TWINERGY

Transactive Energy Module

D7.7

April 2022

Deliverable

PROJECT ACRONYM	GRANT AGREEMENT #	PROJECT TITLE
TWINERGY	**957736**	**Intelligent interconnection of prosumers in positive energy communities with twins of things for digital energy markets**

DELIVERABLE REFERENCE NUMBER AND TITLE

D7.7

Transactive Energy Module

Revision: v1.0

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Funded by the Horizon 2020 programme of the European Union
Grant Agreement No 957736

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Version History

REVISION	DATE	AUTHOR	ORG...	DESCRIPTION
V01	24.03.2023	Ivan Sulev	WEC	First Draft of Report
V02	28.03.2022	Ivan Sulev, Rick Landman	WEC	Applying edits and comments
V03	29.03.2022	Konstantinos Plakas John Gialelis	UoP	Applying edits and comments from UoP
V04	04.04.2022	Ivan Sulev Konstantinos Plakas	WEC/ UoP	Applying edits and comments from WEC/UoP
V05	21.04.2022	Dr. Alex Papalexopoulos Konstantinos Plakas	WEC / UoP	Edits and Comments
v0.6	27.04.2022	Ivan Sulev	WEC	Final version submitted PC
v1.0	30.04.2022	Ivan Sulev	WEC	Draft submitted to EC by the PC

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Statement of Originality

This deliverable contains original unpublished work except where clearly indicated otherwise. Acknowledgement of previously published material and of the work of others has been made through appropriate citation, quotation or both.

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Executive Summary

This document represents the Deliverable 7.7 "Transactive Energy Module" of the TwinERGY project, funded by the European Commission's Innovation and Networks Executive Agency (CINEA) under its Horizon 2020 Research and Innovation Programme (H2020).

The purpose of this document is to provide an overview of the Transactive Energy Module which is designed to implement organized nodal electricity markets for the distribution grid, which will revolutionize the relationships among customers, energy companies, and the grid under the new emerging transactive energy paradigm.

Furthermore, the deliverable touches upon the basic elements of the module development process, starting with the analysis and findings of the conditions in the pilot sites which shaped the design and architecture of the module, eventually fortifying the final structure and relations between the involved parties, giving us a clear view of the operational ability of the module, thus, at the end identifying and shaping out 4 transaction types which will fuel the transactive energy market.

Moreover, with the use of state of the art technologies, including blockchain and smart contracts, it is ensured that the trustworthiness of the system is impeccable, that it will empower users to trade power and make transaction in a seamless way, enabling digitization to lead the way to energy transformation and increased use of energy trading.

At the end the document provides brief but essential overview of the Transactive Energy Module functionalities, attempting to showcase the usability of the module with its main operational characteristics.

The actions presented in this document clearly show the results and work carried out in this task and the clear intention and commitment in creating a module that will answer the above mentioned points in detail and in the best possible way, providing ultimate user experience and ultimate value for the user.

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Abbreviation list

BTM	Behind the Meter
DER	Distributed Energy Resources
DERMS	Distributed Energy Resource Management Systems
DR	Demand Response
DSO	Distribution System Operator
EV	Electric Vehicle
IFOM	In Front of the Meter
IoT	Internet of Things
LEM	Local Energy Market
PV	Photovoltaics
P2P	Peer-to-Peer
RES	Renewable Energy Sources
TE	Transactive Energy
TEM	Transactive Energy Module
TEMkt	Transactive Energy Market

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UX	User Experience
UI	User Interface
VPP	Virtual Power Plant

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1/ Introduction

TwinERGY introduces a first-of-a-kind Digital Twin framework that incorporates the required intelligence for optimizing demand response at the local level without compromising the well-being of consumers and their daily schedules and operations. The main idea behind the conception of the TwinERGY project lies on the interest of the project partners to exploit the new business opportunities that project implementation delivers and increase the relevance of the DR optimization tools and strategies in the new generation of energy management systems.

One basic module which is presented within TwinERGY project, includes the Transactive energy module. Transactive Energy Module enables grid decentralization and democratization by connecting the micro-grid operators to the DER managers and their customers. The core development refers to a transactional platform that offers its participants to sell their flexible energy loads and excess capacity on an open market to the (micro) grid operators or to each other for optimally managing their energy needs. To this end, it allows for transactions internally that match supply and demand to alleviate stresses to the external grid.

1.1 Purpose of this deliverable

The purpose of this document is to showcase the preliminary version of the Transactive Energy Module developed as part of the deliverables under TwinERGY project. The objective here is to elaborate briefly on the development process, as well as introduce the reader with the basic functionalities of the module.

1.2 Scope of the deliverable

The scope of this document is to provide an overview of the development process of Task 7.7 and Deliverable 7.7 “Transactive Energy Module” documenting the first version of the module, developed by the World Energy Consortium (WEC), under the framework of TwinERGY project.

Apart from overview of the work done under this deliverable and how the Transactive Energy Modul (TEM) was created, this document further deals and presents the basic components of Transactive energy along with the specific requirements. In addition, the 4 different transaction types between the participants in the pilot sites are identified. The pricing algorithm, followed in this TE market, is analytically described to showcase the rationale behind the pricing methodology.

The main goal is to showcase the operational and functional part of the module and to briefly drive the reader not only through the architectural aspect but also the user experience and usability aspect of the module itself operating under the transactive energy environment.

1.3 Structure of the document

The present document is structured as follows:

- In chapter 2, a basic description of the requirements for the Transactive Energy Environment is given.
- In chapter 3, the Transactive Energy use case is described.
- In chapter 4, the different allowed transactions within the Transactive Energy platform are described.
- In chapter 5, the algorithm for the calculation of the internal LEM price is attached.
- In chapter 6, a short guide to the current TEM release is given.

1.4 Audience

The present document (along with its updated versions) is a public deliverable, which is addressed to the TwinERGY consortium partners, the European Commission services and everyone interested in the rules and procedures of data management in TwinERGY project and will be published through all the appropriate channels of the project.

2/ Objectives of TEM

This section deals with the high-level objectives and requirements of the TEM according to the project scope, defined after detailed coordination with the pilot sites and their stakeholders.

In this respect, the TEM is designed to implement organized nodal electricity markets for the distribution grid, which will revolutionize the relationships among customers, energy companies, and the grid under the new emerging transactive energy paradigm. As illustrated in Figure 1, the module makes the transactive energy paradigm a reality by allowing customers, either as individuals or in aggregate, to actively engage in energy markets by negotiating and responding to "value signals," based on price, demand, time of day, and other grid and market considerations. The transactive energy model, enabled by the TEM, is turning DERs (from solar to storage to EVs and smart appliances) into grid assets which can be deployed to solve grid problems. DERs enable consumers to become prosumers and provide flexibility and other services to the grid. In TwinERGY, we envision that the TEM paradigm will enable grid decentralization and democratization by connecting the micro-grid operators to the DER managers and their customers. It is providing an integrated energy business model through energy service expansion, customer engagement and financial inclusion. The Transactive Energy Module will use

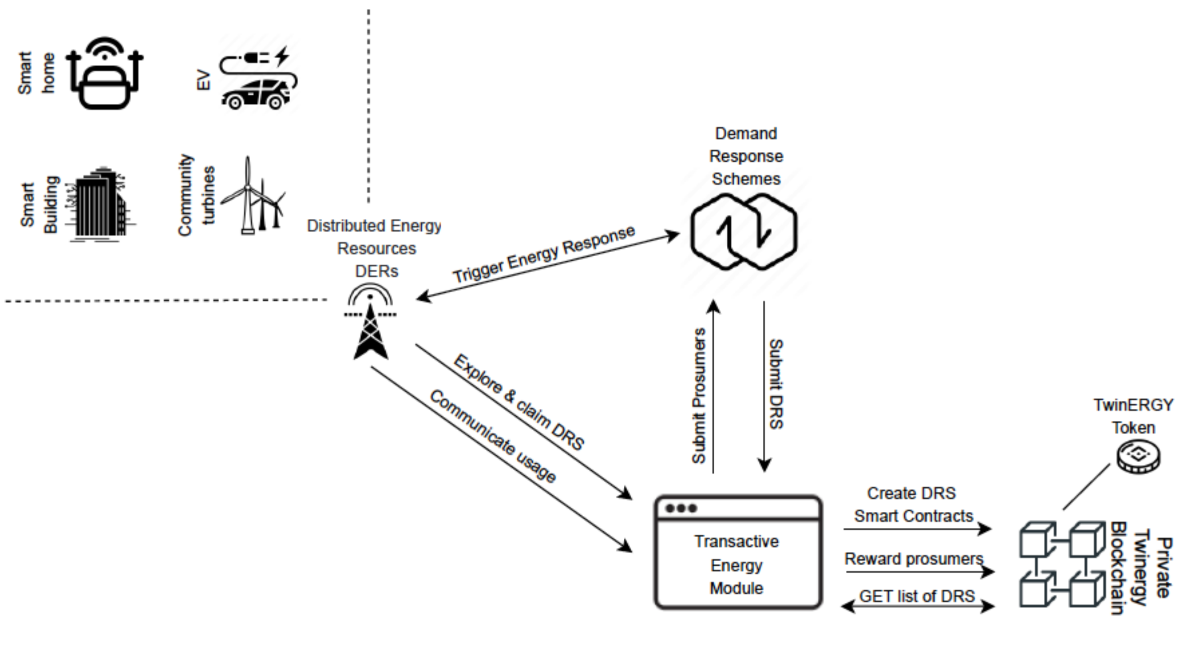

Figure 1. Transactive Energy Module

the Ethereum network and technology to create a thrustless auction house where flexible capacity and demand from DERs will be auctioned off through encrypted, shared, immutable, and publicly auditable Smart Contracts. A cryptocurrency ecosystem is created, which preserves the cryptocurrency asset value, solves volatility problems, and ensures high transaction processing speed. Use Cases where the emerging transactive energy model can offer effective approaches for engaging DERs to achieve Demand response, balance the grid at various levels and maintain grid power quality and reliability are: ● Peak heat day and energy supply ● High penetration of Photovoltaics (PV) and Voltage Control ● Electric Vehicles (EV) on the neighbourhood transformer ● Islanded microgrid energy balancing ● Multi-bilateral trading with product differentiation (such as peer-to-peer trading based on prosumer preferences. (TwinERGY Project)

The Transactive Energy Module, based on Hybrid Blockchain technologies is developed to solve current intractable optimization problems and create a premiere Transactive Energy (TE) protocol layer settlement process, marketplace, and governance framework to allow energy-related Apps to be written and interoperate with each other. For the purpose of TwinERGY an Ethereum based blockchain instance will be created for demonstration purposes.

3/ TEM Use Case Definition

TwinERGY TEM framework is built for the 21stcentury grid, characterized by active "prosumer" (both producer and consumer of energy) participation in energy markets, bidirectional power flows (e.g., net metering of Behind-The-Meter (BTM) resources), and sophisticated financial transactions between prosumers, utilities, and third-party service providers is something that can create this positive improvement of value and is a business model worthy of a future. TE transactions BTM and In Front of the Meter (IFOM) are already on a hockey-stick shape of growth as they are now merging with the increased adoption of smart Internet of Things (IoT) devices, such as connected thermostats and other newly networked Distributed Energy Resources (DERs) such as renewable energy sources, electric vehicles (EV), and Electric Storage Resources at the edge of the grid.

Our module aims at creating a TE market, which will likely alter the behaviour and perception of the participants in the electric market as such, and be able to improve the business models with the addition of the TE features. (Cazalet et al., 2016) The ability to create and hold value will be the leading factor in the decision making process, much different from today's focus mostly orbiting around revenues. New business models will emerge to serve consumer needs in TE markets and others may change to meet the needs of those markets. Some new market participants will likely be customers or aggregations of customers that supply electric services to the transactive marketplace. (Cazalet et al., 2016)

Furthermore, with the TE model in TwinERGY project, we are also bringing to activation the concept of digitalization and how the digitization aspects can improve the current market situation, thus, bring new solutions to life. In a sector which is filled with complex operational models, integration of services and solutions is gaining relevance where digitisation is leading the road to transformation of the energy markets. Many new companies are entering the market with innovative products based on digital solutions. Companies from the information and communication sector and other companies from outside the industry increasingly drive the change. New entrants from other sectors can provide essential skills for the provision of innovative value propositions by entering the energy sector. However, traditional companies in the energy industry can also expand their product portfolio based on their expertise within their value creation network. (Giehl et al., 2020)

Blockchain, which involves decentralized transaction verification will potentially empower individual customers to trade power and make payments in a seamless way. Digitalization can help with better network and congestion management, assisting with the renewable generation intermittency problem, allowing more effective network monitoring and more efficient network operation. It also provides digital platforms for demand response, and Peer-to-Peer (P2P) energy and carbon credit trading. (Kufeoglu et al., 2019)

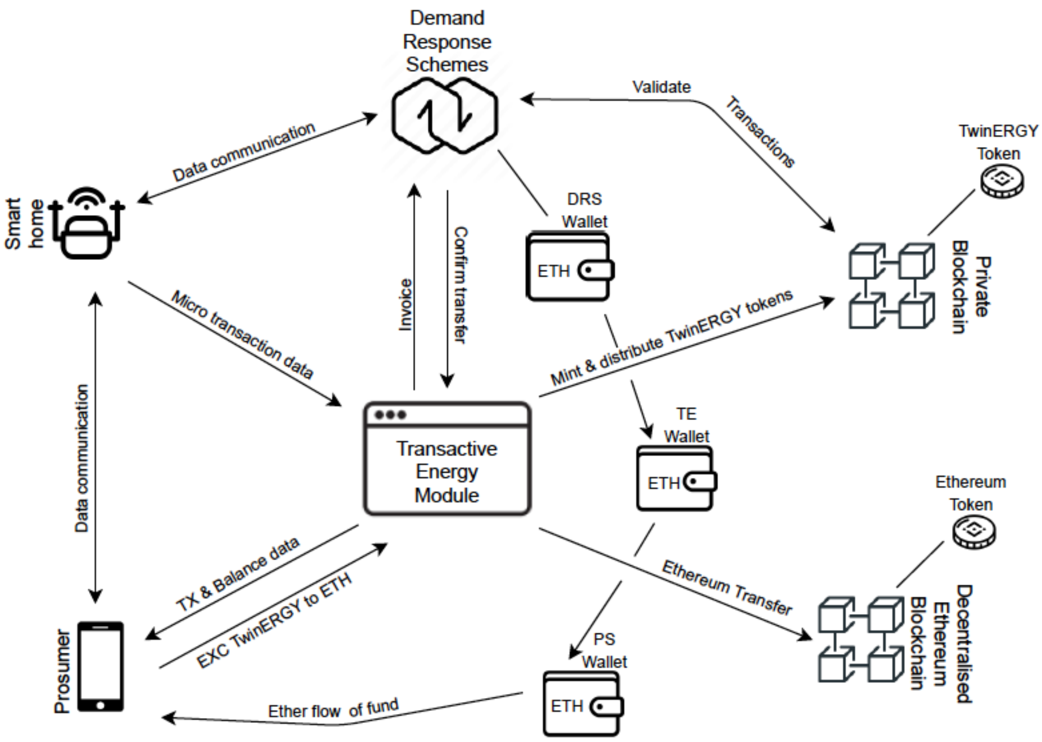

Figure 2. WEC's Transactive Energy Module Architecture

The benefits of the TE model (Figure 2) come, firstly, from the fact that there is a direct link between the consumer and the producer, with the scale tilted towards the consumer as he can choose, on its own, from where they will purchase their power. This decentralises the situation dramatically and provides additional value to the consumers because of the increased competition in the market. Secondly, the additional value proposition of this model comes through price-time-shifting as consumers have total visibility when they are purchasing power and from where. All this helps the market to achieve greater matching of demand and generation which can reduce network pressure and creates benefits for the consumers through flexibility markets, and reduced charges and enables generators to sell power at better prices in order to maximise their exposure. (Hall et al., 2020)

3.1 Scope of Transactive Energy Use Case

The scope of Transactive Energy Module (TEM) is to provide solutions to transactive energy uses cases and enables grid decentralization and democratization by connecting the micro-grid operators to the DER managers and their customers. It aims for an integrated energy business model through energy service expansion, customer engagement and financial inclusion. It allows them to balance the grid and provide solutions to a number of grid problems, such as grid power quality and reliability. The core of this use case is a transactional platform that offers its participants to sell their flexible energy loads and excess capacity on an open market to the (micro) grid operators or to each other. Microgrid operators provide balancing and grid services at a local and micro-grid level. A micro-grid could be a collection of a) IoT devices, b) buildings, c) neighbourhoods/substations, and d) regions that operate at a regional level to balance multiple neighbourhoods, districts and/or substations. It could potentially include the high voltage grid. Each component of the system (e.g., device, building, neighbourhood, distribution grid and transmission grid) is a self-contained ecosystem, replicated and nested within the next layer of the system, like in a fractal configuration. All components operate with identical information and control models and each have operational decision-making capabilities. This module offers a path to grid decentralization, energy democratization, and a way to effectively leverage and monetize the emerging DER infrastructure. (A.Papalexopoulos, 2021)

The Transactive Energy Module (TEM), based on Hybrid Blockchain technologies will be developed to solve current intractable optimization problems and create a premiere Transactive Energy (TE) protocol layer settlement process, marketplace, and governance framework to allow energy-related Apps to be written and interoperate with each other.

Through the application and study of this module in three of the TwinERGY project pilot sites (Hagedorn in Germany, Bristol in the United Kingdom and Benetutti in Italy), grid infrastructures would be analysed to implement state-of-the-art equipment that can monitor and track energy consumption and distribution. Pilot sites, consisting of apartment buildings and individual houses will be equipped with smart meters, local and public storage facilities and IOT devices such as smart plugs. These are integrated with the Transactive Energy Module giving prosumers a powerful insight of their power consumption and redistribution to the local energy market (LEM).

The TEM will allow for prosumers to buy and sell energy from the LEM. It will also allow TE participants to transact in a P2P configuration outside an organized LEM/DSO or an ISO/TSO market. These transactions are stored as an immutable record on the blockchain specifying the actors participating in the transaction and the origin of the energy. (A.Papalexopoulos, 2022)

To further support the LEM, the TEM will process and broadcast price forecasting of the DNO and LEM. Other TwinERGY modules will be able to listen to the broadcast and make energy consumption or discharge decisions on behalf of the prosumer. (A.Papalexopoulos, 2022)

For non-ISO/TSO and non LEM/DSO organized energy market transactions one pricing option could be to use a double-sided market in which TE participants pay a unique price based on their preferences and local supply and demand conditions (analogous to the stock market). Another option could be to use a proxy market price using a reference market price of the LEM organized market or the ISO/TSO market, (e.g., the 5-minute real-time auction price. (A.Papalexopoulos, 2022)

4/ Prototype transactions

4.1 RES to Storage

In this use case scenario, multiple parties (a "transaction consortium") jointly own or share a RES such as a PV system or wind turbine. When the RES charges the battery, the physical energy is stored in the battery and the balance in kWh is stored in a dedicated blockchain ledger. In this scenario the balances on charging are equally divided among the transaction consortium members.

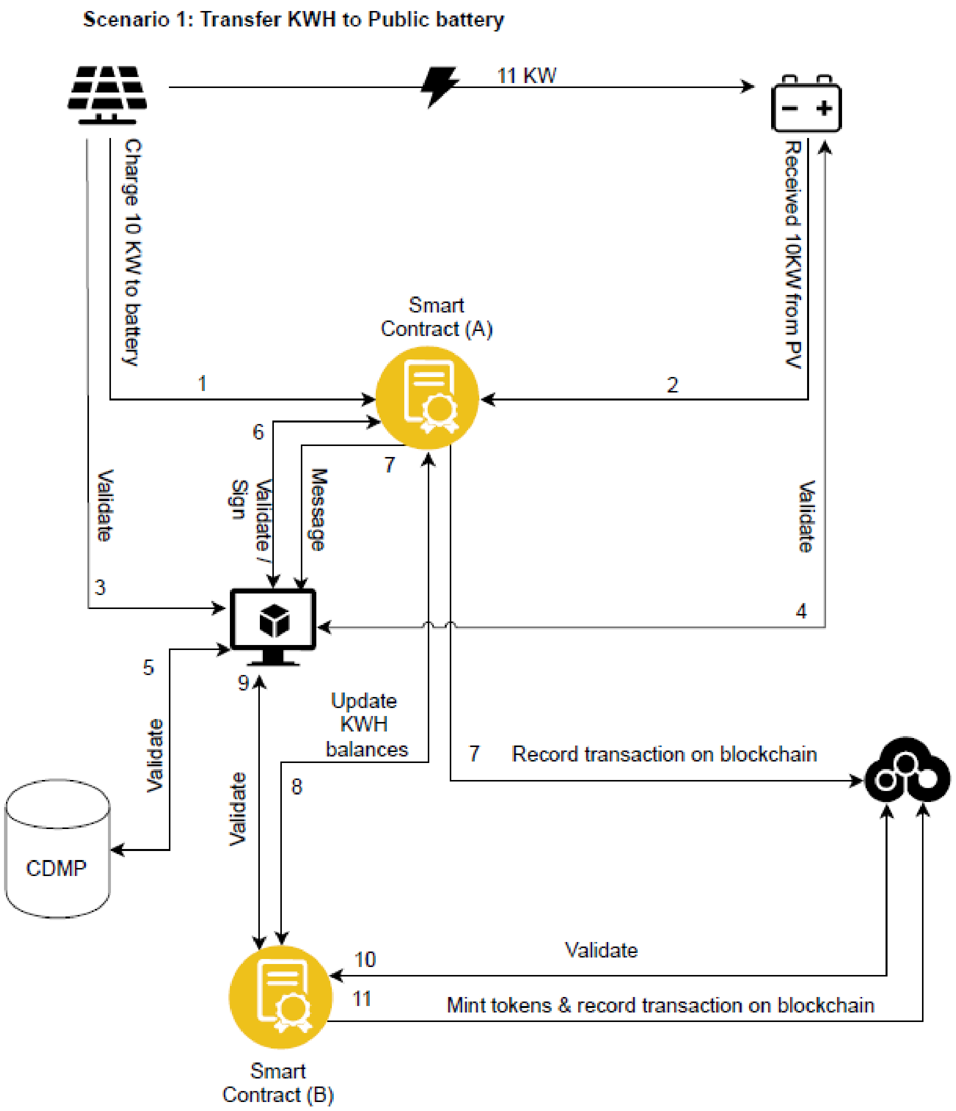

Figure 3. RES to Storage

4.2 Storage to Dwelling

In this scenario a prosumer consumes energy from storage (public/private) and where the energy consumed is owned by the prosumer. The physical energy is transferred from the battery to the dwelling and KwH balance (reflected in tokens) are burned.

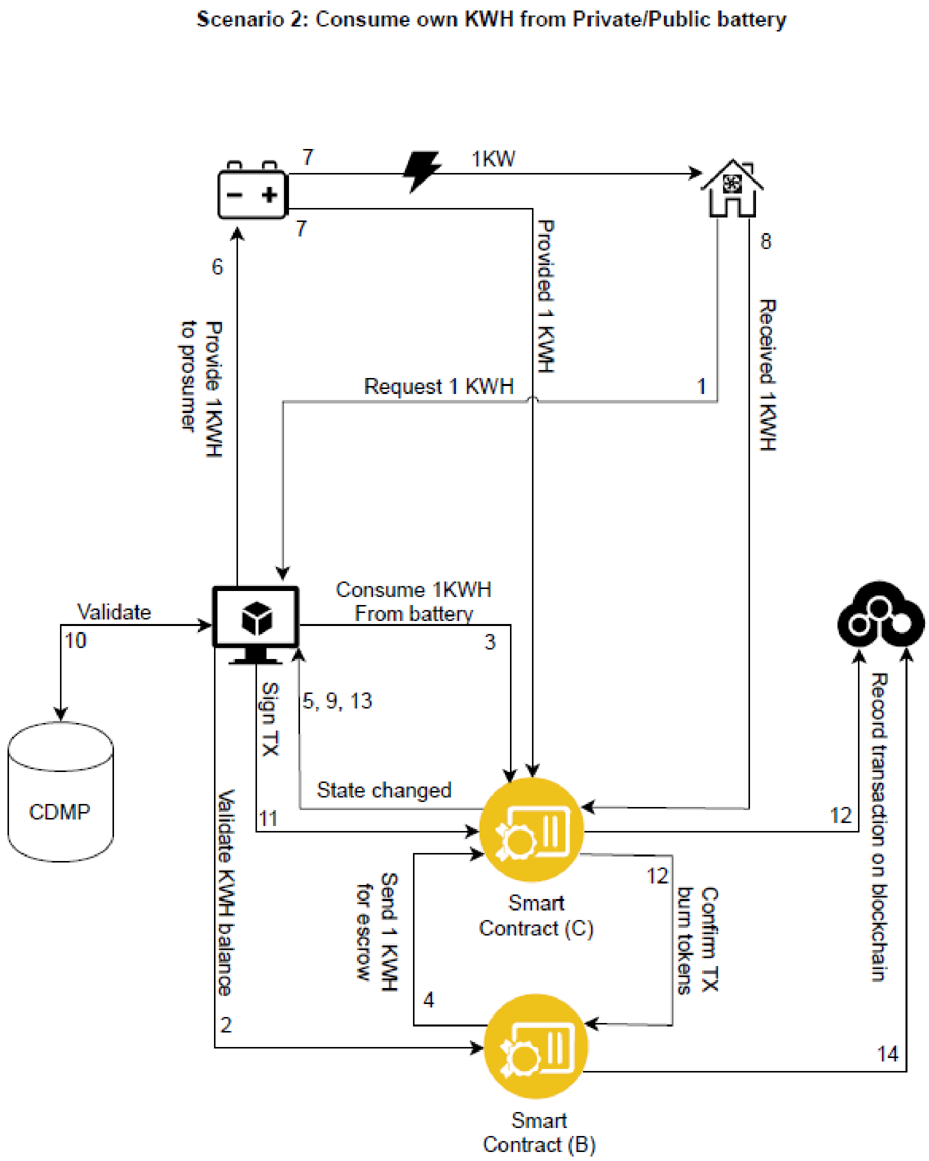

Figure 4. Storage to Dwelling

4.3 Prosumer 2 Prosumer

In this use case scenario, a prosumer offers to sell the generated energy to another prosumer. This type of transaction is executed in an auction style fashion where the seller puts the energy up for sale when the price of the local energy market is within a certain range. A buyer submits a buy order that contains specific detail regarding the amount of energy and the price as well as the date and time of delivery. A matching service executes the transactions which in turn informs the battery to perform the physical supply and the ledger records the KWh and transaction of tokens between prosumer wallets. Prosumer to prosumer transactions can take place from a battery directly to a dwelling or from battery to battery.

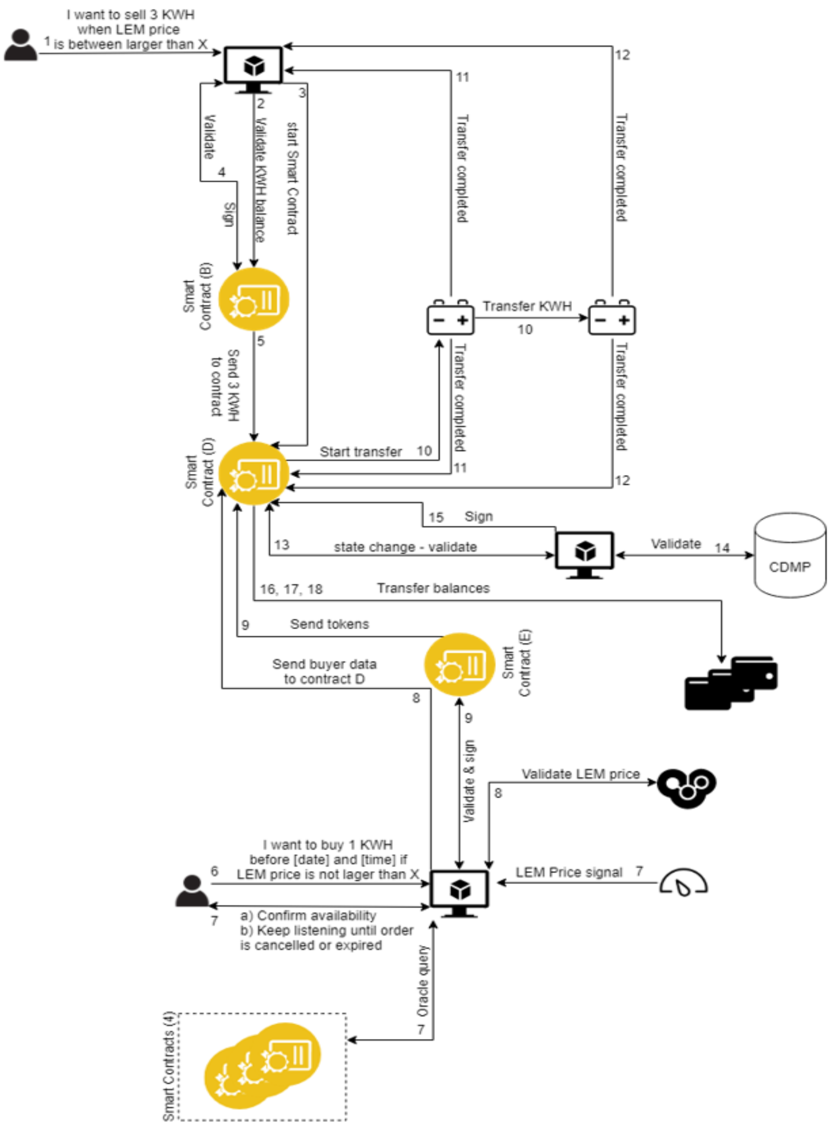

Figure 5. Prosumer 2 Prosumer

4.4 DR Reward

The DR event is based on load forecasting of RES. This forecast is then used in a flexibility module where prosumers are recommended to adjust the consumption of high consuming appliances on different times. There are two scenarios, one where the flexibility is based on load/price and the other on the availability of RES, i.e., when there is not much RES and the load increases, prosumers are requested to reduce their energy consumption. Similarly, when there is a high amount of RES forecasted, prosumers are advised to run larger loads during those times.

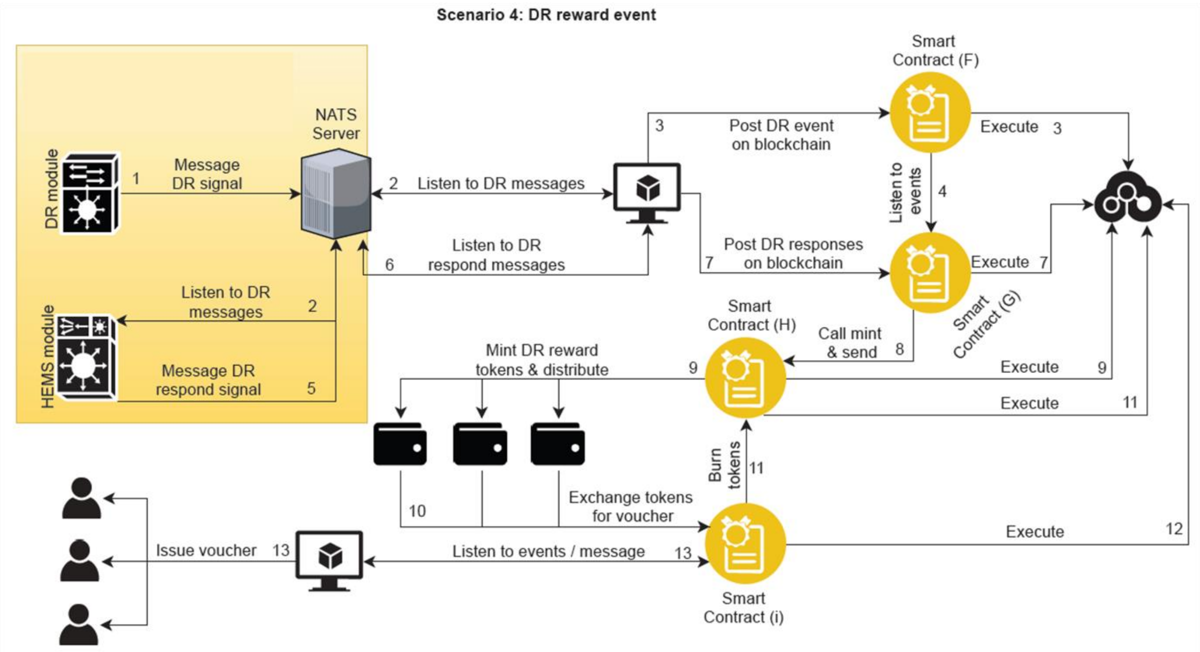

Figure 6. DR Reward

4.5 Transaction Settlement (Smart Contracts)

Transactions are settled based on Active Power & Active Energy values in 5 minute intervals. Each transaction settles the complete flow of energy to include:

- PV generated energy, feed in to main grid, consumption from main grid, charge of battery, discharge of battery, total consumption of dwelling, active sales or purchase contract over period, energy sold, energy purchased.

- ○ Battery charging & discharging as well as Energy sold or purchased includes minting, burning or transferring "kWh tokens" which represent energy in kWh and "TwinERGY tokens" which represent fiat currency

Figure 7 shows an example of settlement on Smart Contracts:

- Each smart meter post values directly to the Blockchain
- Each grid/circuit infrastructure type will have its own Settlement Smart Contract
- Each settlement contract interacts with sales contracts, token contracts and other settlement contracts
- Settlements are recorded on the Blockchain via a logic and data contract. This provides flexibility and scalability

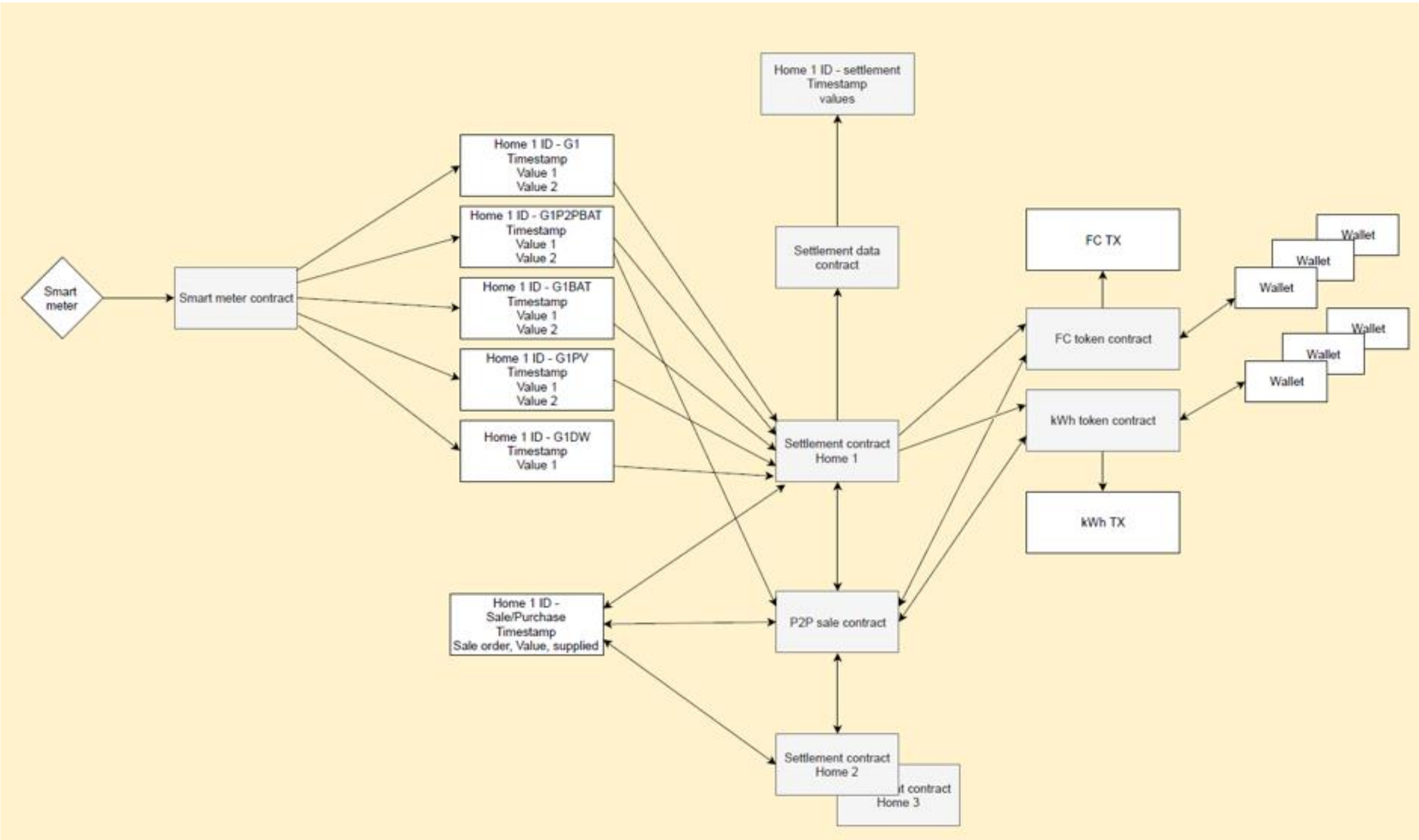

Figure 7. Settlement on Smart Contracts

5/ Pricing Methodology Algorithm

5.1 Background Information

The participants in a local energy market environment can be of different types and needs (e.g. prosumers, consumers etc.). Participants who produce part of their energy needs are called prosumers, while the ones who do not have a production asset and rely 100% on the external grid or on the other participants within LEM are consumers. As shown in Figure 8, all these different types of participants are able to form an energy consortium in which the transactions are first settled locally, and any energy deviations are covered by the external grid.

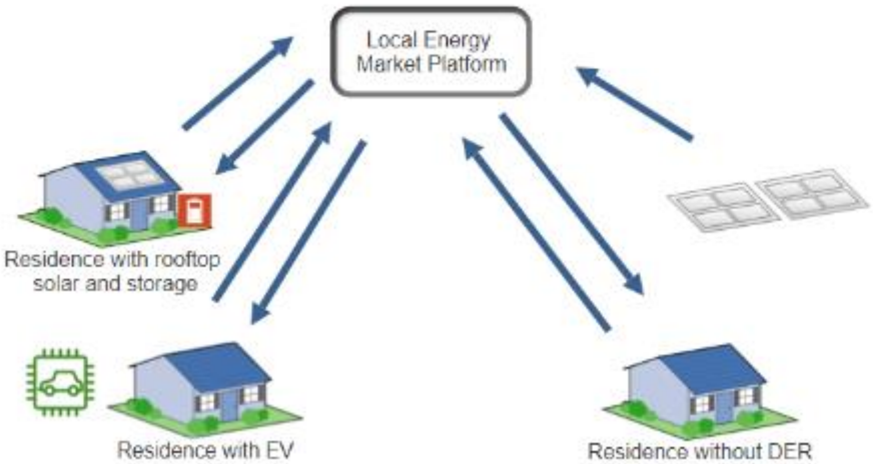

Figure 8. Simple framework of a Local Energy Market Platform

To this end, the market design of a Transactive Energy Market (TEMkt) is an important feature for the operation of the market environment. The pricing rules and the overall market architecture should be clear and known to the market participants to ensure the transparency of the market.

The transactions are facilitated between the different market participants (consumers or prosumers). The minimum number of participants which define a Transactive environment is two, since a transaction can be established. The operating costs within such an environment should be minimized.

A fundamental pricing property of a Transactive Energy Environment is that a potential transaction is settled at a lower price, in comparison with the external DSO pricing, to provide the necessary incentives for participation. Specifically, a two-sided market is considered, in which players both from supply and demand side respond actively to changes in price. A two-sided energy market will unlock data on consumer side that is hidden 'behind the meter', and add value to the household energy technology. (P.Pinson, 2017)

For the market price determination, a pool-based approach is considered. To be more specific, the energy within the Transactive environment (both from supply and demand side) becomes available for transactions between the participants. As already highlighted, the energy within TEMkt is lower compared to the external pricing, creating an arbitrage and thus incentivizing the participation. The proposed pool-based market approach has certain advantages which are listed below:

- **Minimal market participation:** The participation of a consumer/prosumer in a market environment should be expected to be relatively small. Therefore, an approach in which a direct bidding from each market participant is required, even in the case of higher economic benefits, would be harder to be successful due to non-consistent market participation. Therefore, in our proposed market approach the active participation though a direct bidding of a market player is not required as the price is deducted centrally from the pricing algorithm and the only input required is the available energy.
- **Easier access for many participants:** The criteria for entering the transactive environment under the proposed pricing approach are minimal. This makes it easier for new players to enter the market. In case the new players have production assets (e.g rooftop PV plants/batteries), they are prosumers and enter the market from supply/demand side, otherwise they are just normal consumers (demand side).
- **No exert of market power:** Market power refers to the ability of manipulate the market price by manipulating the level of supply, demand, or both. Considering that direct bidding is not allowed by the market participants, market power from a participant (if present) cannot be exerted. For e.g. in case of a market environment in which above 50 % of production assets belong to the same participant, this participant could definitely influence LEM's price in case direct bidding was allowed. On the other hand, in the pool based approach without

bidding, the extra energy becomes available to the whole energy community and the price is centrally computed by the operator of the market.

- **Easy applicability:** The applicability of the proposed algorithm is straightforward since all the necessary data are either taken directly from smart meters or other IoT devices.

5.2 Necessary Inputs

For the proposed pricing methodology, there is a list of necessary inputs which are considered important for determining the price at which the transaction within the market environment is settled. The list of inputs refers both to production and demand side within a Local energy environment. The production and demand levels (which are taken by the necessary modules) are aggregated for the participants of the community and are considered input parameters in our algorithm. It is important to define accurately the production and demand levels within the community as both are key signals of the final deducted price. As far as the granularity of the LEM price is concerned, and how often this value shall be updated, this will be deducted from the granularity of the necessary input parameters.

The fundamental market property which implies that in time intervals with high demand and low supply levels, the price is high also rules the proposed market structure. The exact opposite holds true for hours in which the demand is low and the production levels high. These 2 cases constitute the solution limits of our proposed pricing methodology. For all the other cases the price will lie in between these 2 'extreme' scenarios. Nevertheless, in all cases the price should be beneficial (in terms of monetary profit) for the participants in the market. This is constantly ensured by having the external DSO tariffs, as inputs to our pricing algorithm to define the upper/lower limits of the proposed solution. Without taking DSO pricing into consideration, it can be ensured the financial viability of the Local Energy Market. For cases in which the DSO pricing changes depending on the hour of the day (for e.g 2 different tariffs), different limits are considered to be included in order to incentivize LEM participation.

5.3 Output of the pricing algorithm

As already described in the previous sections, the main output of the pricing methodology algorithm is the price at which the transactions among the different participants in the energy community will settle. The monetary benefits of market's participants will be computed based on this price depending on the amount of transacted energy in every market interval.

The solutions given by the proposed algorithm, can be also represented in a 3-D plane for clarity purposes. In Figure 9, the plane of the accepted LEM prices for different levels of demand and production within the market, is illustrated. The accepted price range is bounded by the maximum and minimum limits set by the DSO. For the illustration of Figure 9, dummy data were considered that are not relevant with data coming from TwinERGY's pilots. (N.Andriopoulos,2020)

To this end, it is evident that in market intervals of High demand / Low generation, LEM's price is considerably higher compared to intervals which the opposite criterion stands (Low demand/ High generation). In any case, the accepted prices do not violate the DSO pricing 'external threshold'.

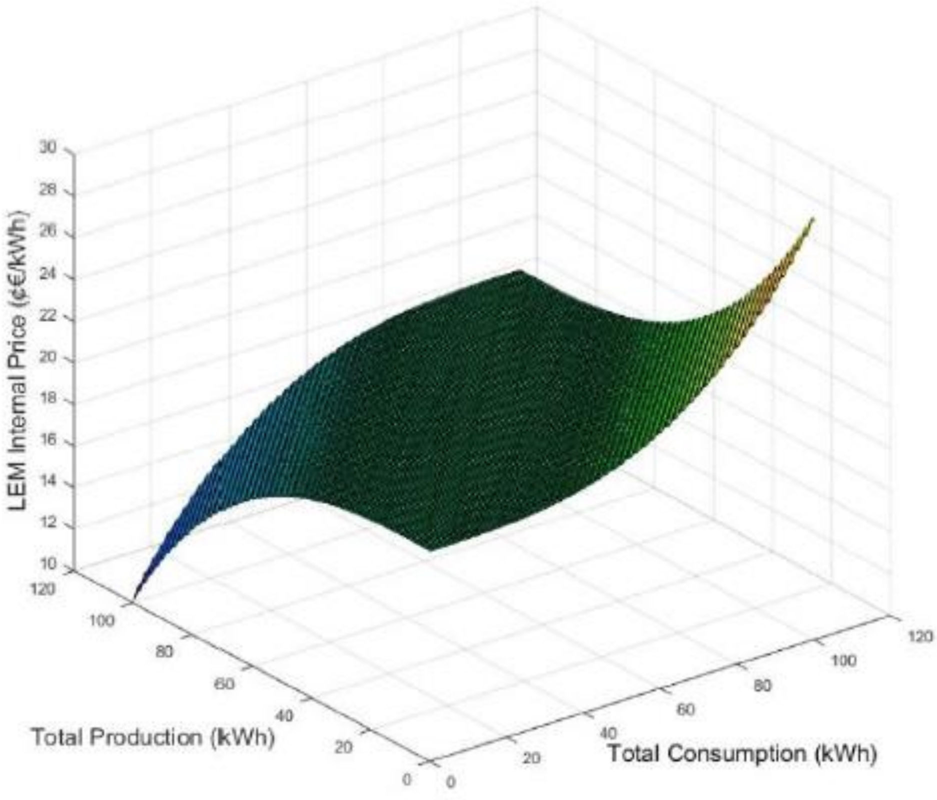

Figure 9. Local Energy Market price plane

Finally, in Figure 10 a pseudocode snippet of the pricing algorithm is given. In the snippet, the different inputs (already described) are given and they are processed to deduct the final internal LEM price. The algorithm that determines the final pricing surface is predetermined by the LEM operator and it communicated to the participants. The main characteristic that the proposed function shall have, is the smoothness of its gradient. By having this feature the pricing will depict better the changes in local production/demand and the pricing will be calculated in more fair way. In Figure 9 the function that is utilized is the x^3, however one can choose other similar function like the Sigmoid, the logistic etc. (N.Andriopoulos,2020)

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Algorithm 1 Pricing algorithm

Input: feed-in tariff (π_{buy}), feed-out tariff (π_{sell}), production (p), consumption (c)
Output: internal clearing price(π_{int})

Get π_{buy}, π_{sell}
Surface representing production and consumption
Assign fair values to surface
if ($c = 0$) **then**
    $\pi_{int} \leftarrow \pi_{buy}$
end if
if ($p = 0$) **then**
    $\pi_{int} \leftarrow \pi_{sell}$
end if
if ($c = p$) **then**
    $\pi_{int} \leftarrow (\pi_{buy} + \pi_{sell})/2$
end if
Interpolate the diagonals with a predetermined function
Mirror the results to the remaining diagonals
Do a weighted interpolation from the closest calculated values

Figure 10. Local Energy Market pricing algorithm (pseudocode)

6/ TEM Demonstration

The purpose of this section is to demonstrate the different functions developed under the Transactive Energy Module and how they interact with the user in order to provide the necessary effect prescribed in the specifications above, as well as, reach the goals and objectives of the TwinERGY project in general.

The functionalities of the system are presented in the following sections for better understanding of the TEM concept.

6.1 Login and Authorization

As soon as the user accesses the Transactive Energy Module, either through desktop, laptop, tablet or mobile device, he/she will see the starting splash screen (Figure 11) of the module. The module has fully responsive design so the experience is equally enjoyable between the different type of devices.

Figure 11. Splash Screen

From here, the user is directed either to the login screen or to the registration screen (if it is a new user and this is the first time use of the TEM).

If the user has already registered a profile in the TEM, it can login by using its credentials (username and password) or, if enabled, it can go in straight into the module dashboard by providing a pre-set passcode or face recognition (provided that the device has that option available as security login option) (Figure 12).

Option 1: Username & Password

Option 2: Passcode or face recognition (optional and limited to device type)

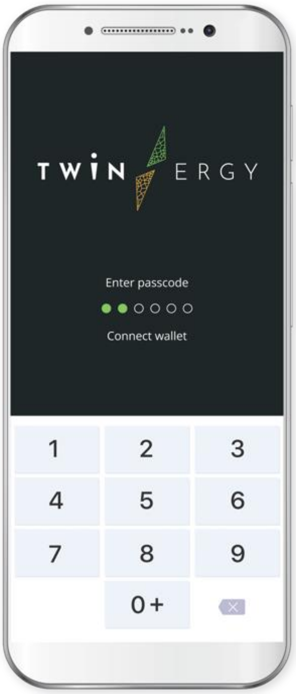

Figure 12. Login option

In case that the user has no registered profile with TEM yet, then a basic profile registration is required. In this process, apart from the general information of the user (such as name, surname, address, email etc.), it is of essential importance that the user

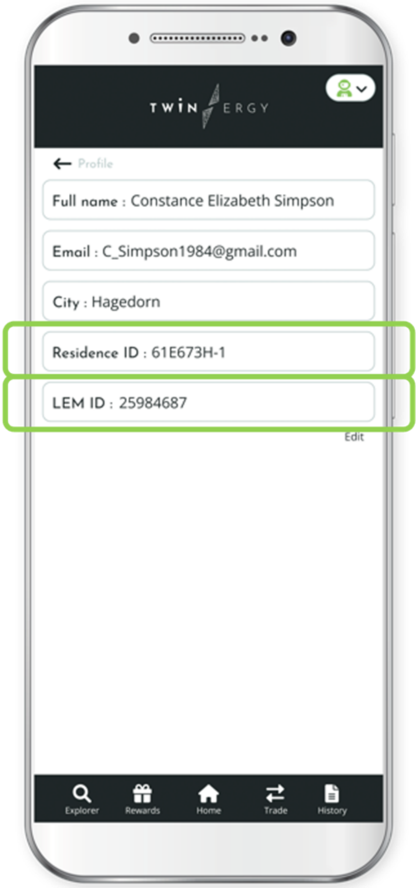

Figure 13. Correct User Registration

correctly administers the unique Reference ID and LEM ID since these will be crucial for proper operation of the module (Figure 13).

In case there is a mistake of the user information and especially the association to the user IDs needed for proper system operations, then an edit option is available in order to remedy swiftly the wrong information input (Figure 14).

Figure 14. Edit User Profile

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6.2 Home Page / Dashboard

Given that the user has successfully registered and/or logged in the TEM, the home screen or what we call the main dashboard will be the next thing visible on the screen. On this screen the user will be able to access and navigate through all necessary functions and have the most important information on display for quick overview or access.

Figure 15. Home Screen

Figure 16. Intuitive UI

The information visible to the user, as seen on Figure 15, is the following:

- LEM location
- LEM price chart
- LEM price
- Token balances
- kWh sale offers.
- User Profile
- Main Navigation Bar

Additionally, having in mind the importance of User Experience (UX) in the success rate of digital modules, we have made our User Interface (UI) to be fully intuitive, displaying explanation about a specific field when the user hovers over that exact field/object on the screen (Figure 16).

6.2.1 Home Page Display and Elements

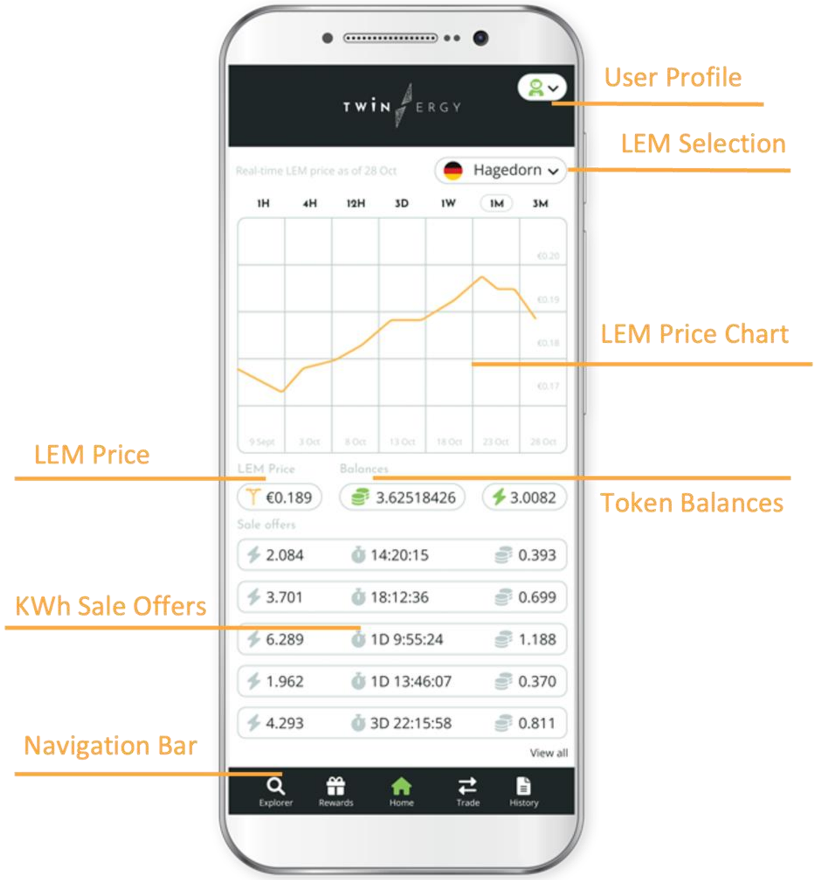

Figure 17. Home Screen Details

As seen on Figure 17, the user can manage the main navigation through this screen. The "User Profile" option will take the user to the Profile screen, where user information can be seen and edited. The "LEM Selection" option will enable the user to choose in which LEM the module will operate and display information accordingly. Hand in hand with the previous option is the "LEM Price Chart", on which the user can monitor historical data in comparison between time and price of the designated LEM. The next option in line for notice is the "Token balance". Here the user can clearly see the current balance that is available under the specific profile and LEM input. The balance can be altered during the buy/sell process or by adding more token through the wallet option, which will be explained further along this document. The "LEM Price" option shows the current, at the moment, market price. Furthermore, the "KWh offers" show the top selected offers which the algorithm has chosen as the most applicable options at that given moment for that current user. The "view all" option gives the possibility for the user to have a complete overview of all existing offers and not be limited only to the highlighted ones. At last, but not least, the "navigation bar" is a quick launchpad between different features which TEM offers. From there, the user can jump to explore/search keywords in the app connected to transactions, have a shortcut to visit the rewards screen, jump to the trade options or view historical data.

6.3 Settings Menu

The settings menu is quite important menu from the TEM, since here the user has the possibility to set up important information, necessary for proper operation of the module. As seen from Figure 18, from this menu, the user can:

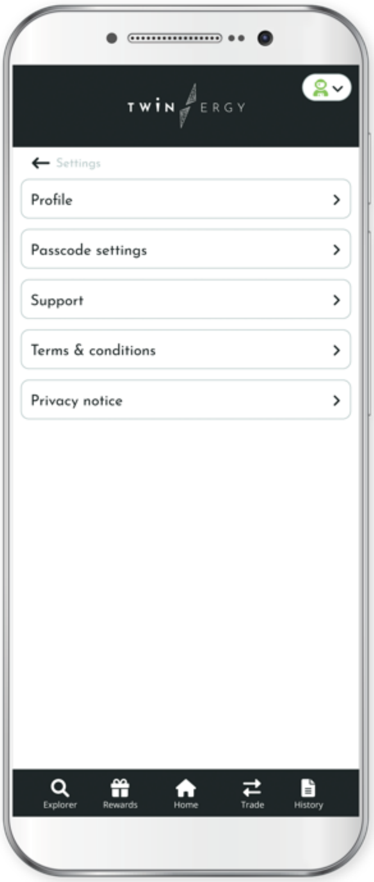

Figure 18. Settings menu

- Access the profile screen where profile information can be amended. Whether it is basic information, such as, name/surname, email address or more specific information in terms of LEM ID etc., this options offers quick and user friendly information process toolbox.

- The passcode settings are another important part for proper operation of the TEM, but also of crucial importance for security issues and concerns for the user personally. From here the user can change its passcode and security login information and options. Anytime the user feels that security may be compromised, he/she should immediately and without hesitation use the provided options to change the passcode and login credentials in order to ensure that the account is properly protected.

- Support provides direct access to our support team, which are highly trained and always happy to help the user solve any issue concerning the flawless operation of TEM.

- Terms and conditions, together with privacy note are at user's disposal in order to be fully informed by the legal acts accompanying the use of TEM.

6.4 Energy Trading Options

Without any doubt, this part constitutes the core and essence of the TEM operational existence. Here the users are enabled to buy and sell energy, participate in the LEM and trade according to the options provided by that specific LEM.

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6.4.1 Buy KWh Options

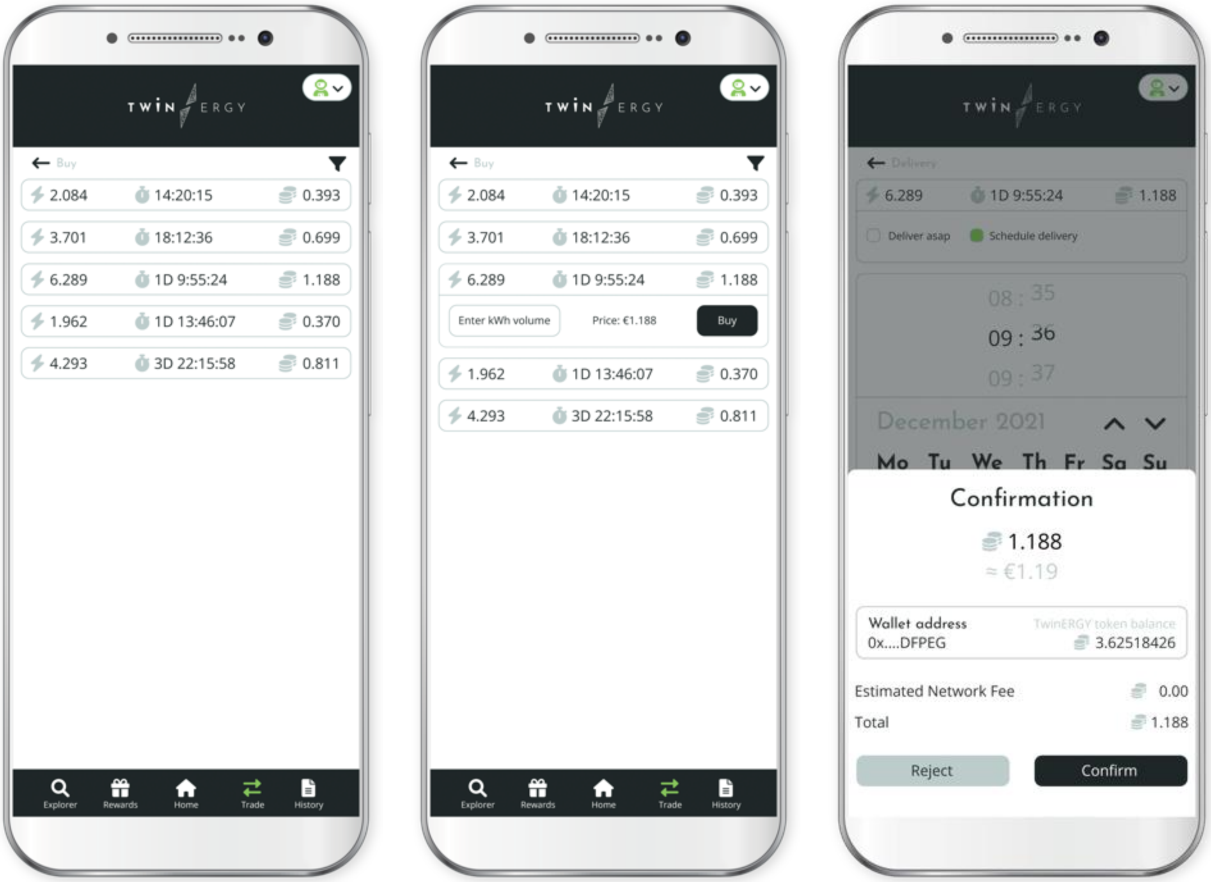

Figure 19. Buy Option Screens

The Buy Option is designed in order to provide the best and frictionless user experience for the user in order to be able to trade and in general use TEM with full satisfaction and enjoyment. As shown on Figure 19, the user can clearly see the current offers for buying in the market and according to that can make its calculation and decision. Again, as mentioned before, all fields have intuitive UI, displaying descriptions when hovered on top of them.

The first field represents the available KWh capacity under that offer, the second field represents the timing of the offer availability and the third fields denominates the value of that specific offer in tokens. (Figure 20)

Figure 20. Buy offers

Furthermore, for enhanced UX, TEM offers two options: direct buy or scheduled delivery buy. In case the user decided to go for the direct buy option, all that is needed is to select the desired offer, insert the KWh (in case it doesn't want to purchase the entire amount), verify the offered price and accept the purchase by clicking the "Buy" button (Figure 21).

Figure 21. Direct Buy Screen

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The second option provided in TEM is the scheduled delivery buy option. Here, as illustrated on Figure 22, the user gets to choose a date when the buy process should be closed and put into effect. From here the user can select the date and time of the delivery and see the information associated with that purchase. If the transaction and the conditions are acceptable the user can confirm the transaction, otherwise, if not satisfied by something in that specific transaction the user can also reject it.

Figure 22. Scheduled Delivery

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6.4.2 Sell KWh Options

This option as part of the TEM, offers to the user the possibility to sell KWh on the market. The design is done in accordance with our principle for clear and user friendly interfaces throughout the whole TEM concept.

Figure 23. Sale Order Screen

The process starts with creation of the sales order once the user decides to offer KWh to the market. As seen on Figure 23, in order to place the sales order, the user must fill in key information in order for the system to accept and post that sale. Here, the user must provide the volume of KWh that is for sale, set an expiry date after which the sale will not be active anymore and confirm the stated information. The confirmation process is similar to the one explained briefly before in the buy section (Figure 24).

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Figure 24. KWh Sale Confirmation

Once this is done, the sale is active in the TEM system and other users can see it. During this process, the KWh tokens are escrowed until delivery. When the sale is completed, the user gets notification and the tokens are released and transferred to his/her wallet, updating the balance in TEM for that user.

Figure 25. Sales order notification

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6.4.3 View Pending and In Process Transactions

This is a very nice and simple option where the user can have a fast overview of the transactions which are pending, but also transaction which are in process. As illustrated in Figure 26, the fields providing information are:

- Type of transaction – buy or sell
- Status – weather is pending or in process
- ID – association with the user in relation to the transaction
- Purchase and delivery dates
- Expiration date
- Delivery progress – concerning transaction which are still in progress, so the user can monitor directly how the progress is going.
- KWh involved in the deal
- Transaction unique ID in the blockchain

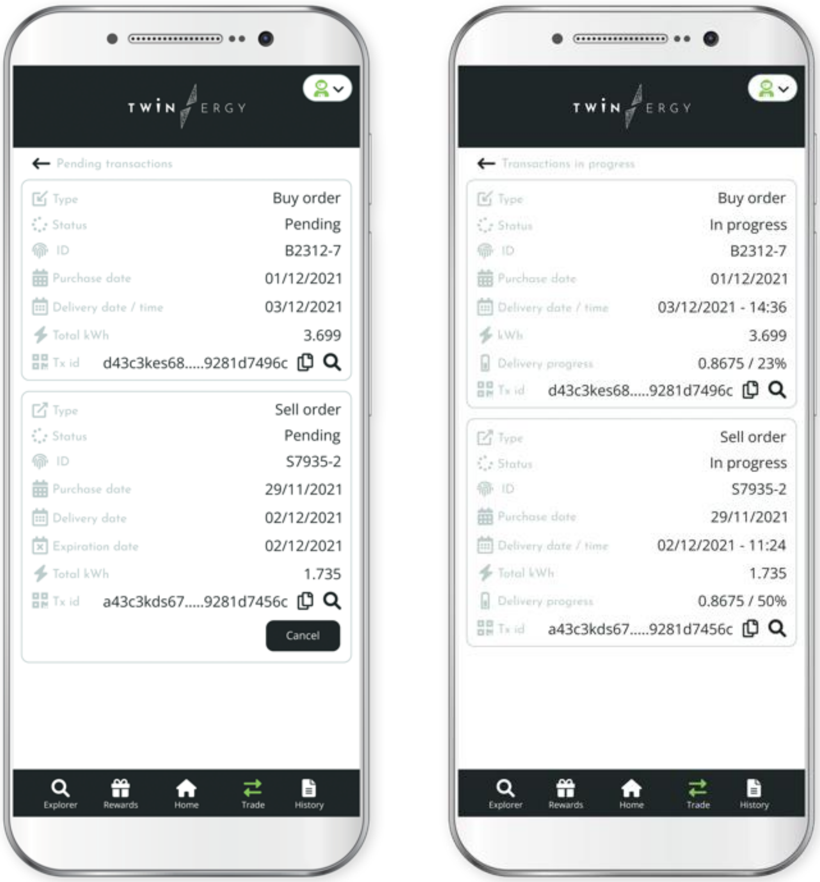

Figure 26. Pending & In Process

6.5 Rewards

This option in TEM comes very handy since the user is able to convert DER tokens to vouchers or other type of incentives and rewards, especially in markets where monetisation of the actions and transactions is not yet possible. In this way, the user will be able to rip the benefits of the transactive energy paradigm in a satisfactory and meaningful way. The screenshot (Figure 27) shows an example of an available reward offered to the user. The user has an overview of its own points balance and also can see each available offer in value, so he/she can decide which one to peruse or otherwise abstain and wait for other offers.

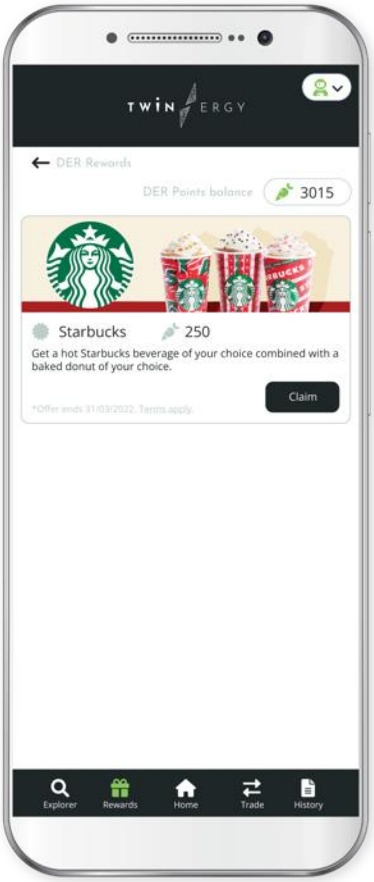

Figure 27. Rewards

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6.6 History and Explore

History and explore options give the possibility to the user to browse through different transactions, make its own analysis, draw conclusions and possibly formulate future strategy and actions in TEM. As illustrated in Figure 28, there are several filtering and search options available.

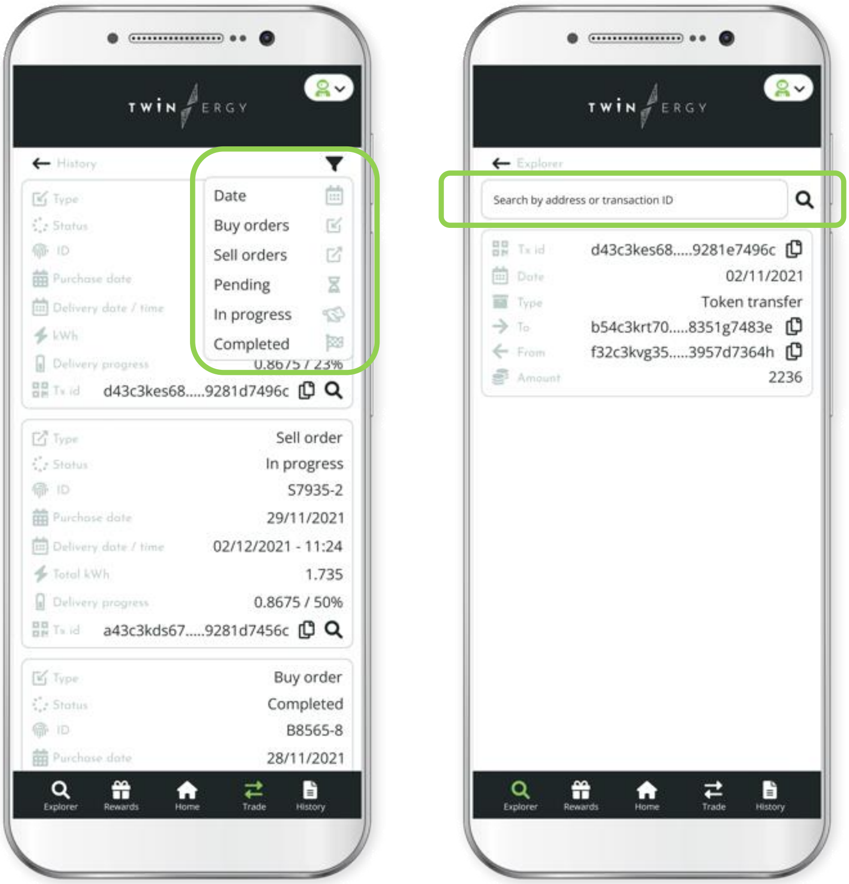

Figure 28. History & Explore

7/ Conclusion

This documents manages to capture the essence of the Transactive Energy as a state of the art concept and how this is translated into development of the Transactive Energy Module as part of our TwinERGY project.

It manages to capture the development process of the Transactive Energy Module, from the beginning phase of setting up the basic requirements, introduction to the issues which we faced in the pilot sites, the solutions which are developed to overcome those issues, all the way to the very end of having a working solutions presented to the user with all of its operational beauty, user experience and features.

The basic components of Transactive energy module along with the specific requirements are presented. In addition, the 4 different transaction types between the participants in the pilot sites are identified. The pricing algorithm, followed in this TE market, is analytically described to showcase the rationale behind the pricing methodology.

The deliverable exposes the results of the work carried out under Task 7.7 "Transactive Energy Module", whose aim is to design and develop a module that provides high-value services to TE markets.

The working solution will be pilot tested in real TE environment in the project pilot sites in Germany, Italy and UK.

Reference List

Andriopoulos, N., Bachoumis, A., Alefragis, P., & Birbas, A. (2020, September). Optimization of a local energy market operation in a transactive energy environment. In 2020 17th International Conference on the European Energy Market (EEM) (pp. 1-6). IEEE.

Cazalet, E.; De Martini, P.; Price, J.; Woychik, E.; Caldwell, J. - Transactive Energy Models. *NIST Transactive Energy Challenge: Business and Regulatory Models Working Group,* September 2016

Giehl, J.; Gocke, H.; Grosse, B.; Kochems, J.; Muller-Kirchenbauer, J. – Survey and Clasification of Business Models for the Energy Transformation. *Energies 2020,* 13, 2981; doi:10.3390/en13112981

Hall, S.; Brown, D.; Ehrtmann, M.; Holstenkamp, L. - Business Models for Prosumers in Europe. *PROSEU D4.1 (2020), Horizon 2020 PROSEU project (H2020-LCE-2017)* Grant Agreement N 764056

Küfeoğlu, S; Liu, G.; Anaya, K.; Pollitt, M.G. - Digitalisation and New Business Models in Energy Sector. *Research Gate,* Technical Report, June 2019

Papalexopoulos, A.; Hansen, C.; Frowd, R.; Tuohy, A.; Lannoye, E. - Impact of the transmission grid on the operational system flexibility. *In Proceedings of the 2016 Power Systems Computation Conference (PSCC)*, Genoa, Italy, 20–24 June 2016; pp. 1–10.

Papalexopoulos, A; – WEC internal research work (2021)

Papalexopoulos, A - WEC internal research work (2022)

Pinson, P., Baroche, T., Moret, F., Sousa, T., Sorin, E., & You, S. (2017). The emergence of consumer-centric electricity markets. Distribution & Utilization, 34(12), 27-31.

TwinERGY Consortium, "TwinERGY - Innovation Action," 2020.