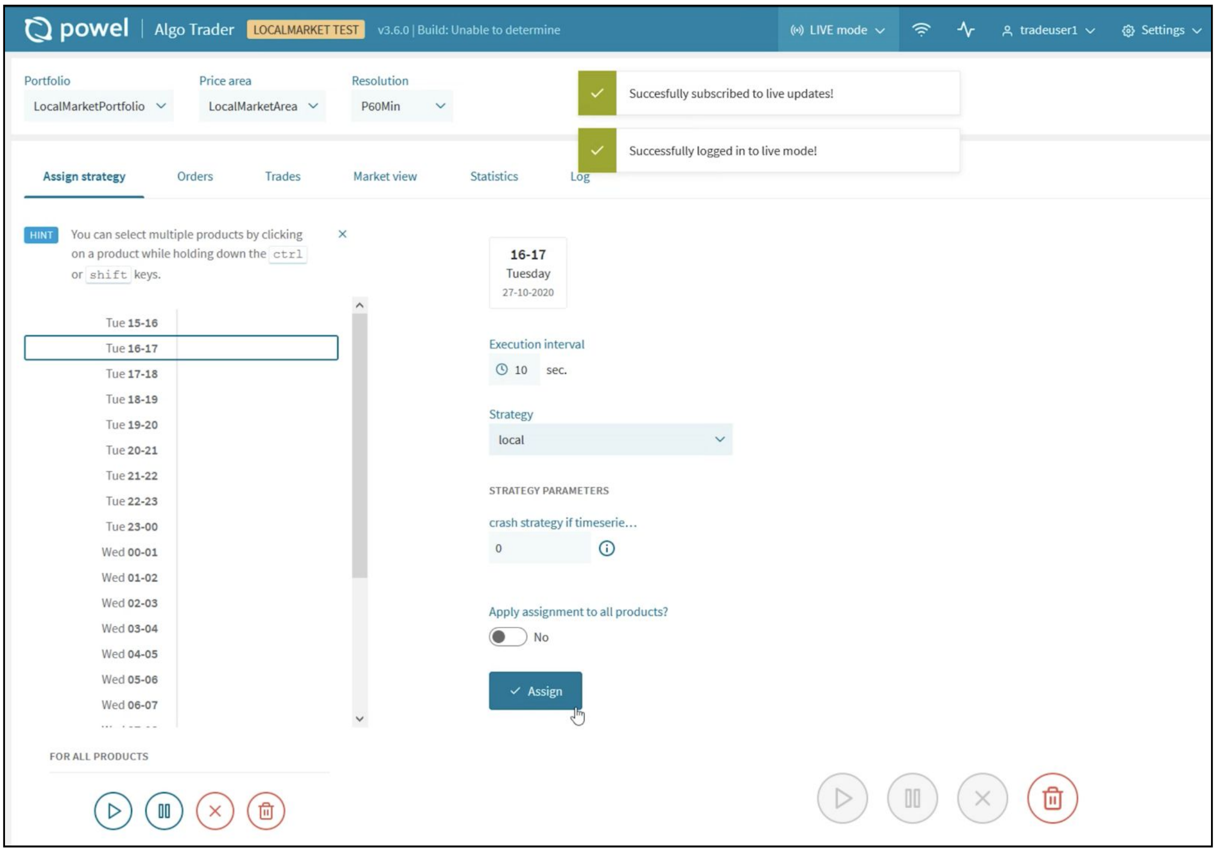


Figure 4.5 User interface for how to choose trading strategies for a specific period.

4.5 From received bid to executed trade

The bid (buy and sales offer) is made as a result of the trade strategy modelled for each asset/actor. In figure 4.6 it is presented as an example of how the actor or market operator will have an overview of the implemented and modeled strategy assigned in the market. This example is for Tuesday the hours from 16 to 18 for a product with time resolution of 60 min. Executed within a time interval of only 10 seconds.

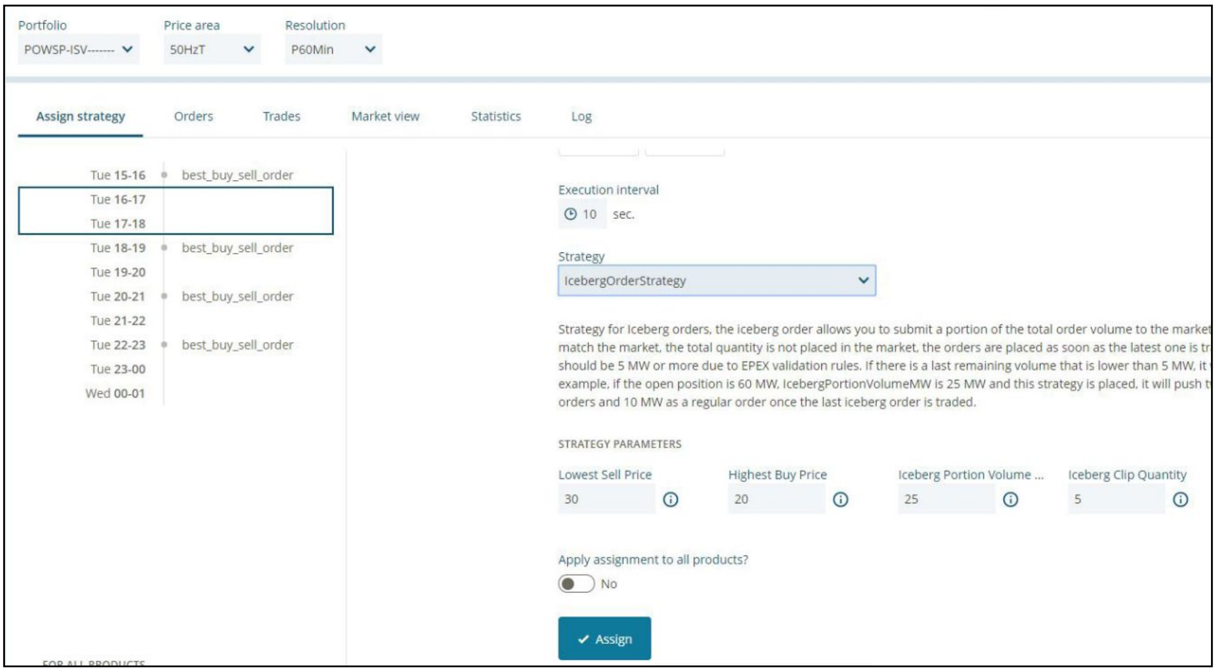


Figure 4.6 User interface for showing the assigned trade strategy for a specific product at a specific period of time.

The pre-defined strategy has 3 variations; one for buying, one for selling and one that can handle both positions. Best buy order and best sell order. This strategy will ensure that you have the best buy or the best sell order in the market depending on the imbalance position at any given time. The order created by this strategy will always be the best order in the market limited by assets individual price limitations. The strategy aggresses in the market even if we have the best order until we get a match and close the position or we reach our price limits given by the strategy parameters or the security thresholds of the system.

4.6 Market matching of bid and ask orders

Powel Digital marketplace matches all incoming bids and asks orders 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

Since the local market is mirroring the logic in the continuous intraday power markets, 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. Figure 4.7 presents a screenshot showing the Digital marketplace with bids (buy) and offers (sell) during a day.

Figure 4.7 Screenshot of Powel Digital Marketplace, showing bids (blue) and offers (orange) provided by the local market participants.

4.7 Settlement and invoicing routines

The goal of the settlement and invoicing process is to ensure that everyone gets paid correctly for what they have sold and pays correctly for what they have bought. The main difference from the wholesale market is the need to account for two counterparts for each meter: The volume traded in the local market towards the local market operator and the additional volume towards the general supplier. The settlement routine is illustrated in figure 4.8.

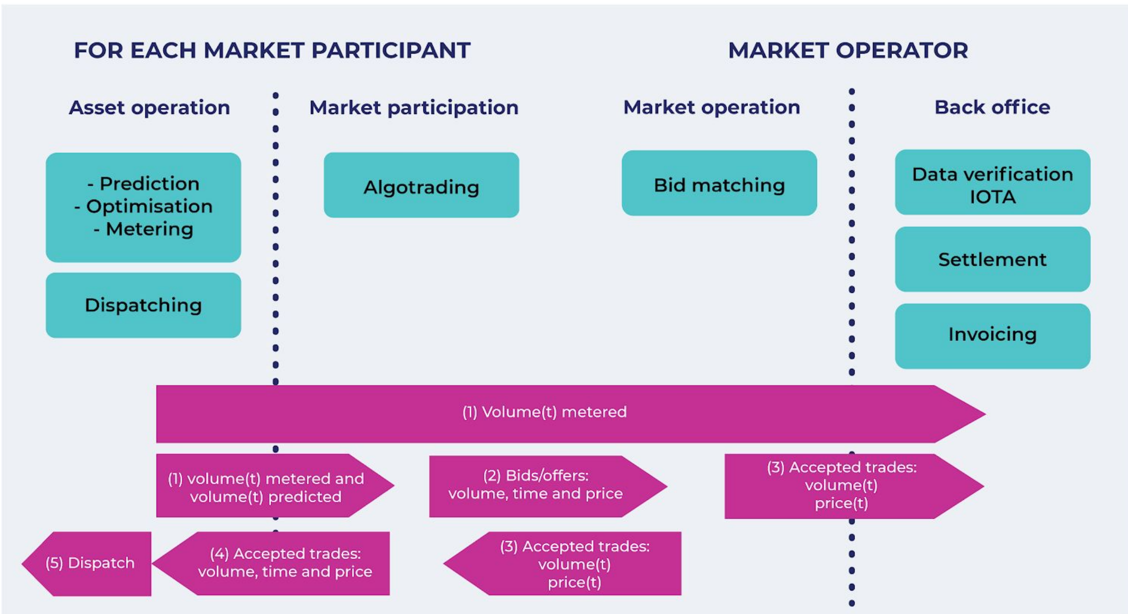


Figure 4.8 The settlement process for a local power trade.

The five(5) different settlement steps for an actual asset described in the figure are:

1. Consumption and/or generated power:
    a. Metered Volume(time) sent from ABB OPTIMAX®/asset to the Powel Algotrader and the IOTA tangle for data verification
    b. Predicted Volume(time) sent to Powel Algotrader as foundation for trading strategies.
2. Bids and offers from the trading strategies based on predicted and metered volume is placed on the Powel Digital marketplace [hh:mm, kWh/h, €/kWh]
3. At the local marketplace the bids from all assets are received and the accepted local trades(asset, volume, time, price) are further managed as follows:
    a. Accepted trades exported to IOTA tangle for data verification.
    b. Accepted trade for an actual asset is reported back to Algotrader.
4. Powel Algotrader exports to ABB OPTIMAX® accepted local trade for dispatch if required.
5. ABB OPTIMAX® sends dispatch signals for accepted local trade to asset/local energy management systems.

The market operator uses metered and predicted data linked to accepted local trades for invoicing. This is a part of the back office process which includes the steps as described in figure 4.9.

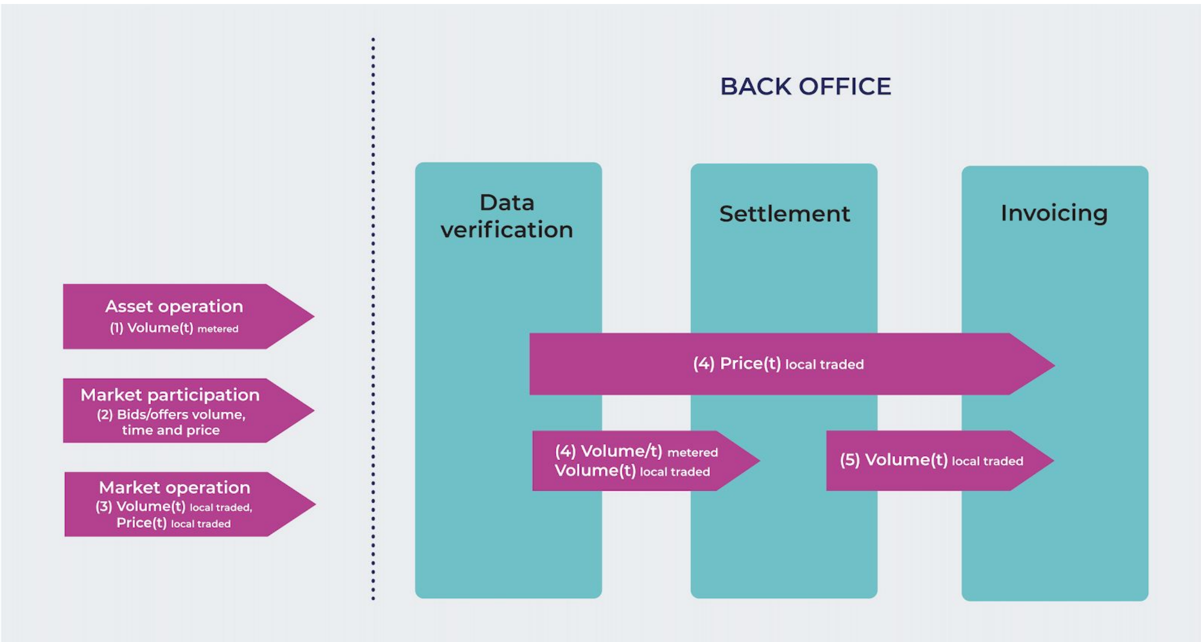


Figure 4.9 The invoicing process for local power trade - a stepwise description.

The invoicing process relies on data from IOTA tangle and the settlement process to ensure what is traded is actually delivered. As described in figure 4.9 required data from these subsequent steps are received as follows:

1. From the asset operation process it is received metered values for each time step, stored in the IOTA tangle.

2. From Powel Digital marketplace it receives all accepted trades [hh:mm, kWh/h, €/kWh]
3. The resulting invoicing in the local market is $\text{Volume}(t)_{\text{local traded}} * \text{Price}(t)_{\text{local traded}}$

When all information is received for the back office process, the first step is to verify the data. This action, numbered as the 4th in figure 4.10, is executed by the IOTA solution as described in chapter 4.8.

The settlement step, numbered as 5th in figure 4.9, applies verified trade data which is compared with metered data for the actual period. The major test in this step is to ensure that traded volume in a period is not exceeding metered volume for the same period. After this test, the volume and price are sent to the invoicing system for billing. In the demonstration it is the market operator that is given the responsibility to send bills.

4.8 Immutable DLTs for data verification - IOTA service

The Verification Service has been developed in order to guarantee 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 DataIntegrity Infrastructure, as seen in the Technology Layer of the Enterprise Architecture (EA) shown in figure 4.1, needs to be leveraged.

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.

To provide this immutable ledger store infrastructure, we use the IOTA Tangle. The IOTA Tangle is a third generation distributed ledger (of which blockchain is one technology) which retains the feature of traditional blockchain but overcomes some of its drawbacks, such as scalability and costs. The IOTA Tangle does not need blocks nor miners and it does not require any fee. This makes it particularly suitable to process not only value but also data transactions.

To leverage the feature of IOTA Tangle, included in the Data Integrity Infrastructure, the Verification Service, presented in the Service Layer of the EA, has to provide the ability for different services to store various pieces of information generated by their internal systems. The stored information should be future searchable and accessible in order for a requesting party to prove that data on internal records hasn't changed from the value agreed at a previous point in time. The service is mainly used by the marketplace back office and accessed by the Settlement layer as shown in figure 4.9.

The architecture of the Verification service is presented in figure 4.10. Different connected services (Asset Operation and Trade) store information locally or exchange them directly.

Once relevant information is generated and its integrity needs to be guaranteed, then the requesting service logs a copy of it (or its hash[1]) in the IOTA Tangle.

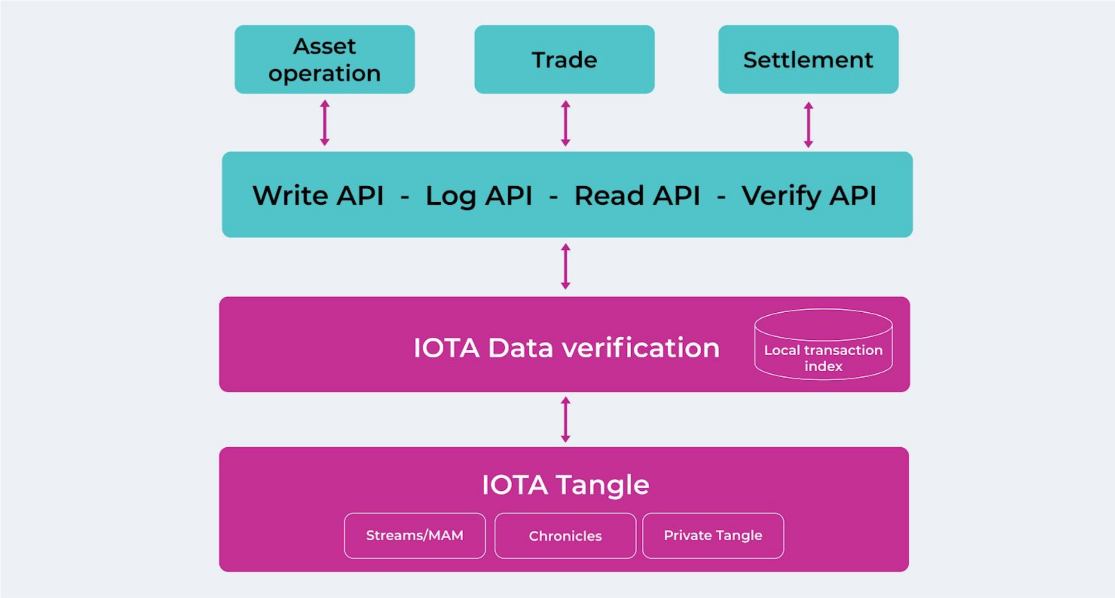


Figure 4.10 Architecture for the IOTA verification service.

The actual APIs in figure 4.10 are defined as follows:

- Write API:
    - In: UUID, Version, Type, JSON payload
    - Out: MAM root, Version, Transaction URL
- Log API:
    - In: UUID, Version, Type, Transaction URL
    - Out: Success/Fail
- Read API:
    - In: UUID, Version, Type
    - Out: transaction payload, Transaction URL
- Verify API:
    - In: UUID, Version, Type, Transaction payload
    - Out: Success/Fail

This can be done using the Write API. The IOTA Verification Service provides the implementation of such API and manages the writing of information into the IOTA Tangle. The API returns some metadata for further access to the stored information. In case the requesting service does not provide local storage and indexing of such metadata, the Verification Service offers the opportunity to maintain this locally. Such functionality is triggered calling the provided Log API.

The Local Transactions Indexing is local to the IOTA Verification Service and maintains information indeed to retrieve required immutable transactions and data based on metadata provided by the Read and Verify APIs.

[1] an irreversible encoding of data into a small, fixed size.

The Write and Log APIs are used by the Trade platform to store matched bids and by the ABB OPTIMAX® system to store energy readings.

When the verification of data integrity is requested by a service, such as the Settlement in the Market backend, the following process is triggered:

- The Read API is called by providing the information metadata.
- The metadata is used for searching the Local Transaction Indexing and obtains the corresponding IOTA Tangle transaction.
- The transaction is accessed and its content is returned to the requesting service.
- The requesting service compares the returned information with the one already obtained; this might request to compare the given data or their hash.
- Alternatively, the Verify API is called by providing the information that has to be verified.
- The Data Verification service performs the steps above to retrieve the information stored on the ledger and return true or false depending on the information immutability being verified or not. In addition Verify API returns also the address of the immutable, timestamped transaction storing the corresponding data for direct check by the requesting service.

A number of IOTA Technologies are used inside the Verification Service. IOTA Streams are used in order to link together transactions generated by the same service. This allows the IOTA Tangle to act as a time series database, where each transaction in a stream can represent a different version of the same information.

In order to be able to retrieve information from the IOTA Tangle (whether arranged in Streams or not) it is necessary to maintain an indexing of them. IOTA Chronicles nodes are used to provide a permanent indexing of this information. Depending on the nature of the shared information the IOTA Tangle will be deployed in a permissioned environment with a node of the ledger managed by each participating organization. Information stored on the Tangle can be encrypted if needed.

5 Trade ecosystems – IOTA, ABB and Powel

The trade platform solutions for the demonstrated local market is developed by the partners Powel, IOTA and ABB. The technologies are parts of the individual company's technology ecosystems and will be further innovated in line with its strategy - in addition to be demonstrated in the +CC project. In this chapter each ecosystem is given a comprehensive description and evaluation.

5.1 The IOTA ecosystem for power trade

The Verification Service described in Section 4.8 has been implemented in order to simplify integration of existing infrastructure, including input data, Algotrader and marketplace backend functionalities, and to guarantee integrity of data shared across different systems and stakeholders. This makes it possible to increase trust and transparency in a multi-stakeholders ecosystem thanks to the immutability guaranteed by the IOTA Tangle distributed ledger technologies. However distributed ledgers like IOTA are not only suitable for sharing immutable data but also to process peer to peer payments, without any added fees. Leveraging these features allowed us to explore the concept of a fully decentralized energy trading marketplace, where input data are directly injected by monitoring devices deployed at the edge of the energy infrastructure, and the settlement and payments are processed based on information shared on the ledger. Optimization tools, such as Algotrader can be plugged on the backend of this decentralized infrastructure, to directly access data and create bids that do not require further verification.

To demonstrate this opportunity, an IOTA enabled energy marketplace has been prototyped.

In order to provide the decentralized marketplace infrastructure a number of HW and SW components are developed. A simplified high-level overview of the implemented architecture is shown in figure 5.1.

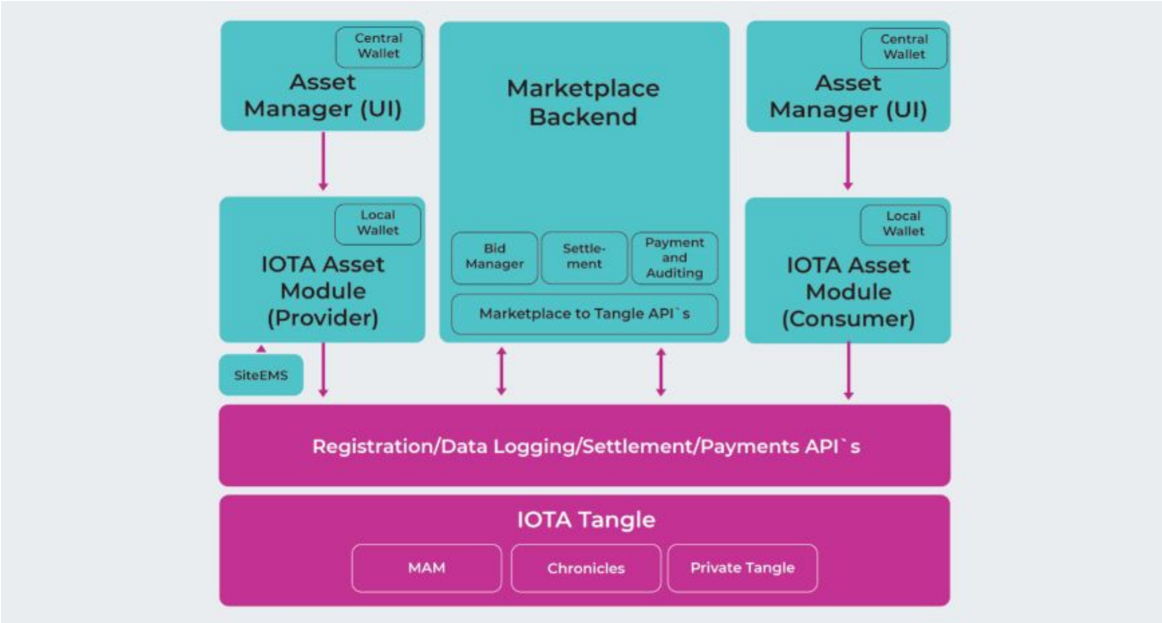


Figure 5.1 Simplified high-level overview of the IOTA implemented architecture.

The focus is on the data and payment infrastructure built on top of the IOTA Tangle, however to demonstrate its value some additional components have been implemented. The ambition in integrating IOTA is to bring the decentralization of this energy trading process to the edge of the electricity network and the ability to directly connect energy assets to the infrastructure. To this purpose we first developed a prototype of an IOTA Asset Module, see figure 5.2. It is an embedded IoT device (using a PyCom board) with an integrated energy meter and an IOTA Cryptocore that allows each energy asset to directly publish data onto the IOTA Tangle. The module can connect to local WiFi or to an LTE-M network, allowing it to be deployed over a range of energy assets and scenarios. It is compatible with different standards and can measure the connected asset energy either directly or through an asset integrated energy meter (i.e., ABB OPTIMAX®) connected through a provided HAN port. The device registers its identity (public key) on the IOTA Tangle thus allowing it to encrypt and sign all the generated messages.

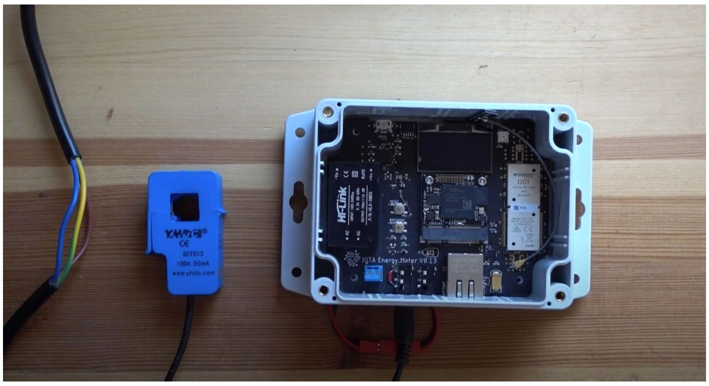


Figure 5.2 IOTA asset module with an integrated meter for publishing asset metered data onto the IOTA Tangle.

An Asset Manager UI is shown below and allows owners to configure the module with parameters such as cost for energy sold or price for energy purchased. Payments are performed directly from the device, which hosts an IOTA Wallet that can be funded using the same UI. The desired amount of tokens can be moved from a central wallet to the device wallet using the same UI. Alerts for when the local wallet balance falls below a threshold can also be set up as well as periodic withdrawals when the wallet balance exceeds a predefined limit. All the transactions on which the device is involved in are logged on the IOTA Tangle and visible using the UI auditing features.

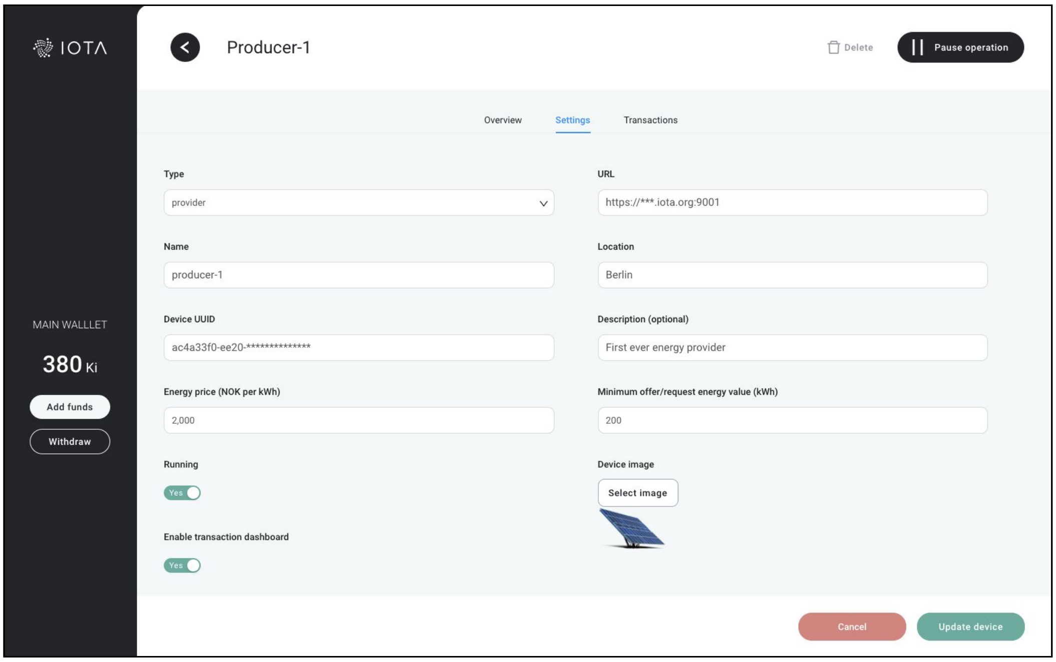


Figure 5.3 Asset configuration by using the IOTA device.

After initial configuration as shown in figure 5.3, the module automatically generates energy excess offers and demands for the connected asset, based on the predefined parameters and posts them onto the Tangle infrastructure, using a secure MAM channel which is an encrypted portion of the ledger that allows the source of shared data to control who can access it.

A number of standard APIs (Platform to Tangle APIs) allows our backend (developed for demonstration purposes) or any other backend optimization algorithm (such as AlgoTrader) to extract these demands and offers (if access to the relevant channels is granted by its owner), validate the integrity of their source and automatically match them in order to maximise a given output.

At this stage a very simple matching strategy was implemented in the connected Bid Manager (i.e., energy surplus offered is more than energy requested and price is lower than price offered). However, any more complex strategy can be adopted by platforms connected using the provided APIs. Once a match is created, an agreed bid is stored by the Settlement module on the Tangle infrastructure (using the same standard APIs) for auditing purpose and a notification sent to the involved producer and consumer assets.

An exchange of energy can then be monitored by a Settlement module that osserves energy measurement posted by producing and consuming assets in a dedicated MAM channel opened for this specific purpose. Energy sent and received at asset level is measured by the connected IOTA Asset Module. Once an exchange of energy is confirmed the Payment and Auditing module is triggered and a payment request from consumer to producer is logged in the same MAM. The IOTA module monitors that the requested IOTA payment is processed, before triggering a dispute resolution process.

With the current implementation the workflow as described in figure 5.4 can be demonstrated, using the information shared on the Tangle infrastructure.

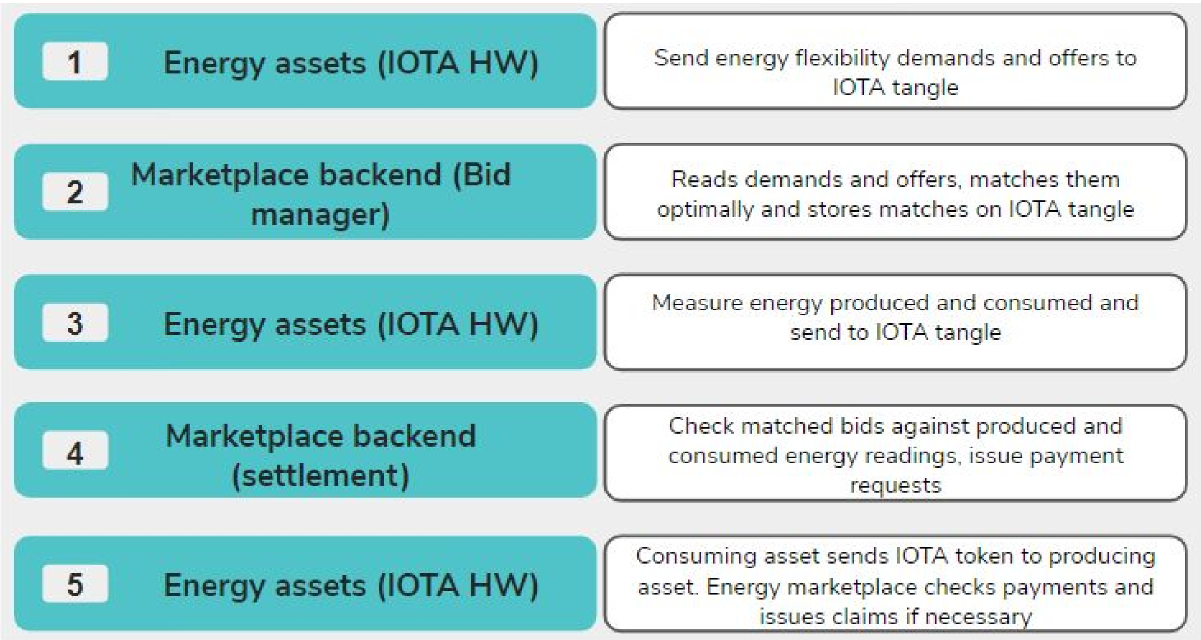


Figure 5.4 Workflow description - the IOTA verification process.

5.2 ABB energy management for sites

OPTIMAX® [9] is a part of the ABB Ability™ energy management platform. The project will utilize the extensive interfaces and flexible setup of OPTIMAX® by deploying various setups adapted to the differing sites and 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 one has therefore developed pragmatic solutions that will work for all types of assets, from PV panels to snow melting facilities. As seen in figure 4.1, OPTIMAX® will interact with a variety of assets, meters, IOT Devices and Energy assets. It is in charge of forwarding data and broker communication between the assets in the physical infrastructure layer and the trade platform in the Application and Data processing layer.

Some assets are connected and controlled through a building automation system that is running in a local network. To interface those assets, they must be accessed through the building automation system. This will be achieved by installing a physical or virtual machine that runs OPTIMAX® in the same network as the building automation system. The enabled machine is then granted access to the assets(s) by communication via the building automation system. Other sites, that do not have local networks or the same level of local control, will be interfaced directly, using a protocol converter with 4G modem that communicates with a cloud version of OPTIMAX®.

Fundamental for the assets participation in the local market is communication and dispatching provided by OPTIMAX®, as shown in figure 4.5 and described in chapter 4.7. It will administer the forwarding of metered and predicted volume as well as the accepted trades' volume, price, and time and their actual dispatch.

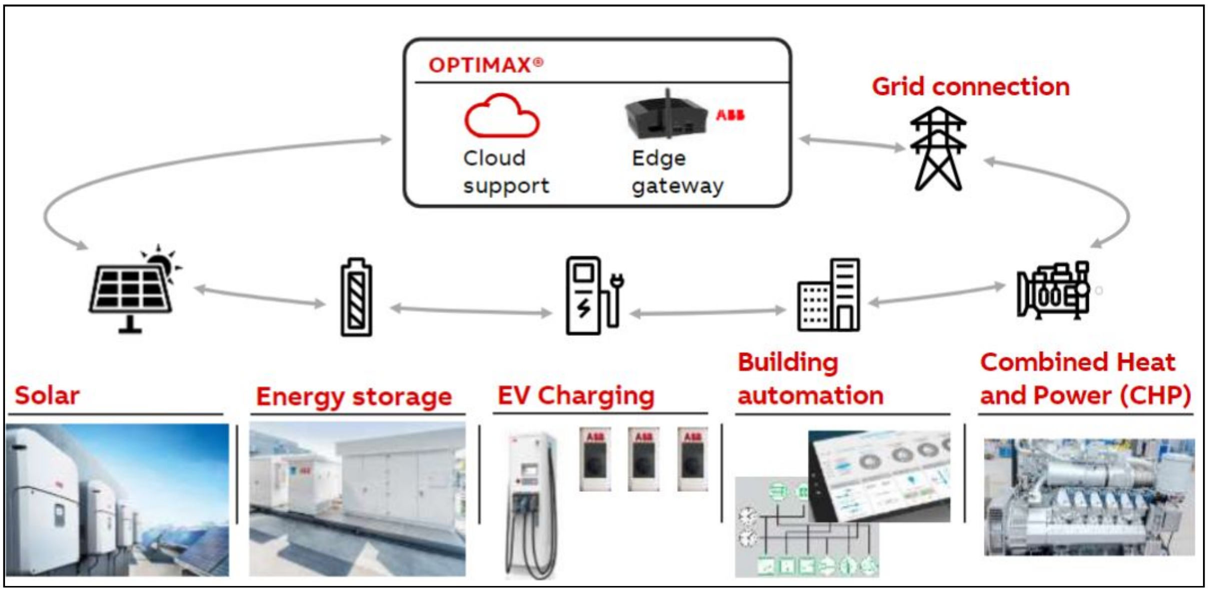


Figure 5.5 Asset aggregation in OPTIMAX® [9]

OPTIMAX®is the family name of three different products: Smart Charging, Virtual Power Plant and Energy Management for Sites(SiteEMS). The project will implement the services covered by the OPTIMAX® SiteEMS product. It optimizes power consumption, while reducing energy costs, and minimizing environmental impact. Especially useful in this project is that in order to perform the local optimization, different kinds of technical assets are aggregated, as visualized in figure 5.5. Also, more renewables can be integrated to minimize the use of costly CO2-emitting fossil fuels without risking reliability or grid stability. The CO2 emission minimization and renewables optimization can be monitored in a local or web dashboard as shown in figure 5.6.

OPTIMAX® SiteEMS offers energy costs minimization, peak shaving, self-consumption or grid-independency maximization, CO2 emission minimization and forecasting. Its core functionalities are 3-horizontal energy management (real-time, intra-day, day-ahead) with trading interface, sector coupling of electricity, gas, heat or cooling, water & e-mobility, industrial production scheduling, reporting and asset monitoring.

Figure 5.6 Application dashboards in OPTIMAX® *SiteEMS* [9]

OPTIMAX® operates using a microservice architecture that offers system engineering, data logging, user interface via Web server for application dashboards, and APIs to integrate into other interfaces. Real-time Interfaces, like Modbus, OPC UA, ReST, OCPP are supported and it runs on premise and in the cloud, supported by Microsoft in Azure. Interfaces to other cloud solutions or SCADA systems are also supported. This contributes greatly to the pragmatic approach chosen by the project, where we are able to interface and trade with almost any possible asset.

5.3 Powel trade portfolio - global and local markets

Powel has a software suite for a wide range of power production planning, optimisation, prediction and trade. The Powel local market trade solution is developed based on experiences and technology from this trade portfolio software suite. In figure 5.7 it is described the overall scope of the software. It manages a range of power resources as presented at the left side of the figure. It includes both large and small scale/local energy assets.

The solution gives the assets support to optimize their market strategies (optimises production plans) and gives the optimised plans access to the actual markets as described on the right side in the figure. The solution includes algorithm trade for each asset. Powel solution acts as a platform with trade services where demand and supply meet through bids and asks and price is set for the actual contract at the actual time. Settlement is executed and all actual information for the trade process is managed in a secure way.

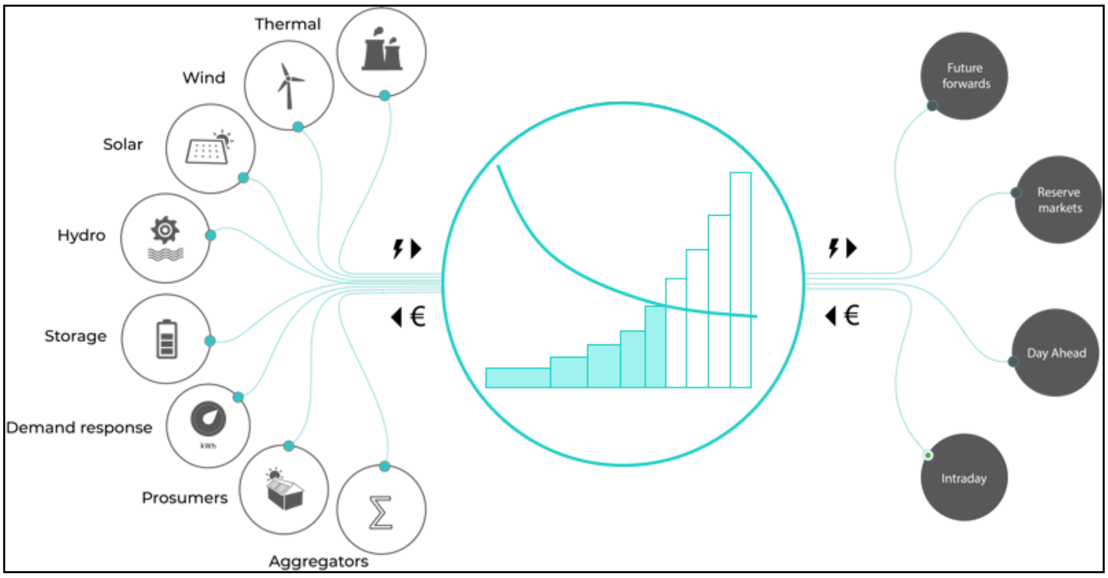


Figure 5.7 Powel (Volue is the new company name from 1.1.2021) software suite for management of power trade.

The solution is in its nature general regarding the type and size of resources that access the market. When the resources make a portfolio for an actor, the Powel solution optimizes the plan to maximize the total portfolio income from the trade. And the optimal plan for the portfolio is presented in the marketplace as a joint bid.

With the extended features developed for the local power market the portfolio is given the dimension of being a future proof IT-toolkit for advanced trade with global and local green resources.

6 Conclusion

6.1 Project background

The products Powel Digital Marketplace and Powel Algotrader for Local Markets have been developed in the +CityxChange-project and are based on existing solutions for the wholesale intraday energy market:

- Powel AlgoTrader.
- Powel Intraday Trading

In addition, the settlement process which is handled by TrønderEnergi, is covered by existing installation of the Powel Settlement solution. The development done in the +CityxChange-project related to the settlement process has been to integrate the existing Powel Settlement with the Powel Digital Marketplace and IOTA Verification Service

The IOTA Verification Service and IOTA Energy Marketplace are based on integration of IOTA technology and solutions, including:

- IOTA Tangle ledger
- IOTA Streams
- IOTA Identities

6.2 Next steps and further work

The international power market is in an innovative phase in Europe. The drivers for this innovation is digitalisation, increased rollout of distributed energy resources - and last, but not least customers/consumers growing focus on climate change and energy transition. The result is a need for renewing energy systems - including the local grid - operation, trade procedures and new business models and services.

This delivery report in +CityxChange is addressing a local market design and operational tool that meet this development with a demonstration that supports this development. It is however in this innovation process identified hinders for setting up local markets for the support of DPEB processes. Among these are precise definitions of market roles and responsibilities in a redesigned energy market. Regulations are experienced to lack coordination and sufficient flexibility to enable adaptation and incentives of new technology, market layout and energy system operation.

The demonstration of the local energy market operation - inclusive flexibility, local generation and storage assets must be evaluated and opened up for design and technical edits with the purpose of improving the incentives of a local market to support the DPEB processes. More precisely it should be focused on how to make the settlement process even more digital and use of more blockchain technology.

Project scope is to make solutions that are scalable and replicable. Further work will address how demonstrated solutions easily may be transferred and demonstrated in the follower cities(FC). The demonstration will be executed in Trondheim, but in parallel it will be demonstrated as a market solution from project partner Mpower in Limerick. Synergies between the two LHC demonstrations will be discussed and lessons learned will be shared.

Next steps and further work will also be addressed in future Deliverables of +CityxChange within WP5, especially D5.5: Energy Trading Market Demonstration; D5.6: Trondheim Flexibility Market Deployment Report; and D5.11: Trondheim DPEB Demonstration.

6.3 Comparison of trade platforms to be demonstrated

The two platforms have some overlap regarding general architecture and features. In table 6.1 it is described more in detail how the platforms are complementary.

Table 6.1 Local market trade platform prototypes characteristics and similarities.

Characteristics	Community Grid Platform (MPOWER)	Local Market Platform (Powel)
Community Grid Framework	x	
IOTA verification procedures	x	x
ABB Optimiser for dispatch/operation		x
Manages all local resources/assets	x	x
Double Auction principle	x	
Bids and Asks for price calculation		x
In line with current EC and REC regulations (compare D2.1 on regulatory aspects)	x	
Algorithm trade		x
Linked to global market (day-ahead)		x
Cloud based	x	x
Scalable due to number of assets	x	x
No lowest limit for participation	x	x
Manage energy, capacity and system service products	x	x

Both trade platforms are at a prototype level and will be demonstrated and evaluated during the project period. It is supposed that features and functions will be further developed and tailored to fulfill project scope. The community grid focused trade platform is demonstrated in the Limerick project area. Further description of the community grid approach and developed trade platform is described and discussed in the D2.6 delivery report "D2.6: Framework for Community Grid Implementation"[12].

7 Appendix

7.1 Powel Algo Trader – fact sheet

Algorithmic power trading on EPEX SPOT and NordPool with open APIs
Powel offers a complete algorithmic trading platform that enables rapid design, testing with historical market data, deployment and refinement of automated strategies, which leverage your unique trading techniques and complex algorithms.
We provide our customers the best operational environment for the traders and support them to create the best intraday trading strategies . As our intraday trading tools connect directly to the markets, you can implement your strategy in Live Mode immediately and monitor your portfolio in real-time, giving you the control and decision Support you need for the best results with super user-friendly user interface to keep control and to interact fast . Powel Algo Trader (PAT) also offers pre-defined strategies that traders can modify or use just as it is covering position closing, marketing flexibilities and utilising batteries.

The future of automatic trading is in a white box
Powel Algo Trader (PAT) speeds up trading dramatically, allowing you to automate complex trading strategies in the intraday market, including EPEX SPOT and NordPool using open APIs. Unlike other algorithmic trading platforms, we have taken a white box approach to create a robust, open-source architecture, allowing customisation for customer-specific strategies. Our solutions offer both standard algorithms for trading strategies and the flexibility to build and test new market strategies in Python with the help of our dedicated microframework for easy coding. High competence for asset backed traders with flexible assets like hydro, thermal or batteries, based on our market leading asset optimisation software and our optimisation competences. Furthermore, Powel Algo Trader (PAT) allows you to test quantitative trading strategies against the historical market data. The solution also takes into account market restrictions like Order-To-Trade ratio (OTR).

Powel Algo Trader (PAT) – the concept
The complete process of strategy development can be complex for traders, from creating the strategies and testing them to take them live. Powel Algo Trader (PAT) helps the traders by providing the complete platform. Testing a strategy has never been easier as Powel Algo Trader (PAT) offers testing on historical market data, test markets and even the Live Market by placing the orders as initially deactivated if needed. The solution offers the support a trader needs throughout the entire process.

Strategy Editor
In the Strategy editor, traders can develop new strategies and edit existing ones at any time keeping track of all the code changes. Strategy editor allows the trader who codes the strategy to put in descriptions and generate parameters with descriptions that can be seen and changed through our dynamic user interface while launching the strategy, this allows

the traders with no coding experience to use the solution as efficiently as the trader who develops the strategy. Strategy editor also includes a number of pre-defined strategies that the traders can test, set live and use as a starting point or modify for their own logic. Strategy editor offers an easy to code interface to the traders and supports the coding process with our dedicated microframework to lessen the code that the trader has to write by offering whatever a trader needs as ready functions.

Data flow into the solution
Powel Algo Trader (PAT) offers a dynamic data flow configuration where every type of data needed for the strategies can be easily configured within seconds and then called from within the strategy code to be implemented into any type of logic that the trader wants to create.

Testing and benchmarking your strategies
In order to test the strength and performance of the strategies, strategies can be run against historical market data, live test market data and live production market data. Powel Algo Trader (PAT) allows the traders to test their strategies and view the results in benchmarking charts with price development and equity curve. This provides a rapid and an easy way to build trust into strategies. The next step is running the strategies Live in either test or production markets and see the results.

Powel Algo Trader (PAT) in relation to Powel Intraday Trading (PIDT)
Powel Intraday Trading (PIDT) and Powel Algo Trader (PAT) are separate solutions that can be used independently of each other. Nonetheless there is great synergy in using these solutions together complementing each other. It is possible to place manual orders as your strategies are placing orders for you too by using two solutions together, it is also easier to keep up with the speed of the Powel Algo Trader (PAT) with PIDT's real time visual interface.

Integrations
Powel Algo Trader (PAT) can be integrated to a portfolio planning or scheduling system, such as DeltaXE and Smart Generation Portfolio (SmG) through either the TSS (Powel Time Series Service) or a generic webservice. Powel Algo Trader (PAT) is connected to the market through the API that the power exchanges offer.

Power Exchanges
NordPool : DK, NO, SE, FI, EE, LT, LV, DE
EPEX : DE, AT, CH, FR

System Requirements
Powel Algo Trader (PAT) is first and foremost a full SaaS(Software as a Service) solution hosted as a cloud service. Access the SaaS solution through a browser – the latest version of Google Chrome, Mozilla Firefox or Opera are recommended.

7.2 Powel Intraday trading (PIDT) – fact sheet

Powel Intraday Trading (PIDT) is a web-based intraday trading tool connected to the intraday market, allowing real time trading. It can be connected directly to your portfolio giving access to all the data including flexibilities of your assets and forecasting data, creating an environment for fast decisions and fast actions. Powel Intraday Trading focuses on increasing speed and decision Support, as well as easy positioning and market overview. Use the chance to automate the whole process from forecasting to production planning and optimization, to trading and scheduling with Powel.

European market under transition
With the increasing amount of intermittent production, it is becoming more challenging for market participants to be in balance after the closing of the day-ahead market. As a result, the interest in the intraday market is increasing. Having the right tools to provide real-time market overview and portfolio data together in a single screen and ability to place the orders in a fraction of a second is providing new opportunities and real value for those active in intraday trading. Using the efficiency benefits automated processes yield, one could achieve a competitive advantage.

About Powel Intraday Trading
Powel Intraday Trading (PIDT) is a standalone, web-based intraday trading solution, designed to connect to the energy exchanges and your portfolio in real-time. It can be connected directly to Powel's portfolio optimisation solutions through time series services or to third party solutions through web services. Our solution has the most user friendly look and feel. Integration with Powel's other solutions will automate the whole process from forecasting, production planning, optimization and to trading to scheduling.

Features

- Real-time connection between your portfolios and continuous EPEX and NordPool intraday markets.
- Detailed views of open positions, free capacities, flexibilities of your assets, marginal costs and market overview will provide the best decision support.
- Detailed views of your asset flexibilities and marginal costs
- Simplified complexity – visual overview of market depth when placing orders
- Link every trade to a production unit or a consumption portfolio to automate production planning
- Easy to connect to external systems using our Web API and interfaces

Energy generator
Increase your profit margins by acting fast on load changes and availabilities, market your free capacity with a single click.

- All relevant data in one tool to Support decision making
- Handling of marginal costs
- Overview of several intraday markets
- Labelling to mark trades to the relevant production unit or portfolio

Power trader
Being always aware of market movements so that informed decisions on orders can be made instantly. Our human-centric simple interface design is easy to use and appeals to different traders 24/7.

- Direct link between portfolio and market to boost speed
- Real-time intraday trading – fast API connection
- All relevant data in one tool
- Several intraday markets
- Extensive decision Support

Direct marketer of renewable energy
Despite growing forecasting accuracy on renewables, balancing will always be needed. Direct connection of your forecasts to the Powel Intraday Trading will have the trader making fast and profitable decisions.

- Trades are linked to assets by labelling to automate the planning process
- Minimising imbalance energy cost
- All relevant data in one tool creating excellent decision support

Balancing group representative or distribution system operator
Different markets brought together. Compare intraday trading and tertiary reserve markets with an informed decision.
Use all available capacity.

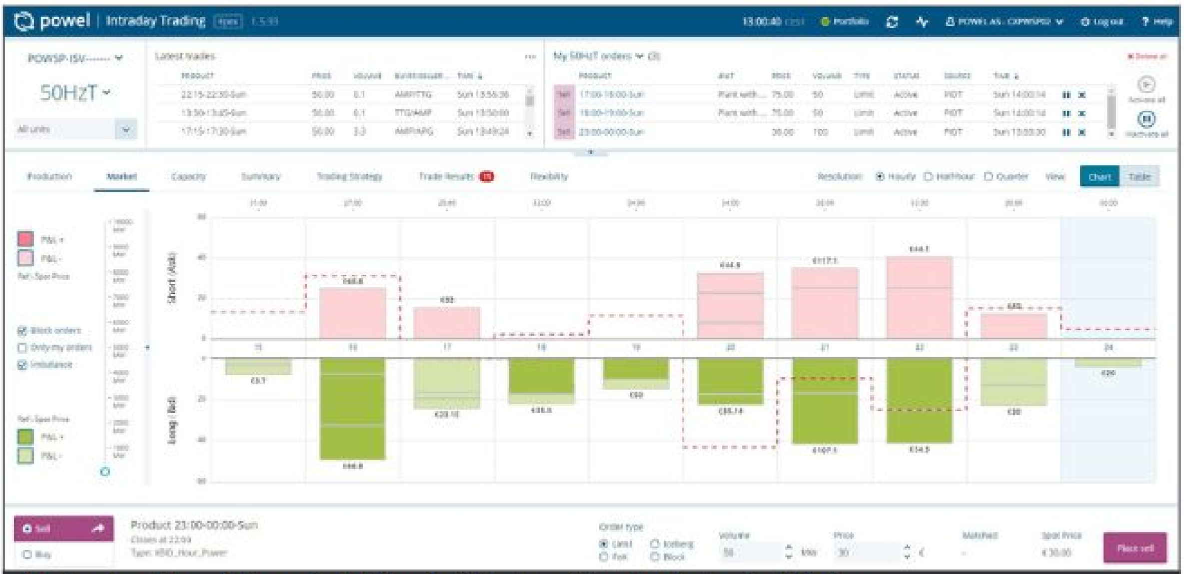
- Minimising imbalance energy cost
- Direct link between portfolio and market to boost speed
- Real-time intraday trading
- All relevant data in one tool creating excellent decision support

Market overview
Market overview is the main view in which a trader can observe the market data, own imbalance, latest trades and own orders for every price area available. The screen is made simple and useful for the traders that will have to deal with the market 24/7. A trader can observe the open positions and place relevant bids, focus on a single generation unit or the whole portfolio. Our fast order placement bar on the bottom of the solution covers all types of orders supported in the market and it is easy to use with several warnings upon placing the bids covering PnL evaluation and security thresholds as well as the market rules.

Select a product or products and place bids instantly by using the "Place Orders" button. The order management on bottom covers the direction of the order, type of the order and Volume and Price parameters of the order. We see the imbalance with the dotted lines, our own orders, market orders and can immediately decide which action to take. Upon the selection of orders in the market, solution creates a matching order and executes the trade. Self-trade attempts and prices that are far-off from the market will be notified to the trader before placing the orders. We see our own orders
also on the top right in "My Orders" list for each price area, covering the "Labelling" of the orders so we know which portfolio or production unit that the order is linked to for

automating the processes. All orders can be removed instantly by using “Delete All” functionality.

The view shows the available products that are in different resolutions in a chart or in a table view. Helping the trader understand the price differences of the orders from the market with color views so that the trader can make fast decisions.



The view shows the available products that are in different resolutions in a chart or in a table view.

7.3 Predicting models for intraday trading strategies

For the ideal functioning of the local market, we built models for predicting the consumption and production. In practice, these can be provided by various partners, but they all are read/written through Data API, same as any other time series. This also includes weather and market predictions, which are also further used in planning and trading processes.

Deliverable: simulation models for 15-minute solar/wind/renewables infeed production relevant to pricing intraday electricity and to form accurate trading strategies.

The summary below offers an overview of the three articles that acknowledge the +CityxChange project:

- Kremer, Marcel; Kiesel, Rüdiger; Paraschiv, Florentina. (2020) An Econometric Model for Intraday Electricity Trading. [Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences.](https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2671379) https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2671379
- Kremer, Marcel; Kiesel, Rüdiger; Paraschiv, Florentina. (2020) [Intraday Electricity Pricing of Night Contracts. Energies.](http://dx.doi.org/10.3390/en13174501) vol. 13 (17). http://dx.doi.org/10.3390/en13174501

- Li, Wei and Paraschiv, Florentina, Modelling the Evolution of Wind and Solar Power Infeed Forecasts (May 14, 2020). Available at SSRN: https://ssrn.com/abstract=3600775 or http://dx.doi.org/10.2139/ssrn.3600775

"With a large amount of wind and photovoltaic power integrated into the European power systems in recent years, the intraday market traders recognize the importance of renewables forecasts. Furthermore, the integration of European electricity intraday markets triggers advanced research for improved trading strategies. We analyse the eight days' evolution of 15-minute updated forecasting errors of wind and photovoltaic (PV) for a specific quarter-hourly product traded in the intraday market. Typically, market participants in the intraday electricity trading aim at balancing out their positions after the closing of the day-ahead market. Given the volatile input from renewable energies, there is an increasing need for intraday trading. Since the updated weather (wind and solar) forecasted values can deviate significantly from the values published by the Transmission System Operators (TSOs)day-ahead, participants in the intraday market closely follow the evolution of updated forecasting errors. Updates are available every 15-minute from the moment when the intraday market opens until shortly before the end. Based on the updated information of renewable forecasts obtained from weather data providers on a 15-minute basis, market participants adjust production schedules and price bids for specific quarter-hourly products (see the studies of Kiesel and Paraschiv (2017); Kremer et al. (2020a, b)).

The data set of intraday evolution of forecasting errors of solar and wind is not directly available to researchers ex-ante, but only ex-post, which is a drawback, given the market mechanism. Indeed, each trading day, market participants bid in the day-ahead and intraday markets at EPEX. Price bids in both markets are based on expected values of supply/demand side explanatory variables, which are directly observable day-ahead from the TSOs. In the day-ahead market, electricity is traded for each hour of the next day, separately. However, due to the large forecasting errors in demand/supply variables and due to the increase of intermittent solar and wind infeed, there is a need to correct initial positions at a higher resolution. Thus, trading in the intraday market balances out excess demand/supply of electricity. An emerging challenge is how to secure adjustment capacity to respond to prediction errors and output fluctuations for renewable energy power generation.

Updated information of wind and photovoltaic infeed forecasts are essential supply-side variables for the adjustment positions in the intraday trading. As shown in the study of Kremer et al. (2020a), renewable forecast updates are reflected in the prices of 15-minute contracts within one trading minute. Furthermore, Kiesel and Paraschiv (2017) show that intraday prices adjust asymmetrically to forecasting errors in renewables. In particular, there is a 15-minute periodicity in the liquidity pattern in intraday trading which originates from newly arriving updated renewables forecasts. Renewable forecasts are updated in 15-minute intervals and traders continuously adjust their bids to updated information from the weather data suppliers. It becomes increasingly significant to develop reliable methods to simulate and predict the evolution of wind and PV updates that are practically useful for electric power industries or for designing optimal trading strategies.

To the best of our knowledge, we are the first to explore accurate forecasting and simulation models for the evolution of wind and PV updated forecasting errors, which are a useful tool to participants in the intraday market for building optimal trading strategies. Clearly, our results break ground for several applications to intraday trading. Best simulators can support investors to test virtually any trading strategy at low risk. Besides, the accurate prediction of renewables forecasting errors can help power producers to better organize and adjust their production schedule, further decreasing the risk of blackout and voltage collapse.

In Li and Paraschiv 2021, we tested the in- and out-of-sample fit of six several models applied to 365 paths of updated renewable forecasts, wind and PV, for a given quarter-hourly product, available in 15-minute updates over eight days. In particular, we assess comparatively the performance of stochastic models chosen in line with the statistical patterns in the data versus a GMM model. Robustness checks suggest that GMM is a reliable tool to simulate the updates in the weather data, showing a superior simulation performance versus the classical stochastic models OU, CKLS and CIR. For the out-of-sample analysis, we find that the proposed models have different prediction performances, depending whether the weather forecast updates follow a low- or a high-frequency pattern. The latter is recognizable the closer we come to the delivery period. In particular, the GMM performs better than the stochastic models during the low-frequency-update period. However, in the high-frequency-update period, when time approaches the forecast period, stochastic models show superior performance, as updated renewables forecasts show an accentuated autoregressive nature. We furthermore show the distribution of model parameters over the 365 analysed paths of renewables forecasts, which can be explored in stress-testing exercises or in hedging upside/downside risk. In further research, one can explore this prior information of parameters in a Bayesian approach. Furthermore, accurate models for wind and PV updated forecasting errors can be used to enhance existing econometric models for intraday electricity prices. Simulations performed in this study are useful input to stochastic programming applications for optimal electricity production planning.

Based on simulated weather data of solar and wind infeed in 15-minute frequency, we build an econometric model to forecast and simulate electricity intraday prices. We analyse a novel and unique data set of high-frequency transaction data, fundamental supply and demand data, and intradaily updated forecasts of wind and solar power generation. The nature of our data set allows the model specification to solely include ex-ante market information by exploring the typical seasonality patterns. We observe that liquidity increases sharply within the last trading hour before gate closure. Our empirical analysis also indicates that renewable forecast updates are reflected in intraday prices within one trading minute.

We refine the econometric model by Kiesel and Paraschiv (2017) along three dimensions by incorporating: (i) the slope of the merit order curve, (ii) price changes of neighbouring 15-minute contracts, (iii) the 15-minute intraday auction price. We calibrate our econometric model to market data for a selection of morning, noon, and evening contracts.

A threshold regression model is used to examine how 15-minute intraday trading depends on the slope of the merit order curve.
Our estimation results reveal that autoregressive price changes up to the third order are highly statistically significant and negative, independent of the time of day. This behaviour provides clear evidence of mean reversion in the price formation mechanism of 15-minute contracts. Additionally, price changes of neighbouring contracts exhibit strong explanatory power and a positive impact on price changes of a given 15-minute contract. We observe an asymmetric effect of positive and negative renewable forecast changes on intraday prices depending on the merit-order-curve slope: Renewable forecasts affect electricity prices more severely in the steep than in the flat merit-order regime. In general, renewable forecast changes have a higher explanatory power for pricing noon than morning and evening contracts, but price information is the key driver of 15-minute intraday trading. Overall, we conclude that the importance of influencing factors on the intraday electricity market has changed from fundamental towards trade-related factors.

As our econometric model exclusively involves ex-ante market knowledge, it allows us to develop trading strategies for intraday electricity markets, tailor-made for each contract. Furthermore, it helps to design forecasting models for single intraday transaction prices in the continuous trading – to our knowledge, an unexplored territory of scientific research hitherto. Moreover, our model provides a valuable step towards the optimization of the bidding behaviour on intraday markets. Eventually, our insights should prove useful to energy companies within the process of automating intraday electricity trading."

Source: Li and Paraschiv, (2021)

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