Roadmap for virtual transaction platform - P2P Tractebel platform for a residential neighbourhood

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 837758.

Acknowledgement

This report has been produced within the SocialRES project "Fostering socially innovative and inclusive strategies for empowering citizens in the renewable energy market of the future".

WIP Renewable Energies coordinates the SocialRES project.

The consortium involves 13 partners in 9 European Countries.The logos of the partners cooperating in this project are shown below and information about them is available in this report and at the website: www.socialres.eu

This report has been written by Petrică Radan, Daniela Leonte, Florin Ciausiu, Alexandru Costeniuc from TRACTEBEL. The authors thankfully acknowledge the valuable contributions from all project partners.

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 837758.

Technical References

Project Acronym	SocialRES
Project Title	Fostering socially innovative and inclusive strategies for empowering citizens in the renewable energy market of the future
Project Coordinator	Silvia Caneva WIP – Renewable Energies silvia.caneva@wip-munich.de
Project Duration	44 months (May 2019 – December 2022)

Deliverable No.	**D4.5**
Dissemination level*	PU
Work Package	WP 4 - Networking, co-creation and mutual learning
Task	T4.4 - Development of innovative business models
Lead beneficiary	TRACTEBEL
Contributing beneficiary/ies	
Due date of deliverable	31 July 2012
Actual submission date	14 September 2022

* PU = Public

PP = Restricted to other programme participants (including the Commission Services)

RE = Restricted to a group specified by the consortium (including the Commission Services)

CO = Confidential, only for members of the consortium (including the Commission Services)

v	Date	Beneficiary	Author
1.0	15/08/2022	TRACTEBEL	Petrică RADAN, Daniela LEONTE, Florin CIAUSIU, Alexandru COSTENIUC
2.0	06/09/2022	WIP	Silvia Caneva

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Table of Contents

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 837758.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 837758.

List of Tables

List of Figures

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List of Abbreviations

Acronym	Description
ACER	The European Union Agency for the Cooperation of Energy Regulators
ANRE	National Authority for Energy Regulation
AON	All or None
BRP	Balance Responsible Party
CACM	Capacity Allocation and Congestion Management
CET	Central European Time
CMBC-EA	Centralized Market of Bilateral Contracts with Extended Auction
CMBC-EM	Centralized Market of Bilateral Contracts with Extended Auction mechanism
CMBC-FP	Centralized Market of Bilateral Contracts with Fuel Processing mechanism
CMLT	Centralized Market for Long Term Electricity Contracts
CM-OTC	Centralized Market with Double Continuous Negotiation for Electricity Bilateral Contracts
CME-RES-GC	Centralized Market for Electricity from Renewable Sources Supported By Green Certificates
CMUS	Centralized Market for Universal Service
DAM	Day Ahead Market
DR	Demand Response
DSO	Distribution System Operator
ESS	Energy Storage System
EU	European Union
EV	Electric Vehicle
FOK	Fill or Kill

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GHG	Greenhouse Gas Emissions
GFS	Good for Session
GTD	Good till date
IDM	Intraday Market
IOC	Immediate or Cancel
LCM	Electricity Market for Large Consumers
LV	Low Voltage
MCP	Market Closing Price
MV	Medium Voltage
NEMO	The Operator of the Electric Energy and Natural Gas Market "Opcom" S.A.
NFA	Authorized physical notification
OMP	Organized Market Places
Opcom	Romanian gas and electricity market operator
PCR	Price Coupling of Regions
P2P	Peer to Peer
PE/PPE	Balancing Market / Balancing Market Participant
PV	Photovoltaics
RE	Renewable Energy
REC	Renewable Energy Community
RED	Renewable Energy Directive
RES	Renewable Energy Sources
SEN	National Electric Power System
SIDC	Single Intra-Day Coupling
SME	Small and Medium Enterprises

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TSO	Transport system operator
UD/CD/ISD	Dispatchable Unit / Dispatchable Consumer / Dispatchable Storage Facility

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Executive Summary

The Electricity Market Directive (EU) 2019/944, the Regulation (EU) 2019/943 and Renewable Energy Directive (EU) 2018/2001 emphasize the concepts of ‘citizen energy communities’ and ‘renewable energy communities’. Moreover, the terms 'aggregator' respectively 'independent aggregator' and 'peer-to-peer energy trading' are defined in order to enable for example prosumers to actively participate in the energy market and consequently contribute to its democratization.

As member of the project consortium SocialRES, TRACTEBEL contribution to foster socially innovative and inclusive strategies for empowering citizens in the renewable energy market of the future consists in developing a pilot trading platform for virtual energy transactions and a recommendation for actions needed to enable in the reality the concept of energy trading between smaller market actors, being consumers, producers, prosumers, energy communities and cooperatives or aggregators.

For the time being, although EU legislation foresees definitions and explanations for the necessary ‘roles’ of ‘energy citizens’ and corresponding interaction schemes, there is still great need for clear, precise, and compulsory EU directives and especially local legislative action to pave the way for all these concepts implementation.

For example, the Renewable Energy Directive II obliges member states to transpose the ‘aggregator’ concept and definition into national legislation but although this already happened, the reality in Romania is that aggregators are regulated only for the balancing market, and they manage only large production and consumption capacities.

Grid transport & distribution tariffs still reflect the old, centralized power generation model, meaning that a customer pays the same grid taxes whether he/she buys energy from a prosumer located in the vicinity or in another geographical region.

It would make sense for an energy community to acquire and manage the local grid in order to lower the energy transactions costs between members and enable a more efficient aggregation behind the utility meter; however, there are only few member states, who allow this, and energy distribution is mainly an oligopol market.

The Tractebel case study intends to demonstrate that legal concepts such as energy communities and aggregator are appropriate means to empower citizens in playing an active social role in the energy transition and simultaneously enjoy financial benefits.

The study briefly describes the functioning of energy markets, the concepts of energy community and aggregator and concentrates farther on the benefits of a virtual energy trading platform, that could empower these actors to efficiently join the energy market(s). Considering the status-quo of the energy market formation and the potential of new market actors such as energy communities and aggregators, the study concludes whether such new concepts would enable a democratic citizens’ social participation at new green energy trading and during which timeline.

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The economic-financial results following the simulation of the calculation of the revenues and expenses associated with the TEAP platform it will show the motivation "why to move forward" and what are the key actions for Energy Aggregator Concept Implementation.

The intent of this roadmap is to provide:

- Wholesale Energy Market Architectures Description
- A succinct description of Energy Communities' Concept and Energy Aggregator Concept
- The Aggregation Business Models
- Presentation of the Tractebel Energy Aggregation Platform (TEAP) Business Logic
- TEAP Application Design Architecture
- TEAP Case Study Results
- Future Monetization of Tractebel Energy Aggregation Platform
- Key Actions for Energy Aggregator Concept Implementation

The roadmap also highlights a strong positive gain for participants in a platform for virtual energy transactions as compared to the classic energy supplier scheme, highlights the energy regulations and bureaucratic barriers, highlights that these services need to be priced in a manner that incentivizes efficient behavior.

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Context

During the 2015 Paris climate conference, the EU and its Member States have committed to limit global warming well below 2°C with reference to pre-industrial levels in the legally binding Paris Agreement. The agreement targeted low carbon innovations in all sectors. The transition towards clean energy systems required particular attention, having a share of two thirds in the current greenhouse gas emissions. For this purpose, changes had to come.

The maximized deployment of RES (Renewable Energy Sources) with a share of >80% and a fully - integrated internal energy market within an Energy Union are part of the enablers to achieve a climate neutral, fair economy in Europe.

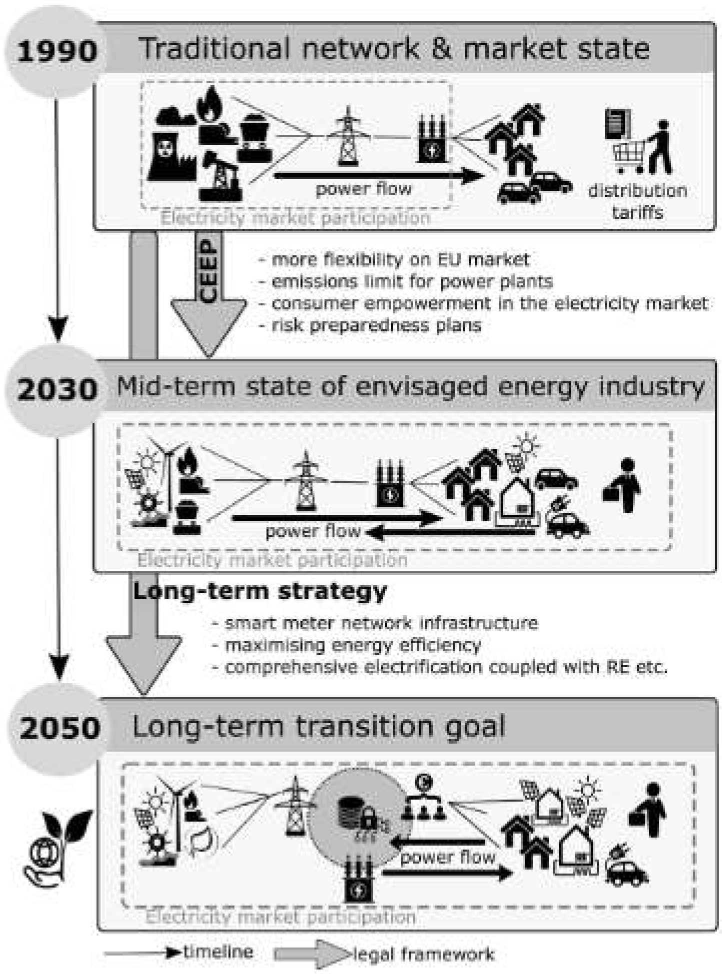

Figure 1 Summarizes simplified the envisaged transition of the European electricity network with focus on the residential network connection (Electrical Power and Energy Systems 134 (2022) 107361)

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The 2030 - goal introduces the combination of many small producers of RE (Renewable Energies), with ESS (Energy Storage System), EV (Electric Vehicle) integration and regular power plants. DR (Demand Response) coordination leads to a bidirectional power flow, which imposes different requirements on the existing infrastructure.

New business models, relying on adjusted legal regulations, are aspired to enable electricity customers to participate in the electricity market. The opportunity of new value streams and revenues entails a changing role of DSOs (Distribution System Operator) and TSOs (Transport System Operator) in the market. Load control and market participation of customers is enabled particularly through residential RES (Renewable Energy Source), ESS, EV and DR flexibility, which needs to be pooled and coordinated by an aggregator, for instance.

The long-term goal of the European Union is to achieve a climate neutral economy, with the energy industry at its heart. A maximized RE deployment of minimum 80% is thought to contribute to GHG emission reductions between 80–100% compared to 1990-levels.[1]

The collaboration between TSO, DSO, and all other stakeholders involved in the energy industry aims at providing a high level of energy security in Europe. Diverse market participants and asset owners, such as active interacting electricity consumers, participate in a sustainable, fair and transparent market competition.

Legislative parameters have to be reset in order to confer a more flexible design to the electricity market. The required steps and regulations for the transition of the electricity market in particular are designed in the (EU) 2019/943 Electricity Regulation and (EU) 2019/944 Electricity Directive.

"Market participation of final customers and small enterprises shall be enabled by aggregation of generation from multiple power-generating facilities or load from multiple demand response facilities to provide joint offers on the electricity market and be jointly operated in the electricity system, in accordance with Union competition law"[2]

[1] International Journal of Electric Power and Energy Systems, Electrical Power and Energy Systems 134 (2022) 107361

[2] Regulation (EU) 2019/943 of the European Parliament and of the Council of 5 June 2019 on the internal market for electricity, Art. 3 e)

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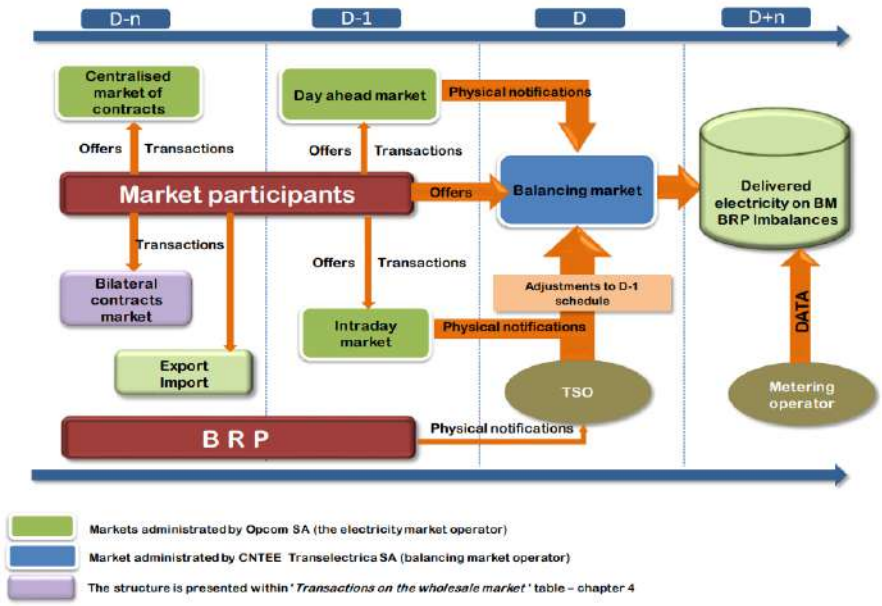
Wholesale Energy Market Architectures Description

Introduction

The size of the market is determined by the sum of all trades with wholesale energy products made by market participants, in which are included the resales made in order to adjust the contractual position or to obtain financial benefits, thus exceeding the amount of electricity physically transmitted from production to consumption.

The participants in the wholesale electricity market may conclude trades on organized markets, directly negotiated bilateral trades or electricity import and export trades.
The centralized markets, currently functional are the Day Ahead Market (DAM), Intraday Market (IDM), Centralized Market of Bilateral Contracts with Extended Auction mechanism (CMBC-EA-flex), with Continuous Negotiation mechanism (CMBC-CN), Centralized Market with Double Continuous Negotiation for Electricity Bilateral Contracts (CM-OTC), Centralized Market of Bilateral Contracts with Fuel Processing mechanism (CMBC-FP), Electricity Market for Large Consumers (LCM), Centralized Market for Universal Service (CMUS), Centralized market for electricity from renewable sources supported by green certificates (CME-RES-GC) and the Centralized Market for Long Term Electricity Contracts (CMLT).



[3]

Figure 2 Structure of the wholesale electricity market in Romania

[3] Energy Market Report – The national Authority for Energy Regulation

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Besides the markets organized and managed by the Romanian gas and electricity market operator (Opcom SA), trades are also carried out on the basis of bilateral contracts concluded through other OMPs (Organized Market Places), on the basis of electricity export and import contracts, as well as on the basis of directly negotiated bilateral contracts (including on contracts still pending at the time of the introduction of the legal obligation of transparent, public, centralized and nondiscriminatory trading on the competitive electricity market, according to Article 23, Law 123/2012).

Day-Ahead Market (DAM)

The Day-Ahead Market is a voluntary market, open both for the purchase and sale of electricity to all market participants: producers, suppliers, traders, network operators, system operators, under the conditions established by the applicable regulations in force. The Day-Ahead Market (DAM) was the first wholesale electricity market established in Romania in 2000. The DAM is a spot market, which reflects the short-term selling / buying intentions (quantities and prices) of the participants (for the next day) and usually creates the benchmark for evaluating the value of electricity. DAM creates a centralized market framework for the sale and purchase of electricity by all participants in Romania, necessary for:

- Facilitating the establishment of a wholesale electricity market under conditions of competition, transparency, and non-discrimination;
- Reduction of electricity trading prices;
- Establishing reference prices for other transactions on wholesale electricity markets;
- Optimizing the use of limited interconnection capacities with neighboring countries by applying the implicit allocation mechanism.

On DAM, firm electricity transactions are concluded for each dispatch / trading interval of the delivery day based on the offers submitted by the participants. DAM is a balancing market between demand and supply, their correlation (intersection) is carried out through the auction mechanism established according to the PCR (Price Coupling of Regions), determining the quantity that will be traded for a certain time interval, as well as the related price.

The market closing price (MCP) represents the sale price of energy for all sellers who offered a sale price lower than the MCP, respectively the purchase price for all buyers who offered a purchase price higher than the MCP. Each transaction corresponds to a physical delivery of electricity in the national electric power system (SEN) at a constant power on the delivery day of the respective trading interval.

Transactions concluded on the DAM at positive prices determine an obligation of the DAM participant to deliver electricity, if the transactions were based on sales offers, or an obligation to accept the delivery of electricity, if the transactions relied on purchase offers.

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Transactions can also be concluded at negative prices, with the meaning of providing a service of "removal" of electricity, by the participant who receives the respective energy to the participant who delivers it, not having the meaning of the delivery of goods by the participant who delivers the energy.

The delivery period has 24 trading intervals, except for Daylight Savings Day, which has 25 trading intervals, and Daylight Savings Day, which has 23 trading ranges. The peak period is between the time intervals 7-22, and the empty period between the intervals 1-6, respectively 23-24, time zone CET (Central European Time). Regarding the volatility and price level in the market, DAM is considered a market with high volatility and high prices.

Electricity prices are limited. This limit is periodically updated by National authority for energy regulation (ANRE), allowing free competition, but also prohibiting speculation.

In recent years, there has been a strong upward trend in the upper end of the price scale, enhanced by market coupling and unification of the electricity market in Continental Europe. The price scale in force for today's market published by the Market Operator OPCOM is comprised of [-500, +3000] EUR/MWh.

The **Table 1 Arithmetic average annual prices traded in DAM** shows the average annual values in DAM as well as the price variation for each year of analysis compared to 2020. It can be observed that there is a price decrease of -28.20% in 2020 compared to 2019.

Table 1 Arithmetic average annual prices traded in DAM

Year	2015	2016	2017	2018	2019	2020	2021
Average price (Jan-Dec)	161.84	149.56	219.96	215.95	238.55	196.56	539.00

Regarding anomalies (data outliers), the most anomalies were in 2017, 2019 and 2020. In 2015 there are no anomalies of price, therefore the price values are within the maximum and minimum limits. Values greater than Q_3 or less than Q_1 are considered anomalies. The limits considered in this analysis were determined with the following calculation formulas:

- Lower limit = Q_1 (25% percentile) – 1.5 * IQR,
- Upper limit = Q_3 (75% percentile) + 1.5 * IQR,

where IQR = Q_3 (percentile 75%) – Q_1 (percentile 25%),

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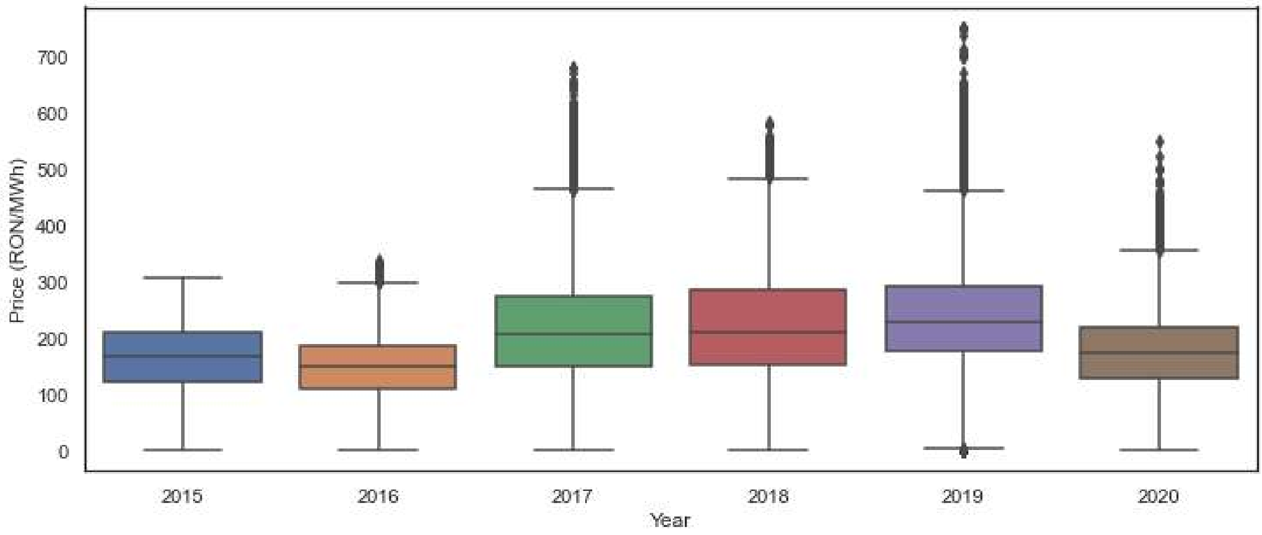

Figure 3 Average annual price values in the DAM market.

Table 2 Average monthly prices traded in DAM shows that the average monthly data has the trend of increasing prices in the market. This trend also can be observed during the year, which shows a strong seasonality. This is due to the increased demand for electricity in the cold season.

Table 2 Average monthly prices traded in DAM

Month/year	2015	2016	2017	2018	2019	2020
January	177.51	184.38	337.74	155.70	352.19	252.30
February	164.50	118.43	243.14	178.15	230.79	193.69
Apple	143.47	116.51	165.54	156.03	182.82	143.13
April	116.34	129.41	172.38	121.28	214.50	123.30
May	122.43	120.83	193.61	189.52	193.88	120.24
June	146.96	135.10	193.99	221.75	183.74	146.71
July	186.13	137.65	230.94	181.49	261.49	179.41
August	180.00	140.93	260.42	242.77	284.58	183.19
Septum	182.47	159.21	197.66	276.19	287.23	222.69
October	173.30	189.81	216.61	287.55	272.54	204.29
November	163.91	167.96	256.63	282.48	203.53	236.84
December	185.04	194.45	170.92	298.47	195.34	296.37
Average (year)	**161.84**	**149.56**	**219.96**	**215.95**	**238.55**	**176.89**

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Regarding price anomalies at the month level, from the analysis, most anomalies are present in the months of February and September, and the fewest are present in the summer months.

[4]

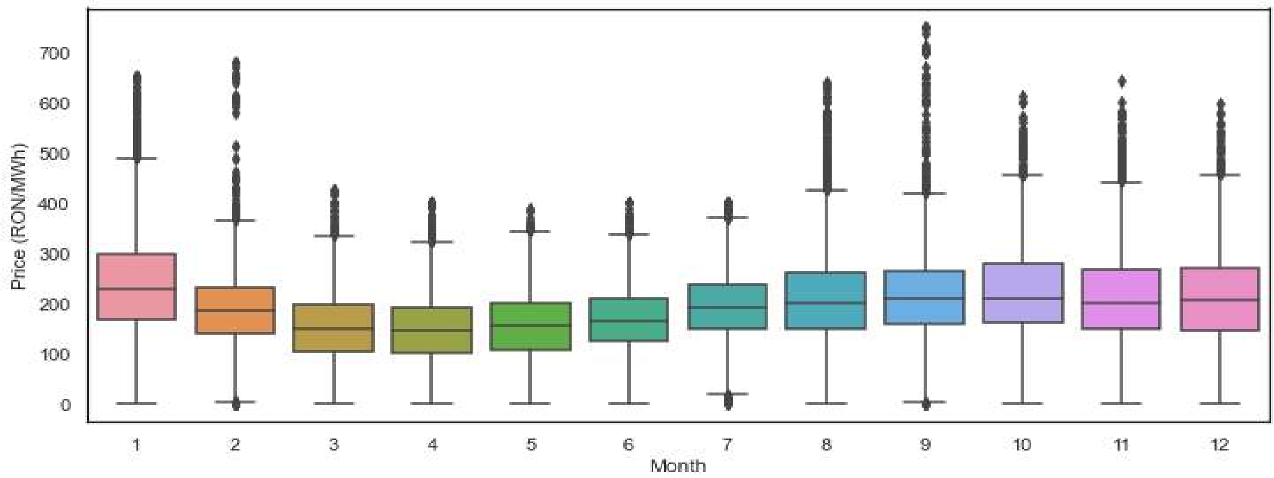

Figure 4 Average monthly prices in DAM.

Intra-Day Market (IDM)

The Intra-Day Market (IDM) is part of the wholesale electricity market where firm trades are concluded for each trading interval of the corresponding delivery day, starting with the day before delivery day after the Day-Ahead Market trading has finished and 1 hour before starting the delivery.

Starting with 19.11.2019 the Romanian Intra-Day Market is functioning in coupled mode with the markets from the other 22 countries participating in the European project SIDC-Single Intra-Day Coupling (previously known as XBID) with the goal of introducing pan-European cross-border trading on the Intra-Day horizon, respectively Austria, Belgium, Bulgaria, Croatia, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Hungary, Latvia, Lithuania, Luxembourg, Norway, The Netherlands, Poland, Portugal, Slovenia, Spain, Sweden and Italy (Italy is part of the European project known as SIDC – Single Intra-Day Coupling, as of 21 September 2021).

As the amount of intermittent production from renewable resources increased, interest in trading on Intra-Day Markets intensified, as it became increasingly difficult for market participants to establish a balanced position after closing the Day-Ahead Market.
Balancing as close to the time of physical delivery is beneficial for both market participants and energy systems, reducing, among other things, the need for reserves and the associated costs.

[4] Energy Market Raport - Romanian and Gas electricity market operator

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In addition, the Intra-Day Market is an essential tool that allows market participants to consider unexpected changes in consumption, as well as accidental interruptions.

The Intra-Day Market is a continuous market, with trading taking place every day up to one hour before delivery. In order to respond to the dynamics of supply and demand, OPCOM offers participants defined products in the context of the single intraday markets coupling. A product defines the rules that govern the generation of contracts. The relationship between products and contracts is 1 to 'n', meaning each product will have several contracts and each contract will belong to one and the same product.
The continuous matching trading algorithm will support the following types of orders:

Simple orders (also known as limit orders): Orders for buy or sale with a specified quantity and price, where the orders can be executed at that price or at a lower price and where the orders for sale can be executed at that price or at a higher price. Simple orders for the predefined market can be registered with NON, FOK (Fill or Kill) or IOC (Immediate or Cancel), (IOC) execution restrictions. Simple orders for the user-defined market always have the AON (All or None), execution constraint. All simple orders can be registered with GFS (Good till date) and GTD validity restrictions

Correlated offers: in the case of submitting related orders, either all the orders can be executed in full, or no order will be executed at all. An orders group can be submitted with this submission restriction, if it includes orders that have only the FOK execution restriction and if all the orders have been registered for the same trading area of a NEMO (Operatorul Pieței de Energie Electrică și de Gaze Naturale “Opcom” S.A. as a "nominated electricity market operator” (NEMO)).

Iceberg orders are simple orders that can be seen with only part of their total quantity on the market, while their full quantity is displayed on the market for correlation. The hidden part of the quantity will be visible for trading as soon as the slice that was visible has been executed.
The continuous correlation trading algorithm supports OPCOM products or a combination of them as follows:

Hourly: the product supports trading on 24 electricity contracts, one for each hour of the day. The system automatically generates these contracts and makes them available for trading the day before the delivery day at 3:00 pm CET.

User defined products: these are combinations of hourly contracts, defined by the market participant. The delivery period of the user-defined products must always be covered by several contracts defined during the product market periods (hours) and with consecutive delivery times, which must be executed together. A user-defined product order cannot be an iceberg order.

Quarterly: the product supports trading on 96 electricity contracts, one for each 15-minute interval of the day. The system automatically generates these contracts and makes them available for trading one day before the delivery day at 15:00.
The continuous matching trading algorithm supports the following order execution restrictions:

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NON – An order submitted with the execution restriction NON is either executed immediately, or, if the order cannot be correlated immediately, it is registered in the shared order book. Partial execution of orders is allowed and NON orders may be correlated with existing orders and may create more trades.
Fill or Kill (FOK) - the order is fully traded at a time immediately after the order is submitted to its full quantity or deleted without being registered in the shared order book. FOK orders can be correlated with multiple orders existing in the order book. FOK orders cannot have a validity restriction.

Immediate or Cancel (IOC) – the order is either traded (in any amount) at a time immediately after the order is submitted or, if the order cannot be correlated, is deleted without being registered in the shared order book. Partial execution is allowed, and IOC orders can be executed based on multiple orders and can create multiple trades. An order with the IOC execution restriction cannot have a validity restriction.

All or None (AON) – An order submitted with the AON execution restriction is either executed exactly on the basis of another order with its full quantity or is registered in the shared order book. Partial executions are not allowed. AON execution restriction is allowed only for user-defined orders.
The continuous correlation trading algorithm will support the following restrictions on the validity of the orders:

Good for session (GFS) – the time validity of the order is determined by the validity of the appropriate trading session of the contract. The order is automatically canceled when the definite validity of the trading session corresponding to the contract expires.

Good till date (GTD) – the time validity of the offer is determined by the date and time. The offer is automatically canceled when the validity defined in time expires.

The intra-day system capacities are provided by the transmission system operators (TSOs) and are determined by the relevant TSOs after establishing the cross-border flows following the day-ahead auction. The exact timing of the allocation of capacity varies and depends both on the operational procedures and the agreements between TSOs on the different borders. Intra-day capacities are automatically updated, depending on the volume and direction of the intra-day trades. The intra-day market is open 24/7, 365 days a year, offering hourly and block products that provide the flexibility needed to meet market needs. The trades are concluded at the price of the existing order in the trading system.

The introduction of orders and trading is done in EUR / MWh, while the receiving rights and payment obligations are made in RON, in accordance with the provisions of the applicable Romanian National Bank regulations. Each IDM participant who recorded trades for a delivery day can access two Daily Settlement Notes for the respective delivery day, namely a Daily Settlement Note that contains prices and values in EUR and a Daily Settlement Note that contains the prices and the values in RON. For a day of delivery, the prices and values in RON from the Daily Settlement Note are determined at the exchange rate established by the BNR, prior to the opening time for trading the contracts for the respective day of delivery (15:00 CET).

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The collateral guarantee, in EUR, is updated daily at 15:00 CET based on the net payment obligations of the IDM participant for all trades concluded for the previous delivery day (s) and for the current delivery day, determined at the currency exchange rate established by the RNB, used for the next delivery day (s). The collateral guarantee will be automatically diminished by the value of the active orders / trades made by buying at positive prices / selling at negative prices.

Participation in the Intra-day Market is voluntary and is allowed to all License holders and economic operators, foreign legal entity to whom ANRE was granted by decision the permission to carry out in Romania the supply activity or the activity of trader, registered as Participants in IDM (electricity producers, suppliers, traders and network operators, aggregate entities). One of the mandatory conditions that the applicant must fulfill for registration in the IDM is to prove that he has concluded with the TSO the Agreement to assume the responsibility of balancing or that he has transferred the balancing responsibility to another Balancing Responsible Party.

IDM participants obtain information regarding their own trades concluded within the Intraday Market by accessing the M7 Trading system. OPCOM transmits to the TSO prior to each delivery hour and facilitates the balancing responsible Parties (BRP) access to the Physical Notifications corresponding to the IDM trades, by providing the hourly trading data, before the delivery time, through the post-trading system. OPCOM offers to the participants, also through the post-trading system, the settlement notes for a delivery day, the day after the delivery day.

Table 3 Annual average price in coupled IDM

Year	Average price (RON/MWh)	Average volume (MWh)
2015	139.46	8,651
2016	126.12	14,951
2017	178.85	17,402
2018	105.89	18,149
2019	178.84	42,800
2020	175.35	63,510

From the analysis of the latest reports presented by OPCOM (2020, 2019), the number of active market participants is on average 150±10. The data presented (**Figure 5 Intra-day market results at RO and EU level**) represent average monthly values concluded in the intra-day market. In terms of seasonality, this is a typical one, with high prices in the winter and low prices in the summer.

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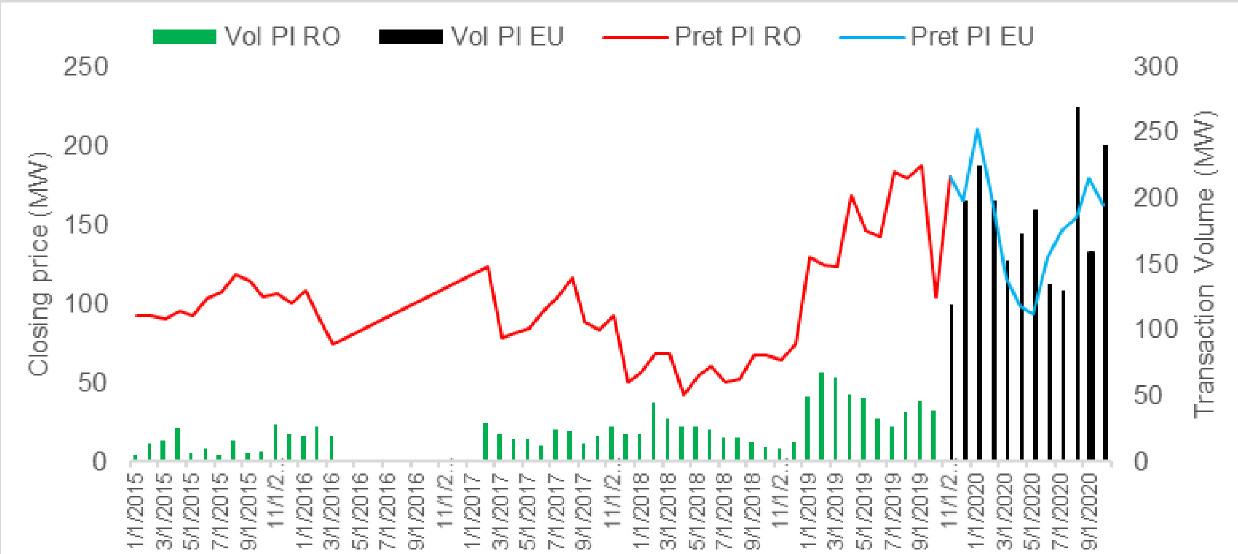

Figure 5 Intra-day market results at RO and EU level

Table 4 Results of the coupled intraday market (monthly average values) presents the average monthly values recorded in the period November 2019 - October 2020.
The "Minimum" and "Maximum" columns represent the lowest/highest price at which transactions were concluded. ROPEX_ID_H is the weighted average price of completed trades. Buy/Sell Vol represents the hourly traded quantity plus energy import/export.

Table 4 Results of the coupled intraday market (monthly average values)

Date	Minimum (RON/MWh)	Maximum (RON)	Last price (RON)	ROPEX_ID_H (RON)	Purchase Vol (MW)	Sales Volume (MW)
2019	**187.16**	**223.10**	**204.20**	**203.50**	**146.46**	**88.03**
November	203.36	231.65	217.25	216.26	99.91	77.74
December	181.19	219.95	199.41	198.81	165.79	92.03
2020	**139.09**	**207.44**	**176.74**	**175.35**	**155.99**	**132.89**
January	205.61	293.54	252.37	252.89	187.03	116.56
February	153.05	233.41	202.48	200.89	165.75	92.66
Apple	117.46	163.24	137.20	140.05	126.99	98.76
April	95.04	140.92	118.00	117.55	144.35	83.86
May	91.54	135.27	112.81	111.58	159.39	125.24
June	119.95	191.05	162.52	155.37	112.24	109.85
July	119.65	208.42	180.28	175.29	108.52	157.07
August	149.79	212.25	184.40	184.80	224.61	156.37
September	172.44	259.18	217.88	214.97	132.76	196.33
October	162.62	231.58	194.37	195.34	200.95	165.80

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Block Transactions - Sales Vol represent the sum of the block quantities traded per sell side broken down by each block interval (includes export). Import/Export represents the sum of the quantities transacted cross-border on the buying/selling side (hourly and broken down by each hourly interval of a block).

Table 5 Average monthly results Block and Cross-border transactions

Date	PMP (RON/MWh)	Block Vol Buy (MWh)	Block Vol Sales (MWh)	Import (MWh)	Export (MWh)
2019	**24.87**	**39.24**	**39.24**	**29.44**	**16.59**
November	33.80	31.62	31.62	18.30	12.48
December	19.70	43.65	43.65	32.85	17.66
2020	**26.54**	**26.11**	**26.11**	**30.29**	**24.63**
January	24.45	37.05	37.05	35,42	20.10
February	41.65	44.83	44.83	29.64	15,20
Apple	37.80	40.60	40.60	25.14	19.38
April	16.69	8.63	8.63	27.99	15.35
May	16.73	7.42	7.42	30.99	23.93
June	15.64	7.08	7.08	23.04	21,26
July				21.03	29.99
August				44.99	28.01
September	120.00		2.00	23.48	37.80
October				40.28	31.36

Balancing Market (BM)

Balancing market is the last stage for energy trading. It plays an essential role, as production and consumption levels must match during the operation of electric power systems. Through the balancing market, it is possible to take balancing actions, to identify the need of production or consumption adjustment. Thus, the balancing energy is used either to cover a production deficit or a surplus of consumption.

The Rules of the Balancing Market (BM) create the legal framework for the sale and purchase by the Transmission and System Operator (TSO) of Balancing Energy, necessary for:

ensuring the flexibility and stability of the SEN;
commercial resolution of SEN Network Restrictions;

On the Balancing Market, the Transport and System Operator buys and/or sells active electricity from/to market participants, holders of dispatchable units/consumptions, in order to compensate for deviations from the programmed values of electricity production and consumption. For each PPE (Balancing Market Participant) that has contracted reserves with the TSO, it is mandatory to offer to the BM (Balancing Market) the balancing capacity contracted for each type of reserve and each direction, based on the (UD)/Dispatchable Consumer (CD)/Dispatchable Storage Facility (ISD) capacity available after scheduling.

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Any PPE has the right to offer on the PE the available capacity of the UD/CD/ISD they operate. If a CD has traded on a pre-PE market with delivery in an ID, that ID is no longer allowed to bid on the PE based on its load.

The corresponding balancing energy is traded on the PE:

Secondary regulation (aFRR)
Fast Tertiary Adjustment (mFRR)
Slow tertiary regulation (RR)

PPE submits bids on each ID for any UD/CD/ISD for the amount of balancing energy it wishes to make available, separately for:

power increase
power reduction

For any UD for which it is responsible, the PPE submits a power reduction offer which in relation to the planned production in the NFA (Authorized physical notification) reflects the minimum power up to which it is valid and a power increase offer which in relation to the planned production in the NFA reflects the maximum power until which it is valid; these limits must be within the available production capacity included in the availability statement. Transactions on PE are concluded by the partial or total acceptance of offers by the TSO.

In the situation where a transaction concluded on the PE through the partial or total acceptance of the offers by the TSO would endanger the safety and stability of the operation of the SEN, the provisions on resolving network restrictions apply. The transactions concluded on the PE establish the obligation of the respective PPE to provide the service accordingly to the TSO, in accordance with the specifications in the offer and the dispatcher provisions issued by the TSO.

Transactions are specific to a specific ID. The determination of payment obligations/rights of collection in the case of transactions concluded on PE is based on:

of the smallest quantity between the quantity accepted by the TSO and the quantity actually delivered by the PPE and

the marginal price or, in the case of transactions used to resolve network restrictions, the bid price.[5]

Table 6 Average balancing energy prices and system imbalance

Date	Surplus Price (RON/MWh)	Deficit Price (RON/MWh)	System imbalance (MWh)
2020	**1.88**	**555.41**	**318.92**
January	12.70	619.62	280.77
February	6.34	559.28	297.29
Apple	6.12	513.69	435.17
April	7.98	490.69	504.22

[5] Energy Balancing Report – National Romania Transport System Operator (Romania TSO-Transelectrica)

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May	3.31	501.80	506.37
June	2.66	514.07	240.52
July	4.94	521.37	228.58
August	6.64	544.57	229.77
September	-18.17	641.69	237.28
October	-14.18	649.01	226.04

Positioning Consumers in a Liberalized Electricity Market and Decentralized Electricity System

In order to align to EU Energy Directives, the Romanian Government issued in late Dec 2021, an Emergency Ordinance amending and supplementing the Law on Electricity and Natural Gas no. 123/2012 as well as the amendment of the Law for establishing the system for promoting the production of energy from renewable energy sources no. 220/2008.

This was highly necessary in order to align the internal energy market with the Directive (EU) 2019/944 on common rules. According to the 123/2012 and 220/2008 Romanian Laws, the prosumers are regulated and defined as users that have installed on their premises an “on-grid system” that is producing electrical energy using photovoltaic (PV) technology.

A more comprehensive definition of the Prosumer – according to Law 184/2018 – the prosumer is the final customer who owns energy production facilities including cogeneration, but whom specific activity is not the production of electricity, which consumes and can store and sell energy (electricity) produced from Renewable Energy Sources (RES), in his building, including an apartment building, a residential area, a service location shared, commercial or industrial or in the same closed distribution system, provided that, in the case of non - self - employed energy consumers from renewable sources, these activities should not be their primary activity commercially or professionally.
Consumers who own renewable power plants (e.g., “prosumers”) with an installed capacity of up to 400 kW per place of consumption may sell the electricity produced and delivered on the electricity grid to the electricity suppliers with whom they have concluded electricity supply contracts, according to ANRE regulations.

Prosumers (up to 200 kW power) will benefit from quantitative compensation, and electricity suppliers are obliged to purchase electricity, at the request of prosumers who produce electricity in power generation units with an installed capacity between 200 kW and 400 kW. Also, the local public authorities that have the capacity to produce electricity from renewable sources made, in part or in full, from the Structural Funds, benefit from the suppliers with whom they have a contract for the supply of electricity, on request, the financial regularization service between delivered energy and energy consumed by the network.

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Benefits for prosumers up to 200kW installed power

Electricity suppliers are obliged, at the request of prosumers, which produce electricity in electricity generation units with an installed capacity of up to 200 kW and with which they have concluded electricity supply contracts:

a) to make a quantitative compensation in the prosumers' invoice, respectively to invoice only the difference between the amount of energy consumed and the amount of energy produced and delivered in the network;

b) to carry in the invoices of the prosumers, in the situation when the amount of energy produced and delivered in the network is greater than the amount of energy consumed, the difference between the amount delivered and that consumed, the prosumers can use the amount of energy carried over for a maximum period of 24 months from the date of invoicing.

Note: Quantitative compensation for consumers with installations up to 200 kW will be granted only until December 31, 2030, in the context of measures and actions related to meeting the commitments on the share of renewable energy in 2030 specified in the National Plan for Energy and Climate Change, according to an ANRE methodology, and after this period the respective prosumers can sell the electricity produced under the conditions provided in par. (3), lit. a) for prosumers with an installed power between 200 kW and 400 kW.

Benefits for prosumers with installed power between 200kW and 400kW

Electricity suppliers are obliged, at the request of consumers, who produce electricity in power generation units with an installed capacity between 200 kW and 400 kW and with which they have concluded electricity supply contracts:

- to purchase the electricity produced and delivered at a price equal to the weighted average price recorded in the Next Day Market in the month in which the energy was produced;
- to carry out in the prosumers' invoice the financial regularization between the delivered electricity and the consumed electricity from the network.

No Authorization Required

Prosumers may carry out the activity of trading the electricity produced in the electricity production units they own, without registering and authorizing their operation.

Free Connection to the National Grid

The electricity distribution operators are obliged to execute the grid connection for prosumers and public authorities in accordance with the specific regulations issued by ANRE for this purpose.

[6] https://energie.gov.ro/prosumatorii-vor-avea-parte-de-compensare-cantitativa/

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Energy Communities' Concept

Definitions

Energy communities are likely to play a central role not only in the future energy market design in the European countries but also in the more important mission of climate goals achievement.

There are two formal definitions of energy communities: '**citizen energy communities**' which is included in the revised Internal Electricity Market Directive (EU) 2019/944 (European Parliament & Council of the European Union, 2019), and '**renewable energy communities**' which is included in the revised Renewable Energy Directive (EU) 2018/2001 (European Parliament & Council of the European Union, 2018).

Citizens' energy communities are legal entity that meet cumulatively the following conditions[7]:

a) are based on voluntary and open participation and effectively controlled by members or shareholders, natural persons, local authorities, including municipalities, or small businesses;

b) have as main objective the provision of environmental, economic, or social advantages for its members or shareholders or for the local areas where they, rather than generating financial profits;

c) may engage in production, including production from renewable sources, distribution, supply, consumption, aggregation, energy storage, energy efficiency services, or charging services for electric vehicles or may provide other energy services to its members or shareholders;

'**Renewable energy community**' means a legal entity[8]:

(a) which, in accordance with the applicable national law, is based on open and voluntary participation, is autonomous, and is effectively controlled by shareholders or members that **are located in the proximity of the renewable energy projects** that are owned and developed by that legal entity;

(b) the shareholders or members of which are natural persons, SMEs (Small and Medium Enterprises) or local authorities, including municipalities;

[7] Internal Electricity Market Directive (EU) 2019/944 (European Parliament & Council of the European Union, 2019)

[8] Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018, Art.22

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(c) the primary purpose of which is to provide environmental, economic or social community benefits for its shareholders or members or for the local areas where it operates, rather than financial profits;

The Electricity Market Directive (EU) 2019/944, the Regulation (EU) 2019/943 and Renewable Energy Directive (EU) 2018/2001 represent the European legal fundament for green energy transition and also for the energy communities.

In Romania the Law no. 123 of July 10, 2012, with subsequent modifications and additions coordinates the electricity and natural gas markets. The legal changes required by the new European energy policy were implemented in the national legislation by the emergency ordinance no. 143 of December 28, 2021.

This transposition confers rights and obligations to local energy communities:

(1) Citizens' participation in an energy community shall be open and voluntary, and its members or shareholders shall retain their rights and obligations as household customers or active customers;
(2) Citizens' energy communities shall be subject to non-discriminatory, fair, proportionate and transparent procedures and tariffs, including registration and licensing, provided for in the regulations issued by ANRE;
(3) Citizens' energy communities may participate in activities in the energy sector and engage in production, including from renewable sources, distribution, supply, consumption, aggregation, energy storage, energy efficiency services or charging services for electric vehicles or may provide other energy services to its members or shareholders, including through such integrated activities;
(4) Citizens 'energy communities shall cooperate with distribution operators in order to facilitate transfers of electricity within citizens' energy communities subject to fair compensation established by the regulatory body (ANRE) regulations;
(5) Citizens' energy communities:

a) may access all electricity markets, directly or through aggregation, in a non-discriminatory manner and are open to cross-border participation;
b) are treated in a non-discriminatory and proportionate manner with regard to their activities, rights and obligations as final customers, manufacturers, suppliers, distribution system operators or market participants involved in the aggregation;
c) are financially responsible for the imbalances they cause in the energy system;
d) may act as parties responsible for balancing or may delegate their balancing responsibility;
e) are assimilated to active customers for the consumption of electricity produced;
f) network tariffs calculated separately for electricity supplied to the grid and for electricity consumed shall be applied to them in a transparent and non-discriminatory manner;
g) have the right to organize within their community the sharing of electricity produced by the production units owned by the community, between its members, conditioned by the maintenance of the rights and obligations of the members as final customers in compliance with the provisions and without modifying the network tariffs and established fees, according to the ANRE methodology;

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(6) The energy communities of the citizens have the right to own, to set up, to buy or to rent distribution networks and to manage them autonomously, benefiting from the provisions applicable to the closed distribution systems;

(7) Citizens' energy communities may autonomously manage the distribution networks located in their area of consumption, in accordance with the regulations issued by ANRE;

(8) The energy communities of the citizens managing the community network:

a) have the right to conclude an agreement on the operation of their network with the distribution system operator or transmission system operator to which the network is connected;

b) are subject to appropriate network tariffs at the connection points between their network and the distribution network outside the citizens' energy community and that these network tariffs separately account for electricity supplied to the distribution network and electricity consumed from the distribution network from outside the energy community of citizens;

c) do not discriminate or harm customers who remain connected to the SEN;

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Design Aspects of Energy Communities

The technical functional aspect of an energy community can be analyzed with help of a 3D multi-layer model.

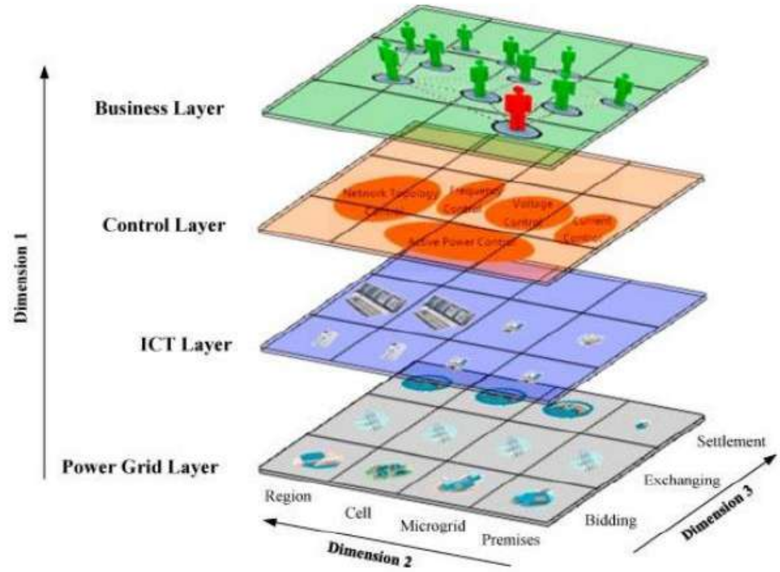

Figure 6 A four-layer system architecture of Peer-to-Peer energy trading[9]

One dimension comprises the key functions in **local energy trading**.

The power grid layer consists of all physical components of the power system, including feeders, transformers, smart meters, loads, distributed energy sources, etc. These components form the physical electricity distribution network where P2P energy trading is implemented.

The ICT layer consists of communication devices, protocols, applications, and information flows. Communication devices refer to sensors, wired/wireless communication connections, routers, switches, servers, and various types of computers.
Protocols include TCP/IP (Transmission Control Protocol/Internet Protocol), PPP (Point-to-Point Protocol), X2.5, etc. Communication applications can be various, such as information transfer and file exchange. The information flow refers to the senders, the receivers, and the content of each message transferred among communication devices.

The control layer mainly consists of the control functions of the electricity distribution system. Different control strategies are defined in this layer for preserving the quality and reliability of power supply and control the power flow. Voltage control, frequency control and active power control are examples of possible control functions in the control layer.

[9] Zhang, C., Wu, J., Zhou, Y., Cheng, M., Long, C., 2018. Peer-to-Peer energy trading in a Microgrid. Applied Energy 220, 1–12

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The Business layer determines how electricity is traded among peers and with the third parties. It mainly involves peers, suppliers, distribution system operators (s) and energy market regulators.

Another dimension considers the **number of participants in peer-to-peer energy trading** and their geographical distribution.

The house/apartment connected to the electricity distribution system represents the cornerstone.

The Microgrid consists of a collection of houses/apartments and distributed energy sources in a local geographical area that shares the same medium-voltage/low-voltage (MV/LV) transformer. Microgrids are electricity distribution systems containing loads and DERs, which operate in a controlled and coordinated way either connected to the main power network or islanded.

A Cell may contain several Microgrids and may also operate in either grid-connected or islanded mode.

A region can be as large as a city or a metropolitan area which consists of multiple Cells. The European Commission sees the spatial extension of energy communities as premises, microgrids or cells but not as a region.

A third dimension considers **the time sequence of the local energy trading process**.

Bidding is the first process of local energy trading when energy generators or consumers reach trading agreements with each other before the energy exchange takes place. During the bidding process, energy customers interact with the trading platform or each other through the trading platform and agree on the price and amount of energy to be traded.

Energy exchanging is the second process, during which energy is generated, transmitted, and consumed.

The settlement is the final process when bills and transactions are finally settled via settlement arrangements and payment. [10]

[10] Improvement of PV4Grid concepts, 2018, TU Vienna

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Added Value of Energy Communities

Energy communities unite customers and generators on a local level and create values for both participants.

Regarding consumers, energy communities help decrease the transactional costs by reduction of market participants within the value chain and increase of competition. They may also help to establish technologies for residential consumers, such as energy storage systems.

Energy communities may not be economical due to the design of grid charges and taxes however local technical solutions may keep track of energy flows within the community and increases the transparency.

As DERs and ESSs are mostly installed on a local level, it fits to the real physical flows. Energy communities increase the possibilities of local flexibilities for valorization and the consumption of local energy.

Another added value for consumers is that they can express their preferences (e.g., cost reduction, value for emission reduction an individual share of local consumption). The preferences may result in the different level of willingness-to-pay.

On the other hand, energy communities generate value for prosumers and small producers. They open the possibility to market their generation directly to the consumers.

They also create values for retailers: if the retailer runs the trading platform, monetary losses may be compensated. Still, the balancing party is necessary to balance the community. The retailer may be capable of providing this service. So, the retailer generates additional costs (imbalance, balancing, metering, and billing) and revenues. Also, the retailer has an opportunity, because the individual marketing of generators and supply of customers might lead to higher profits.

The lack of tracking energy flows on a local level, the lack of visibility of the generation, potentially leads to a grid being used less efficiently. Also, a grid potentially needs investments to meet the future power flows. As an alternative, energy communities match their generation and consumption on a local level to meet the restrictions of the grid. Therefore, new grid investments may not be necessary, and both the DSO/TSO and consumer/generator benefits from the savings.

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Challenges

Energy communities could play a role either in energy production from renewable sources, in distribution, supply, consumption, aggregation, energy storage, energy efficiency services, or charging services for electric vehicles or may provide other energy services to its members or shareholders.

Regarding the organizational form of energy communities, there is no European standard and several member states list potential options for the type of legal entity that may be chosen. Greece and Sweden prescribe a specific legal body; while in Greece a specific type of cooperative is foreseen for energy communities, in Sweden an "Economic Association" is to be formed.

In some countries, energy communities are embedded in existing concepts for local or regional initiatives. In particular Ireland represents a specific case, as it links energy communities to two other types of initiatives; "Sustainable Energy Communities" as regional concepts, and "community-led projects" that rather refer to the local level and need to be owned to at least 51% by a REC. In Spain, for instance, a dedicated legal framework already exists for Energy Consumption Cooperatives.[11]

Romania doesn't provide a dedicated legal entity for energy communities nor can be one of the existing ones applied, the alternative is to establish a European cooperative legal person. However, this requires 30.000 Euros subscribed capital instead of 200Ron (40Eur) required by the most common legal entity in Romania, the limited liability company (SRL).[12]

While generally open and voluntary participation are highlighted, this does not necessarily mean that joining and leaving an energy community is possible at any time. Luxembourg foresees a minimum duration for the participation in a REC of one year.

Regarding production, energy communities still face barriers concerning generation capacity limits. The limits are also different in nature, with some referring to total power within an entire initiative, some to the power of individual installations. For instance, in Greece, the maximum power for an installation within an energy community is limited to 1 MW.

In Italy, individual generation plants must not exceed 200 kW. In Slovenia, the sum of RES production should not surpass 0.8 times the sum of the coupling capacities included in the collective scheme, and in France the maximum total power that may be installed within a CSC (common share consumption) scheme on the continental metropolitan territory is 3 MW. In Switzerland, a minimum production capacity is defined (10% of the grid connection capacity of the community).[13]

[11] Collective self-consumption and energy communities: Trends and challenges in the transposition of the EU framework, 2020

[12] https://cooperativadeenergie.ro/ghiduldeenergie-ce-sunt-comunitatile-energetice/

[13] Collective self-consumption and energy communities: Trends and challenges in the transposition of the EU framework, 2020

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Romania limits the prosumer installed capacity at 400kW and only renewable generation sources up to 3 MW can close bilateral contracts with energy suppliers for energy marketing.

Furthermore, an energy community which wishes to engage in energy supply and distribution has to meet the national authority for energy regulations set requirements. For example, in order to grant the energy supplier license, ANRE requires among others that the company has a customer service hotline, a dedicated department with specialized personnel and previous experience in the field of energy supply, a minimum working capital quote of 25% of sales volume but not less than 100.000Eur.[14]

For energy distribution license, among others, the energy community has to employ dedicated authorized personnel and the acceptance of the concessionaire distribution operator.

Local energy allocation can decrease local peak demand and the payment for grid services, but it may still increase costs somewhere else in the system. If more prosumers use electricity generated locally in the community and aggregate their consumption profiles, the power flows from the main grid will decrease. Self-consumption in a community will therefore reduce recovery of distribution network costs and policy charges and levies.[15]

Network costs are distributed equally amongst system users as the same type of grid warrants the same cost allocation. Therefore, the network operator will try to compensate the resulting loss of revenue by increasing the tariff to the remaining customers in the system who might not own a renewables installation.[16]

This regressive effect creates a social discrepancy between members of the community and non-members – the latter including those individuals that cannot afford to invest in renewables but indirectly supporting the former group by contributing to renewables support schemes.[17]

[14] https://www.anre.ro/ro/energie-electrica/informatii-de-interes-public/info-licente-autorizari/mod-de-solicitare-de-licente-autorizatii/solicitare-documentatie-licente-autorizatii1387205027
[15] Abada, I., A. Ehrenmann, and X. Lambin, On the Viability of Energy Communities, Cambridge Working Paper in Economics 1740, Cambridge, 2017
[16] Brown, A., and L. Lund, 'Distributed Generation: How Green? How Efficient? How WellPriced?', Electricity Journal, Vol. 26, No. 3, 2013, pp. 28–34
[17] Yildiz, Ö., B. Gotchev, L. Holstenkamp, J.R. Müller, J. Radtke, and L. Welle, 'Consumer (Co-)Ownership in Renewables in Germany', in J. Lowitzsch (ed.), Energy Transition - Financing Consumer Co-Ownership in Renewables, Palgrave Macmillan, Cham, 2019

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Energy Aggregator Concept

Definition of Aggregators

For decades' electricity was produced by big power plants which generated enough power to cover society's demand. However, the increasing share and variable nature of electricity produced by distributed renewable energy sources means that a reform of this system is inevitable. One of the ways to achieve a cleaner, more secure and more efficient electricity grid is not only through cleaner energy sources but also through, to a certain extent, making electricity consumption and production more flexible.[18].

The aggregator, as a new participant in the electricity market can stand up to the degree of flexibility required by the transition towards green energies.

The Electricity Market Directive (EU) 2019/944, the Regulation (EU) 2019/943 and Renewable Energy Directive (EU) 2018/2001 introduce the aggregator concept.

The EU 2019/944 Electricity Directive defines aggregation as a "function performed by a natural or legal person who combines multiple customer loads or generated electricity for sale, purchase or auction in any electricity market".

Moreover, the directive confers the independent aggregator the role of intermediary between customers group and the market.[19] The Art. 17 regulates the demand response through aggregation and also indicates "the right for each market participant engaged in aggregation, including independent aggregators, to enter electricity markets without the consent of other market participants".

Aggregation is a commercial function of pooling decentralized generation and/or consumption to provide energy and services to actors within the system. Aggregators can be retailers or third parties. They may act as an intermediary between customers who provide flexibility (both demand and generation) and procurers of this flexibility.

They would identify and gather customer flexibilities and intermediate their joint market participation. This could be done via flexibility products or simply by selling and buying aggregated energy (kilowatt-hours) at optimal points in time[20]

The aggregator is an official designated enabler for self-consumer(prosumer) to generate renewable energy, including for their own consumption, store and sell their excess production of renewable electricity, including through renewables power purchase agreements, electricity suppliers and peer-to-peer trading arrangements.[21] He is also a

[18] Electricity Aggregators: Starting off on the right foot with consumers(2018)
[19] (EU) Directive 2019/944 (39), Art. 2 (19)
[20] Flexibility and Aggregation Requirements for their interaction in the market (eurelectric,2014)
[21] (EU) 2018/2001 Art.21 2 a)

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certified third-party market participant for peer-to-peer trading of renewable energies[22], the fundament for energy communities.

According to RED II ‘peer-to-peer trading’ of renewable energy means “the sale of renewable energy between market participants by means of a contract with pre-determined conditions governing the automated execution and settlement of the transaction, either directly between market participants or indirectly through a certified third-party market participant, such as an aggregator”
The right to conduct peer-to-peer trading shall be without prejudice to the rights and obligations of the parties involved as final customers, producers, suppliers or aggregators;

An independent aggregator refers to a market participant engaged in aggregation who is not affiliated to the customer's supplier.

In Romania, Law 155/2020, Art. 3-4 transposes the aggregator and independent aggregator into national law.
Furthermore Art. 10 (2) i) foresees that ANRE can issue licenses for the aggregation business activities.

Benefits & Challenges of Energy Aggregator

Benefits

Aggregation is the combination of individual electricity buyers (and their loads) into a large pool. Other factors being equal, suppliers prefer dealing with larger groups, which have more purchasing leverage. This purchasing power can be used to obtain cost savings, a different combination of services, or more favorable service terms. Aggregation also reduces transaction costs for the members of the buyers group and for the suppliers.

From the electricity supplier perspective, aggregation lowers its marketing and customer acquisition costs, and may improve its load factor.

Aggregation can benefit both large and small customers. Large customers have been the quickest to benefit from aggregate purchasing of electricity.

A number of technologies can provide flexibility, including centralized or de-centralized generation, demand side participation and energy storage. However, only very large customers, e.g., industrial customers, find it easy to sell their flexibility on an individual basis and participate in the flexibility market today.

Smaller residential and commercial customers may face high barriers in accessing these markets. Transaction costs of such participation are too high if managed at individual

[22] (EU) 2018/2001 Art.2 (18)

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level. Aggregation offers the opportunity for smaller residential and commercial customers to exploit their flexibility potential.

Concomitant with the increase in intermittent RE generation comes the requirement for adequate control mechanisms and strategies such as Demand Side Management (DSM) and Demand Response (DR) to ensure system reliability. The absence of strategies for the integration of high-penetration RES in the traditional networks has demonstrated grid congestion and voltage violation issues.

The liberalization of the energy markets necessitates new business models for flexibility activation and demand generation integration via e.g., aggregation of many small prosumers and other stakeholders. Small prosumers do not possess sufficient capacities for market bidding and may lack the knowledge of market interactions.

The integrated or independent aggregator enables this interaction between prosumers and the market. In a similar vein, the European authorities have defined aggregation as an enabler for prosumer market participation. Decentralized coordination may yield locally optimal solutions, providing system resilience, data privacy, and high scalability at distributed energy sources integration.

A centralized controller can target at optimizing the entire integrated power system, but majorly relies on a single entity for system functioning and faces heavy computational burdens. Distributed control strategies can be perceived as compromise between central and decentral control however distributed algorithms over centralized ones pose certain advantages, such as improved cyber security, system robustness, and potential computational superiority regarding maximum problem size and solution speed.

More competitors in the market may also result in more competitive prices, which benefits the system value. Grid operators can benefit from aggregation due to the improved matching between generation and consumption. Appropriate distributed energy sources integration can decrease requirements for substation upgrading or power line expansion. Aggregators will also facilitate the achievement of climate goals because they are coupled with the defossilisation of the energy industry.

Potential social benefits of aggregation for consumers and prosumers represent the dispose of their own data, better service quality, according to their own needs; they save time, no longer concerned with the multitude of suppliers; receive better incentives, optimize consumption, and understand bills and markets, development of new life - style models, family budget savings.

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Challenges

DSOs mainly serve residential customers and small businesses and may in the future interact with a new actor, the demand response aggregator (DRA).

There is no uniform structure of DSOs in Europe with major deviations in size, governance, and average distribution tariffs even within member states.

A new market participant has to demonstrate in advance that it can fulfill all requested technical requirements to the TSO in order to get permission to provide ancillary services. It is essential that this prequalification can be provided at the pooled DRA level, instead of at the customer level for the individual assets. The direct access of consumers' assets without requiring special permissions through the BRP or retailers, is seen as an enabler for aggregator operation.

The investment responsibility for smart meter and software infrastructure enabling automated processes is not resolved.

Asymmetry in the bidding offer allows an aggregator the grouping of mere production assets to participate in the bid, for instance. If symmetry is required, this aggregator type would be excluded from the bidding process as it might not be able to provide balancing in the case of network overloads.

Since the availability of flexible loads is determined by the customers' comfort levels, there is a natural restriction to the maximum activation duration of assets. Generally, shorter activation periods are advantageous to increase the DRA participation. Similarly, tender periods with at least daily auctions enable the DRA to make more prompt and possibly accurate predictions on the clients' behavior and facilitate participation in the bidding process.[23]

The vast majority of aggregator services currently focuses on large customers only, rather than targeting residential customers as well.
This can be explained by several arguments, such as:

- the existing infrastructures: the diffusion of basic energy metering in the industry, for instance, facilitates the identification of DR potentials;
- forecasting: the baseline electricity consumption in the industry tends to be rather predictable due to commonly planned consumption profiles, and applicable large-scale RES forecasting models exist;
- data privacy: non-disclosure agreements are already a common practice in industrial collaborations;

Furthermore, network tariffs represent another constraint. The tariff style depends on the country and varies from extremes such as 100% energy component based for households in Romania, to 100% fixed and capacity components based for households in the Netherlands, as well as a combination of the two in other countries.

[23] Barriers to Independent Aggregators in Europe, University of Exeter, 2019

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The network and market system referred to as traditional state, is dominated by large producers such as nuclear or coal/gas-fired power plants. This vertically integrated electricity system is characterized by a unidirectional power flow. The network infrastructure and its sizing are laid out for this operational mode. The electricity market is dominated by distribution tariffs for either fixed + capacity components or an energy component.[24]

Considering that grid taxes at low voltage distribution level account for about 50-60% of network tariffs there is a major discussion potential on how new tariffs structures should adapt to the renewable energy transition.

Overall participation costs, technical requirements, data management, cybersecurity, data protection, old fashioned network tariffs represent main barriers for the aggregators.

And last but not least the consistency of legislation represents a major challenge. For example ANRE enumerates the necessary documents for the aggregator license such as the confirmation issued by the transport and system operator which validates the fulfillment of the communication and integration requirements in the IT systems of the transport and system operator, the operation requirements, integration in the dispatcher structures and integration in the measurement system;

Aggregation Business Models

The multitude of aggregator examples in Europe demonstrates that economic value creation from aggregation is possible at the current state, despite yet remaining regulatory, economic, and technical barriers. There are a number of ways to think about electricity aggregation activities, especially from the **organizational perspective**.

Business and Industry Associations

Established industry associations may wish to serve as aggregators to offer their members savings on electricity costs, provide their members with differentiated power products, or expand their membership. They may be either buyer agents or energy providers. Typically, these groups are involved in **association-based or affinity-based aggregation**.

Local Governments and Schools

City governments and school districts may be interested in aggregating their electricity purchases to obtain a better rate, reduce transaction costs, or purchase power generated from sustainable energy sources. School systems may be interested in purchasing power from renewable resources to educate students about renewable energy technologies and the benefits of clean power. Typically, these groups are aggregating their own loads and, thus, are an example of **self-aggregation**.

[24] European regulatory framework, International Journal of Electrical Power and Energy Systems (2022)

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Government Agencies

As large purchasers of power, state agencies may be interested in aggregating their loads to obtain price breaks or to reduce procurement costs. Some government agencies, such as those involved in environmental or natural resource protection, may be interested in purchasing green power for its public environmental benefits. Like local governments, government agencies are typically involved in **self-aggregation**.

Third Party Buyer Agents or Brokers

Private, for-profit companies may serve as buyer's agents or brokers in markets where there is enough margin to make such transactions profitable. Typically, these for-profit companies focus on achieving cost savings for customers as opposed to offering differentiated electricity products, such as green power. These groups typically form **buying pools**.

Energy Cooperatives / Communities

In newly competitive markets, energy cooperatives and communities offer a variety of benefits and services to small customers, including cost savings, consumer protections, energy efficiency services, reliability and quality of service improvements, and renewable energy options. These are generally energy providers rather than buyers' agents and fall under the category of **member-based aggregation**.

Self-aggregation and buying pools are the most common aggregation organizational models but it is expected that member-based aggregation will increase in popularity as energy communities become indispensable.

From the **economical-technical perspective**, Figure 7 confers a good overview of the most common European aggregators business models.

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Business Model	Explanation
Combined aggregator - supplier	Supply and aggregation are offered as a package and there will be one BRP per connection point.
Combined aggregator -BRP	There are 2 BRPs on the same connection point, the BRP (independent aggregator) and the BRP (supplier). The supplier is compensated for imbalances.
Combined aggregator - DSO	*NOT tackled: regulated and unregulated roles should not be combined.*
Independent aggregator as a service provider	The aggregator is a service provider for one of the other market actors but does not sell at own risk to potential buyers.
Independent delegated aggregator	The aggregator sells at own risk to potential buyers such as the TSO, the BRP and the wholesale electricity markets.
Prosumer as aggregator	Large-scale prosumers choose to adopt the role of aggregator for their own portfolios.

Figure 7 Business model example[25]

The integrated aggregator type supplies energy to prosumers whilst offering flexibility contracts, holding the entire balancing responsibility.

Prosumer as Aggregator

Commercial and industrial prosumers can choose to adopt the role of aggregator for their own portfolios.
For domestic prosumers, it will be a lot more difficult to do this but it is possible that one actor such a transaction platform aggregates a lot of small household volumes.

For this reason, there is an important role for renewable energy aggregators who act on behalf of consumers and use technological solutions and ICT for optimization.

They are defined as legal entities that aggregate the load or generation of various demand and/or generation/production units and aim at optimizing energy supply and consumption either technically or economically.

In other words, they are facilitators between the two sides of electricity markets. On the one hand, they develop energy services downstream for industrial, commercial, or domestic customers who own generation and storage units or can offer demand response.

[25] Best practices and implementation of innovative business models for renewable energy aggregators, BestRES, 2016

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On the other hand, prosumer energy aggregators are offering value to the market players upstream such as BRPs, DSOs, TSOs and energy suppliers to optimize their portfolio and for balancing and congestion management.

The combined aggregator-supplier/BRP are the most frequent aggregator models but in light of green energy transition with more and more distributed energy sources, prosumers as aggregator and independent aggregator as a service would take over.

Current classification of PV Prosumers

Single use

One consumer directly uses the generated PV electricity on site. The public grid is only used for the residual electricity consumption and possible feed-in of excess electricity. Self-consumption can be increased due to the implementation of energy storage systems, electrification of heat production (heat pumps, boilers), demand side management (DSM), etc.

Local collective use of PV in one place (e.g., in one building)

Several consumers share the generated PV electricity using the public or private grid (owned and/or operated by DSOs). The public grid is used for the residual electricity consumption and possible feed-in of excess electricity. Each consumer can increase the share of self-consumption by specific measures (storage, demand-side management, etc.).

District power models

Several consumers directly consume locally generated PV. The PV energy is shared using the public or private local grid on low voltage level (limitation could be the same substation). District storage devices can be used to increase the share of self-consumption, in addition to the individual measures.

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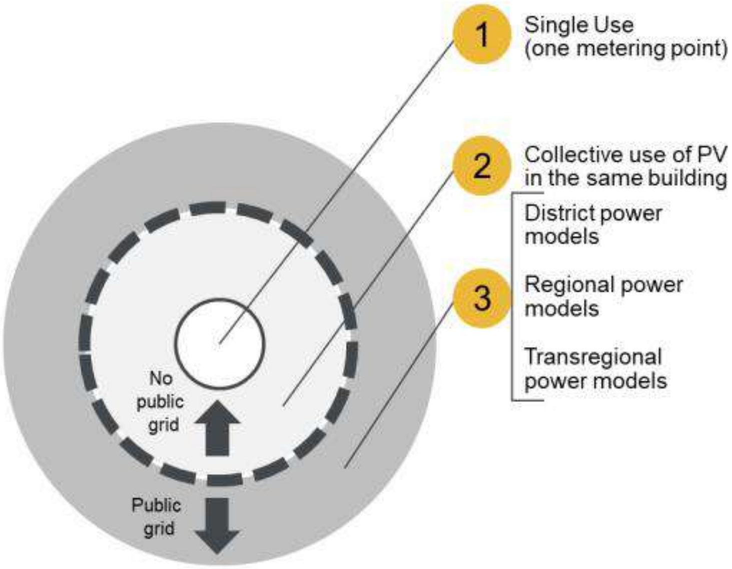

Figure 8 Spatial classification of PVP concepts according to their system boundaries

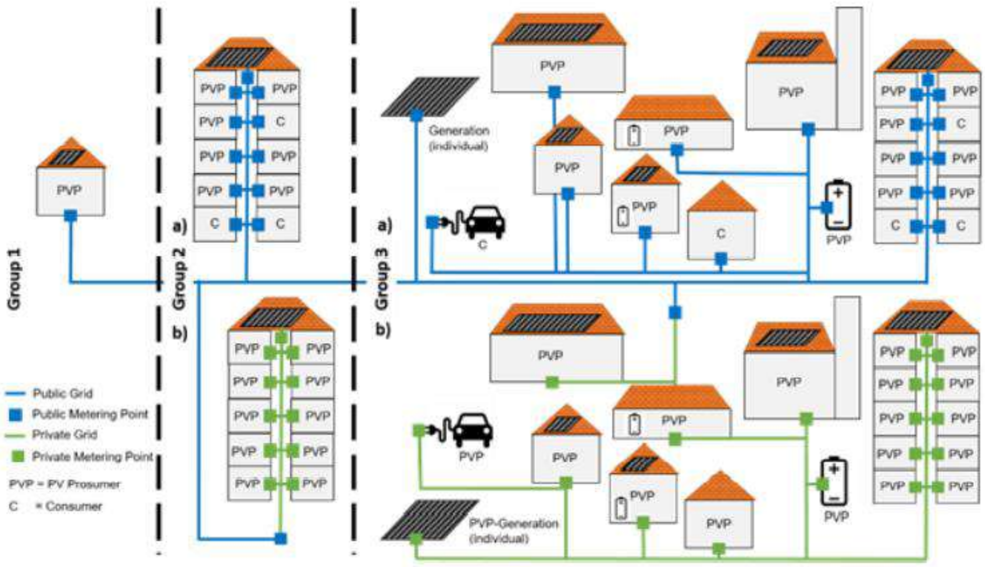

Figure 9 Classification of possible PVP concepts according to their system boundaries[26]

From the **market perspective** it can be differentiated between production, demand, and commercial aggregators.

The production aggregator enables economies of scale for market access by grouping small generators, mostly in the role of an independent aggregator.

[26] Improvement of PVP4grid concept, Vienna, 2018

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Prosumers with storage and/or production capacity can interact with other market players, e.g. retailers or DSOs, through the demand aggregator.

The commercial aggregator may be balance responsible, supplying energy and buying locally generated electricity. Considering the traditional grid formation, the commercial aggregator is the most common aggregator business model. For example, in Romania only this type of aggregator is regulated both in the dedicated legislation and on the operational level.[27]

However, demand response seems to be more practical for the growing reality of IoT. Demand response provides an opportunity for consumers to play a significant role in the operation of the electric grid by reducing or shifting their electricity usage during peak periods in response to time-based rates or other forms of financial incentives.[28]

EU Member States prove different existing country-specific regulations, with very little DR engagement (e.g., Croatia, Bulgaria, Portugal, Spain), to enacted DR reforms enabling DR and independent aggregation (e.g., Belgium, France, Ireland, UK).

The Spanish national commission on markets and competition (CNMC) has enacted a resolution at the end of 2019, which formulates equal conditions for balancing service providers possessing generation, DR, or storage assets, and enables the aggregation of generation assets for system balance services within further specified frame conditions.

The production aggregators will follow closely as prosumers and small RES spread through the national grids. [29]

[27] Official Gazette no. 1055 of November 10, 2020; Order no. 196 of October 28, 2020, Art. 2 (1) Operational procedure, TEL-.07.VI ECH-DN/25, TSO Transelectrica S.A.

[28] www.energy.gov

[29] The Consumer Voice in Europe, Electricity Aggregators, 2018

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Digitalization as Enabler for Aggregation

In European markets, there are limited examples of independent aggregators engaging with residential consumers. Existing aggregators are mainly working with industrial or commercial customers. However, it is expected that new technologies will make it possible for residential flexible electricity consumption to become more commercially attractive and play a bigger role in the stability and efficiency of the system.

The reason for this future potential in the household sector is twofold. First, through digitalization, energy supply and demand can be matched almost in real time. As a direct consequence many consumer products such as smart meters, thermostats, heating, and cooling appliances can be integrated into networks that can help to optimize energy consumption. Also, home automation will further facilitate flexible energy consumption in the residential sector. [30]

Second, transport will increasingly use electricity as its source of power. The fact that more and more consumers may be switching to electric vehicles means that car batteries could be integrated in the grid as a storage facility for surplus energy and become a source of energy supply when the car is not in use. Adjusting electricity consumption in order to reduce peaks in demand or take advantage of renewable sources is often described as 'demand side flexibility.

DER assets include, for instance, ESS, PEV, heat pumps, combined heat and power systems (CHP), rooftop PV, among which some of the former mentioned may serve as controllable loads providing DR services, washing machines, dishwasher, or heating are shiftable, or curtailable loads, respectively, possibly available for DR.

The development tends to an increase in RE penetration in power systems, as well as a higher transport electrification and efficient heating facilities. Most small DER assets are connected on distribution grid level with significant impact on the power systems' planning and operation.

Aggregation relies on software, smart appliances, and intelligent energy management devices that allow the remote adjustment of electricity consumption. Connected devices used in home energy management make it technically possible to store and process consumers' personal data. As they control vital activities of a households' everyday life the remote reading of electricity consumption can provide a detailed insight into households' private sphere.

Aggregators requesting consumers' data should provide justification on the necessity of the data and should be able to access it only after the explicit consent of the consumer.

The Smart Meter and IOT equipment represent the cornerstone for aggregation. They enable almost just-in-time remote monitoring of energy flows at grid connection points and production/consumption nodes.

[30] European regulatory framework, International Journal of Electrical Power and Energy Systems (2022)

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Operational concepts of Smart Metering

Single metering point

This operational concept is the most used concept for DER with ESS. This concept is closely linked to "self-consumption". Self-consumption means that the consumer uses or stores locally generated energy at the point of production. Only the surplus electricity is fed into the public grid for remuneration according to the conditions of the corresponding market player.

The economic viability of this model lies in the fact that local generation covers a significant part of the electricity consumption (in exceptional cases even the total electricity consumption) and therefore less energy bought from a retailer has to be purchased from the grid. Savings thus result from every self-consumed kilowatt-hour. The maximum of self-consumption optimization has already established itself in the field of private home ownership and a paradigm shift is also noticeable in the commercial segment.[31]

Fluctuating DER generation during a day, replaces the external procurement from the grid partially or completely. If the PV generation is higher than the load, the surplus energy can be fed into the grid or be saved in ESS if available. The electricity feed-in is remunerated by a market price. Market prices can be fixed feed-in tariffs, green premium tariffs, or the "wholesale" price.

A DER-ESS combination leads to a higher degree of self-consumption and other potential benefits, such as peak shaving, tariff shifts, etc. If the PV generation exceeds the consumption and if no ESS capacity is available, surplus DER generation is fed into the grid.

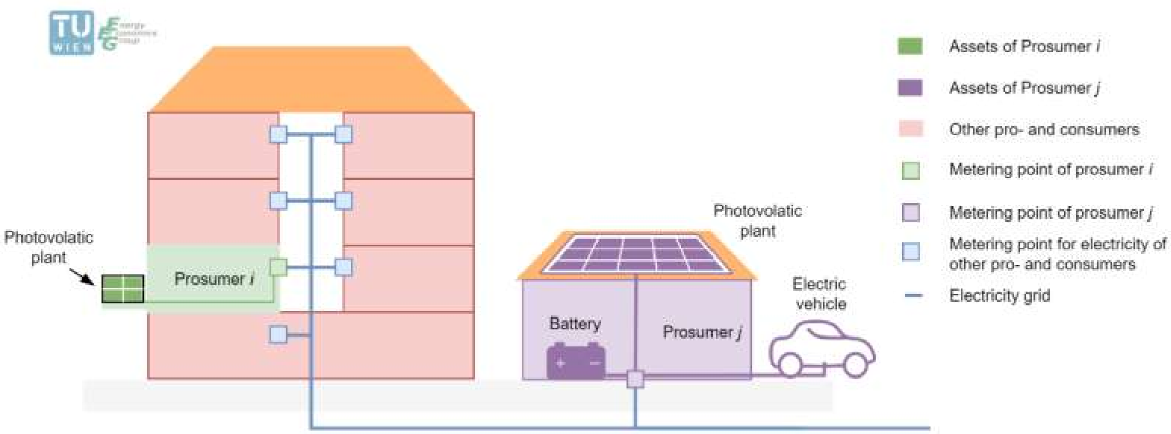

Figure 10 Single metering point from the perspective of two prosumers, i and j[32]

[31] Teoh, M., Liebl, V., Leitfaden zu PV-Eigenverbrauchsmodellen,2016
[32] Improvement of PV4Grid concepts, TU Vienna, 2018

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Virtual metering

An improvement for single prosumers is the Virtual Metering (VM) approach. Figure 11 shows an example of VM from the perspective of prosumer i. The prosumer lives in an apartment house and owns three assets: a share of the PV plant, a battery not located on the housing site and an EV. This model increases the matching of generation and consumption for prosumers. Figure 11 shows the assets allocated to prosumer i with the dotted line. This model is very interesting for EV, as it is not always possible to park and connect the EV at the physical metering point of the generation site.
VM enables prosumers to access DER produced energy, even if they cannot put solar on their roofs or do not have suitable land for a solar array. In its most basic form, VM allows prosumers to generate energy in one place and use it in a different place.
VM is applicable in scenarios where an organization or homeowner wants to install solar but does not have suitable property conditions (legal issues, small roof, too much shading, in need of repair, structural issues, etc.) for on-site solar. [33]

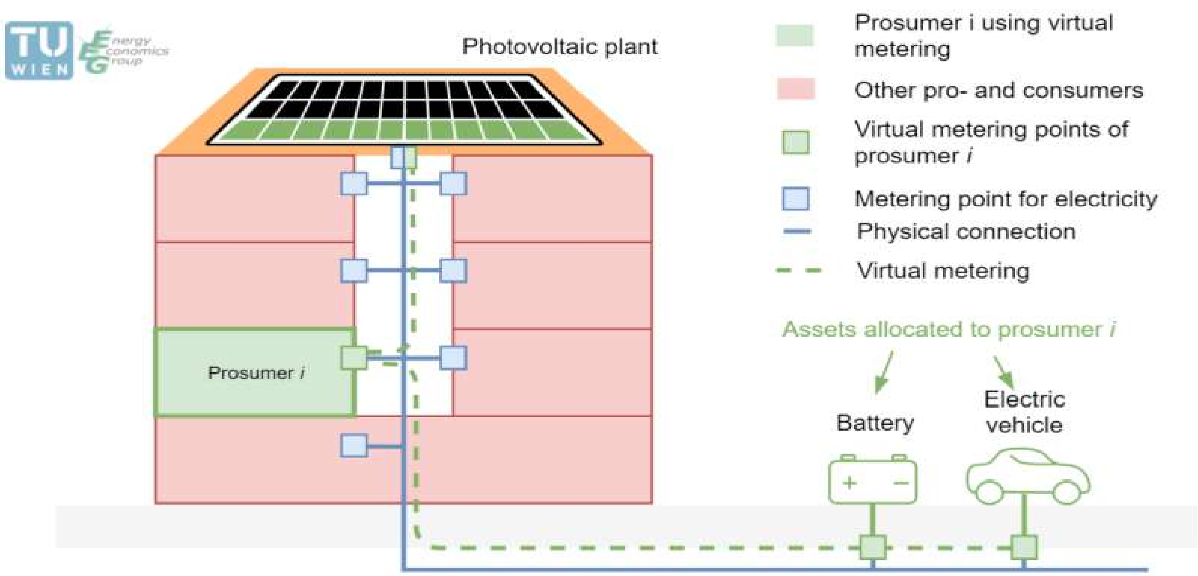

Figure 11 Virtual metering point from the perspective of two prosumers i and j[34]

[33] Solect Energy, 2015. Net Metering, Solect Energy. URL https://solect.com/net-metering-101/
[34] Improvement of PVP4Grid concepts,Vienna, 2018

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Energy community

Energy communities are entitled to share electricity from generation assets within the community between its members or shareholders through peer-to-peer trade arrangements. Many experts as well as the Commission expect energy communities' electricity trading with and without the need for retailers or conventional utilities to increase, as the awareness of the shared economy has grown and DERs and ESSs are spreading. Furthermore, the development of renewable energy technology and internet technology will accelerate the dissemination of the new system.[35]

Energy communities may be organized in two different ways: (1) centralized or (2) decentralized. While the first one requires a central platform to match generation and consumption, the second one foresees this capability to the consumers/generators. Central trading platforms (at least for larges sized generators, retailer, etc.) are widely established in the energy markets, but not for small-sized entities.

Besides the setup of the energy community, the most relevant actors are generators, consumers, the trading platform, and the retailer.
Such a model requires a high rate of data exchange between the participants via the platform.

The role of prosumers may change from generators to consumer and vice versa. Most important is the local matching of generation (generators) and consumption (customers). A synchronized matching requires a technical solution, e.g., by a central software platform (including an operator) or decentralized applications performing this task on behalf of the generators/consumers. Not only matching of generation and consumption can be provided by such a common platform, but additional information such as prices and the origin of electricity generation and consumption may also be visualized. Similar to the food retail sector such a concept allows to satisfy the customer's need in consuming "local products" and increases the economics of DER and ESS. [36]

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[35] Pause, F., Wimmer, M., 2018. The impact of the CE4AE-Package on legal and regulatory problems for aggregators, encountered in the BestRES project, bestres.eu

[36] Park, C., Yong, T., 2017. Comparative review and discussion on P2P electricity trading. Energy Procedia, International Scientific Conference "Environmental and Climate Technologies", 2017

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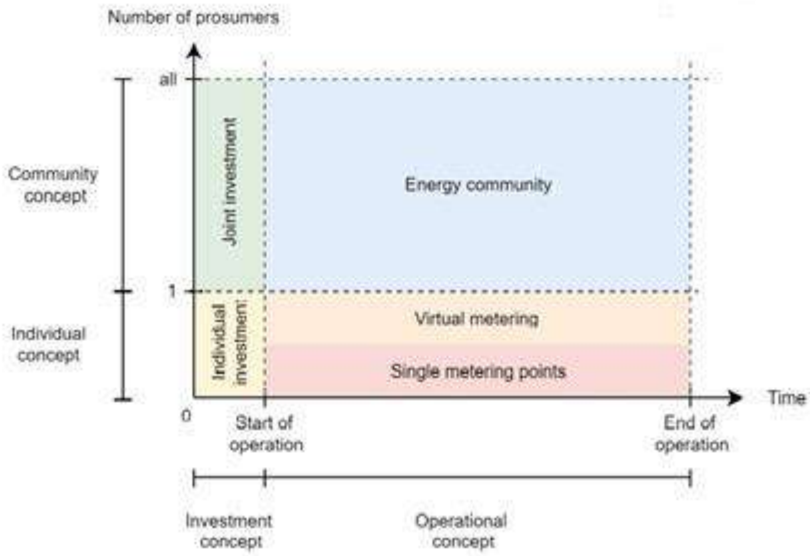

Figure 12 Classification of PVP concepts according to the parameters time and number of prosumers

The difference to the standard energy-only-market (EOM) is that grid characteristics may be included in the matching algorithm. So, potentially it removes the need for costly future improvements to create additional network capacity to meet increased peak demand flows or gives the prosumer the possibility in monetarizing their investments by a new way.

Although the design of grid charges and taxes does not reflect and support the local matching, we expect that it will play a role in the future; in the UK, Open Utility concluded that the current grid tariff design offers no financial incentives to either generators or end-users to join an energy community. [37]

[37] Barriers to Independent Aggregators in Europe, University of Exeter, 2019

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Business Model Concept

Considering the grid dynamic in the context of green energy transition, the past, present and future relationship between power generation and energy consumption, the advantages and disadvantages of aggregation typologies and the future role of energy communities, Tractebel proposes a business model consisting of the interaction between a virtual energy transaction platform and combined aggregator-supplier.

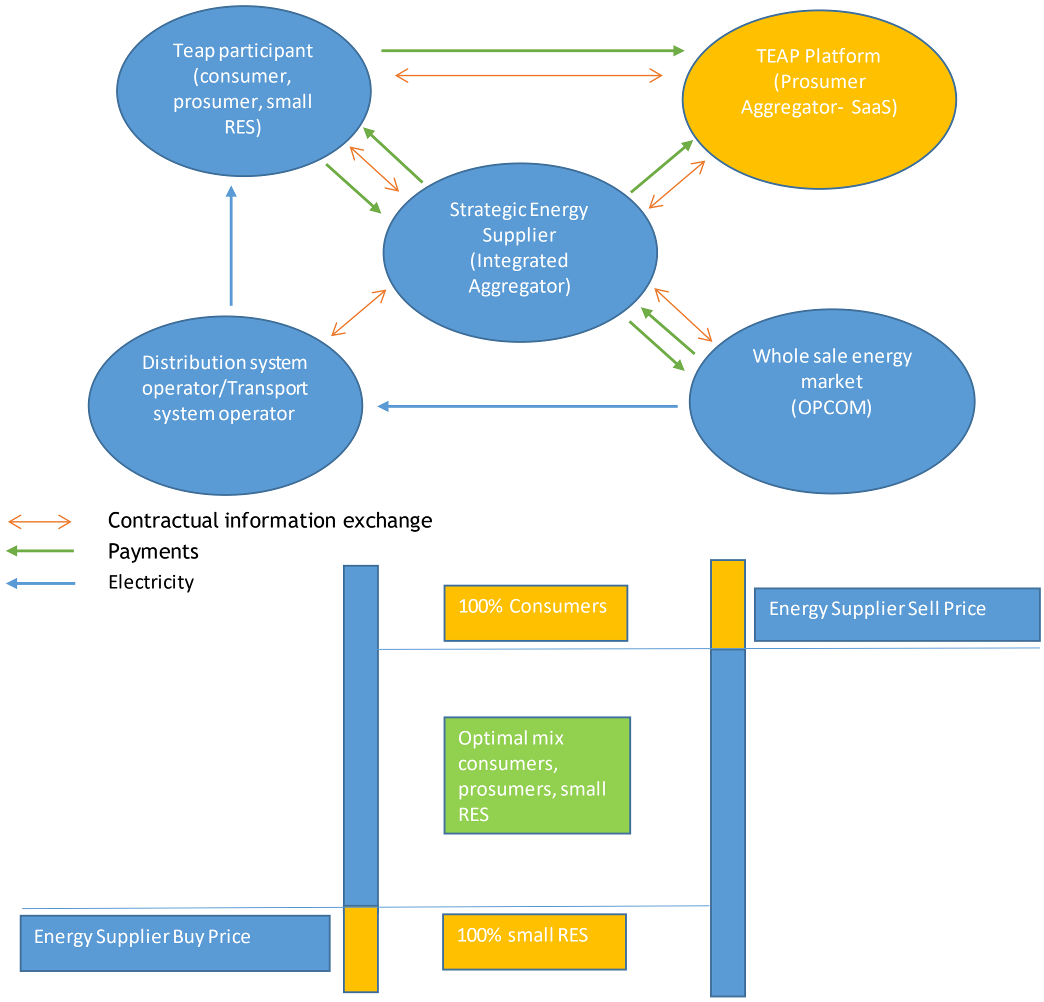

Figure 13 Business model concept

The business model includes following stakeholders:

- Trading platform for virtual energy transaction as software as a service with an independent administrator (TEAP – Tractebel Energy Application Platform)
- TEAP participants (consumers, prosumers, small renewable energy producers)
- Strategic energy supplier with the role of combined aggregator-supplier (SEP)
- Distribution and transport system operator
- Wholesale energy market (e.g. romanian OPCOM)

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The business model has two main enablers, the remote monitoring of energy flows at participants' grid connection points through the analyzers(smart meter) and the peer-to-peer virtual energy transactions between participants through the platform algorithms.

Due to complexity and the ahead of time status, IoT equipments were not considered. But this is an aspect that would have to be integrated in the concept, as soon as protocol standards between and to inteligent equipments are set, in order to allow a viable demand response management.

Consumers, prosumers or small energy producers can join the TEAP by signing a tripartite contract with both the platform administrator and the strategic energy supplier. This way they would give up their energy supplier and engage in a monetary beneficialy energy trading. Moreover they have to acquire a proper smart meter that supports the data interface with the trading platform.

Considering the price limitations set by the administrator in the trading platform (SEP sell/buy prices) and the present prosumer legislation, the installed capacity of a small RES would not surpass 400kW.

The business model is sought to serve a local community, such as a residential neighborhood but it also finds applicability on a wider geographical area, which makes sense because small RES will be most likely located elsewhere as within the residential area.

Small RES's and prosumers are needed in the appropiate mix, because otherwise the business modell wouldn't confer advantages for them compared to buying/selling contracts with a clasic energy supplier. For example, if the trading platform would comprise only consumers then the transactional costs of the platform would surpass the classic supplier scheme. The strategic supplier as aggregator and balance responsible party will close the gap with TEAP, supplying the energy deficit and acquiring the surplus energy to flexible TEAP Balancing Market prices.

Moreover the strategic energy supplier is responsible for invoicing the TEAP participants for their traded energy according to the platform clearing prices and his agreed flexible sell/buy prices. SEP pays the prosumers and small RES' for the in TEAP sold energy and cashes in from the consumers, for the energy they bought in TEAP. Moreover the strategic supplier trades the energy excendent from TEAP on the whole sale market and acquires the deficit for the energy which couldn't be internally covered.

The TEAP participants pay the platform administrator 20% of the saving generated by virtual energy trading in the platform. SEP pays also a contractual fee to the TEAP administrator. The real energy is supplied both by TEAP and whole sale market and transported/distributed by TSO/DSO according to the SEP signed contracts.

Grid tarrifs don't play a role in the energy trading on the platform, they are invoiced normally for the participants' traded energy quantity. However they could represent the second flexibile component for participants' gain maximization, along with the active

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energy component. Thanks to TEAP, the SEP has acces to energy consumption and production aggregation of participants and can trade efficiently on the wholesale market.

In the TEAP platform can participate any user who is willing and currently has an energy supply contract with a standard energy supplier. For joining TEAP commercially, the user must conclude a commercial contract with the TEAP operator and also start up a contract with the strategic energy supplier/aggregator in the platform. Also, the user must accept and cover the energy metering devices costs that are integrated into the platform or accommodate the integration costs for other devices if they have such.

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Tractebel Energy Aggregation Platform (TEAP)

The TEAP application can be accessed by the user through a web browser using the address: http://www.teap.ro.

The main objective of TEAP is to allow virtual energy transactions between participants in the platform and to optimize the savings of the users. Monetization of trades is performed in TEAP coins (T.C.s). During the trading session, the participant's identity remains anonymous.

Participation into TEAP platform can bring benefits for the participating users in terms of reduced cost of energy supply, being environmental conscious and limiting CO_2 footprint as energy used in the community is mostly produced from renewable sources (supplied by the prosumers and RES participating in the platform) and last but not least, the sense of wellbeing for supporting an independent community and sense of belonging to a group.

TEAP Business Logic

The TEAP business model implies that users aggregate and perform energy transactions (selling and buying energy) on virtual energy markets that are present in the platform. Therefore, for the purpose of market transactional roles, TEAP has implemented 3 core energy wholesales markets in the platform, namely:

- Day Ahead Market (DAM),
- Intra-day Market (IDM) and
- Balancing Market (BM)

In case of the Day Ahead Market (D.A.M.), transactions are realized when the market will be closed. The trading is completed when there is a match between the submitted request and offers under the price/validity conditions previously established between the users involved in the transaction. The equilibrium price or Market Clearing Price (M.C.P.) is the selling price for all participants that offered a lower selling price than M.C.P., respectively the purchase price for all buyers that offered a buying price higher than M.C.P.

Transactions in the Intra Day (I.D.M.) market occur when there are two equal prices between a purchase offer and a sale offer. When a transaction is generated, the balance of users involved in the transaction decreases/increases with the value of the transaction.

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Information Exchanges

The information exchange between the users and members of the energy trade exchange is done via the TEAP platform, specifically thru the orders and transactions modules where all users place information of their orders in the marketplace and when offer meets demand the platform automatically close the respective order into a transaction and record the credit or debit to the respective accounts of the traders.

Also, users in the platform can see all their transactions done in the platform, whereas the administrator or the strategic supplier roles can see a level further, e.g., all the transactions from all users in the platform.

Market Stakeholder Interfaces

The interfaces used by participants include an overall dashboard interface for all transactions, energy, and wallet account reporting; a dedicated main interface for entering energy orders into the market ("buy/sell") and confirming transactions and reports on market orders. Also, there is a specific interface for energy parameters and quality reporting and for energy forecasting.

Last but not least the users have also a dedicated reporting interface for personal user results and overall results at the platform level.

The Strategic Provider in the TEAP platform has the role of establishing and compensate the energy price for deficit and surplus on the Balancing Market for the energetic imbalances. The Strategic Provider does not perform trading operations; it does not participate on the active market of the TEAP platform. The deficit/surplus energy price is set by the TEAP administrator. It is defined by the price set in the section References Prices: Supplier - Buy and Supplier Sell.

- The deficit energy price: Supplier - Sell price from Reference Prices module (the same for the 24 time slots);
- The surplus energy price: Supplier - Buy price from Reference Prices module (the same for the 24 time slots);

The sections available for strategic provider role are:

Dashboard;
Board;
Markets;
Imbalance Manager;

Therefore, by expanding the current case study into a real business model, the Strategic supplier has also to develop some additional interfaces towards the OPCOM market for aggregating energy and selling surplus and also with the standard distribution operator, for metering and billing purposes (APIs with distributor metering system for energy consumption validation data).

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TEAP Coins (T.C.s) Acquisition

TEAP coins (T.C.s) are TEAPs virtual platform money that needs to be acquired as part of the initial user registration. **The objective** of the T.C. acquisition business subprocess is to allow the purchase of T.C. coins for energy trading.

Every transactional user who wants to exchange energy on the platform must purchase T.C. virtual coins. The submitted applications are approved/rejected by the TEAP administrator.

After authentication, a transactional user will access the *Virtual coin acquisition* option, complete the value he wants to purchase and press the *Save* option.
Each request to purchase T.C. coins will be sent to the platform administrator. After viewing a request to purchase T.C. coins, the platform administrator can either approve the request; which will increase the user's balance by acquisition value or reject the request.

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Day Ahead Markets (D.A.M.)

Day Ahead Market is the primary market where all the action takes place on the platform. Users meet and place put-together orders for buying or selling energy at required quantities (per individual forecast) and market-set prices. Once an offer for energy meets the demand of energy, a transaction is made automatically on the platform, and each participant in the respective transaction gets credited (when selling) or debited (when buying energy) a certain amount of Tractebel TEAP Coins (TC's) depending on the ask/bid price set for the transaction.
The DAM market allows electric energy trading with delivery the next day after the trading day. Electric energy trades are concluded daily for each hourly interval within the next delivery day based on offers submitted by DAM participants. Offers are submitted in the trading system according to the trading schedule pre-established.

Features of the DAM.:
- Each DAM participant makes purchase / Sale electricity offers;
- An offer is defined by one quantity-price pair. Quantity is expressed in **kWh** with two decimals, and the price is expressed in virtual coins with two decimals;

Opening price:
- Minimum price / Supplier-Buy Price - (P_{min});
- Maximum price / Supplier-Sell Price - (P_{max});

The DAM trading schedule during a normal day is (in EET time):

12 a.m. (D-1)	Defining the day ahead market
9 a.m. (D-1)	Opening the trading day & Distribution of market parameters
3 p.m. (D-1)	Gate Closure Time, Calculate M.C.P., Generate transactions

**D-1: the day before the day of delivery*

The following information can be viewed in the module:
- List of transactions – with details;
- List of orders – with details;

All the participant's orders transmitted on the DAM market are grouped by Type: Purchase / Sale electricity orders. After that, purchase orders are sorted by price descending, and sale orders are sorted automatically. For each time slot, M.C.P. (Market Clearing Price) is calculated to check which orders should be accepted and for what price.

An order which is:
- In-the-money is fully accepted
- Out – the- money is entirely rejected
- At the money is accepted

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 837758.

To define the users who have the right to perform transactions on the DAM market, the ***EUPHEMIA (Pan-European Hybrid Electricity Market Integration)*** algorithm was used. Euphemia solves the problem associated with the coupling of the day-ahead power markets. First, market participants start by submitting their orders on DA Market. All these orders are collected and submitted to Euphemia, that has to decide which orders are to be executed and which orders are to be rejected in concordance with the prices that will be published.

EUPHEMIA computes a ***market clearing price (M.C.P.)*** for each time interval, which is calculated as the arithmetic mean between the highest price of the purchase offers and the lowest price of the sale offers when there is no intersection between the market prices. In case of an intersection between the purchase and sale prices, M.C.P. will be represented by the value of the intersection price between supply and demand. This provides solutions like:

Orders in-the-money are fully accepted

- Supply at price < = MCP
- Demand at a price >= M.C.P.

Orders out-of-the-money are entirely rejected

- Supply at a price> M.C.P.
- Demand at a price < M.C.P.

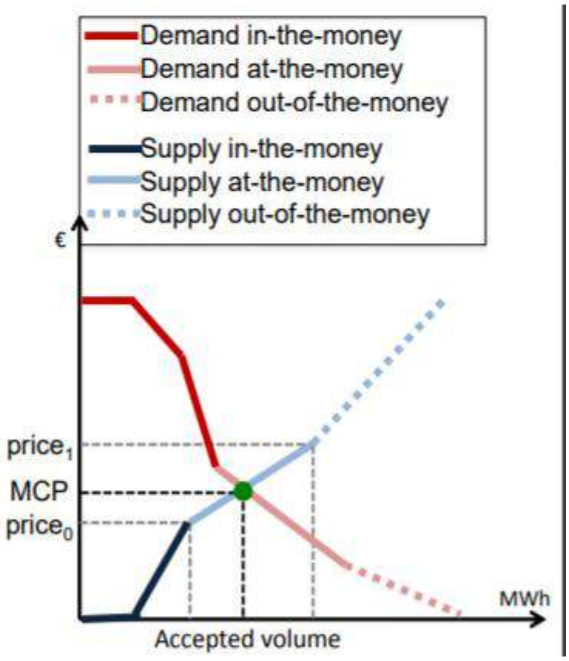

Figure 14 Market Clearing Price (MCP) calculation method

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 837758.

The following nomenclature is used when speaking about *hourly orders and market clearing prices*:

- On-demand (resp. supply) hourly order is said to be in the money when the market clearing price is lower (resp. higher) than the price of the hourly order;
- On-demand or supply hourly order is said to be at the money when the price of the hourly order is equal to the market clearing price;
- On-demand (resp. supply) hourly order is said to be out-of-the-money when the market clearing price is higher (resp. lower) than the price of the hourly order;
- For linear piecewise hourly orders starting at price p0 and finishing at price p1, p0 is used as the order price (except for energy at the money, where the market clearing price is in the interval [p0, p1]);

The **rules** that apply for the acceptance of hourly orders in the algorithm are the following:

- Any order in-the-money must be fully accepted.
- Any order out-of-the-money must be rejected.
- Orders at the money can be either accepted (fully or partially) or rejected.

The trading is completed when there is a match between the submitted request and offers under the price/validity conditions previously established between the users involved in the transaction.

MCP Price calculation

The equilibrium price or Market Clearing Price (M.C.P.) is the selling price for all participants that offered a lower selling price than M.C.P., respectively the purchase price for all buyers that offered a buying price higher than M.C.P. In the case of the reports corresponding to the trading data within the DA market, the following indicators are calculated:

1. **Base price [T.C. coins/ kWh] -** the daily arithmetic average of the Day Ahead Market (D.A.M.) clearing prices:

$$Base\ Price\ = \frac{\sum_{j=1}^{24}\ p_j}{24}$$

   This price index is determined for every day of the selected period as the arithmetic means of the clearing prices corresponding to the 24-hourly intervals.

2. **Base volume [kWh]** - the sum of hourly volumes traded on The Day, Ahead Market:

$$Base\ volume\ = \sum_{j=1}^{24}\ volume_j$$

   This volume is determined every day of the selected period by adding up all hourly traded volumes (for 24 intervals).

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3. **Peak Price [T.C. coins/ kWh] -** the arithmetic average of Day Ahead Market clearing prices corresponding to the peak hours:

$$Peak\ Price = \frac{\sum_{j=7}^{22} p_j}{16}$$

This price index is determined for every day of the selected period as the arithmetic means of the prices corresponding to the 16 hourly intervals, considered peak hours (including 7^{th} and 22nd intervals).

4. **Peak volume [kWh] -** the sum of the hourly volumes traded on the Day-Ahead Market, corresponding to peak hours:

$$Peak\ Volume = \sum_{j=7}^{22} volume_j$$

This volume is determined every day of the selected period by adding up the hourly traded volumes corresponding to the 16 hourly intervals, considered peak hours (including 7^{th} and 22^{nd} intervals).

5. **Off-Peak Price [T.C. coins/ kWh] -** the arithmetic average of the D.A.M. prices corresponding to off-peak hours:

$$Off - Peak\ Price\ = \frac{\sum_{j=1}^{6} p_j + \sum_{j=23}^{24} p_j}{8}$$

This price index is determined every day of the selected period as the arithmetic mean of the prices corresponding to the eight hourly intervals, considered off-peak hours (including $1^{st} - 6^{th}$ and $23^{rd} - 24^{th}$ intervals).

6. **Off-Peak volume [kWh] -** the sum of the hourly volumes traded on Day-Ahead Market, corresponding to off-peak hours:

$$Off - Peak\ Volume = \sum_{j=1}^{6} volume_j + \sum_{j=23}^{24} volume_j$$

This volume is determined every day of the selected period by adding up the hourly traded volumes corresponding to the eight hourly intervals, considered as off-peak hours, including $1^{st} - 6^{th}$ and $23^{rd} - 24^{th}$ intervals).

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Intra-Day Market

Intra-Day Market (IDM) – is the secondary market, where only surplus or deficit energy that has not been fully traded in the primary DAM market is available for transaction. Next to the Day-Ahead Market, the Intra-Day Market supports reaching the balance between demand and supply because the participants have the opportunity to trade in this market the energy, they failed to trade in the DA market. The Intra-Day Market is a continuous market, trading every day up to one hour before delivery. The intra-day market is open 24/7, 365 days a year, offering the flexibility needed to meet market needs. Every user can only send an order in an ID market.

Next to the Day-Ahead Market, the Intra-Day Market supports reaching the balance between demand and supply because the participants have the opportunity to trade in this market the energy; they failed to trade in the D.A.M. market.

The Intra-Day Market is a continuous market, trading every day up to one hour before delivery. The intra-day market is open 24/7, 365 days a year, offering the flexibility needed to meet market needs. Every user can only send an order in an I.D. market.

Features of ID:

- The trading day is each calendar day;
- The trading interval is an hour;
- The sale/purchase offers for electricity are simple quantity-price offers/orders;
- An ID participant can submit orders to buy and sell for each trading interval;
- The offers are accepted in the market until an hour before the market closes.

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Offers with the same trading price define the Intra-day market principle. When a user defines a sale offer with a specific price, and another user defines a purchase offer with the same price defined by the first user, the transaction will be made automatically between these two offers. If there is a difference between these two offers, a sale/purchase order with a different quantity will be automatically created and sent to the I.D.M.

12 p.m. (D-1)	Defining the Intraday market
3 p.m. (D-1)	Opening the trading day & Distribution of market parameters
11 p.m. (D)	Gate Closure Time

** D-1: the day before the day of delivery*
** D: day of delivery*

The intra-day market module can be accessed from the platform's main menu (Market → Intra-day market). In the case of the reports corresponding to the trading data within the I.D. market, the following indicators are calculated:

1. **Base Price [T.C. coins/ kWh] -** the daily arithmetic average of the Intraday Market prices set for each hourly interval:

$$Base\ Price\ = \frac{\sum_{j=1}^{24} p_j}{24}$$

   This price index is determined for every day of the selected period as the arithmetic mean of the prices corresponding to the 24-hourly intervals.

2. **Peak Price [T.C. coins/ kWh] -** the arithmetic average of hourly prices corresponding to the peak hours on the Intraday Market:

$$Peak\ Price = \frac{\sum_{j=7}^{22} p_j}{16}$$

   This price index is determined for every day of the selected period as the arithmetic mean of the prices corresponding to the 16 hourly intervals, considered peak hours (including 7^{th} and 22nd intervals).

3. **Off-Peak price [T.C. coins/ kWh] -** the arithmetic average of the I.D. prices corresponding to off-peak hours:

$$Off-Peak\ Price\ = \frac{\sum_{j=1}^{6} p_j + \sum_{j=23}^{24} p_j}{8}$$

   This price index is determined every day of the selected period as the arithmetic mean of the prices corresponding to the eight hourly intervals, considered as off-peak hours (including $1^{st} - 6^{th}$ and $23^{rd} - 24^{th}$ intervals).

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4. **Peak volume [kWh] -** the sum of the hourly volumes traded on the Intraday market, corresponding to peak hours:

$$Off - Peak\ Volume = \sum_{j=7}^{22} volume$$

This volume is determined every day of the selected period by adding up the hourly traded volumes corresponding to the eight hourly intervals, considered off-peak hours, including $the\ 7^{th}$ and 22nd intervals.

5. **Off-Peak volume [kWh] -** the sum of the hourly volumes traded on the Intraday market, corresponding to off-peak hours:

$$Off - Peak\ Volume = \sum_{j=1}^{6} volume_j + \sum_{j=23}^{24} volume_j$$

This volume is determined every day of the selected period by adding up the hourly traded volumes corresponding to the eight hourly intervals, considered as off-peak hours, including $1^{st} - 6^{th}$ and $23^{rd} - 24^{th}$ intervals).

6. **Base volume [kWh]** - the sum of hourly volumes traded on the Intraday market:

$$Base\ volume\ = \sum_{j=1}^{24} volume_j$$

This volume is determined every day of the selected period by adding up all hourly traded volumes (for 24 intervals).

Balancing Market

The last and final market is similar to the actual operations, the **Balancing Market (BM)**, a closure and penalizing market, where users are analyzed based on their forecasted consumption/production vs. actual measured consumption/production, and balancing coefficients are applied to balance the market (differences of forecasted vs. actual quantities are bought or sold at balancing market prices). Through the balancing market, it is possible to take balancing actions to identify the need for production or consumption adjustment. Thus, the balancing energy is used to cover a production deficit or a surplus of consumption.

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The balancing market is the last stage for trading electric energy. It plays an essential role, as production and consumption levels must match during the operation of electric power systems.Through the balancing market, it is possible to take balancing actions to identify the need for production or consumption adjustment. Thus, the balancing energy is used to cover a production deficit or a surplus of consumption.

For the imbalances created, users can either pay additional T.C. at the aggregate price of the imbalance if actual consumption/production was higher than the consumption forecast/production forecast, or they can receive T.C.s at the surplus price initially received from the supplier.

The balancing process is described below: Balancing for the difference takes place in the following situations:

- Real volume > traded volume;
- Real volume < traded volume;

In a dual-price imbalance system, deviations from the production schedule are traded at different prices, conditional upon the imbalance sign. When the deviation of the producer and system imbalance occurs in opposite directions (i.e., the producer helps in reducing the system imbalance), its deviation is traded at the day-ahead market price, avoiding possible bonuses. Conversely, when the two imbalances occur in the same direction, the deviation of the producer is priced at the balancing market price (i.e., usually penalized).

The values from transactions and actual consumption/real production are taken as absolute values to calculate the user-level imbalances.

User Type	**Imbalance algorithm**
Consumer user	***ID transaction type =B:*** Imbalance = Real Consumption Volume - D.A.M. Traded Volume - I.D. Traded Volume ***ID transaction type =B:*** Imbalance = Real Consumption Volume - DAM Traded Volume + ID Traded Volume
R.E.S. Producer	***ID transaction type =B:*** Imbalance = Real Production Volume - DAM Traded Volume + ID Traded Volume ***ID transaction type =S:*** Imbalance = Real Production Volume - DAM Traded Volume - I.D. Traded Volume
Prosumer user	***Real Production Volume >Real Consumption Volume and / or ID transaction type =B:*** Imbalance = ABS (Real Production Volume - Real Consumption Volume) - DAM Traded Volume + ID Traded Volume ***Real Production Volume >Real Consumption Volume and / or ID transaction type =S:***

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Imbalance =ABS (Real Production Volume - Real Consumption Volume) – DAM Traded Volume - ID Traded Volume

Real Production Volume <Real Consumption Volume and / or ID transaction type =B:

Imbalance = ABS (Real Production Volume - Real Consumption Volume) – DAM Traded Volume - ID Traded Volume

Real Production Volume <Real Consumption Volume and / or ID transaction type =S:

Imbalance = ABS (Real Production Volume - Real Consumption Volume) – DAM Traded Volume + ID Traded Volume.

On the day the energy was purchased, the real values for consumption and production (Production achieved, respectively consumption achieved) will be considered.

The difference between them will be calculated, highlighting the Type of user of the prosumer for each time interval (it functions as a consumer if production achieved < consumption achieved and as a producer if the sign of inequality is reversed).

The difference between the forecasted value (Sale value or Purchase value) and the difference presented above for the realized production and consumption represents the imbalance introduced by that user in the platform (Imbalance).

There are, therefore, three cases of interest:

1. *Imbalance> 0*: This case is associated with a higher real production / consumption than forecast production / consumption
2. *Imbalance <0:* This case is associated with a higher forecast production/consumption than real production/consumption.
3. *Imbalance = 0*: This case is associated with a correct forecast. The value of the imbalance will, in this case, be 0 T.C.

For the imbalances created, TEAP users may pay additional T.C. at the aggregate price of the imbalance (revised TEAP internal deficit price platform) if actual production was lower than the production forecast or may receive T.C. at the surplus price originally got from the supplier for the additional power produced which will be discharged into the supplier's network.

Total P.R.E. = the sum of the imbalance values for each time interval for all users
Unbalance cost = negative imbalance x price for the energy deficit
Unbalance cost = positive imbalance x price for surplus energy
Total Unbalance Cost= the sum of the imbalance cost for each time interval for all users
Total PRE_UnbalanceCost = negative Total PRE x price for energy deficit
Total PRE_UnbalanceCost = positive Total PRE x price for surplus energy

The internal redistribution of payments is used as a method of internal allocation of costs/benefits generated by Imbalances for members registered within TEAP

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Costs calculated in case of individual participation = Total_UnbalanceCost
PRE costs (TC) received from OPCOM = Total PRE UnbalanceCost
Absolute Earnings (T.C.) = Costs calculated in case of individual participation - P.R.E. costs (T.C.) received from O.P.C.O.M.
dezPRE = the sum of the absolute values of the imbalances for each time interval
unit earning = Absolute Earnings (TC) / dezPRE
Revised Price for Energy Deficit = unit earning - Price for Energy Deficit
Revised Price for Energy surplus = **unit earning + Price for Energy Surplus**

The allocation among the members of a P.R.E. of the costs/revenues generated by the imbalances of the P.R.E. is performed for each time interval according to the following algorithm:

- The financial values of the imbalances (T.C.) with the sign "+" represent costs, and those with the sign "- "represent revenues.
- The physical values of the imbalances (MWh) with the sign “+” represent a surplus of sold energy, and those with the sign “- “represent a necessary energy deficit to buy.

The costs are determined by multiplying the negative imbalance with the price for energy deficit, respectively, the positive imbalance with the price for surplus energy for each hour.

Energy Orders

The Orders module's objective is to offer users the possibility to define the requests for sale and purchase of electricity, as well as to set prices at hourly intervals for them. After defining the demand, the user has the possibility to send the offers/requests within the markets in which he wants to trade energy.

Note: At the D.A.M. market, a user can only transmit one offer per day on any selected date.

Based on user preferences, orders are defined automatically based on forecast volume and forecast price. TEAP automatically generates orders based on a cron job that runs at 12 a.m., at the time slot interval with pre-completed values, which each user can update until the time interval expires. If the user does not send the order to the market, it will be automatically sent to the market when the market closes.

Also, if a user is a group member, every order will be transmitted to the association leader, who will have the responsibility to send it to the market. If the association leader does not send the order to the market, when the market closes, all aggregated orders will be sent automatically.

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Energy Transactions

The *Transactions* business sub-process aims to allow virtual energy transactions between participants in the platform. Monetization of traders is performed in **TEAP Coins (T.C.)**. During the trading session, the participant's identity remains anonymous.

In the case of the DA market, transactions are realized when it will be closed. The trading is considered completed when there is a match between the submitted request and offer under the price/validity conditions previously established between the users involved in the transaction. The equilibrium price (M.C.P.) is the selling price for all participants that offered a lower selling price than M.C.P., respectively, the purchase price for all buyers that offered a buying price higher than M.C.P.

Transactions in the I.D. market occur when there are two equal prices between a purchase offer and a sale offer. When a transaction is generated, the balance of users involved in the transaction decreases/increases with the value of the transaction.

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Association/User Groups

The objective of the User Association business sub process is to allow to define the groups within the TEAP application to trade energy at the group level.

The participants in the business sub process are:

- Association leader (transactional user);
- Group member (transactional user);

Platform interaction is done by:

- ***Independent users*** - also, in the TEAP platform, users can interact with the platform, with each other individually, as single users or
- ***In groups -*** where two users or more users are decided to form a transactional group, assign a group leader, and make transactions (buy/sell) as one entity, the group, rather than individual users. Each transactional user can be a member of only one group. When he becomes a member, the orders defined within the markets in the platform are sent to the association leader, and after he checks them, he has the responsibility to send all the orders at the group level in the market. If the administrator forgets to send the orders to the market, when the market closes, they will be sent automatically. At the end of the transactions, the gain or the loss is distributed among the group members according to each member's share (%) of participation or share (%) of generating profit/loss.

Within the Association module, an authenticated user can manage the groups he owns as well as those he belongs to. The association is represented by an association leader, who will trade and represent the association related to the energy trading exchange.

A user also can join an existing association. The group leader can accept or reject the invitation. When a user adheres to a group, he will be considered a member of that group (when his request is accepted).

Each transactional user can be a member of only one group. When he becomes a member, the orders defined within the markets in the platform are sent to the association leader. After he checks them, he is responsible for sending all the orders at the group level in the market. If the administrator forgets to send the orders to the market, they will be sent automatically when the market closes.

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In the association module, the users can view the following information:

- **My Groups:** all the groups the user is affiliated with as a member or administering as an admin of the group.
- **All Groups:** all the groups in the platform, besides the ones that it is a member or affiliate in
- **Requests for membership:** all the user's membership applications are submitted for the groups.

The association leader can only define one group. As soon as it defines the group, not only does it become the leader of that group, but also a member. The association leader is responsible for sending orders in the group's name based on the aggregated orders.

The member becomes part of a group after he transmits a request to a certain group in advance. As soon as the application for membership is accepted, it becomes a member of the group. If a member is part of a particular group, he can no longer adhere to another group.

Based on the estimated consumption from the forecast, the system automatically generates the orders for D.A.M. (based on a CRON job run at 00:00). The orders are set for each time frame with pre-filled values that each member can update until the expiration of the time slot set for changes and updates by the association.

Each member with a trading account who wants to trade at the group level must submit **T**.C. acquisition requests. These requests are accepted/rejected by the TEAP Administrator. If the request is accepted, the member's balance is automatically updated with the requested value.

Each member's orders are visible to the leader in a dedicated interface. All orders sent by the members to the association leader are aggregated at the quantity ordered level, and an aggregate order is formed on behalf of the group. After the order is defined, the association leader can transmit the order to the D.A.M. Market. At this point, the market status will be **pre-open** or **open**.

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TEAP Application Design Architecture

Application Programming

TEAP is a web application that operates in an open-source software environment that has the following basic components:

- OS Distributor ID: Ubuntu 18.04.5 LTS
- Web Server: Package: apache2 Version: 2.4.29-1ubuntu4.19
- Server version: Apache Tomcat/9.0.16 (Ubuntu)
- Server number: 9.0.16.0 JVM
- Version: 1.8.0_292-8u292-b10-0ubuntu1~18.04-b10
- Package: mongo dB Version: 1:3.6.3-0 ubuntu1.4

The following programming languages and frameworks have been used to implement the application's functionalities:

- Vue 2.6.10 Framework and vuetify 2.2.11 CSS Framework;
- JavaScript;
- Java Spring Framework - Java 1.8;
- MongoDB: MongoDB Query Language (M.Q.L.).

The document-oriented model was chosen for the database design. MongoDB is a cross-platform document-oriented database program. Classified as a NoSQL database program, MongoDB uses JSON-like documents with optional schemas.

Module Descriptions

The following modules/processes facilitate the automation and monitoring of operations within the TEAP platform:

- User Registration
- TEAP coins (T.C.s) acquisition
- Energy Markets
- Energy Orders
- Transactions
- Automatic energy forecasting
- Manual input of energy data
- Association / User groups
- Energy data
- Reports
- Strategic provider
- Management

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Middleware layer for measuring device interface / IoT / 3rd party API interface for market integration;

- Automation layer for the control and operation of the business processes and usage of the open-source technology;
- MongoDB Compass database for storing and processing consumption / calculation / historical data.

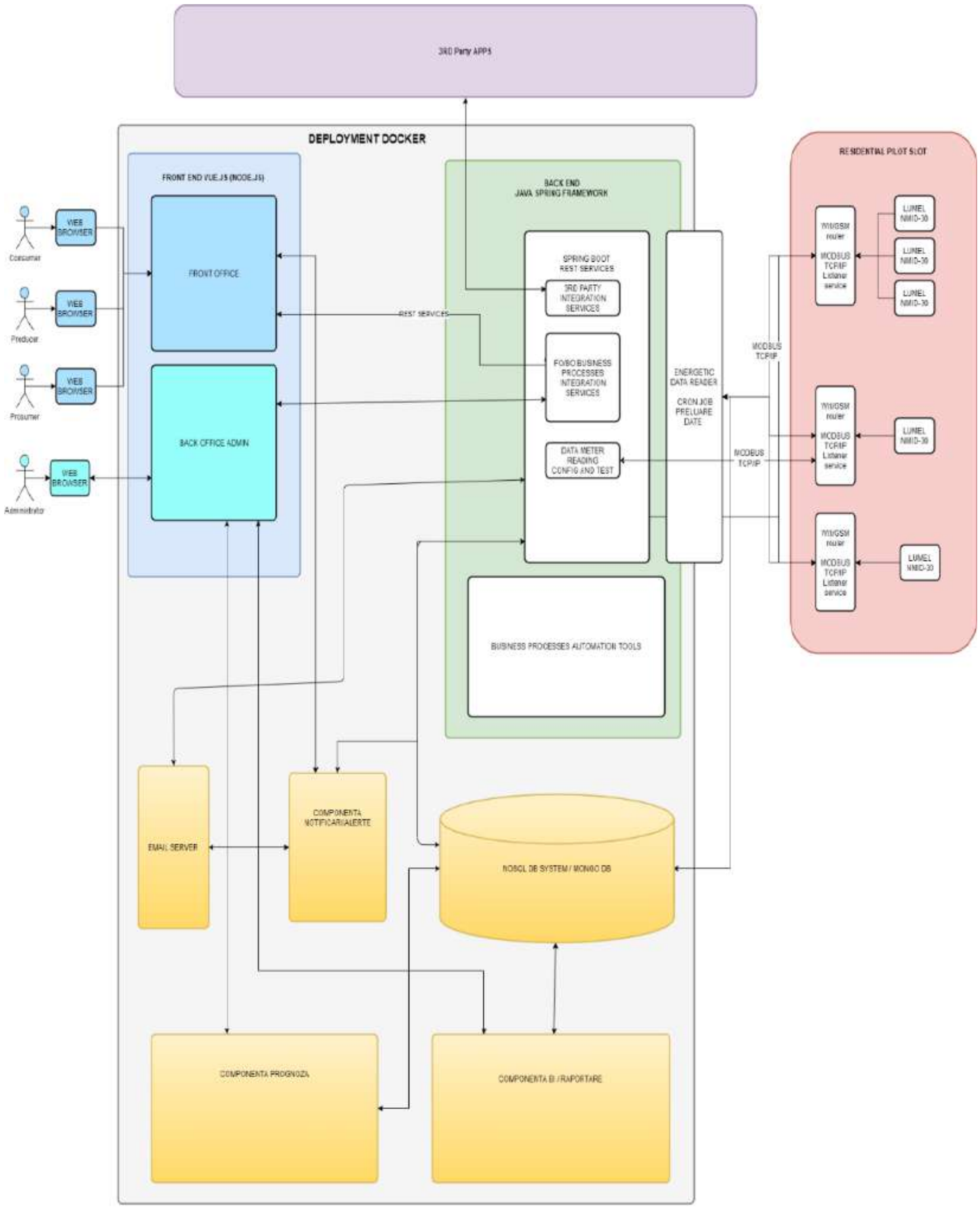

Figure 15 TEAP Logical architecture design

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User Registration

From the point of view of the developed software application, users of the platform are:

- **Unregistered users** - are only visitors, having the possibility to view just the homepage.
- **Admin user (TEAP admin)** - can perform operations like market administration, analyzer administration, user management, and accept T.C. purchase requests.
- **Unregistered users** - are visitors only, having the possibility to just view the homepage.
- **Admin users** (TEAP admin) – these are the specialized users that can perform operations like market administration, analyzer administration, user management, and accept T.C. purchase requests.
- **Standard users** – are the users that have provided data for opening a standard account. The data provided for a standard account are surname, name, username, e-mail address, and password. Standard users use access credentials to log into the platform (a username and password created by the user when creating the account). The standard users can become transactional users by providing more information like user type, address, phone number, etc. The standard users have access to the platform but can't perform transactions.
- **Transactional users** - only users with a standard account can apply for a transactional account. These types of users can make transactions on the platform. The trading account is assigned to a "virtual account" for the virtual coins used in the transaction. The transactional users have access to all the application's functionalities, including the possibility to perform energy transactions.

Standard users

When an unregistered user accesses the TEAP platform, general information about the facilities offered by the platform is submitted. Also, the user has the following options:

- to create an account within the platform to have access to the facilities offered by the application (Sign UP option);
- if the user has an account, he can authenticate within the application by accessing the "Login" option;

The registration confirmation mechanism implies that the standard user has to respond to a "Confirm Registration" e-mail sent after the registration was successful in verifying his e-mail address and activating his account. The user clicks a unique activation link sent to him over e-mail. After that, the user can authenticate in the application with his username and password in the registration form.

If a user forgets his password, he can recover it by providing the account's e-mail address. After that, he will receive a reset password link. By clicking the link, he will be redirected to the application, where he will create a new password. The objective of the

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Transactional user business sub process is to allow the definition of transactional accounts in TEAP.

Transactional

The platform aggregates the following types of transactional users:

- Consumers – users that are only consuming energy and forecast the energy they need to purchase from the market
- Prosumers – users that are both consuming and producing energy, so they forecast both consumption and production and buy or sell energy in the market accordingly
- Small Renewal Energy Producers (R.E.S.) – users that are small energy producers (R.E.S.) that produce energy from renewable sources (photovoltaic panels P.V. or wind W.D. sources).
- Strategic provider – traditional large energy providers whose role is to balance and compensate the market.

After authentication, a standard user has the opportunity to apply to generate a transactional account. In this case, he will fill additional data, such as telephone, address, and Type of transactional user. The purpose of using a transactional account within the application is to allow users who adhere to it to perform energy transactions.

Automatic Energy Forecasting

The *Forecast* business sub process aims to allow the energy traders to forecast how much they will consume/produce in the future to place their orders in a specific market. Therefore, the *Forecast* module was developed. Energy traders can use forecast volumes to predict the consumption/production in a market. Also, based on forecast prices, they can have a perspective about the prices for every time slot. The forecasted volume is calculated using the most recent one-year historical user consumption/production. To calculate this, a cron job was defined and will run when a new consumption/production data is read/uploaded.

Based on the energy data corresponding to the previous actual consumption/production, the forecast volume is calculated as the arithmetic means of the consumption/production prices (order price and trade price) from one year ago. To determine the price forecast, the last year's trading prices from DAM and I.D.M. markets are considered at the time slot level, and it is calculated as the arithmetic mean between the sum of trade prices and order prices. The data obtained within the forecast module are used to determine the energy demands and offers within TEAP.

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Manual Input of Energy Data

If a user does not own an analyzer, he can provide energy data by manually uploading an Excel file with the energy data. After authentication, a transactional user will access the *Energy Data -> Manual input* menu. TEAP will display the page for viewing energy data and the *Add New Energy reading* option. When accessing this option, the upload page of the consume / production file will open. To get the file format necessary to complete the energy data, the user will access the button *Download template file* for hourly energy data. After filling the data in the template file, outside TEAP, it will return to the data upload page, access the *File input* option, chooses the file it wants to upload and access the *Import* button. After uploading the data, he can view it in the application, selecting the period for which he uploaded data.

Energy Data

In the TEAP platform, the energy data module refers to 3 main functionalities as follows:

- **Energy Analyzer** – analyses the quantity and quality of the energy received or produced and injected into the network using integrated energy analyzers Lumel NMID30. The module allows the user to select one of the analyzers configured in the application for its respective profile and to check various energy parameters such as injected/consumed energy, power incl. resistive, apparent, reactive power, etc., line voltages, line currents, quality of the supply incl. power factor (P.F.), distortions (% T.H.D.), frequency (Hz), etc.

NOTE: the parameters mentioned above are valid for the specific analyzers configured within the TEAP application (e.g., Lumel NMID30). For any other types of analyzer/intelligent meters etc., additional integration will be needed to pass data into TEAP's application.

- **Actual Energy** functionality enables the user to:
    - Check the actual (measured) energy consumption and production of energy (if it is a prosumer / R.E.S.).
    - Manually introduce new data for consumption or production (based on an input template the user can download).
- **Forecast** – forecasting functionality that gives the user a prediction for future energy consumption and production based on the historical data inputted or data present in the TEAP system.

The main objective of the Energy data module is to allow the recording of actual energy consumption & energy production data specific to each transactional user. It allows the application's users to provide energy data as follows:

- automatically, by adding connection data specific to a particular analyzer integrated into the TEAP platform or
- manually, by importing Excel files with energy data for consumption and production as the case might be.

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The processes employed by the Energy data module are depicted below. The participants in the business sub process are:

- Lumel ND20 energy analyzer;
- Transactional user;

Strategic Provider

The objective of the *Strategic provider* business sub process is to offer an environment for a strategic provider to view information about balancing coefficients applied to balance the market (differences of forecasted vs. actual quantities bought or sold at balancing market prices) and to identify the need for production or consumption adjustment. Thus, the balancing energy is used either to cover a production deficit or a surplus of consumption.

The Strategic Provider has the role of establishing and compensating the energy price for deficit and surplus on the Balancing Market for the energetic imbalances. The **Strategic Provider does not perform trading operations** and **does not participate in the active market**.

The **deficit/surplus energy price is set by the administrator**. It is defined by the price set in the section References Prices: Supplier - Buy and Supplier Sell.

- The deficit energy price: Supplier – Sell price from Reference Prices module (the same for the 24-time slots);
- The surplus energy price: Supplier – Buy price from Reference Prices module (the same for the 24-time slots);

Reports

The Reports module aims to present synthetically information about prices and volumes traded within the D.A.M. and I.D. markets. After authentication, a transactional user will access the reports menu, select the period for which he wants to view a report, choose a report type, and select the option *Generate report*. TEAP will display the corresponding report based on the user's selections.

Energy Analyzer

As mentioned above TEAP platform integrates specific energy analyzers, namely LUMEL NMID30. These analyzers can sample at every 15' all the energy that passes thru, is injected into, or drawn from the grid and evaluate the quantity and quality of the energy. The technical installation and energy measurement of the analyzers is done with minimal impact and intrusion via non-contact inductive line transformers.

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Depending on what data has been selected to be displayed, the following information may be available to the user:

- Reading code – internal application code for reference of the measurement
- Timestamp – a moment when the measurement was registered
- T.W.H. - total net energy (produced/consumed), in kWh
- E.W.H. – net produced energy, exported into the grid, in kWh
- I.W.H. – net imported (consumed) energy from the grid, in kWh
- P.A. – active power, in Watts
- PA1 – active power on line 1, in Watts
- PA2 – active power on line 2, in Watts
- PA3 – active power on line 3, in Watts
- PF – power factor of the energy
- U – average line voltage in volts (V)
- U1 – voltage on line 1, in volts
- U2 – voltage on line 2, in volts
- U3 – voltage on line 3, in volts
- I – average line currents, in amps (A)
- I1 – average line 1 current, in amps (A)
- I2 – average line 2 current, in amps (A)
- I3 – average line 3 current, in amps (A)
- THDL_N – average line voltage distortions (%)
- THDL_N1 – line 1 voltage distortions (%)
- THDL_N2 – line 2 voltage distortions (%)
- THDL_N3 –line 3 voltage distortions (%)
- THDI_N – average line current distortions (%)
- THDI_N – average line 1 current distortions (%)
- THDI_N – average line 2 current distortions (%)
- THDI_N – average line 3 current distortions (%)
- FREQ – supplied frequency (Hz).

From a technical point of view, it is necessary to associate energy measuring devices for analysis and forecasting.

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The process of extracting data from analyzers is as follows:

- The measuring device, the energy analyzer, is connected to the measuring point to the connection to the grid network through a single / three-phase current transformer (30-100A). The data transfer is via serial cable to the meter/energy analyzer;
- After being received in the energy analyzer, the energy data is further analyzed, processed, and then transmitted to a GSM/3G/4G modem with the purpose of transmitting data upstream towards the TEAP platform;
- The GSM/3G/4G modem (IOG500-0T001) is connected & associated with the energy analyzer by a RS-485 MODBUS serial physical connection (cable) between modem and analyzer;
- The energy analyzer transmits the selected measurement data in RS 485 **MODBUS** TCP over Ethernet, and then further, the modem transmits the data over GSM;
- The modem uses Vodafone M2M data transmission service (GPRS, GSM data dial-up, SMS calling) with Vodafone A.P.N. over a VPN encrypted tunnel to a VPN server;
- Once decoded in the VPN server, the I.P. address (fixed) of the data SIM from the GW GSM is interrogated periodically, which must answer and send data to the TEAP platform. The interrogation is done at the level of registries for each specific value that is requested.

The process of storing/retrieving / processing extracted data:

- Information about consumption/production is collected from the users involved in the project
- Consumption/production information is collected by using Lumel ND20 energy analyzer devices
- Consumption/production data are recorded as historical information in the platform and are used in the analysis and forecasting modules.

MODBUS READING

Type : Tx Message	Type : Rx Message
Timestamp : 10:09:53:468	Timestamp : 10:09:53:514
Transaction ID : 0001	Transaction ID : 0001
Protocol ID : 0000	Protocol ID : 0000
Length : 0006	Length : 000F
Unit ID : 0E	Unit ID : 0E
Function Code : 03	Function Code : 03
Starting Address : 1004	Byte Count : 0C
Quantity of Registers : 0006	Register Values : 00 00 00 00 00 00 00 00 00 00 00 00

Figure 16 Modbus Reading

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After connecting to the devices, the following information's collected:
- Current, voltage, frequency (A, V, Hz)
- Active, reactive, apparent power (M.W.)
- Power factor (tan /cos f)
- Active energy consumed and produced (KWh)
- Inductive/capacitive reactive energy (kWArh)
- Distortion / harmonic factor (%)

The data presented in the table below were used to extract data from the analysis devices:

The NMID30-1 utilizes the latest microprocessor and technology. It has 16 different measuring parameters. This includes a negative power reading to indicate a reversal of C.T. installation or connection. Input registers are used to indicate the measurement's present values and calculate electrical quantities.

Table 7 Annual Parameters vs. Energy Analyzer Registry:

Registry	Parameter name	Description
30343	TWH (kWh)	Total active energy (kWh)
30073	IWH (kWh)	Imported energy (kWh)
30075	EWH (kWh)	Exported energy (kWh)
30053	PA (Watts)	Total system power (Watts)
30013	PA1 (Watts)	Phase 1 power (Watts)
30015	PA2 (Watts)	Phase 2 power. (kW)
30017	PA3 (Watts)	Phase 3 power. (kW)
30063	PF	Total system power factor
30043	U (Volts)	The average line to neutral (Volts)
30001	U1 (Volts)	Phase 1 line to neutral (Volts)
30003	U2 (Volts)	Phase 2 line to neutral (Volts)
30005	U3 (Volts)	Phase 3 line to neutral (Volts)
30047	I (Amps)	Average line current (Amps)
30007	I1 (Amps)	Phase 1 current (Amps)
30009	I2 (Amps)	Phase 2 current (Amps)
30011	I3 (Amps)	Phase 3 current (Amps)
30249	THDL_N (%)	The average line to neutral volts T.H.D. (%)
30235	THDL1_N (%)	Phase 1 L/N volts T.H.D. (%)
30237	THDL2_N (%)	Phase 2 L/N volts T.H.D. (%)
30239	THDL3_N (%)	Phase 3 L/N volts T.H.D. (%)
30251	THDI_N (%)	Average line current_THD (%)
30241	THDI1_N (%)	Phase 1 Current T.H.D. (%)
30243	THDI2_N (%)	Phase 2 Current T.H.D. (%)
30245	THDI3_N (%)	Phase 3 Current T.H.D. (%)
30071	FREQ. (Hz)	Frequency of supply voltages (Hz)

Note: the mentioned parameters are valid for the analyzers that are configured within the TEAP application (Lumel NMID30). For any other types of analyzer/intelligent meters etc., additional integration will be needed in order to pass data into TEAP's application.

Each electrical analyzer corresponds to a user, who can view specific data provided by the device that belongs to him. To associate an analyzer, the user accesses the menu Energy data -> Energy Analyzer, Analyzer List tab. TEAP will display a list with all energy

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analyzers associated with the user and *Add* button - which allows the addition of a new device. The user completes primary data of energy analyzer like: I.P., Port, Device ID. After that, the user will view the analyzer added to the Energy analyzer list.
To view the energy data corresponding to an energy analyzer, in the tab Reading data, the user will select the period, the parameters, and the analyzer for which he wants to view the data. TEAP will display energy data corresponding to the user data and the graphics corresponding to each parameter group. The user can download the data visualized within the application outside TEAP in Excel format.

Platform Management

For TEAP Management process has been identified as the following level 1 processes:

- Users management;
- Markets administration;
- Financial Transaction;
- Analyzer administration;
- Imbalance manager.

Users management

The *Users Management* business sub process aims to provide a user management area to the TEAP administrator and to define the roles and responsibilities assigned to each user within TEAP. After authentication, the TEAP administrator will use the *Admin Board* section and could perform the following actions:

- Edit user data;
- Delete user accounts;
- Defining a new role;
- Modifying an existing role;
- Activation / Inactivation of an existing role;

The process of removing the user's accounts is done by deactivating them. The process of removing personal data is done in compliance with the G.D.P.R. legislation in force, as follows: the data is anonymized unexpectedly, through an internal procedure, transactions remain registered but can no longer be identified as the user who generated the transactions. This process is implemented to maintain a transaction log (audit trail) and the subsequent possibility of data processing for forecast analysis.

Markets

The *Markets* business sub process aims to provide the administrator the possibility to define and manage the markets within the application. After authentication, the TEAP administrator will access the *Markets* section, and he can perform the following actions:

- Add market;
- Edit Market;
- Open the market;
- Close the market;
- View market details.

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Financial Transactions

The financial transaction module allows the administrator to manage the requests related to the acquisition of TC sent by application users. The administrator can accept or reject the user's requests after submitting a TC purchase request. The ***settlement button*** in this section updates the balance of each user, depending on the transactions he has performed.

Energy Analyzer administration

This section is dedicated to the administration of electrical analyzers for a user. The platform administrator also has the option to assign each user to appropriate electrical analyzers by accessing the "Add Analyzer" button.

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Amber Gardens - TEAP Case Study

The applicability of the aggregator concept and the decentralized market application and platform has been run on the TEAP application platform for several months, from Jan – June 2022 period, with up to 100+ users, whereas the user base is a mix of consumers (33), prosumers (65), a number (2) of small providers of energy from renewable sources (RES) and one (1) strategic energy supplier to compensate and balance the market and to see the outcome results of the pilot.

The TEAP platform development and case study have considered the implementation of all operational aspects associated with the activity of energy transactions, as seen from the perspective of a licensed electrical energy supplier active in the local market and also from two other points of view:

- From an operational point of view of aspects as per current activity associated with existing electricity market organization;
- From an operational point of view, aspects associated with the readiness of the platform incorporating the forecasted future activity of a BRP focused on addressing the energy transactions as support for the electrical energy consumption of tomorrow.

The case study defined the concept of an integrated utility package for the final consumer, with a focus on the energy source, minimizing energy prices on the market, and the use of Renewable Energy Sources (RES) to promote the environmentally friendly generation and consumption of energy.

The physical location chosen for the TEAP Pilot was the **Amber Gardens Residence** (https://www.ambergardens.ro/), located in the north of the city (Bucharest) in a lush green residential area. At the time of the project start, the Amber Gardens Residence had included 25 households considered for the TEAP pilot. Out of the total Amber residents, though only a limited number of villas (5 villas) accounting for about 20% of the total residents have agreed to participate in the pilot and allowed us to monitor the consumption and production of energy in the TEAP pilot.

Out of the 5-household qualified for the pilot, there were two prosumers (1.5kW - 3.5KWh installed PVs) and three consumers (no photovoltaic panels). The rest of the 20 villas had an estimated up to 350-380kWh per month of energy consumption). All the Amber Gardens residence villas are smart/passive houses, luxury villas type of condominiums, and electric-based utilities, with a minimum of 160 sqr. meters to max 530 sq. meters the largest.

The average household occupancy was 2+2 inhabitants (2 adults and two children), with a minimum of 1-2 cars per household (mostly ICE cars, but about 10% also BEVs electric cars).

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The data in the TEAP pilot was gathered automatically using bidirectional smart energy meters connected to the power connections of the house via isolated current transformers to be able to monitor both influx of consumed energy (for consumers) as well as the out flux of produced energy (spare) that was injected in the local grid (in case of prosumers). The intelligent energy analyzer was Lumel NMID30-1, a new generation modern design power monitor that will measure and display electrical power quality parameters.

The parameters monitored in TEAP are mainly: power mono/tri-phase, energy in/out (active, apparent, reactive, etc.), line voltage/current plus energy supply quality, including frequency stability, power factors (PF), and THD distortions. The data was read from the NMID analyzer using the build in the registry and MODBUS 48 Serial transmission to a local internet 4G/cellular gateway.

From the gateway, the data was then transmitted to the TEAP application platform using public cellular data network services (M2M) from Orange and industrial 3G/4G Gateways from AMIT, AMIT IOG500-0T001 industrial 4G Gateway, and a set-up VPN server for secure connection and data privacy. The secure VPN server transfers data to the TEAP input interface on a polling subroutine. Data was sent to TEAP on a customizable time interval 15-30-45-60 minutes' intervals, 24h/day, 365 days a year.

However, due to some intermittent poor coverage of the cellular services in one of the remote locations, we had to develop and implement a data prediction mechanism (extrapolate data based on similar historic intervals) to be able to gap short data losses and up to 45-60 minutes' intervals in the transmission chain timeline.

The solution for the data acquisition was powered locally from the 230VAC connection (meters) plus on 5V, 12 volts, and 24 volts DC using a MEANWELL PSU integrated into the site plus 12V/24V backup batteries and charge controller were incorporated in specific nodes that were more important for data collection and data continuity.

Note: To expand the number of active users in the platform from 5 to 100, it was necessary to create new (additional) users to simulate the energy mix proposed in the pilot project.

The consumption and production data associated with users are real data from a local energy distributor. All the data has been processed and checked to represent as faithfully as possible the consumption and production profile for each type of user category in the platform to simulate a scenario of using the TEAP platform as realistically as possible.

Although the data provided were for a relatively short period (4-5 months), the data were extrapolated for 2 years. This extrapolation was necessary for the forecasting module of the platform to be able to forecast the energy consumption and production for the next day, but also the energy settlement process following the occurrence of imbalances generated by users.

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Case study results

Consumers – Energy Consumption

Regarding the energy consumers within the pilot program, users (1-30) were considered. The analysis of consumption data was carried out in the period January-June. As can be seen from the figure below, energy consumption is higher in the winter months, but this is not a general characteristic for all analyzed consumers.

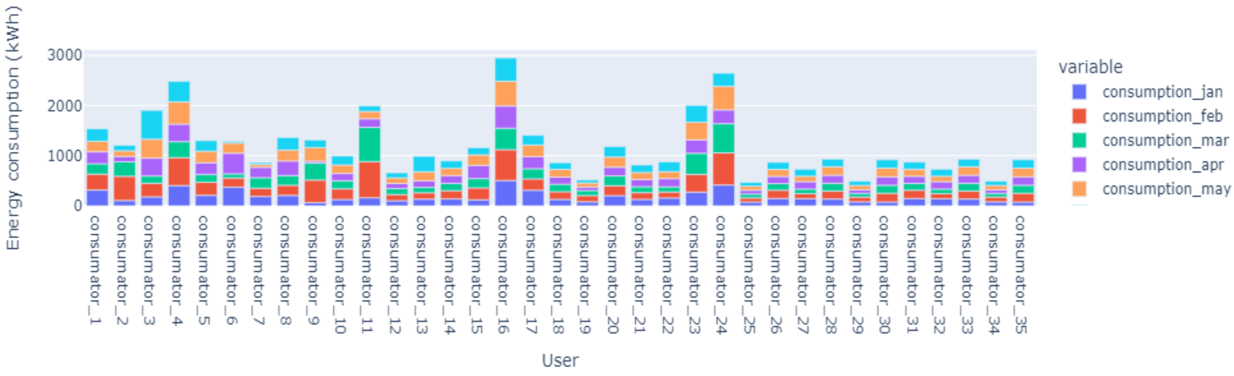

Figure 17 The actual consumption of electricity at the level of the user and the month during the analysis period (kWh/month)

From the analysis of the figure below, we can see more clearly what the energy consumption profile looks like on a monthly basis.

By analyzing the data, there is a slight seasonality of the energy consumption, higher in the winter months and lower in the summer ones, in line with the general market data for consumers. It can be observed that during the analysis period, the electricity consumption was higher in February compared to the other months.

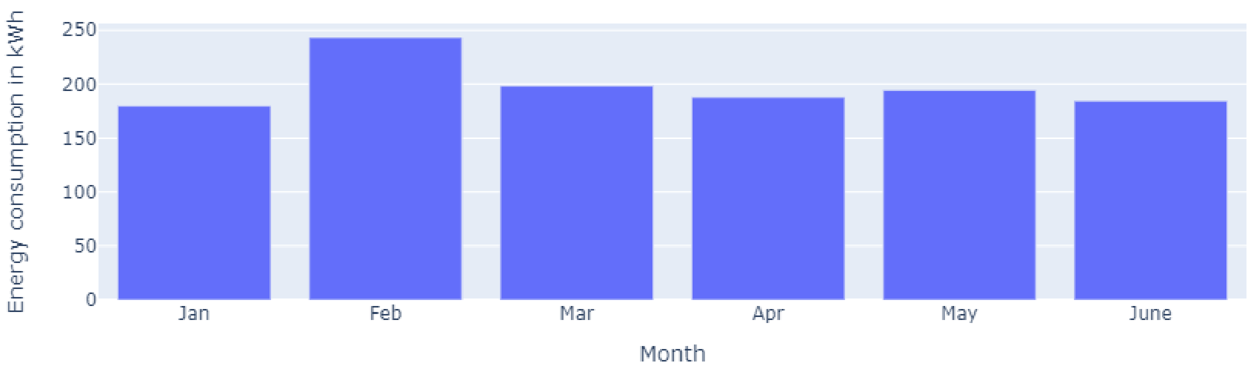

Figure 18 Average real electricity consumption per month (kWh/month)

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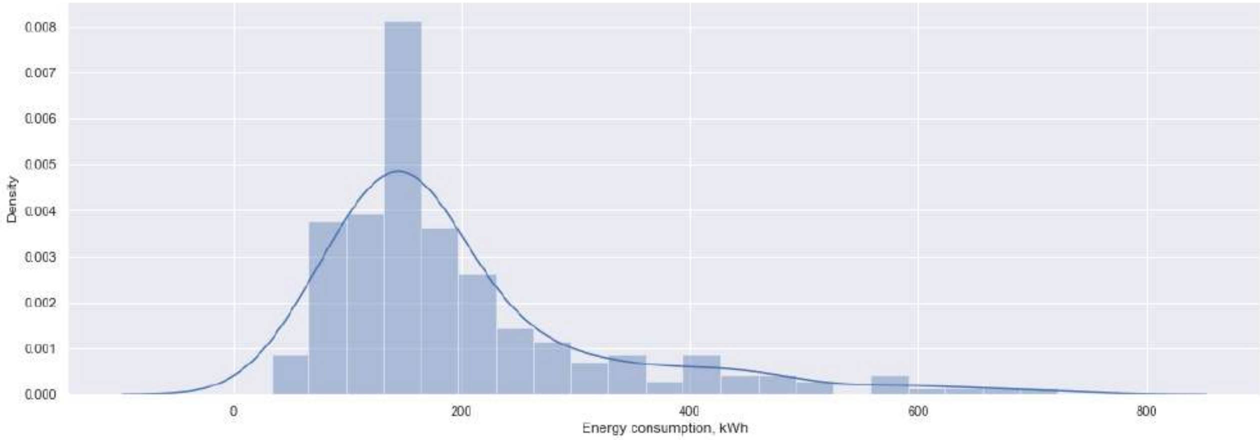

Figure 19 Consumers electricity consumption distribution in TEAP (kWh)

Following the analysis of the distribution of user energy consumption data, we can see that the vast majority of energy consumers within the pilot program are in the range of 80-220 kWh/month, which corresponds to an average energy consumer.

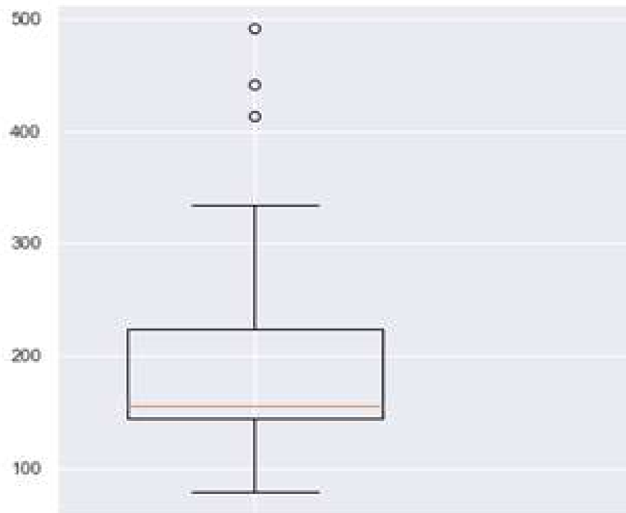

Figure 20 Consumers Energy Consumption (kWh)

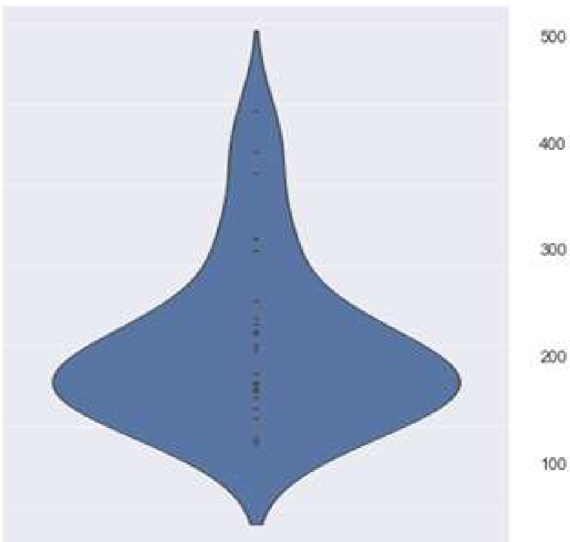

Figure 21 Consumers Energy Consumption (kWh)

However, another category of the consumer exceeds volumes of 400-600kWh/month (in modern all-electric family homes, in energy-intensive application programs, etc.).

Table 8 Statistic results of energy consumption of consumers in TEAP platform

Consumers	Lower whisker	Lower quartile	median	Upper quartile	Upper whisker
Consumption, kWh	**78.03**	**143.65**	**155.40**	**223.12**	**333.96**

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Prosumers – Energy Consumption & Production

Regarding the prosumers within the pilot program, users (1-56) were considered. The analysis of consumption and production data was carried out in the same the period of time, January-June. As can be seen from the figure below, energy production is higher in general than consumption, general characteristic for almost prosumers.

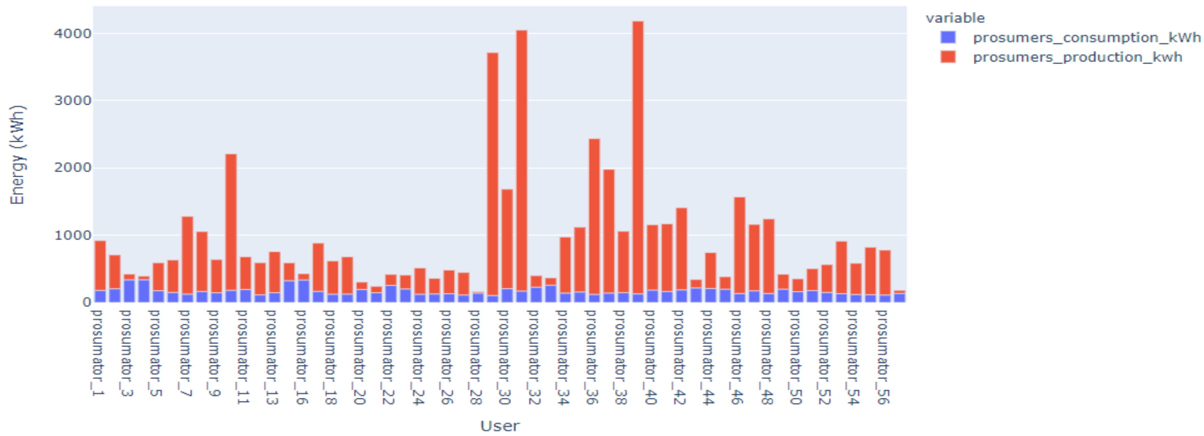

Figure 22 The actual consumption and production of electricity at the level of the user and the month during the analysis period (kWh)

As the data shows, there was a consistently larger level of energy production than consumption in the case of prosumers, some exceeding the 4,000-kWh mark. Considering that the prosumers are in the same producers and consumers of energy, we identified the average level of consumption and production in order to have a general picture of the size of the prosumer within the pilot program.

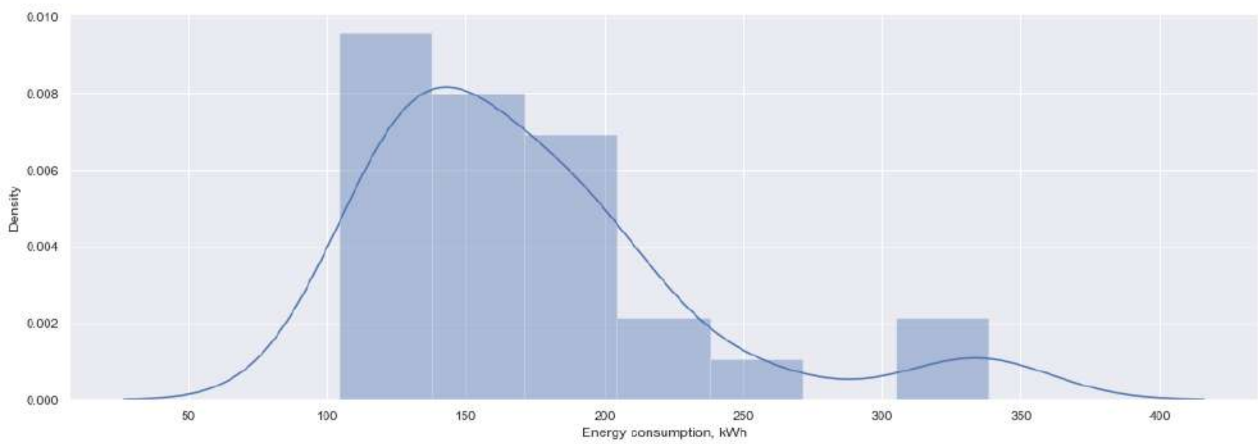

Figure 23 Prosumers electricity consumption distribution in TEAP (kWh)

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By analyzing the distribution above of consumption in the case of prosumers, compared to consumers, there is an identifiable trend of concentration of the most energy consumption levels in the lower quartile of 120 – 220 kWh range.

Also, the **probabilistic distribution of the energy production** in the case of **prosumers** is depicted below, and it shows a concentration of production in the 0 to +1,000 kWh mark for most of the prosumers.

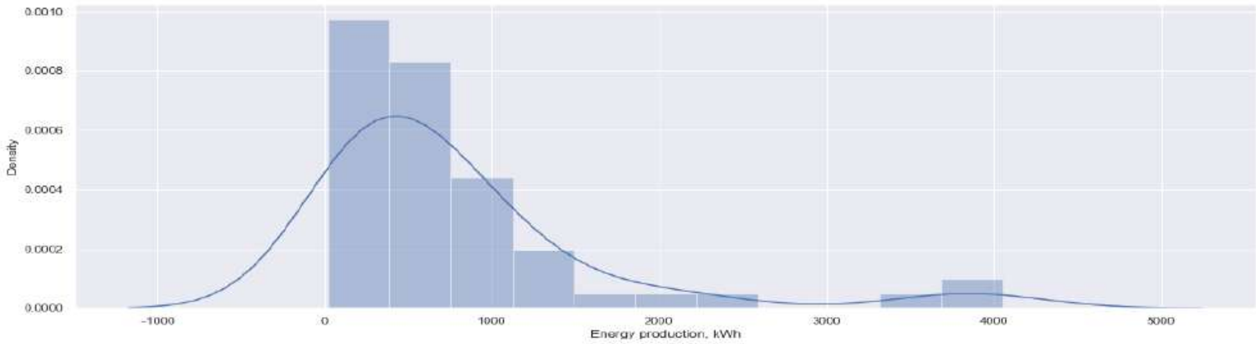

Figure 24 Prosumers electricity production distribution in TEAP (kWh)

These data also can be viewed in the next table where is presented the statistical data of prosumers regarding production and consumption.

Table 9 Statistic results of energy consumption and production of prosumers in TEAP platform

Prosumers	Lower whisker	Lower quartile	median	Upper quartile	Upper whisker
Consumption, kWh	104.18	130.19	158.22	194.92	257.64
Production, kWh	22.77	217.81	494.06	964.66	2026.89

As can be seen from the data, consumption and production has a different profile. If the electricity consumption is relatively constant throughout the period, having a maximum value in February (227 kWh), the production of electricity generated by prosumers increases gradually during the year, reaching a maximum value during the summer, in June. The electricity production being directly proportional to the solar radiation in the respective period. The production of electricity in the case of prosumers is sufficient to cover all the electricity needs of the prosumers, the excess being delivered to the network.

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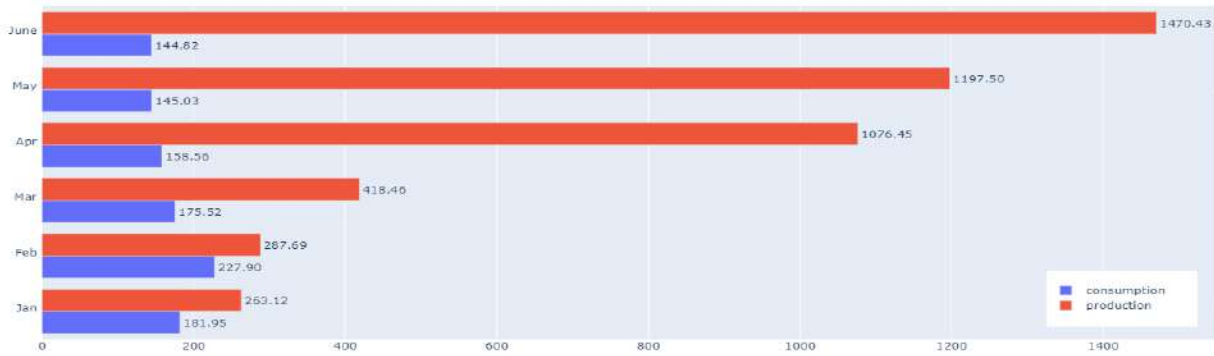

Figure 25 Average energy production and consumption of prosumers

SmallRES – Energy Production

Another important category of users in the pilot were small energy producers (SmallRES), which produced the energy from renewable resources (RES), photovoltaic panels (PV), and a mini wind farm. The electricity productions of the two small electricity producers within the TEAP platform are directly influenced by the atmospheric conditions in the period associated with the analysis (January - June). The small wind power generator is directly influenced by wind speed and direction. Instead, solar radiation and ambient temperature influence the small photovoltaic type of producer.

Suppose we can more quickly estimate the electricity produced by the small photovoltaic producer due to the energy profile, which is the type of a standard Gaussian curve. In this case, it is easier to estimate based on solar radiation. In the case of the small producer, electricity is more difficult to estimate because of the difficulty in estimating the wind speed and the random nature it has, thus making it very difficult to estimate as accurately as possible a production for the next day. Therefore, the level of imbalance created by this type of producer is more significant within the platform.

The average electricity production generated by the two small producers is 37,849 kWh, of which the small wind producer produced an average of 21,228 kWh and the small photovoltaic producer produced an average of 16,621 kWh. The maximum amount of energy produced for the small wind generator is 23,349 kWh and is associated with the winter month of February, while the small photovoltaic generator had maximum energy production in January and April.

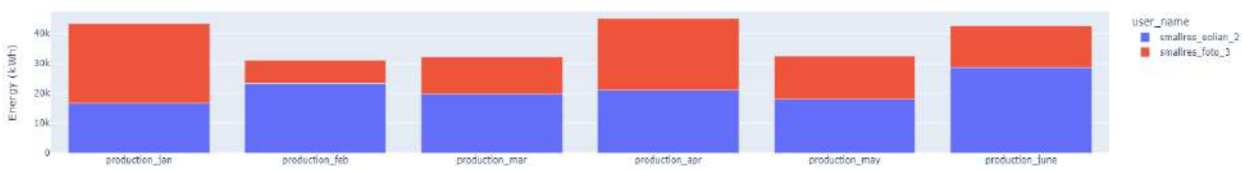

Figure 26 Monthly energy production for SmallRES in TEAP platform

Month /user	smallres_eolian_2	smallres_foto_3

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Table 10 Statistic results of energy production of SmallRES in TEAP platform, in kWh

January	16,698	26,797
February	23,349	7,770
March	19,628	12,587
April	20,972	24,110
May	18,055	14,534
June	28,666	13,932

Consumers – Energy Costs

The calculations for the consumer are very similar to those for the Prosumer, with the mention that there will only be consumption elements. For the imbalances created, consumers can either pay additional TC at the aggregate price of the Imbalance (***Revised TEAP platform internal deficit price***). If the actual consumption was higher than the consumption forecast, or they can receive TC at the ***excess price initially received from the supplier*** (considering that through a lower consumption a surplus of energy has been achieved in the network which will be discharged into the supplier's network).

The TEAP platform reduces the consumer energy cost by optimizing the energy price within the limit of the offer received by the supplier within the platform (see the reference energy price in TEAP). If we want to analyze the average energy cost for users within the platform, we can follow the following graph. The red color shows the average energy cost if the user subscribed directly to the supplier. The purple color in the graph represents the average TEAP energy cost. The data analysis shows that energy costs in TEAP are lower than those of a classic energy supplier.

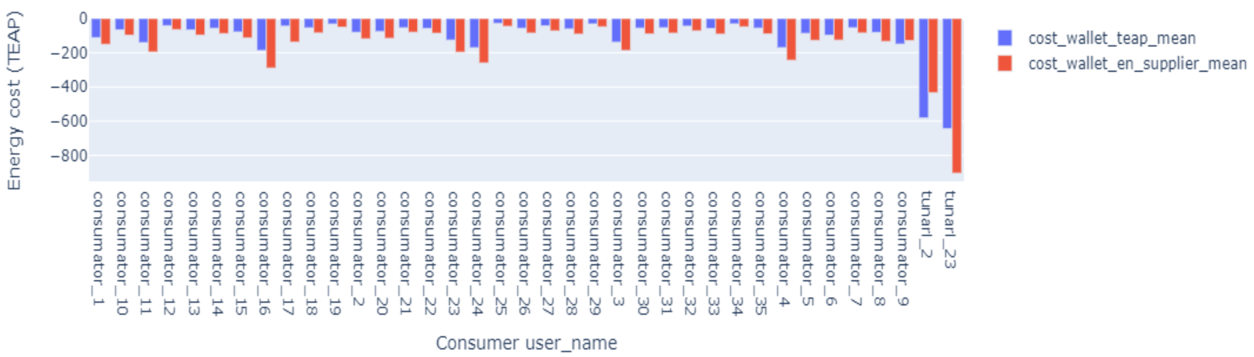

Figure 27 Energy cost for consumers in TEAP vs. Supplier energy cost

We can visualize the savings that TEAP can achieve by optimizing pricing on each user's platform in the following chart.

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The savings are the difference between the cost of energy in TEAP and Supplier. From the data analysis, we can conclude that the TEAP platform can achieve financial savings between a minimum of 27 (TC) and a maximum of 102 (TC), with an average of 37 (TC), depending on the user's energy consumption.

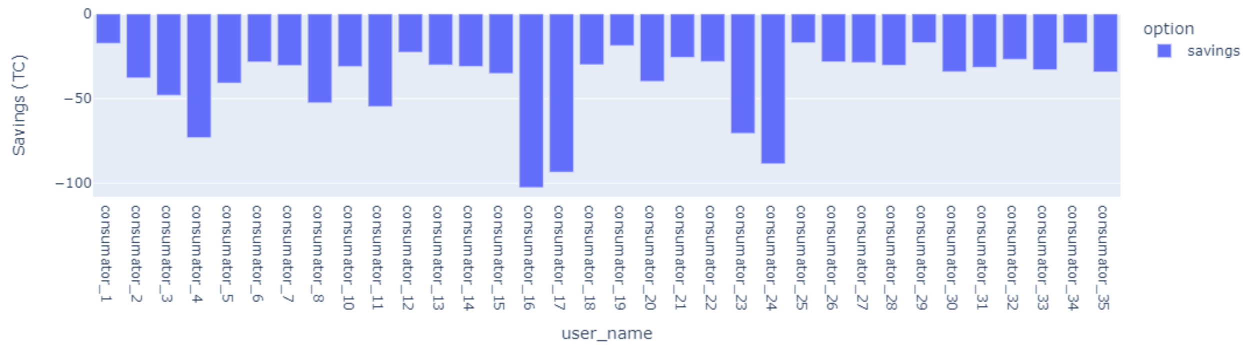

Figure 28 TEAP consumers energy savings

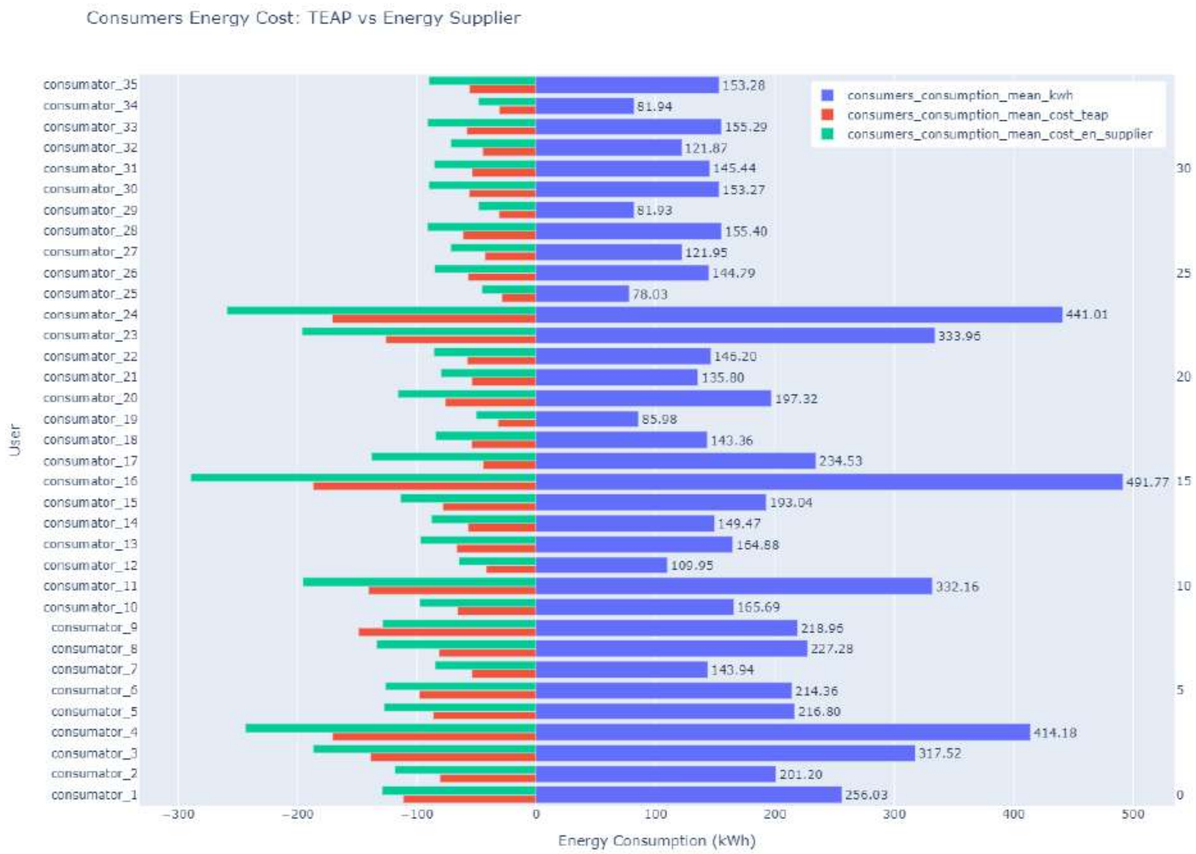

Figure 29 Energy cost and energy consumption for consumers users in TEAP

We also analyzed the average monthly energy cost of TEAP users versus Suppliers for each month from January to June. To get a better picture of the energy cost, we also considered the actual energy consumption of users to see the impact of energy consumption on the cost and the difference between them.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 837758.

Data shows that savings are more significant when users use more energy; for example, in February, users have higher energy consumption and savings.

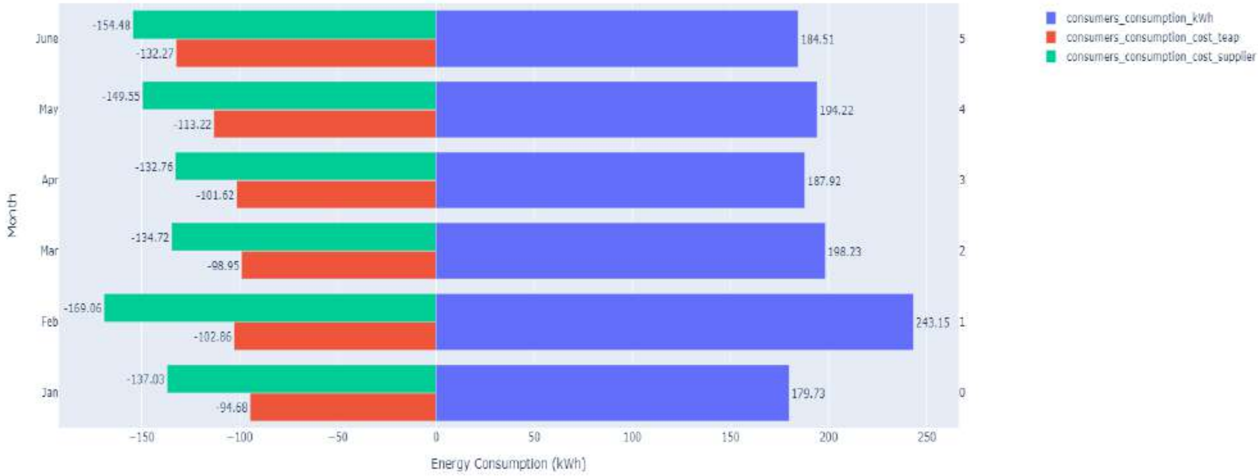

Figure 30 Consumers: TEAP Energy Cost vs. Supplier Energy Cost

We can use scatterplots to show relationships between energy consumption and energy cost in the TEAP platform. If a relationship exists, the scatterplot indicates its direction and whether it is a linear or curved relationship. Fitted line plots are a particular type of scatterplot that displays the data points and a fitted line for a simple regression model[38].

The closer the data points form a straight line when plotted, the higher the correlation between the two variables, or the more robust the relationship. If the data points make a straight line from near the origin to high y-values, the variables are said to have a positive correlation. If the data points start at high y-values on the y-axis and progress down to low values, the variables have a negative correlation[39].

The relationship between energy consumption and energy cost is negatively correlated because the values tend to decrease together.

[38] Statistics by Jim, Scatterplots: Using, Examples, and Interpreting
[39] Texas Gateway: Introduciton to Scatterplots

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 837758.

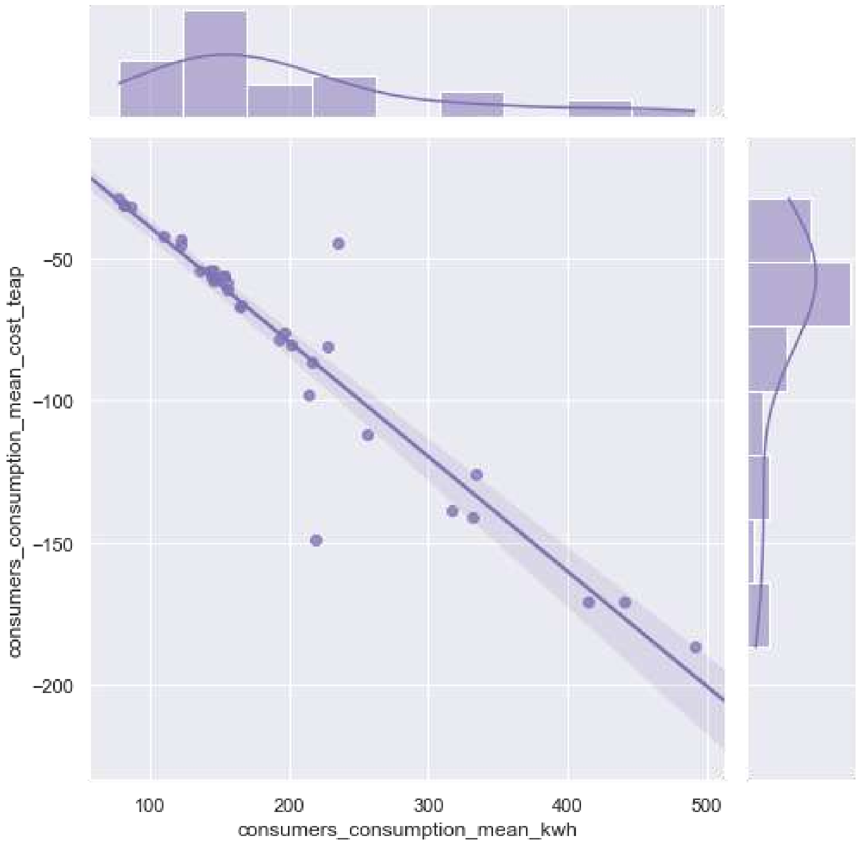

Figure 31 Consumers consumptions vs Consumers consumption cost

The outliers are distanced from other data points, as shown below. Unusual observations have values that are not necessarily extreme but do not fit the observed relationship. In the scatterplot below, the circled point has X and Y values that are not unusual. However, combining the two values does not fit the overall relationship.

We can model the energy cost for future TEAP users by modeling the actual users in TEAP. Using a linear regression model from the SciPy library, we can predict average monthly energy cost by using an energy average consumption of the new user.

$$\overset{\text{Dependent Variable}}{Y_i} = \underbrace{\overset{\text{Population Y intercept}}{\beta_0} + \overset{\text{Population Slope Coefficient}}{\beta_1}\overset{\text{Independent Variable}}{X_i}}_{\text{Linear component}} + \underbrace{\overset{\text{Random Error term}}{\varepsilon_i}}_{\text{Random Error component}}$$

[40] Linear Regression Model - Dannar Mawardi

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Figure 32 Linear regression model (general equation)

```
                                 OLS Regression Results
===============================================================================================
Dep. Variable:     consumers_consumption_mean_cost_teap   R-squared:                       0.890
Model:                                              OLS   Adj. R-squared:                  0.887
Method:                                   Least Squares   F-statistic:                     267.2
Date:                                  Sat, 13 Aug 2022   Prob (F-statistic):           2.20e-17
Time:                                          12:30:06   Log-Likelihood:                -142.67
No. Observations:                                    35   AIC:                             289.3
Df Residuals:                                        33   BIC:                             292.4
Df Model:                                             1
Covariance Type:                              nonrobust
=================================================================================================
                                 coef    std err          t      P>|t|      [0.025      0.975]
-------------------------------------------------------------------------------------------------
const                          1.5720      5.486      0.287      0.776      -9.590      12.734
consumers_consumption_mean_kwh -0.4040     0.025    -16.345      0.000      -0.454      -0.354
==============================================================================
Omnibus:                       29.181   Durbin-Watson:                   1.916
Prob(Omnibus):                  0.000   Jarque-Bera (JB):              193.235
Skew:                          -1.250   Prob(JB):                     1.10e-42
Kurtosis:                      14.236   Cond. No.                         491.
==============================================================================

Notes:
[1] Standard Errors assume that the covariance matrix of the errors is correctly specified.
```

Figure 33 Linear regression model (fitting model results)

Example calculationg by using linear regression model

Intercept = 2.572 , population Y intercept
Model coeficient =-0.4040 , population slope coefficient
Model error = 5.486 , random error term
Model independ_var = 250 , independent variable (real consumption, kWh)
Estimated_cost = intercept + coef*independ_var + error = — 92.942 (TC)

Note: The model has an error of up to 10%. Means the energy cost can variate within this limit.

Prosumers – Energy Costs & Revenue

The prosumers in the TEAP platform have a different status on the platform due to the fact they are consumers and producers at the same time. The prosumers have a unique modeling technique due to their daily behavior.

The total TC calculation (received or paid by a prosumer) will include four components:

1. Sale value;
2. Purchase value;
3. Aggregate imbalance value;
4. Qty share value.

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Prosumers will enter the DAM market with only one value of energy (sold or bought).
If the Forecast of produced energy (***Production forecast***) is higher than the Forecast of consumed energy (***Consumption forecast***), then the Prosumer will participate in the DAM market with a sale offer represented by the difference between the two forecasts (***Sales quantity***). Similarly, if the ***consumption forecast*** is higher than the ***production forecast*,** the Prosumer will participate in the DAM market with a purchase offer represented by the difference between the two forecasts (***purchase quantity***).

Associated with these values, at the closing of the DAM market will correspond the MCP (Market Clearing Price) for each hourly interval, making the match between ***Sale Quantity / Purchase Quantity*** and ***Market Closing Price [TC/kWh]***) will obtain ***Sale Value (1) / Purchase Value (2)*** in TC.

It should be noted that only one of these values will make sense for an hourly interval, the other component being zero (depending on the sign of the difference between the ***Production Forecast*** and the ***Consumption Forecast***). The sell value in TC will always be negative or 0, and the buy value always positive or zero (according to the implemented sign convention).

On the day for which the energy was purchased on the DAM market, the actual values for consumption and Production will be taken into account (***Realized Production***, respectively, ***Realized consumption***). The difference between them will be calculated, and this will highlight the type of user of the Prosumer for each time interval (he worked as a consumer if ***Production carried out*** < ***Consumed*** also as a producer if the sign of the inequality is reversed, and if the two values are equal it acted in the network either as a Consumer with energy 0 or as a producer with power injection 0).

The difference between the forecasted value (***Sale value*** or ***Purchase value***) and the difference shown above for the Production and consumption achieved represents the Imbalance introduced by that user in the Platform (***Imbalance)***.

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The term ***Imbalance*** is calculated as follows: ***(Realized production - Realized consumption) - (Production forecast - Consumption forecast)***
There are therefore, three cases to analyze:

1. ***Imbalance*** > 0: This case is associated with higher Production than Forecast. Thus, there is additional energy for which the Prosumer will receive TC, but at a lower price than the MCP (detailed below).
2. ***Imbalance*** < 0: This case is associated with higher consumption than Forecast. Thus, there is additional energy to be purchased by the Prosumer using the TC, but at a higher price than the MCP (detailed below).
3. ***Imbalance*** = 0: This case is associated with a correct forecast. The imbalance value will, in this case, be 0 TC.

For case 1, a value will be calculated for the Imbalance created by multiplying the ***Imbalance*** with the ***Energy supplier price and buy value*** to simulate an additional injection into the supplier's network at the price at which the supplier buys energy.

For case 2, a value will be calculated for the Imbalance created by multiplying ***the Imbalance*** with the ***Energy supplier price and sell value*** to simulate an additional consumption from the supplier's network at the price at which the supplier sells energy.
These values are stored in the associated cells " ***Individual Imbalance Value***. " If ***Imbalance***> 0, then ***Individual Unbalance Value*** will be negative, and if ***Unbalance*** < 0, then the value will be positive (to respect the sign convention). However, the user will not be assigned an individual imbalance value but an aggregate value that will be presented below. First of all, using the individual values, a total value of the imbalances at the platform level will be calculated: " ***Costs/Gains calculated in the case of individual participation"***.

Additionally, an aggregate cost for the Imbalance will be calculated. Using the " ***Imbalance*** " values of all platform users will calculate an amount in kWh for the Platform. Depending on the sign of this amount in the calculation of the term " ***Costs/Profits at the aggregate level received from the supplier*** ", the amount of energy will be multiplied by the ***deficit price initially received from the supplier / Energy supplier price, sell*** if the amount is less than 0 and with ***Excess price initially received from the supplier / Energy supplier price, but*** if the amount is greater than 0.

Using the above values, an adjustment value of the imbalance prices considered for the individual imbalances (***Absolute Cost/Gain at the aggregate level***) can be calculated by the difference between Aggregate ***Costs/Gains received from the supplier*** and ***Costs/Gains calculated in the case of participation individual***.

If this value is negative, it will be considered a gain for the Platform through aggregation. If the value is positive, it will be considered an additional loss through aggregation. In principle, the second case will be very rarely encountered and will manifest itself only if one of the DAM participants has a very large difference between the Forecast (of consumption/production) and reality. Also, the larger the number of market participants, the higher this error will need to be for aggregation to negatively impact. However, we have chosen to present this case as well (in the case of time slot 4).

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Using the adjustment value presented above, the " ***Revised TEAP platform Internal Deficit Price " is calculated*** by the sum of the ***Deficit Price initially received from the supplier*** and ***the absolute Cost/Profit at the aggregate level*** . Also, ***the revised internal TEAP platform surplus price is calculated*** by the difference between the ***surplus price initially received from the supplier*** and ***Absolute Cost/Profit at the aggregate level***.
These prices will be associated with the term " ***Imbalance*** ". If:

- ***Imbalance*** > 0: ***Aggregate imbalance value (3)*** will be the product of ***Imbalance*** in kWh, ***Revised TEAP Platform Internal Surplus Price*** expressed in TC/kWh and -1 (for sign convention)
- ***Imbalance*** < 0: ***Aggregate imbalance value (3)*** will be the product of ***Imbalance*** in kWh, ***Revised TEAP platform internal shortfall price*** expressed in TC/kWh and -1 (for sign convention)

***Note:** The amount of energy (kWh) that is the subject of the above calculation will undergo a change following the auctions that will take place on the Intraday market (basically by reducing the error between the Forecast and the Real). As the Intraday market has not yet been fully defined, this influence is not taken into account in the calculations in the provided Excel. In the final calculation, the total cost/profit and also the shortfall value for the calculation of the imbalance component will undergo changes.

For the calculation of the last component of the total cost (***Value share Qty*** $_{sp}$) it was assumed that all users provided perfect forecasts. In this case, a new component was needed to take into account the platform-level ratio between production and consumption.

Thus, if the production is higher than the consumption at the platform level, this additional power will have to be injected into the supplier's network at a price lower than the MCP (***Excess price initially received from the supplier / Energy supplier price, buy***). This gain will be shared between all users who produced energy in that time slot (small RES producers or prosumers who in the given time slot generated more energy than they consumed).

Conversely, if the consumption at the platform level is greater than the production, then an additional injection of power from the supplier to the platform users will be required to meet the demand. This injection will be made at a higher price compared to the MCP (***Deficit price initially received from the supplier / Energy supplier price, sell***). The additional cost associated with this exchange will be shared between all users who consumed energy in the respective time slot (consumers or prosumers who, in the time slot in question, consumed more energy than they produced).

The first step consists in identifying the behavior of the Platform towards the supplier (producer type or consumer type). This is done by adding up all the real energy consumed / produced by each individual user.

If their sum " ***Total (-): bought from the supplier with Psell C3, (+) sold to the supplier with Pbuy D3*** " is less than 0, the Platform is of buyer type for that time interval in relation to the supplier. If the amount is greater than 0, then the Platform is of the seller type for that time slot in relation to the supplier.

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For each user of the Platform, a share of energy expressed in kWh will be calculated that he will have to pay / receive as TC depending on the type of Platform for the respective time interval.

The Platform acts as a consumer

Thus, for intervals 1,3 and 4, it is observed that the Platform acts as a consumer. On columns P, R and S, each consumer who acted on the intervals in question is identified and the total consumption associated with the " ***Total Consumption (-) / Production (+) on the Platform*** " element is calculated at the platform level. ***The share Qty $_{sp}$ balancing Pcons and Pgen*** in kWh is calculated by the ratio between the consumption of the user in question for that hourly interval and ***Total Consumption (-) / Production (+) on the Platform***, all multiplied by ***Total (-): bought from the supplier with Psell C3, (+) sold to supplier with Pbuy D3 value of the share Qty $_{sp}$ (4)*** is calculated by the product between the ***share Qty $_{sp}$ balancing Pcons and Pgen*** and the difference between the ***deficit price initially received from the supplier / Energy supplier price, sell,*** and MCP. (with sign adjusted to match sign convention).

The Platform acts as a producer

Thus, for interval 2 it is observed that the Platform acts as a producer. On the Q column, each producer who acted on the interval in question is identified and the total Production associated with the " ***Total Consumption (-) / Production (+) on the Platform*** " element is calculated at the platform level. ***The share Qty $_{sp}$ balancing Pcons and Pgen*** in kWh is calculated by the ratio between the Production of the user in question for that hourly interval and ***Total Consumption (-) / Production (+) on the Platform***, all multiplied by ***Total (-): bought from the supplier with Psell C3, (+) sold to the supplier with Pbuy D3$_{sp}$ share value (4)*** is calculated by the product of the ***balancing Pcons and Pgen share Qty $_{sp\ share}$*** and the difference between the MCP and the ***excess price initially received from the supplier / Energy supplier price, buy*** (with sign adjustment to correspond to the sign convention).

It should be noted that if the Platform acts as a consumer in relation to the supplier, then only the consumers in that time slot will be charged extra according to their contribution (Qty $_{sp}$ ***(4) share price value*** for producers will be 0 TC), and if the Platform acts as a producer in relation to the supplier, then only the producers on that time slot will receive additional TC according to their contribution (Qty $_{sp}$ ***(4) part share value*** for consumers will be 0 TC) Using these elements, it is possible to calculate for each prosumer " ***TOTAL TC***," which in this case can have either the - sign (if it must receive TC) or the + sign (if it must pay TC) for an hourly interval.

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From data analysis on the following chart, we can see that the prosumers have revenue when they produce enough energy for self-consumption and deliver a surplus in the network for other users. But also, the prosumers can have costs with energy on the TEAP platform to cover their demand if they don't produce enough energy for self-consumption.

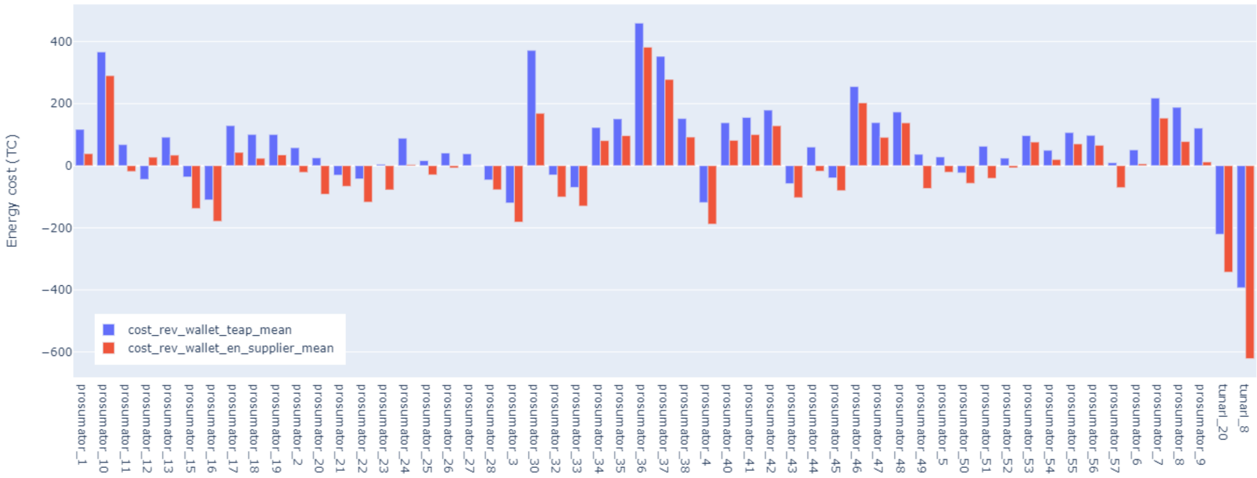
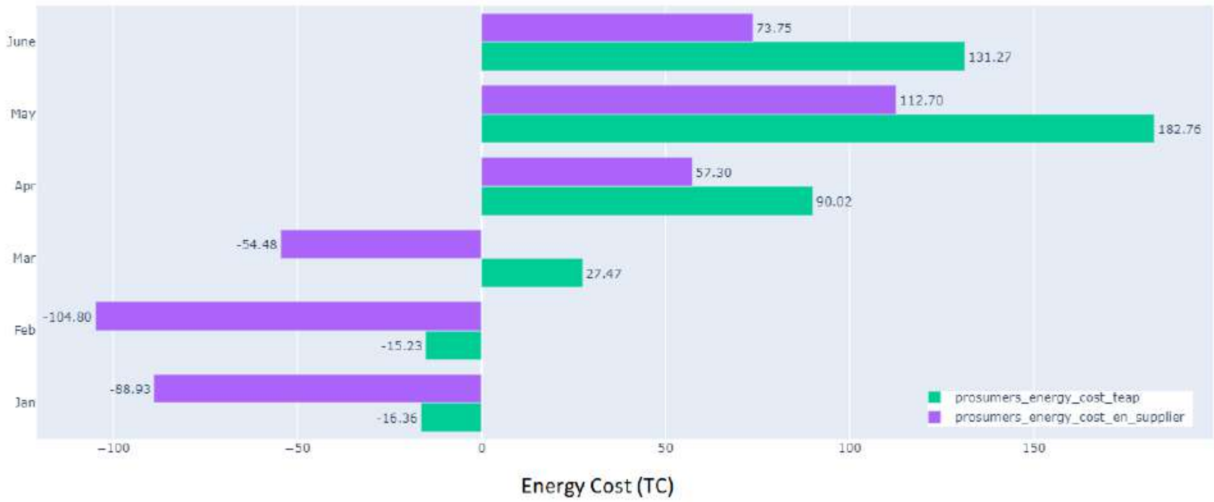


Figure 34 Prosumers Energy Cost / Revenue by month with Classical Supplier

From the data analysis, we can conclude that the TEAP platform can achieve financial savings between a minimum of 20 (TC) and a maximum of 200 (TC), with an average of 65 (TC), depending on the user's energy production and consumption. In the winter season (January and February Months), the prosumer's energy cost is much smaller in TEAP versus classical suppliers. From March, the prosumers in TEAP platforms have revenue compared with classical suppliers when they would have an energy cost.

Starting with April, the prosumers will also have a much higher revenue because of the surplus energy generated, the revenue being higher in the summer when the solar radiation reaches its full potential.



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 837758.

Figure 35 Average energy cost / revenue for prosumers in TEAP platform

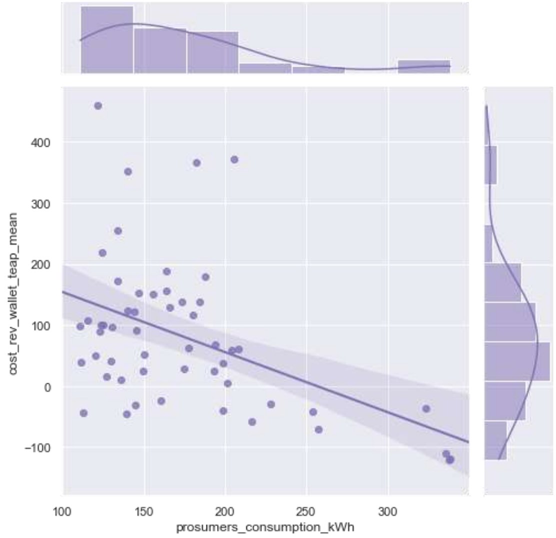


Figure 36 Prosumers consumption vs cost

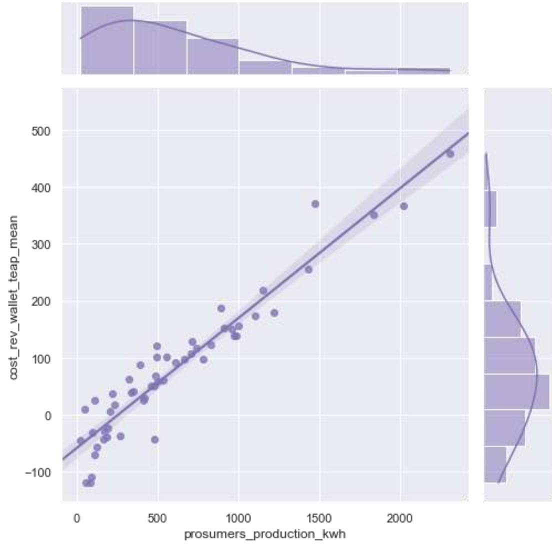


Figure 37 Prosumers production vs revenue

```
                            OLS Regression Results
==============================================================================
Dep. Variable:     cost_rev_wallet_teap_mean   R-squared:                 0.930
Model:                                   OLS   Adj. R-squared:            0.928
Method:                        Least Squares   F-statistic:               334.5
Date:                       Sat, 13 Aug 2022   Prob (F-statistic):     1.14e-29
Time:                               10:24:38   Log-Likelihood:          -259.40
No. Observations:                         53   AIC:                       524.8
Df Residuals:                             50   BIC:                       530.7
Df Model:                                  2
Covariance Type:                   nonrobust
==================================================================================================
                                coef    std err          t      P>|t|      [0.025      0.975]
--------------------------------------------------------------------------------------------------
const                         7.0417     18.127      0.388      0.699     -29.368      43.451
prosumers_consumption_kWh    -0.3326      0.084     -3.951      0.000      -0.502      -0.163
prosumers_production_kwh      0.2151      0.009     22.674      0.000       0.196       0.234
==============================================================================
Omnibus:                      12.257   Durbin-Watson:                   1.970
Prob(Omnibus):                 0.002   Jarque-Bera (JB):               36.081
Skew:                          0.293   Prob(JB):                     1.46e-08
Kurtosis:                      6.999   Cond. No.                     3.20e+03
==============================================================================

Notes:
[1] Standard Errors assume that the covariance matrix of the errors is correctly specified.
[2] The condition number is large, 3.2e+03. This might indicate that there are
strong multicollinearity or other numerical problems.
```

Figure 38 Prosumers linear regressions model fitting results

Prosumers linear regression model example:

Intercept	= 7.0417	, population Y intercept
Consumption coeficient	=-0.4040	, population slope coefficient
Consumption coeficient	= 0.2151	, population slope coefficient
Model error	= 18.127	, random error term
Consumption independ_var	= 180.00	, independent var (real consumption, kWh)

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Production independ_var = 739.00 , independent var (real production, kWh)
Estimated_cost_sav = intercept + consumption_coef*consumption_independ_var + production_coef*production_independ_var + error = + 124 (TC)

SmallRES – Energy Revenues

The calculations for a small RES producer are very similar to those for the Prosumer, with the caveat that there will only be production elements. For the imbalances created, producers can either pay additional TCs at the aggregate price of the Imbalance (***Internal deficit price TEAP platform revised***) if the actual Production was lower than the production forecast (it is considered that through a lower Production, an energy deficit was achieved in the network that will be fed from the supplier's network), or they can receive TC at the ***Surplus Price initially received from the supplier*** for the additional power produced that will be discharged into the supplier's network.

Table 11 Revenue results of SmallRES users in TEAP platform

Month	smallres_eolian_2_TEAP	smallres_eolian_2_Supplier	smallres_foto_3_TEAP	smallres_foto_Supplier
January	3,266.00	3,272.81	3,538.78	5,252.21
February	7,356.00	4,576.40	2,095.00	1,522.92
March	6,097.00	3,847.09	3,353.00	2,467.05
April	3,668.00	4,110.51	3,992.00	4,725.56
May	7,882.00	5,618.54	3,398.00	2,730.67
June	3,892.00	3,538.78	3,445.00	2,848.66

The revenues of the SmallRES within the TEAP panel vary from month to month depending on the source type (photovoltaic or wind), the electricity prices on DAM, the level of imbalance (forecast error), and the prices of imbalance energy. As can be seen, there is no general trend in the revenue of the SmallRES user category within the TEAP platform.

By analyzing the user data of the small photovoltaic energy producer, we can see that the revenues in the winter months (January) are lower and are due to low production and forecast errors in the associated period.On the other hand, if we look at the user data of the small wind energy producer, we can see a relatively opposite trend of revenue per platform. The user has a higher electricity production during these winter months (January and February).

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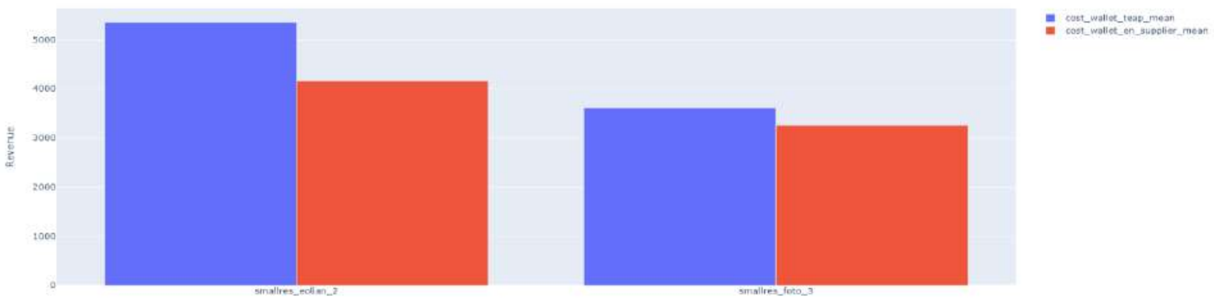

Figure 39 Revenue results of SmallRES users in TEAP platform vs Supplier

Strategic Provider – Energy, Revenues & Costs

The strategic supplier has a vital role within the TEAP platform, to balance the platform in terms of energy when there is a deficit or surplus of energy.

Regarding the management of energy within the TEAP platform, an energy supplier registered on this platform can have quick access to all the information necessary to manage the surplus and deficit of energy considering the features offered by the platform.

Table 12 Strategic Supplier energy, revenues, and cost results

Ref.	Month	Revenue (TC)	Deficit Quantity (kWh)	Costs (TC)	Surplus Quantity (kWh)
1	January	9,651	31,663	-9,309	-22,614
2	February	10,586	38,177	-8,298	-19,175
3	March	29,185	121,596	-9,317	-20,561
4	April	49,861	221,889	-14,593	-26,860
5	May	18,985	82,332	-13,809	-25,006
6	June	8,980	42,977	-15,938	-28,063

Considering that the supplier must offer two prices for electricity, one for sale and one for purchase, the supplier income is directly influenced by these prices. Regarding the income from the sale of energy in the platform for balancing, the revenue for the supplier can be (9000-50000 RON).

The graph below shows the average electricity price in the analyzed period (January-June) paid on the day-ahead market by users within the platform and the energy prices received by the supplier energy operator. As can be seen from the data presented, the average price in TEAP is always between the two limits (the buying price and the selling price of Supplier), thus optimizing the cost of energy for platform users.

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Figure 40 The results obtained regarding the optimization of the energy market price of the TEAP platform

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Future Monetization of Aggregation Concept: way to move forward

TEAP's scope can be expanded for commercial use into a real, small scale open energy market.

Besides adding an aggregation operator on the Strategic Supplier role in the platform and giving the appropriate interfaces to the energy wholesales market, the community can be aggregated and allowed to trade surplus energy or to take in additional consumption on the wholesales energy market.

The following table presents the economic-financial results following the simulation of the calculation of the revenues and expenses associated with the TEAP platform.

For this calculation, an analysis period of a full year of days (12 months) and a mix of 100 users were taken into account, 33 consumers, 65 prosumers, and two small producers. To simplify the calculations, the average values of each type of user were considered to scale later the number of users with the same level of consumption and production.

Table 13 TEAP economical financial **results** - simulation scenario (current number of users 100)

Variable	Unit	Consumers	Prosumers	SmallRES
Users	n	33	65	2
Months	n	12	12	12
Users Consumption	kWh	- 61,380	-123,240	0
Users Production	kWh	0	639,600	454,196
Users Energy Cost / Revenue Supplier	RON	-36,091	52,896	89,022
Users Energy Cost / Revenue TEAP	RON	-24,077	142,740	135,954
Users Gross Savings	RON	12,015	89,844	46,931
	%	33%	170%	53%
TEAP Fee	%	20%	20%	20%
	RON	2,403	17,969	9,386
Users Net Savings	RON	9,612	71,875	37,545
	%	27%	136%	42%
TEAP Revenues	EUR	480.6	3,593.7	1,877.3
TEAP Revenues total	EUR	5,952		

Based on the analyzed data of all users within the TEAP platform, the following average values resulted for each category of users separately:

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Standard Consumer with an average energy consumption of 155 kWh/month.
Standard Prosumer with an average energy consumption of 158 kWh/month and an average energy production of 820 kWh/month.
Standard SmallRES with an average production of 18,924 kWh/month.

Consumers users

Regarding the energy cost for a standard consumer type user (previously defined), we can directly calculate the energy cost in both situations using the energy price offered by the classic energy supplier and by using the linear regression type model in the case of the TEAP platform:

- for the case that the user subscribes directly to the classic energy supplier, with an active electricity supply price of 0.588 kWh, the total associated cost is 91 TC/month.
- for the case that the user is subscribed to the TEAP platform, using the linear regression model, the total associated cost is 61 RON/month.

In the case of electricity consumers registered on the TEAP platform, the user can achieve gross savings of approximately 30 RON per month; from this saved amount, a fee for the platform of 20%, approximately 6 RON. Therefore, the net savings for the consumer user decrease from 33% to 27%.

Prosumers users

Regarding the energy cost and income for a standard prosumer type user (previously defined). We can directly calculate the energy cost and income in both situations using the energy price offered by the classic energy supplier for purchase, respectively sale, and the linear regression model in the case of the TEAP platform:

- if the user subscribes directly to the classic energy supplier, with electricity supply price of 0.588 kWh, the associated energy cost is 92 RON/month, and the income from the sale of energy is 160 RON/month. Therefore, the prosumer has a total net income of approximately RON 68 RON/month.
- if the user is subscribed to the TEAP platform, using the linear regression model, the approximate total net income is 183 RON.

Therefore, the prosumer achieves a gross savings of approximately 115 RON per month. Like the consumers, a platform fee of 20% for this saved amount (approximately RON 23); therefore, the net savings will decrease with this amount.

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SmallRES users

Regarding the income from the sale of energy for a standard prosumer type user (previously defined), we can directly calculate the income using the energy price offered by the classic energy supplier and using the linear regression model in the case of the TEAP platform:

- if the user sells electricity directly to the classic energy supplier, with an active electricity supply price of 0.196 kWh, a total income of approximately 3.709 RON/month would result.
- if the user is subscribed to the TEAP platform, using the linear regression model, the total income associated with the amount of energy sold to users within the platform, the income is 5.665 RON/month.

In the case of prosumers registered on the TEAP platform can achieve an additional gross income of approximately 1.955 RON per month; of this, a 20% platform fee is applied, which means approximately 391 RON.

Supplier user

The revenues and costs associated with energy balancing strategic suppliers within the TEAP platform are influenced by the mix of users on the platform, balancing prices and the amount of imbalance generated by users.

To enter the platform as a strategic supplier, a supplier must provide the administrator with an offer containing a sale price and a purchase price of energy. Depending on the energy production and consumption, the TEAP platform will behave exactly like a prosumer, either selling or buying electricity from the supplier.

Regarding the additional revenues of the strategic supplier, they depend a lot on the purchase and sale prices of the energy from its portfolio. If we consider that the users within the platform represent an additional source of income, the strategic supplier will be on the plus side and will have additional benefits.

Scale up TEAP

Applying the mechanism explained above to a scaling of the number of users within the TEAP platform, we can obtain at least exciting results in terms of the revenues and costs associated with different categories of users, as well as the total revenue of the TEAP platform.

Therefore, to scale the TEAP platform, it was necessary to increase the number of users from 100 to 1010 and change the mix of users to capture different effects on the total revenues of the platform from the mix of users.

In the scaling scenario of the TEAP platform, the analysis period remained identified, still 12 months, but TEAP changed the mix of users. More precisely, the number of consumers

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increased from 33 to 800, the number of prosumers also increased from 65 to 300, and the number of small producers from 2 to 10.

Table 14 TEAP financial results - simulation scenario (scaling up the number of users up to 1100)

Variable	Unit	Consumers	Prosumers	SmallRES
Users	n	800	300	10
Months	n	12	12	12
Users Consumption	kWh	1,488,000	-568,800	0
Users Production	kWh	0	2,952,000	2,270,980
Users Energy Cost / Revenue Supplier	RON	-874,944	244,138	445,112
Users Energy Cost / Revenue TEAP	RON	-583,680	658,800	679,768
Users Gross Savings	RON	291,264	414,662	234,656
	%	33%	170%	53%
TEAP Fee	%	20%	20%	20%
	RON	58,253	82,932	46,931
Users Net Savings	RON	233,011	331,730	187,725
	%	27%	136%	42%
TEAP Revenues	EUR	11,650.6	16,586.5	9,386.3
TEAP Revenues total	EUR	37,623		

According to the data presented in the table above, by increasing the number of users on the platform, the revenues of the TEAP platform increase directly, but most likely, the operating and administration costs also increase. However, TEAP kept the platform fee (20 %) of the revenues obtained by each category of users).

Suppose in the first scenario (100 users), the prosumers represented the most important source of income for the platform (3,593.7 out of 5,952 EUR or 60%), with 1,010 users. In that case, the prosumers have a lower income contribution from 60% to 40% (16,586 from EUR 37,623).

Related the administration/operation/maintenance costs of the TEAP platform depend on a relatively large number of factors, such as printing, the number of active users, the volume of data processed by the platform, the chosen cloud solutions (own private server, Amazon server, Google, Microsoft, etc.), computing power, allocated memory), human resource costs, etc.

Therefore, considering the interests of energy users for new and more efficient solutions in terms of renewable energy supply, the TEAP platform can be an excellent alternative compared to the current supply solutions.

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Key Actions for Energy Aggregator Concept Implementation

The case study results indicate a strong positive gain for participants in a platform for virtual energy transactions as compared to the classic energy supplier scheme.

Considering that the present architecture of energy markets induced an artificial increase of energy prices, platforms like TEAP would attenuate such evolutions due to better transactional costs.

They empower citizens to participate at environment protection and enjoy a better control of their energy supply and independence, not being at someone's hand.

The bureaucratic barriers are still high mainly because application norms lack or are unsubstantial defined. This is a major impediment because compared to legislation and applications norms in the classic energy sector, new energy market actors such as aggregator or energy communities seem to exist only in theory.

The 'old' rules make the market access for new concepts if not prohibitive at least very expensive. For an energy community such as our case study in Amber Gardens would be beyond profitability to become an energy supplier according to existing regulations.

The energy market has its own particularities, especially due to the critical meaning for life and economy but also due to the physics balance requirements. Clear laws and strong regulations are needed but also state of the art technical standards. These are required to cope with the grid transformation and expansion of distributed energy sources, storage systems and transport electrification.

National authorities for energy regulations should consider present and future metering requirements and act accordingly elaborating regulations for virtual metering and differentiated grid tariffs.

In case of TEAP, in order to access the demand response side as an aggregator, would be tremendous difficult to integrate APIs to most of the IoT assets.
Such communication standards are badly needed must ensure reliability. The case study exemplified that difficulties in data transmission due to for example weather conditions can alter the concept.

Despite the barriers, regardless of their origin, legal, technical or acceptance the breakthrough is obvious and needed.

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Compared to project start time, a clear evolution can be noticed; European directives and regulations were or are being transposed in national laws, technologies improve and support actively the transition to smart and distributed energy gird, market awareness has increased, and more and more prosumers connected to the grid, more energy storage systems were installed and there was also an obvious proliferation of electric vehicles.

A good example for this (re)volution are the legislative actions for example in Romania, regarding the prosumer conditions and benefits (the allowed installed power was raised from 27kW in 2019 to 400kW in 2022).

Taking into consideration only a few aspects such the fact that concepts like energy community or aggregator are already anchored in EU and national legislation, that application norms are being elaborated, that prosumer advantages like guaranteed buying prices for surplus energy, that in urban areas the space is scarce and not all roof tops are suited for PV installations, it can be concluded that virtual energy transaction platforms like TEAP represent a great opportunity for citizens to navigate through energy transition.

Although a bit ahead of time, considering the pace of energy transition and technology evolution in the past years, such transaction platforms could become standards no later than 2025.

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References

International Journal of Electric Power and Energy Systems, Electrical Power and Energy Systems 134 (2022) 107361

Regulation (EU) 2019/943 of the Eruopean Parliament and of the Council of 5 June 2019 on the internal market for electricity, Art. 3 e)

Energy Market Report – The national Authority for Energy Regulation

Energy Market Raport - Romanian and Gas electricity market operator

Energy Balancing Report – National Romania Transport System Operator (Romania TSO-Transelectrica)

https://energie.gov.ro/prosumatorii-vor-avea-parte-de-compensare-cantitativa/

Internal Electricity Market Directive (EU) 2019/944 (European Parliament & Council of the European Union, 2019)

Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018, Art.22

Zhang, C., Wu, J., Zhou, Y., Cheng, M., Long, C., 2018. Peer-to-Peer energy trading in a Microgrid. Applied Energy 220, 1–12

Improvement of PV4Grid concepts, 2018, TU Vienna

Collective self-consumption and energy communities: Trends and challenges in the transposition of the EU framework, 2020

https://cooperativadeenergie.ro/ghiduldeenergie-ce-sunt-comunitatile-energetice/

Collective self-consumption and energy communities: Trends and challenges in the transposition of the EU framework, 2020

https://www.anre.ro/ro/energie-electrica/informatii-de-interes-public/info-licente-autorizari/mod-de-solicitare-de-licente-autorizatii/solicitare-documentatie-licente-autorizatii1387205027

Abada, I., A. Ehrenmann, and X. Lambin, On the Viability of Energy Communities, Cambridge Working Paper in Economics 1740, Cambridge, 2017

Brown, A., and L. Lund, 'Distributed Generation: How Green? How Efficient? How WellPriced?', Electricity Journal, Vol. 26, No. 3, 2013, pp. 28-34

Yildiz, Ö., B. Gotchev, L. Holstenkamp, J.R. Müller, J. Radtke, and L. Welle, 'Consumer (Co-)Ownership in Renewables in Germany', in J. Lowitzsch (ed.), Energy Transition - Financing Consumer Co-Ownership in Renewables, Palgrave Macmillan, Cham, 2019

Electricity Aggregators: Starting off on the right foot with consumers(2018)

(EU) Directive 2019/944 (39), Art. 2 (19)

Flexibility and Aggregation Requirements for their interaction in the market (eurelectric,2014)

(EU) 2018/2001 Art.21 2 a)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 837758.

(EU) 2018/2001 Art.2 (18)

European regulatory framework, International Journal of Electrical Power and Energy Systems (2022)

Barriers to Independent Aggregators in Europe, University of Exeter, 2019

Best practices and implementation of innovative business models for renewable energy aggregators, Bestres, 2016

Improvement of PVP4grid concept, Vienna, 2018

Official Gazette no. 1055 of November 10, 2020; Order no. 196 of October 28, 2020, Art. 2 (1)
Operational procedure, TEL-.07.VI ECH-DN/25, TSO Transelectrica S.A.

www.energy.gov

The Consumer Voice in Europe, Electricity Aggregators, 2018

Teoh, M., Liebl, V., Leitfaden zu PV-Eigenverbrauchsmodellen,2016

Pause, F., Wimmer, M., 2018. The impact of the CE4AE-Package on legal and regulatory problems for aggregators, encountered in the BestRES project, bestres.eu

Park, C., Yong, T., 2017. Comparative review and discussion on P2P electricity trading. Energy Procedia, International Scientific Conference “Environmental and Climate Technologies”, 2017

Statistics by Jim, Scatterplots: Using, Examples, and Interpreting

Texas Gateway: Introduciton to Scatterplots

Linear Regression Model - Dannar Mawardi

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N° 837758.