iVPP P2P transactive energy framework

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Executive Summary

This document presents IANOS' Deliverable D4.9 – iVPP P2P transactive energy framework, developed under task T4.5 – Distributed energy transactive framework within VPP Energy Coalitions of Work Package 4 – Multi-Layer VPP Operational Framework.

The purpose of this deliverable is to describe the implementation and operation of a marketplace that manages the exchange of energy within a community of prosumers leveraging on blockchain technology and smart contracts. In the first part of the deliverable are summarized the main technologies that are used by the platform that implements the market: DLT (distributed ledger technology), blockchain technology and in particular the Ethereum blockchain and smart contracts offering the possibility to develop part of the business rules logic on the blockchain in trusted way. Finally, in the second part of the deliverable, the structure and implementation of the platform is described in detail.

A further updated version of this report in D4.10 is planned to be issued at M32.

Table of Contents

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement Nº 957810

List of Figures

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement Nº 957810

Notations, abbreviations, and acronyms

Table 1 Acronym's list

AES	Advanced Encryption Standard
AMI	Advanced Metering Infrastructure
API	Application Programming interface
BMS	Building Management System
dEF-Pi	distributed Energy Flexibility Platform and interface
EMS	Energy Management System
ESB	Enterprise Service Bus
ESDL	Energy System Description Language
ESSIM	Energy System SIMulator
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
FI	Fellow Island
HEMS	Home Energy Management System
IaaS	Infra-structure as a Service
IoT	Internet of Things
iVPP	intelligent Virtual Power Plant
LCA	Life Cycle Assessment
LCC	Life Cycle Cost
LH	LightHouse island
RES	Renewable Energy Source
SIEM	Security Information Event Management
SOC	Security Operations Center
SoC	State of Charge
MW	Market Window
VDC	Virtual Data Centre
DLT	Distributed Ledger Technology

DAG	Directed Acyclic Graph
dapps	Decentralized applications
EVM	Ethereum Virtual Machine
ETH	Ether
PoW	Proof of Work
FT	Fungible Token
NFT	Non Fungible Token
P2P	Peer-to-peer

1 Introduction

1.1 Objectives and Scope

This deliverable provides an overview of the work done to create a market for P2P energy exchange within a community of prosumers. The report summarises how, thanks to the use of blockchain technology and the implementation of a smart contract, the market functions are implemented in a fully automated way. The marketplace workflow covers the entire energy exchanging process and related value transaction leveraging on token, it is implemented in transparent and tamper-proof way.

The work has been done in relation with IANOS project Task 4.5 "Distributed energy transactive framework within VPP Energy Coalitions" part of Work Package 4 "Multi-Layer VPP Operational Framework".

1.2 Relation to other activities

This deliverable takes in consideration the use cases and requirements collected in WP2, in particular Use case 1, Scenario 2. A specific description of the use case for the P2P energy marketplace usage is reported as section in this deliverable together with the reference architecture. For the latter the work done in in T2.5, which provides a description of the system's architecture, was considered as main reference.

Specific relation with other Tasks in WP4 are the T4.1, where the Enterprise Service Bus (ESB) is described, this represents the interoperability module the marketplace leverage on for the provision of meters data. Furthermore, the data coming from the Forecasting Engine related to T4.3, are accessed by the marketplace via ESB.

1.3 Structure of the deliverable

Deliverable D4.9 is structured as follows: Chapter 1 – Introduction aims at presenting the objective of the document and its structure. Chapter 2 – The technological innovation of Blockchain and its impact in the energy sector describes how DLT and blockchain technology work, smart contracts and their use and how a P2P energy trading operates. This chapter also explains the clearing price algorithm. Chapter 3 – Application of Blockchain technology in IANOS project describes how the blockchain technology is applied to the IANOS project, use cases and the system architecture. Chapter 4 – Implementation of a local P2P energy trading platform based on Blockchain describes in detail how the P2P energy marketplace platform is implemented, workflow and interfaces introduction. Chapter 5 – Conclusions and next steps, provides the conclusions and the next steps towards updated versions of the infrastructure and related document.

2 The technological innovation of Blockchain and its impact in the energy sector

2.1 DLT

A distributed ledger (also called a shared ledger or distributed ledger technology or DLT) is a structure conceptually similar to a database that is jointly agreed shared and synchronized across multiple sites, institutions, or geographies, accessible by multiple people. Unlike traditional databases, distributed ledgers do not have a central data store or a central administrator [1]. The participant at each node of the network can access the recordings shared across that network and can own an identical copy of it. Any changes or additions made to the ledger are reflected and copied to all participants in a little time. Each record in the ledger is labelled with a timestamp and a unique cryptographic signature, thus making the ledger an immutable and verifiable registry of all transactions on the network. The transactions, once written on the ledger in fact cannot be modified nor deleted.

The main advantage of DLT is the lack of a central authority, however, this leads to the need for a consensus algorithm. Essentially, every DLT requires a mechanism to find a consensus or commonly accepted truth among all participants/nodes in its network. This "truth" may relate to token transfers, information added to a document, or identities generated and stored. Several DLT consensus mechanisms have been designed, with significant differences, but a common goal: to allow the entire network to decide unanimously and inadvertently which records to include next, and in what order, in the DLT. The simplest and most common type of DLT is the Blockchain in which blocks of data are linked together via data identifiers that begin with a hash. But there are other types of DLT, for example. Directed Acyclic Graph (DAG), which uses a different data structure for its highly efficient consensus mechanism. One of the biggest advantages of DAG is the ability to offer Nano-transactions without fees.

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2.2 Blockchain

The blockchain is a specific kind of distributed ledger. It is defined as a digital ledger whose entries are grouped into "blocks," concatenated in chronological order, and whose integrity is ensured by the use of cryptography [2]. Each block contains a cryptographic hash of the previous block, a timestamp, and the transaction data. The timestamp proves that the transaction data existed when the block was published to enter its hash. Because the blocks each contain information about the previous block, they form a chain, with each additional block reinforcing the previous ones. Therefore, blockchains are resistant to modification of their data because once recorded, the data in a given block cannot be altered retroactively without altering all subsequent blocks.

Its main feature is being able to run a transaction system without the need of a central authority in fact each node in the network adheres to a protocol to communicate and validate new blocks. Each member of the network also has access to the historical log of the transactions of the system and verify the validity, this guarantees a total transparency.

The two most popular blockchains in the world are Bitcoin and Ethereum. Bitcoin is a cryptocurrency created in 2009 by an anonymous inventor, known by the pseudonym Satoshi Nakamoto [3]. Bitcoin does not have a central bank behind it that distributes new currency but is fundamentally based on two principles: a network of nodes, i.e. anonymous and unknown PCs, that manage the currency in a distributed mode and the use of strong cryptography to validate and secure transactions. There are two ways to get bitcoins: buying them by connecting to numerous sites, known as exchanges, that offer the virtual currency in exchange for real money or they are given as a reward to nodes that perform a process known as mining. The term mining in the case of bitcoins represents the process of sharing the computing power of the hardware of network participants. Every 10 minutes or so, the system produces a new block with new transactions awaiting approval, which will be added to the chain once validated. Mining is thus in a nutshell the process of adding new blocks to the blockchain. In exchange for computing power, the system rewards miners with fees. Mining is an extremely expensive and complex activity, both in terms of CPU and power consumption.

Ethereum is a decentralized, open-source platform for the peer-to-peer creation and publication of smart contracts created in a Turing-complete programming language. This programming language allows developers to build and publish distributed applications. The cryptocurrency linked to it, Ether, is second in capitalization behind Bitcoin.

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There are different types of blockchain: private, public, and hybrid. In a public blockchain anyone can become a node, and therefore anyone has read and write permissions, which means that anyone can mine. This type of blockchain is completely decentralized and its level of security and transparency is very high. A private blockchain works in a similar way to public ones. The difference lies in the fact that not everyone can write, and in some cases not even access the data. These permissions are decided by the organization or company running the network. The main advantages of a private network are scalability and speed. Finally, a hybrid blockchain is a combination of private and public blockchain. In fact it uses the features of both types of blockchain.

2.3 Ethereum

Ethereum is a blockchain that allows to build a range of decentralized applications. The idea behind Ethereum was conceived by Vitalik Buterin. He with the help of several co-founders launched the first version of the platform in 2015. Since then, Ethereum has become the second most important cryptocurrency, behind bitcoin. Ethereum works as an open software platform based on blockchain technology. This blockchain relies on many computers around the world; therefore, it is decentralized. Each computer owns a copy of the blockchain, and there must be a broad consensus in the network before any changes are applied. The Ethereum blockchain in addition to storing transaction history, however, allows programmers to build and deploy decentralized applications (dapps). These are also stored in the blockchain along with the transaction record. dapps are open-source software that uses blockchain technology. Unlike traditional apps, these do not need any mediator to work. Groups of smart contracts are used to create dapps. The smart contracts are created using the Ethereum Virtual Machine (EVM) . Once a smart contract runs on the blockchain, it behaves like an automated computer program. It works as programmed, without censorship, inactivity, or third-party influence. Ethereum was the first blockchain to support smart contracts and is still the most notable example of a Turing-complete programmable blockchain [4].

Ethereum, like other blockchains, has its own cryptocurrency called Ether (ETH). Ether are used both as rewards for nodes that practice mining but also to regulate the use of the blockchain's computational resources. One of the most important concepts in the world of Ethereum is Gas. Gas is a unit used to measure the work done by Ethereum to perform transactions or any interaction within the network, in fact gasLimit (the maximum amount of gas that can be spent) and gasPrice (the price-per-gas) are standard transaction parameters. It is very important to understand the difference between Ether and gas: the first is a currency while the second measures the amount of computational effort it will take to perform certain operations. This allows you to have distinction between ETH cryptocurrency value and computational cost.

2.4 Smart contracts

Smart contracts are software based on blockchain technology that help people exchange money, transfer property and anything else of value transparently and without using the services of an intermediary. The first person to theorize the concept of smart contracts was Nick Szabo [5], a legal scholar and cryptographer, in 1994. Ethereum is the reference blockchain for the creation of smart contracts, in fact in Ethereum smart contracts are a key component.

How do smart contracts work in practice? The first step is the stipulation of a contract between two parties, who subsequently transcribe the clauses into a smart contract. Next, the smart contract is entered into the blockchain: the nodes of the chain verify the accuracy of the reported information, then the digital agreement becomes part of a block that is validated through the Proof of Work (PoW) mechanism by the users of the blockchain. Those involved in the block validation in turn receive the Ether cryptocurrency as a reward as seen in Section 2.2. Finally, the block containing the smart contract is added to the blockchain which makes the execution of the smart contract automatic, making it impossible for one of the two parties to disregard the predetermined rules.

Autonomy from a third party entity, money and time savings, data security and greater accuracy than traditional contracts are the main opportunities offered by smart contracts. Theoretically, a smart contract excludes the intervention of an intermediary; there is no need for a notary to confirm the added clauses nor a third party executor. In fact, all transactions are handled by the blockchain automatically. The second opportunity is a consequence of the first. The use of an intermediary, like a notary, places a burden on one or both of the two parties entering into the contract. The blockchain is one of the biggest contributors to data security, which is why smart contracts and the information they contain are much more secure than traditional contracts. Traditional contracts, which are filled out by hand, can be prone to errors or flaws that ruin the content of the contract itself. This situation, on the other hand, does not occur in an IT environment, which is why smart contracts possess significantly greater accuracy.

Smart contracts are also used for tokenization. A token is the digital representation of an asset on the blockchain. This asset can be both digital and physical, as well as tangible or intangible. ERC-20 standard is used for Fungible tokens (FTs), i.e. those that can be replaced with something identical (not necessary to return the same token, but tokens of equal value), while the ERC-721 standard is used for Non-Fungible Tokens (NFTs), which are those that, although they appear identical, each has attributes such as an identification code that makes them unique. The tokens are not native to the blockchain, as is the cryptocurrency associated with it, but must be created and managed via a smart contract.

2.5 P2P energy trading

Peer-to-peer (P2P) energy trading is the buying and selling of energy between two or more grid-connected parties. In fact, traditional energy consumers are becoming prosumers, who can both consume and generate energy. Any excess energy can be stored via energy storage devices or transferred and sold to other prosumers through a secure platform [6]. P2P energy trading allows consumers to decide who to buy electricity from and who to sell it to. Energy trading is done through a secure platform, often using technology such as blockchain. Currently, energy trading is primarily one-way: electricity is primarily produced by large power plants and then distributed to large and small consumers through the transmission grid. All contributions are factored into the supplier's bill, which redistributes the corresponding amount to the different actors. Instead, P2P energy trading encourages the exchange of energy between prosumers belonging to a district or a local geographic area. This simplifies the structure of the system and eliminates intermediaries, thereby decreasing costs.

2.6 Clearing price

Clearing price is the equilibrium monetary value of a traded security, asset, or good [7]. This price is determined by the bid-ask process of buyers and sellers, or more broadly, by the interaction of supply and demand forces. In any exchange, sellers want the highest possible price for a security or asset, while buyers interested in buying it want the lowest possible purchase price. At some point, an acceptable price is reached between buyers and sellers. At this point the market is "cleared" and transactions can take place and the clearing price of a security or asset will be the price at which

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they are traded in the market. In particular for products, the clearing price is determined by the intersection between the demand curve, sloping downwards, and the supply curve, sloping upwards. The point of intersection of these two curves, in fact, represents on the y-axis the equilibrium price, or clearing price, for the product and on the x-axis the quantity of product that will be exchanged on the market, excess quantity of product is not handled in this market.

2.6.1 Example of a Market Clearing Price

In order to make the concept of clearing price easier, a very simple example is given: a market with 5 buyers, 6 sellers and a total of 35 units available on the market. In the Table 2 are reported all the requests of sellers and buyers of this hypothetical market, to find the clearing price is necessary to draw these requests of purchase/sale on a graph: buy requests in order of decreasing price, sell requests in order of increasing price as seen in Figure 1.

Table 2 Initial market situation

BUYERS			SELLERS		
BUYER ID	**QUANTITY**	**PRICE**	**SELLER ID**	**QUANTITY**	**PRICE**
A	**7**	**25**	**1**	**10**	**18**
B	**7**	**23**	**2**	**7**	**20**
C	**10**	**18**	**3**	**8**	**22**
D	**6**	**16**	**4**	**3**	**24**
E	**5**	**14**	**5**	**4**	**29**
			6	**3**	**32**

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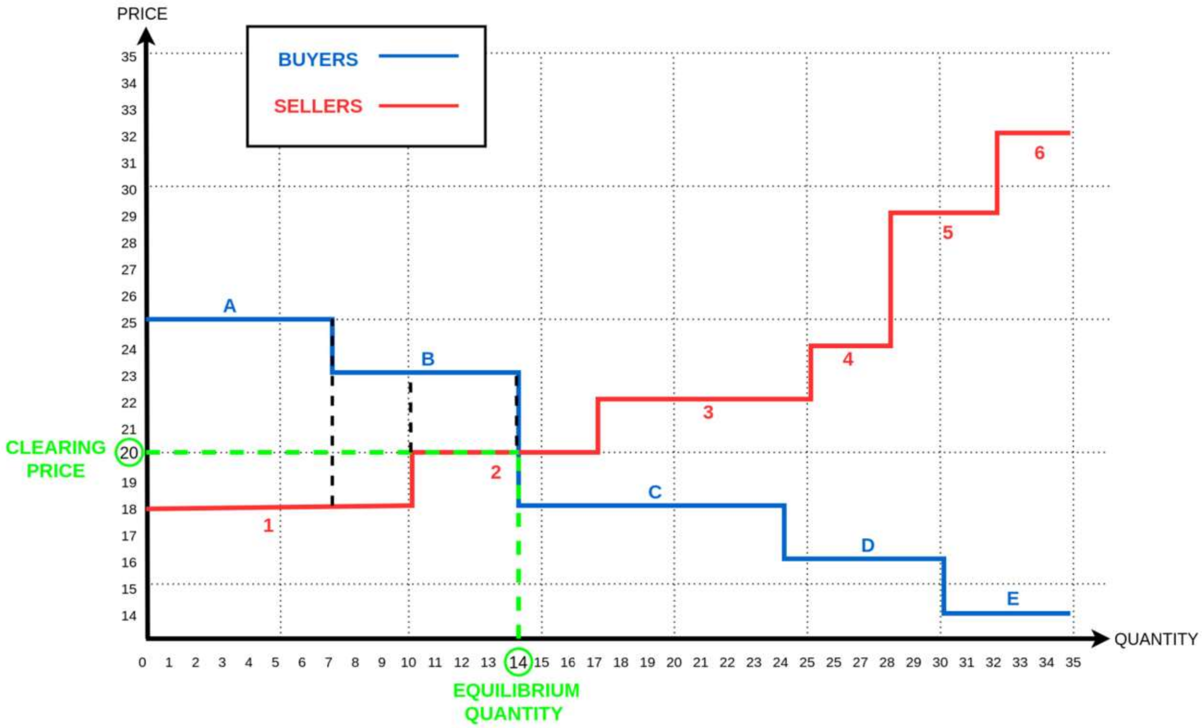

Figure 1 Graph used to find the clearing price

Figure 1 shows in intuitive way like clearing price and equilibrium quantity are found: the intersection of the supply red curve and the demand blue curve indicates the clearing price and the equilibrium quantity. In this case there are 35 units on the market and the equilibrium quantity turns out to be 14 units, this indicates that 21 units are discarded from this market: the sellers and the buyers have too many claims. The sellers demand at too high price, the increasing red line proves it. Vice versa the buyers buy at too low a price, in fact the blue line decreases too much. In conclusion, the transactions made in this market clearing price example are those that are before the green dashed line in Figure 1 and are shown in Table 3.

Table 3 Results of the clearing price algorithm

BUYER	SELLER	QUANTITY	PRICE
A	1	7	140
B	1	3	60
B	2	4	80
CLEARING PRICE=20		QUANTITY=14	

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3 Application of Blockchain technology in IANOS project

3.1 Use case description

In IANOS project the blockchain technology is applied in the context of Use case 1 ”Community demand-side driven self-consumption maximization”, specifically in relation to scenario 2 entitled **Self-consumption maximization through P2P energy trading based on DLT**. The application of a P2P market platform enables prosumers in a local network to directly trade energy with each other, by avoiding RES curtailment and future grid transport costs. The platform, based on blockchain, guarantees the transparency and security of the transaction, which remains permanently recorded in the platform, allowing all parties to audit the results. Fungible tokens based on ERC-20 standard are exploited as a payment for the purchase of energy between prosumers.

The main advantages of the system based on blockchain can be summarised as follows:

- Neutrality of the market: the absence of a central owner of the market guarantees the satisfaction of all stakeholders' interests without any catalysation around big players. Moreover, the adoption of an open mechanism for price calculation (everybody knows the algorithm) is another way to engage prosumers by reducing their worries about system fairness.
- Trustworthiness - transparency and immutability: by design, the transactions in the blockchain are transparent and immutable. This can help the resolution of any disputes among the market participants and ensure non-repudiation for transactions performed.
- Self-enforceability of smart contracts: self-enforceable means that once the smart contract is configured on and running, the execution of its code is automatic and will not require a specific approval. In the proposed system the transfer of tokens between prosumers is performed automatically by a smart contract after the validation of the energy transaction. No central authority can interfere with the transaction.

Figure 2 shows a representation of how the P2P market process works.

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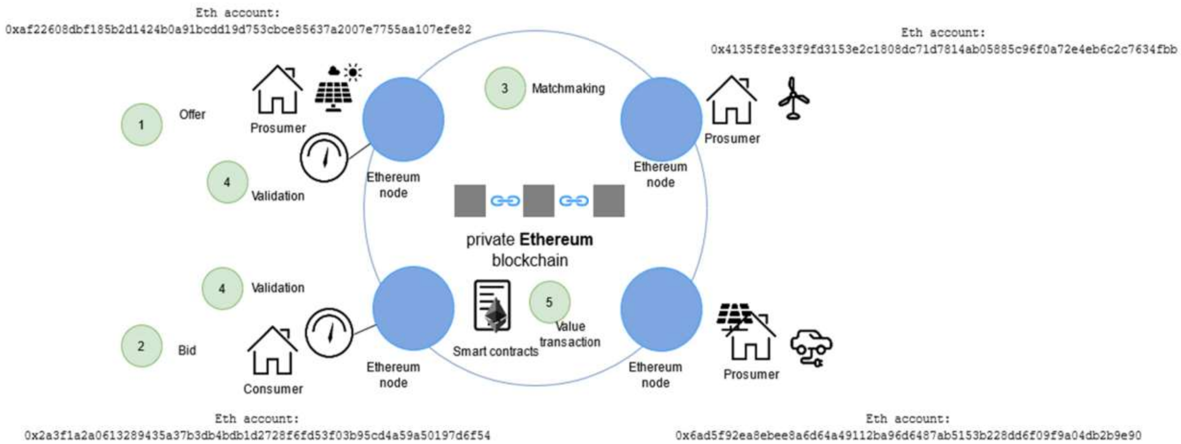

Figure 2 P2P market representation

The blockchain infrastructure provides the use of a private network, capable of supporting programmable smart contracts. The reference platform is based on Ethereum. Prosumers and consumers are active participants of the network by owning their own Ethereum node. Each node has associated an account in the blockchain that can be used to sign transactions and must ensure a connection with the smart-meter. The P2P market collects bids and offers from participants. Each market action refers to an amount of energy and a price for a specific time slot. At the end of each market session, bids and offers are collected and matched together. The final price and quantity are determined adopting the clearing price algorithm. Consolidated market actions are permanently stored on the private blockchain, additionally it is used also to store the measures -timestamped- of the grid power consumptions, provided by smart meters. These measures are used as reference levels to validate market agreements and verify that every participant acts as expected.

Figure 3 shows the representation of the user node which allows the connection between a smart meter of each prosumer and the Ethereum blockchain. Each user node (prosumer or consumer) is composed of:

- Node.JS platform: provides the integration layer for the various components, manages data retrieval logic and requests to services
- Web3.js: Javascript API for Ethereum
- Geth node: most popular software client for running a node on Ethereum network
- Communication interface towards the smart-meter

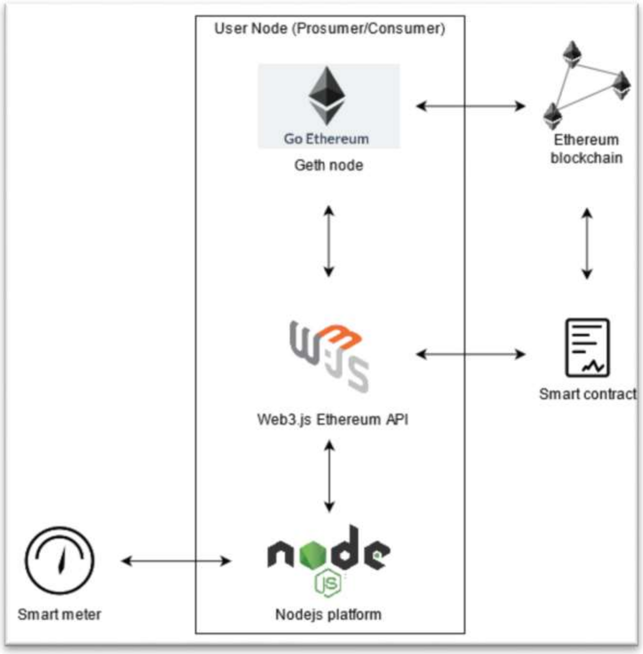

Figure 3 User node technologies

There are several interactions between the P2P market and other tools that are going to be developed in IANOS. In particular, the trigger event that opens a market session is the identification of energy unbalance that occurs due to excess production from renewables. This information can be retrieved by the Forecasting tool. The sequence diagram of Figure 4 shows the interaction between the P2P local market and the forecasting tool and how the market works after the energy unbalance identification.

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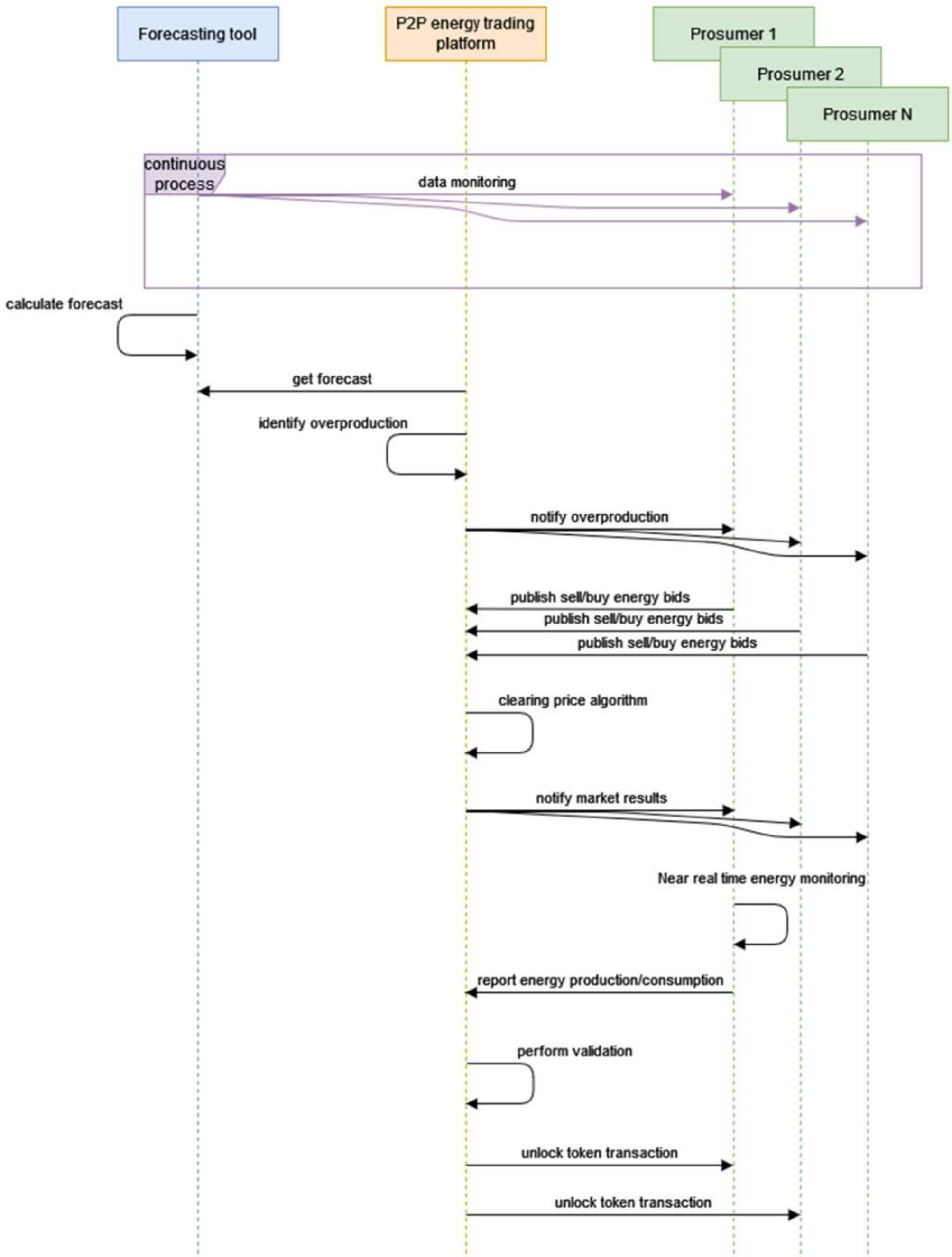

Figure 4 Sequence diagram on how the P2P local market works

3.2 System architecture

The P2P market is mainly composed of three components (see Figure 5):

- P2P energy trading platform implements the business logic of the P2P market, the validation of energy transactions between prosumers, prosumer management, aggregation of production and consumption measures coming from the smart meters.
- DLT services component represents the intermediate level of interaction between the logic of the application and the blockchain infrastructure. The DLT services component mainly retrieves information about users' wallets from the blockchain and invokes smart contract methods to manage the P2P market transactions.
- Blockchain infrastructure is the Ethereum private network able to provide networking, transactions validation, and on-chain storage capabilities.

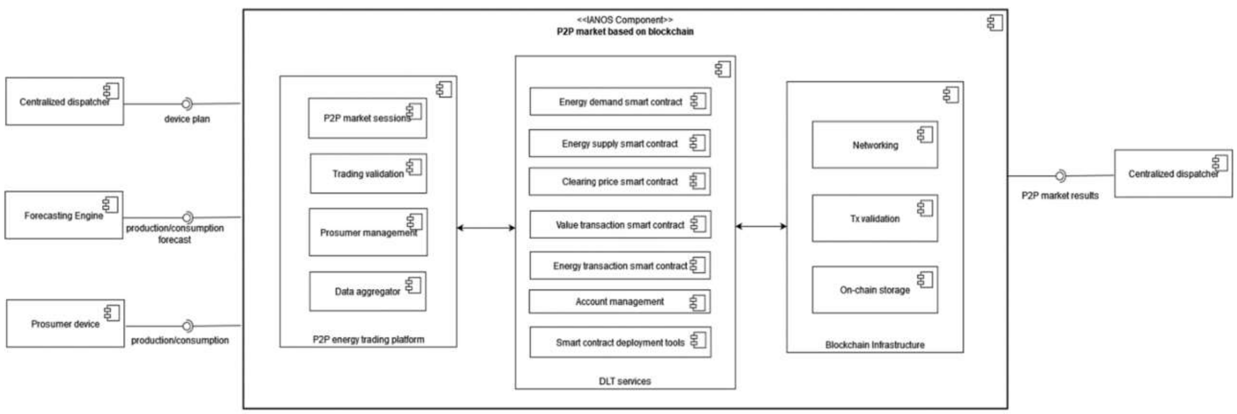

Figure 5 P2P market functionality diagram

The P2P market needs mainly three types of inputs:

- device plans provided by the Centralized dispatcher
- production and consumption forecasts for the identification of energy unbalance
- prosumer consumption and production data for the validation process after the close of the market session.

The P2P market platform should inform the Centralized Dispatcher , so the optimization engine can provide the optimal scheduled program for the next day.

From a deployment point of view, the P2P market will be validated in Terceira and Ameland pilot sites according to the different contexts of application. Figure 6 shows the architecture diagram for the application of the P2P market in Ameland. In this context, the Centralized Dispatcher (in the

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picture represented by Reflex tool developed by TNO) creates for each flexible device a plan. The device plan is the optimal schedule for a device that is providing flexibility and is optimized by Reflex. Using the plans for all devices in a household, it is possible to find if there is an overproduction. This overproduction can be traded in the P2P market, the trading of the over produced energy is not introducing instability in the network. The device plans and the realtime measurements coming from meters are provided through the Enterprise Service Bus (ESB) tool.

Figure 7 shows the application view of the P2P market in Terceira. In this scenario the P2P market calculates the overproduction taking input from the Forecasting Engine and not from the Centralized Dispatcher (in the picture represented by OptiMEMS). Differently from the application context of Ameland, the P2P market, after the validation process, returns the P2P trading results to the Centralized Dispatcher; the latter is requested to provide acknowledgement of the energy transactions agreed to check if further changes in the optimisation plans are requested.

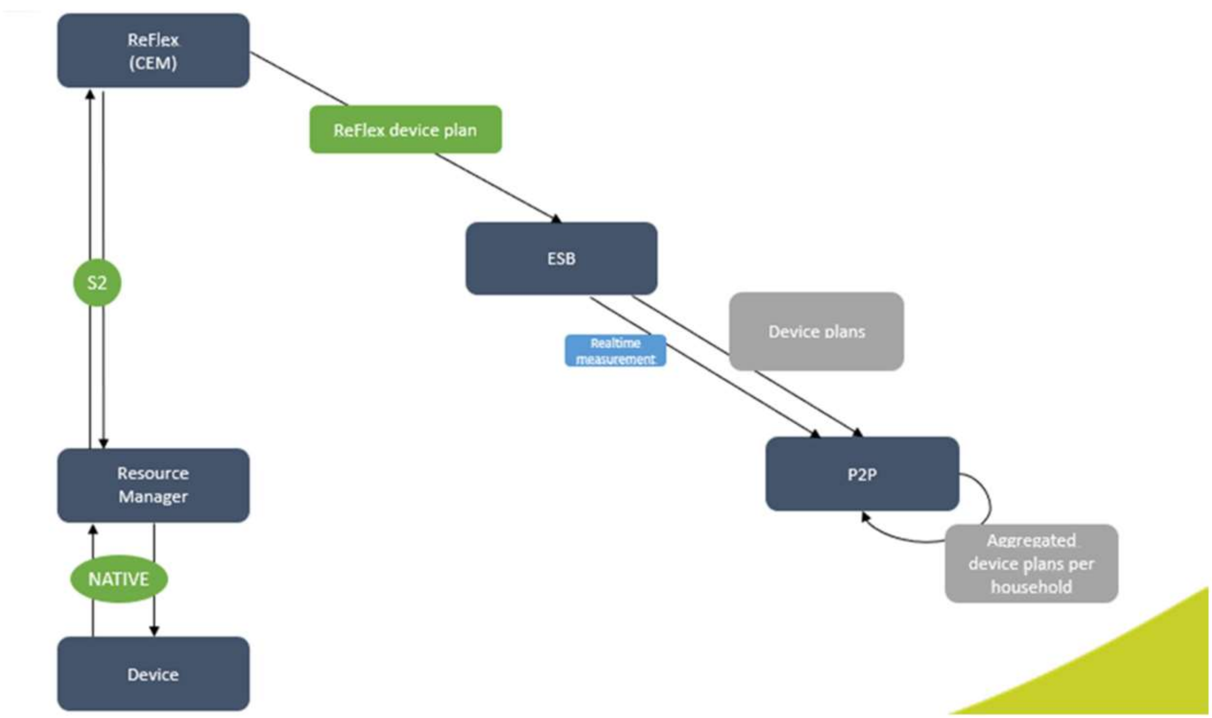

Figure 6 Architecture diagram in Ameland pilot site

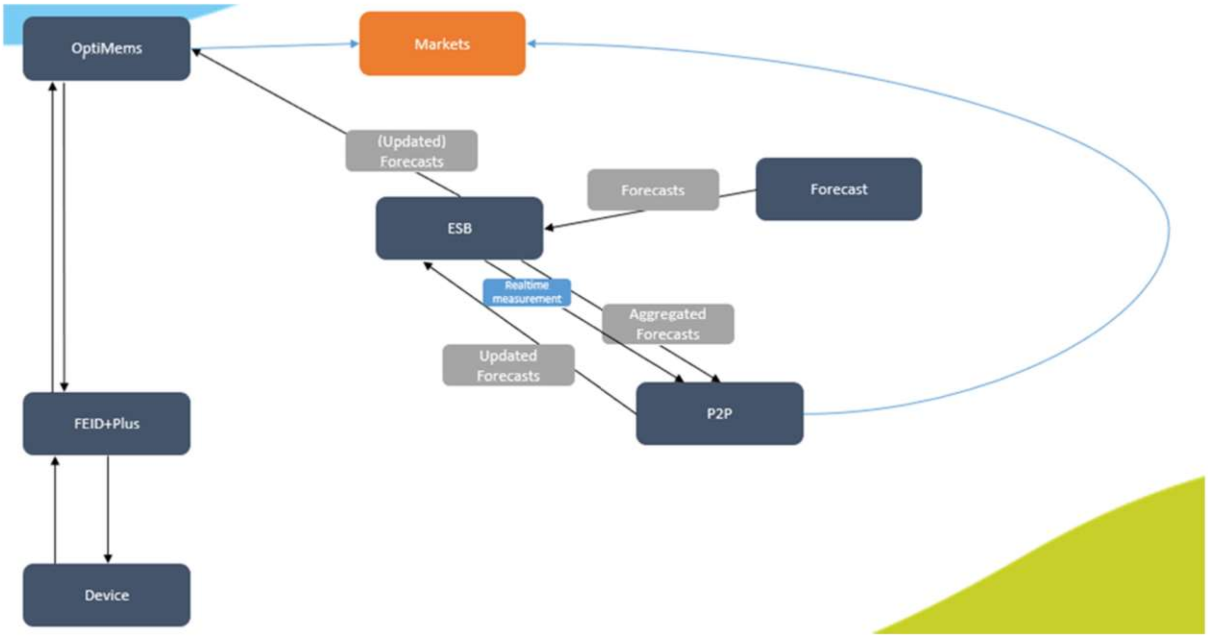

Figure 7 Architecture diagram in Terceira pilot site

4 Implementation of a local P2P energy trading platform based on Blockchain

The iVPP P2P transactive energy framework implements a marketplace that manages the exchange of energy within a community of prosumers leveraging on blockchain technology and smart contracts. The following figure represent the architectural structure of the application, it is realized according to a modules virtualization approach implemented via Dockers containers.

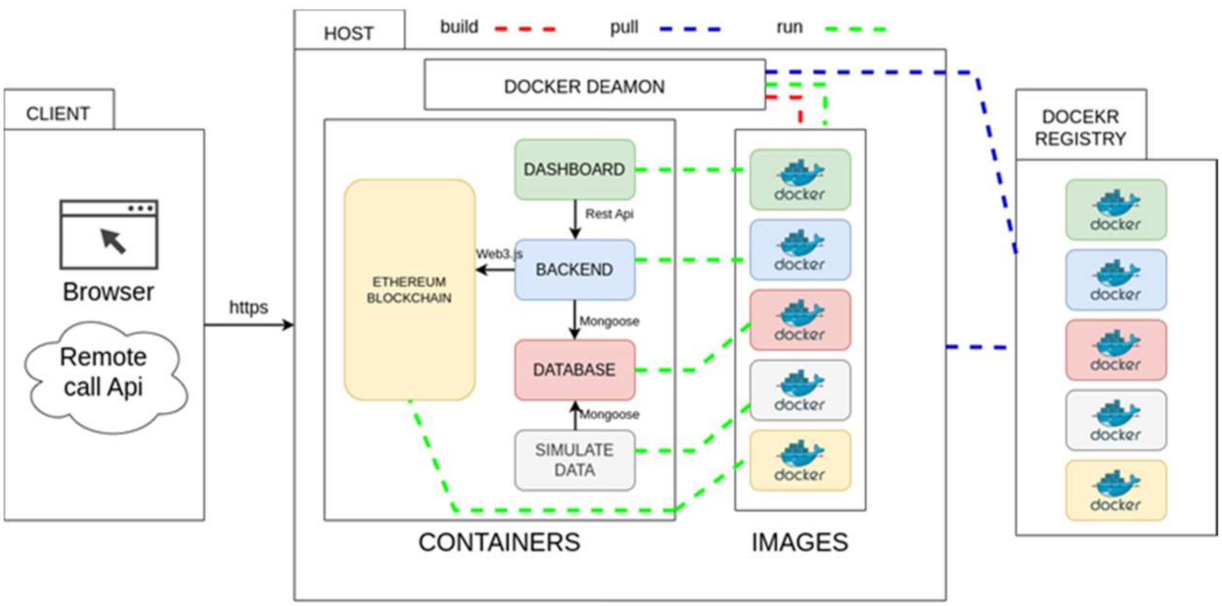

Figure 8 Application structure

4.1 Blockchain & Smartcontract

A key element of this infrastructure is to make data, in particular the one related to energy exchanged and token transactions between prosumers, immutable and accessible. For this reason a blockchain infrastructure is used. For the deployed infrastructure supporting the pilots validation a private blockchain with many nodes will be used, i.e. one node for each prosumer.

Ganache CLI was used for in lab testing phase, it is a fast and customizable Ethereum blockchain emulator. This application was chosen for various reasons: transactions are no cost and are "mined" instantly. Furthermore accounts can be recycled, reset and instantiated with a fixed amount of Ether

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without need for faucets or mining. Twenty-one Ethereum addresses were initialized during testing phase when the Ganache node was run. One of these was only used to deploy the smart contract on the node and for this reason it was not assigned to any prosumer, this is called the main address it is corresponding to the owner of the smart contract. The other twenty addresses were assigned one to each prosumer. In addition, the smart contract manages ERC20 tokens that are used in transactions between prosumers, this allow to keep track of all the energy exchanges that have taken place, both successful and failed.

4.2 Login

The Prosumer Interface shown in Figure 9 is used to authenticate the user. The list of authorised users is saved on the database in the deployment phase. For operational data persistence mongoDb database is used. Each user is associated with a prosumer ID and with an ethereum address. As seen in section 4.1 ethereum addresses are fixed a priori, for this reason each user has to be registered in the system in order to participate to the marketing sessions. Therefore, each prosumer is provided with an username and a password for its authentication and access to the platform. Token-Based Authentication is used as user access mechanism, specifically JSON Web Tokens (JWT). As soon as a user logs successfully, it can use others services of the component.

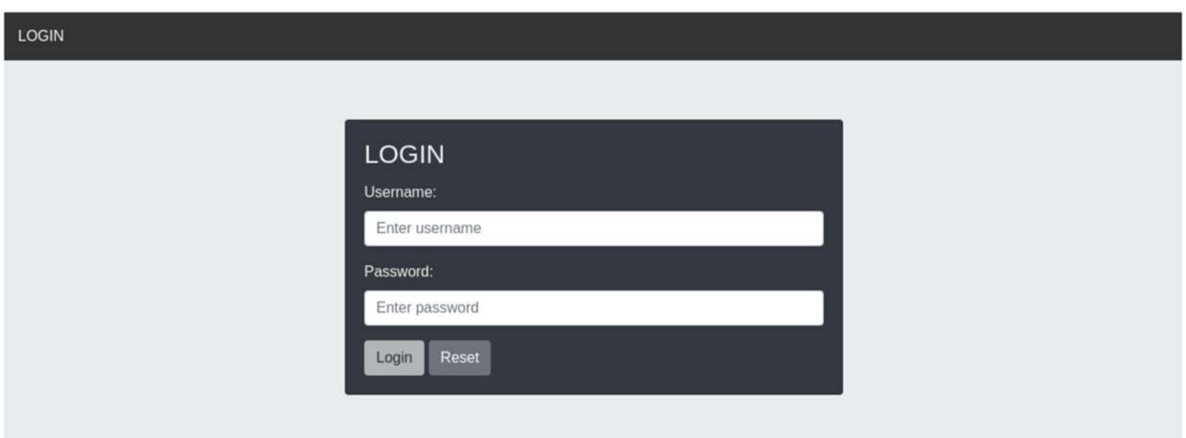

Figure 9 Login page

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4.3 Homepage

Home page is the first view that appears when the user is logged in and contains information about the user and prosumer associated, specifically the list of the related assets usable in the marketplace. An example is provided in Figure 10: the prosumer identified with ID 1 uses a battery storage and a PV system. The specifications of the assets (power, SoC, capacity for the storage battery and power for the PV system) are stored in the database. For the testing phase assets were simulated with realistic specification, actual data will be used for the pilot deployed version in order to support the validation.

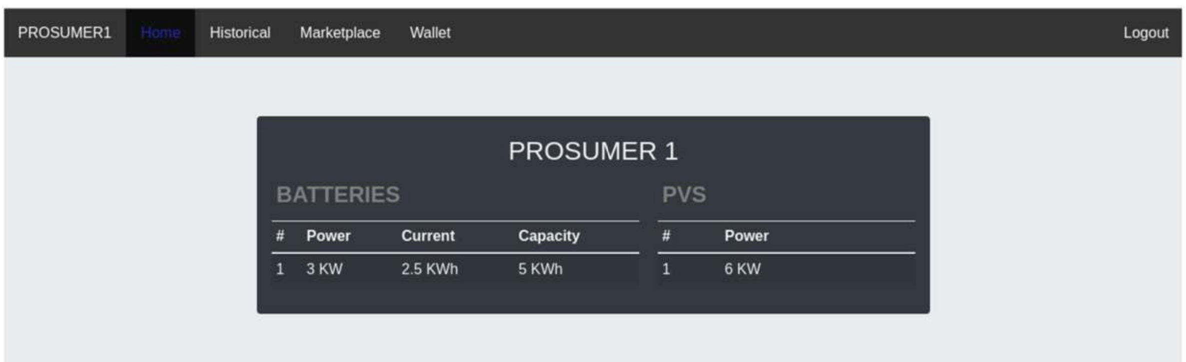

Figure 10 Homepage

4.4 Historical

Once logged in, the user can choose to consult the consumption and production historical data and the related forecasts of its prosumer asset. As shown in Figure 11 through two charts the consumption and production data and relative forecast are available. Data transmitted by the smart meter are shown by the blue line and represent the energy consumption/production in Kwh of the prosumer in the previous hours. While the forecast data are represented by the red line and indicate the energy consumption/production in KWh forecasted for the next hours. In the example in Figure 11 the prosumer 2 from 09:00 to 10:00 produces about 0.2KWh and consumes 0.5KWh, additionally from 11:00 to 12:00 a production of 0.25KWh and a consumption of 0.9KWh are forecasted. For the initial testing phase a service created ad hoc simulates production/consumption data and all the forecast data in independent way assuming they have a frequency of one hour, this is because real data and real forecasts are not yet available at the time of this deliverable writing.

Figure 11Historical page at 10:01

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4.5 Marketplace

This section explains the functioning of the marketplace on which the local P2P energy trading platform is based. The marketplace works automatically and is based on the smart contract described in Section 4.1. It is divided into market windows (MW), each one independent of the others, they have a life cycle of two hours that consists of three phases:

- Creation of the MW session
- Closing of the MW session
- Validation of the MW

Every hour a new empty MW session is automatically created by the application, at the same time the MW session of the previous hour is closed and the MW of two hours before is validated. A life cycle of a single MW is summarised in Figure 12. It is divided into two distinct parts of one hour each: OPEN and IN PROGRESS.

The following sections explain each step in detail.

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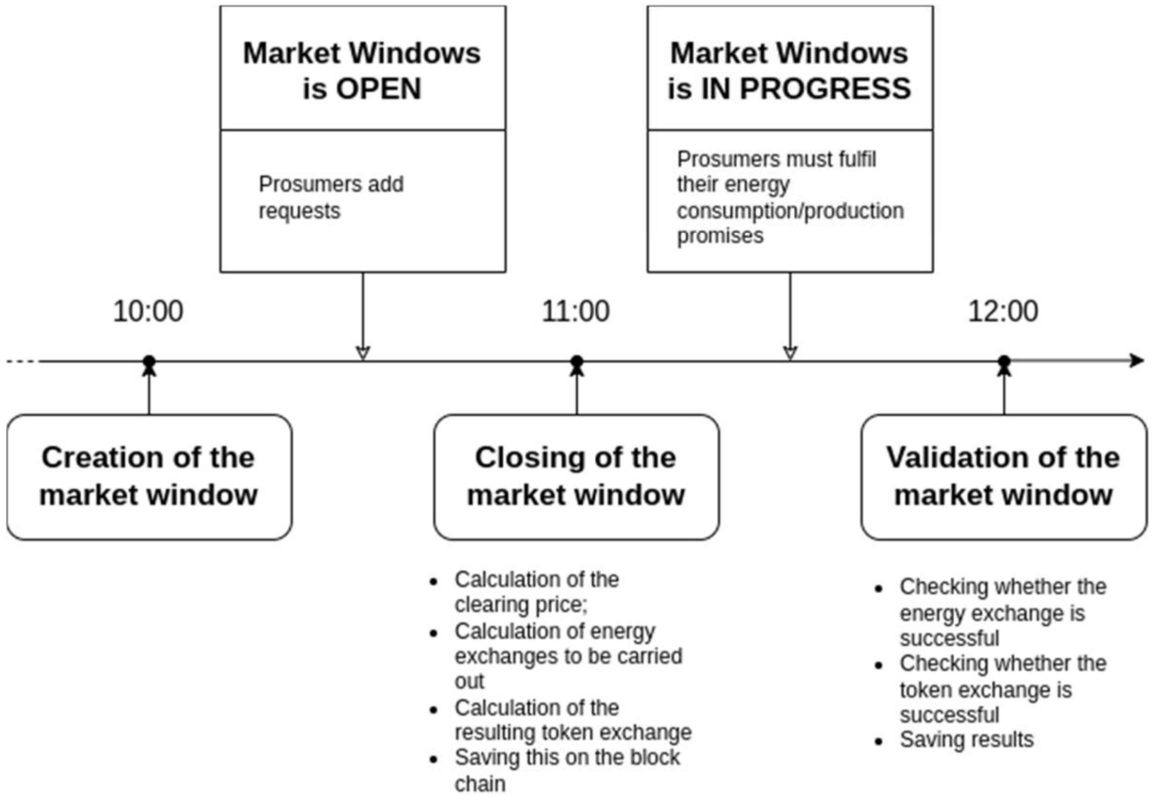

Figure 12 Life cycle of a market window

4.5.1 Creation of the MW

As first step a market window is created: every hour an empty MW is added to the database. Each MW is characterised by a unique timestamp, in fact two MWs cannot exist for the same time period. As shown in the Figure 13 once the MW is created the first hour of its life cycle begins: the market windows status is set OPEN. During this time, requests to sell or requests to buy energy can be added by any user. In the example shown in Figure 14, prosumer 2 has a forecast excess consumption and for this reason the user adds a purchase request of 0.6KWh. To avoid speculation each user can only add one request (sale or purchase) in each MW.

4.5.2 Closing of the MW

At the end of the first hour the MW is closed, now no user is allowed to add any sales or purchase requests to this specific MW. At this point in time, the energy sales and purchase requests added to the MW are processed using the clearing price algorithm, which is explained in detail in Section 2.6. Then the algorithm finds the match corresponding to the amount of energy that will be traded and the price in tokens and in addition, all token and energy exchanges between prosumers are calculated. An example of this is given in Table 3. In order to ensure the transparency and security of transactions and to record them permanently in the platform thus allowing all parties to verify the results, all these results are saved on the blockchain, additional storage in the database is performed for operational optimization. As soon as the MW is closed, its second hour of life begins: the market window status switches to IN PROGRESS. During this time slot, the prosumer is obliged to respect the consumption/production he offered: for example, in the case given in Table 3 the prosumer 1 must have an excess production of at least 10KWh, so that it can fulfil its duty to supply 7KWh to prosumer A and 3 KWh to prosumer B.

4.5.3 Validation of the MW

When the MW reaches this phase its life cycle ends. In order to prevent transactions being manipulated, the results obtained from the session closing, which are necessary for MW validation, are read from the blockchain and not from the database. After obtaining all the necessary information, the application checks the validity of each transaction. There can be two reasons why a transaction may fail:

- The prosumer has not consumed/produced the necessary energy
- The buyer does not have enough tokens to pay the seller prosumer.

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As production and consumption data are simulated during the test phase, the first check is not implemented yet in this version of the application but will be added in the next versions to support the pilot validation having the data transmitted by the smart meters.

In this version of the application to make a transaction valid, the check performed is related to the availability of buyer's tokens. Starting from the example reported in Table 3, let's suppose that prosumer B has 120 tokens available, in this case his first transaction (3KWh and 60 tokens to prosumer 1) is validated while the second one (4KWh and 80 tokens to prosumer 2) is labeled as failed, in fact after the first transaction prosumer B has only 60 tokens left against a transaction that costs 80 tokens. Obviously if a transaction for some reason is not validated the exchange of tokens between prosumers does not take place, vice versa it does. Furthermore, the information regarding the status of the transaction, i.e. *ACCEPTED* if it is validated and *REJECTED* otherwise, is added to the blockchain and after that the MW life cycle is over.

In addition to adding energy sales/purchase requests, the user can consult the history of MWs, on the section “Past Market Windows” see Figure 13 and Figure 14. The main characteristics of each MW are showed, in addition to its status there is the energy in KWh that is exchanged in that specific MW and the amount of tokens to which the energy is sold. Figure 13 and Figure 14 represent two examples of the same page at two different times: in the first image the MW at 10:00 is still IN PROGRESS while in the second image the same MW is CLOSED. This happens because, as described at the beginning of this section, every hour a new MW is created and the previous one is closed.

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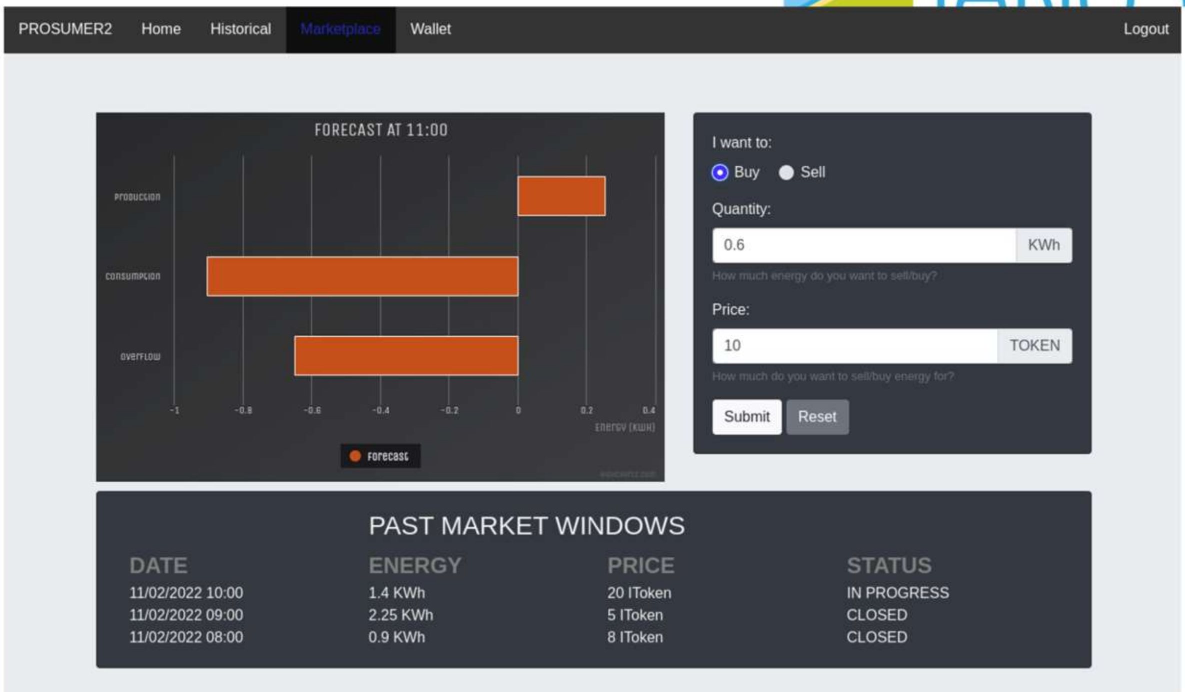

Figure 13 Marketplace page at 10:01

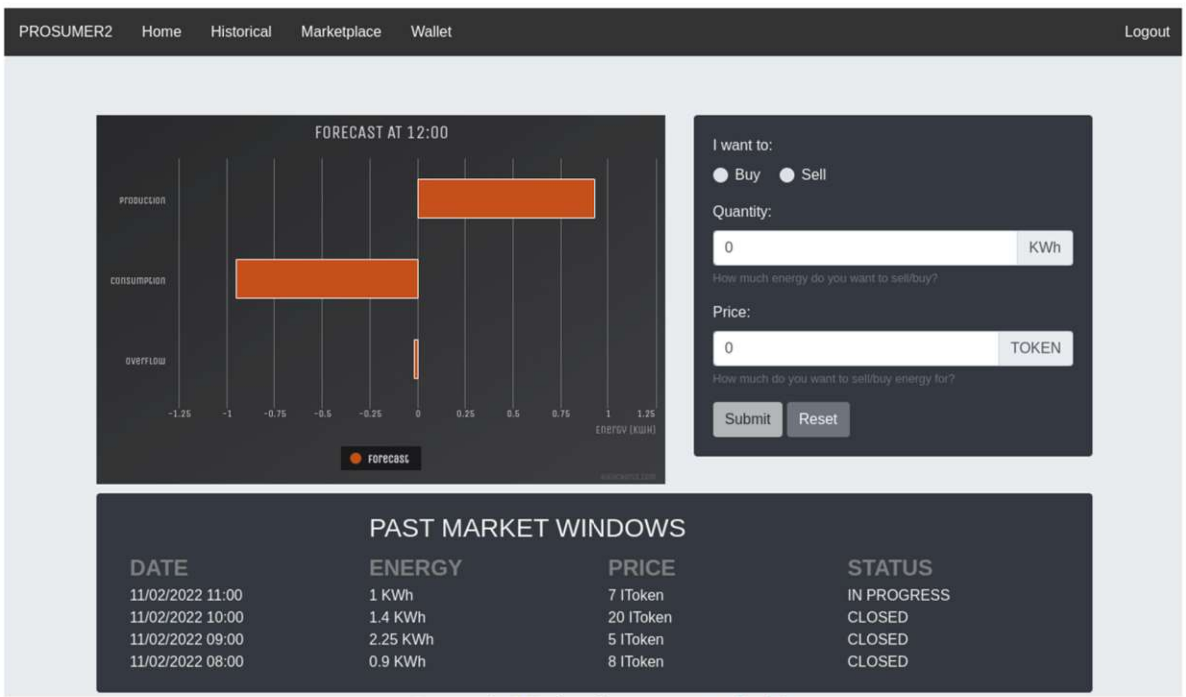

Figure 14 Marketplace page at 11:01

4.6 Wallet

To control their portfolio, the amount of tokens they own and the status of financial transactions in the market, users can leverage on the interface showed in Figure 15 and Figure 16. All past

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transactions can be viewed, those are grouped according to the MW they belong to for easy reference. To make it easier for the user to read, transactions in which he participates are written in bold (the first transaction shown in the two figures below, in fact, writes the address associated to prosumer 9 in bold), while colours help to have a quick understanding of the status of the transaction. In Figure 15 all transactions are highlighted in yellow, indicating that the transactions are pending, since at that moment the MW created at 10:00 is closed but still to be verified. More interesting is the situation shown in Figure 16, the image shows the same transactions as in the previous case but one hour later, i.e. with the MW verified. The colours in this case are very intuitive: the transaction is written in green if it is successful, otherwise it is written in red. Specifically, the first transaction fails because the user associated with prosumer 9 has to pay 14 tokens but without having this amount available, this situation leads to a failure of the transaction.

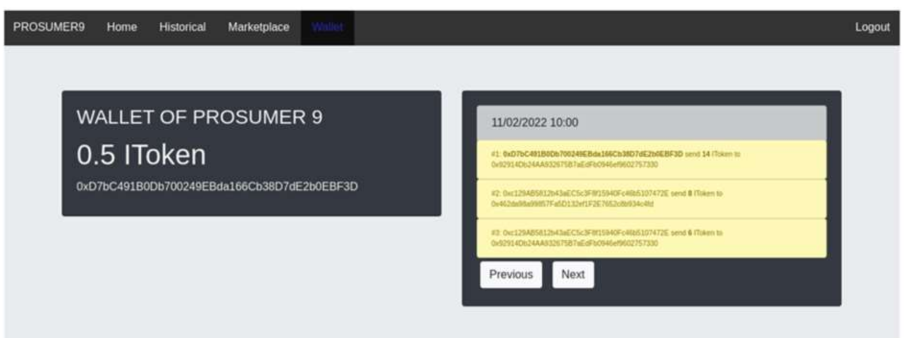

Figure 15 Wallet page at 10:01

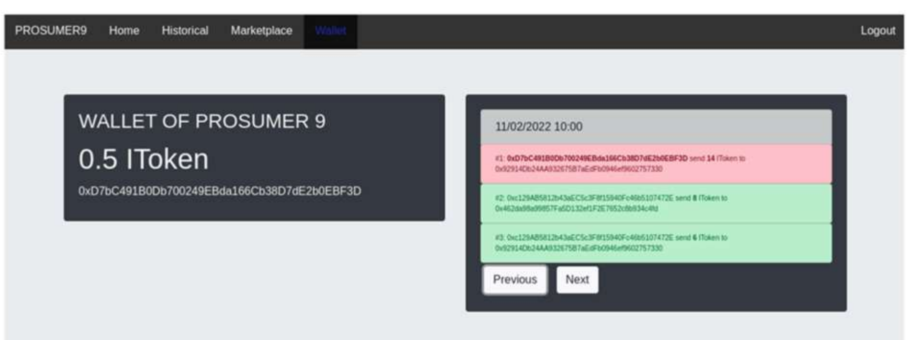

Figure 16 Wallet page at 11:01

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5 Conclusions and next steps

In this deliverable, we described a solution for constructing and managing energy exchange among prosumers in a P2P way. This application uses blockchain technology and thanks to the use of a smart contract all relationships between buyer and seller are tamper-proof and transparent. The actual fulfilment of energy exchanges, on the other hand, is guaranteed by the use of smart meters, which transmit the energy consumption and production of each prosumer to the application via the ESB. Tokenized approach is used for the value exchange among the prosumers participating in the marketplace in correspondence to the energy offered.

The next steps include the collection of pilot data and the implementation of the proposed marketing activity on it. Functionalities will be validated and feedback retrofitted in order to accomplish evolved requirements and scenarios.

An new version of this document is already planned at M32 with deliverable D4.10, it will report all the advancement up to that time and preliminary validation feedback. .

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