Participation of Prosumer in Local Energy Market based on Preferences

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December 2021

***Abstract*—Over the time, many peer-to-peer energy trading mechanisms have been proposed. Nonetheless, they continue to face challenges in terms of infrastructure spending and environmental value creation. The main goal of this thesis is to improve the socioeconomic aspects of the local energy market by designing a simple trading mechanism in which environmental influences play a significant role in trading decisions. The proposed method is tested on a 14-player market, and simulation results are compared to those of the existing python library Pymarket, which is a key enabler of ongoing research in the Local Energy Markets (LEM). The findings show that the proposed strategy produces more environmental value and higher profits for market participants than the traditional game theory-based approach.**

***Index Terms*—Game Theory, Local Energy Trading,Peer-to-Peer trading, Pymarket, Sustainable Value.**

I. Introduction

Global population and industrialisation have grown significantly over the years, increasing our consumption and demand for energy. The increase in energy demand over recent decades and advancements in technologies have created the need to improve the distribution network. This development in technology enables residents to have their own Distributed Energy Resources (DER) - Rooftop solar, microturbines, battery storage, and electric vehicles are some examples of DER. By integrating these DERs into the distribution network, an active system capable of bidirectional power flow should be created. Furthermore, when compared to the traditional power network, this decentralised energy system has numerous environmental and operational advantages. Technological advancements in smart energy meters, home batteries, and other Internet of Things devices enable customers to become prosumers—people who consume and produce energy—which has encouraged DER installation in the local community. Despite this, the increased DER penetration has caused a number of operational and technological problems dependent on their geographic location. People began local energy trading within their communities to solve these geographically based limitations. Local energy trading is gaining traction in the field of distribution networks.

In traditional power system the consumers purchase energy from utilities or retailers. Traditional markets, in some ways, resemble vertically integrated operations as described in figure 1. Consumer tariffs in the traditional market are extremely high when compared to their buy-back rates, resulting in a lower number of participants in the energy market [1]. People are getting increasingly interested in the sharing economy notion as a result of the success of business strategies such as Airbnb and Uber. This prompted them to apply these business models to the electricity grid and create a Local Energy Market (LEM), a trading platform where people can sell and buy energy, thereby encouraging more renewable deployment within the community. Participation in LEM, on the other hand, gives consumers greater control over their electricity consumption, price, and system flexibility. Furthermore, local energy trading allows individuals to contribute to their communities by allowing them to use green energy while earning more from distributed generation, with or without storage systems. Simultaneously, through LEM, people who lack the infrastructure to access renewable energy can benefit from local renewable energy installed by neighbors within the community through local energy trading [2]. The following are the objectives of local electricity markets [3]:

- Local demand must be managed to match intermittent supply.
- Congestion and transmission/distribution constraints should be considered.
- Participants' financial management should be supported, taking into account their location and network requirements.
- Replace/postpone grid investments with utilisation of local flexibility.

The challenges and implementation of local electricity markets differ from those of traditional power markets, which do not necessarily require such close attention to the distribution grid. As a result, the challenges of local electricity markets are closely linked with those of optimal distribution grid operation. These five factors have been identified as the primary sources of difficulties in establishing and operating a local electricity markets [3].

- Optimized use of distributed supply.
- Optimized utilisation of demand response.
- Localized markets must be operated in an efficient and secure manner, as well as technically implemented.
- Existing and emerging legal frameworks.
- Human interaction and socioeconomic aspects

The LEM approach can simplify system operation when there is a high penetration of DERs at interconnected nodes

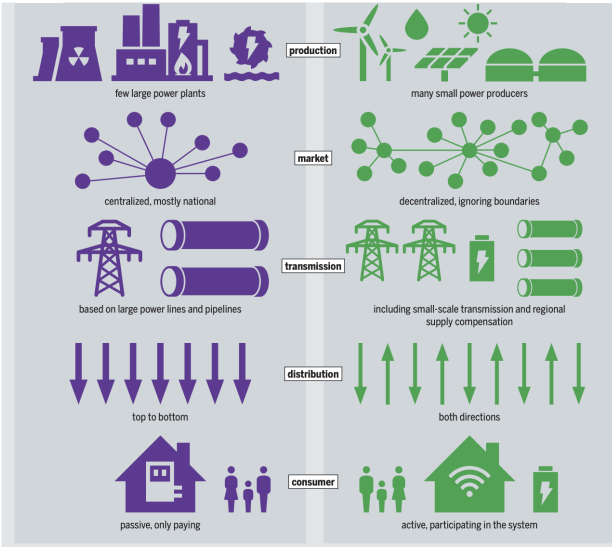

Fig. 1. Traditional Energy Market vs Decentralised Local Energy Market [4]

in a network. LEM can also be used to operate intra/inter microgrids and Virtual Power Plants (VPPs), resulting in a scalable, flexible, and dependable power system. Furthermore, LEMs flexibility services are changing distribution companies' approaches. Bilateral energy exchange, market decentralization, and widespread end-user participation are some of the distinguishing features of such a market. Prior implementations, on the other hand, were all aimed at achieving technical and/or economic goals. As a result, the primary goal of this thesis is to enhance the social aspects of the LEM market [5].

II. Motivation

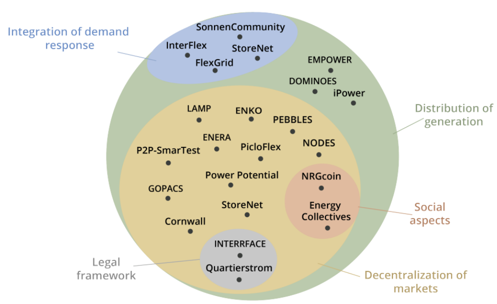

Fig. 2. LEM challenges addressed by existing projects [3]

From Figure 2, it is possible to see that the majority of existing projects aimed to improve factors such as integrated demand response, generation distribution, and market decentralisation. Whereas the fewest projects concentrated on improving social aspects and the legal framework. One of the advantages of the local energy market over traditional markets is the ability to address the various preferences of consumers and prosumers in a more assertive manner. The *NRGcoin*[1] project proposes trading energy between renewable energy producers and local consumers using smart contracts in an LEM. The project's goal is to make it easier for end users to express their preferences for local emission-free energy by lowering volatility [6]. *Energy Collective* uses consensus-based pricing in a local market environment, where user pricing is determined by individual user preferences [7]. The purpose of this thesis is to improve the social aspects of the LEM, by developing a merit order list based on participants transmission distance and bidding price. This merit order list is used to generate trading pairs for energy trading. Furthermore, it covers the transmission loss by penalising market participants based on transmission distance.

[1]https://nrgcoin.org/

This thesis is structured as follows: Section III describes the current state of the art in the local energy market, including market topologies, market clearing mechanisms, and prior implementation on the local energy market. The mathematical model and Python implementation of the proposed solution are explained in section VI. Section IX describes the SMILE project's simulation results based the one-day simulated market result.

III. Local Energy Market

In traditional power supply, consumers purchase energy from a utility/retailer for fixed or time-of-use tariffs, while prosumers sell their excess energy at buy-back rates. Despite this, consumers' electricity market tariffs are very high when compared to their buy-back rates, and these consumer tariffs do not include the other benefits that renewable generation brings to the power system [2]. In traditional system, the entire market is designed to deliver generated power from a couple of large power generation sites to multiple customers. The decentralized energy market, on the other hand, brings together a large number of small-scale prosumers and DERs [8].

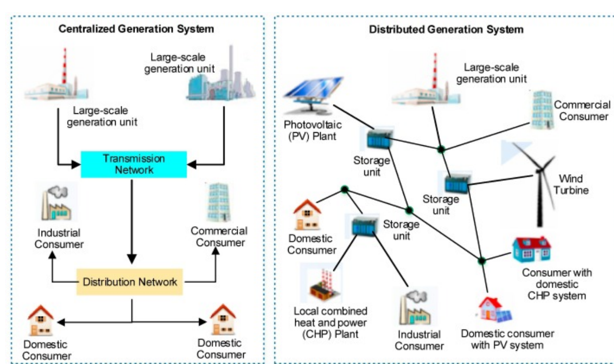

Fig. 3. Centralised vs Decentralised Energy Market [9]

A. Market Design

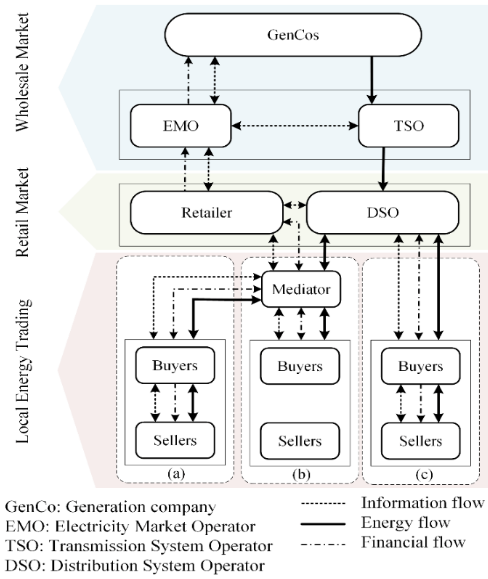

Fig. 4. Local Energy Market Design [5]

Local energy trading, in general, refers to the transfer of energy from a prosumer with excess energy to consumer with a deficit. Local energy trading is divided into three groups based on the association of market agents, as described in Figure 4 [5].

a) **P2P energy trading:** In the full P2P market, market participants interact directly with one another without the use of middlemen.
b) **Trading of energy through a mediator:** A mediator participates in the market on behalf of sellers and buyers, allocating energy from sellers to buyers, while customers act as price-takers in a passive role.
c) Sellers and buyers can trade energy directly or through a middleman.

Market Participants

Seller : Participant with the ability to generate or store energy can be a seller in the LEM.
Person who owns one or more DER, such as Distributed Generations (DGs), Plug-in Hybrid Electric Vehicles (PHEVs), energy cells, etc. ...
Buyer : Participants who purchase energy from LEM. Energy can be purchased from the market by both consumers and prosumers. In fact, prosumers with excess energy are sellers, and if they require more energy, they will enter the market as buyers.
Mediator : An independent agent who negotiates the purchase of electricity from retailers by combining two or more consumers into a single purchasing unit.

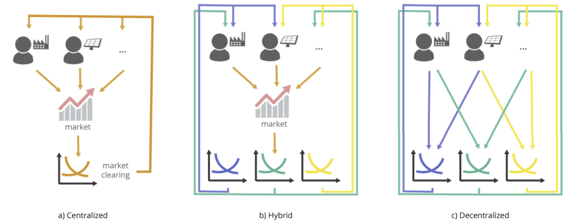

Fig. 5. Different Local Energy Market Topology [3]

IV. Market Topologies

a) **Centralized / Pool Market Trading** - The coordinator acts as a communication bridge between market participants in centralized / pool market trading. The coordinator gathers information from market participants and decides on market transactions and energy import/export between market participants.
b) **Hybrid** - A hybrid market is one that combines centralized and decentralized elements. In this market, the coordinator usually indirectly influences market participants by sending pricing signals, rather than directly instructing market participants about market transactions.
c) **Decentralized / Full Peer to Peer** - There are no centralized coordinators in decentralized Peer to Peer (P2P) energy trading markets, and market participants can directly trade with one another. Market participants' privacy is well protected in decentralized markets, and information is partially shared among market participants.

V. Trading Mechanisim

Market Clearing Methods	
Distributed Method	Decomposition Method
	Networked Optimization
	Game Theory Based
	Multi - Agent System
Other Methods	Auction Based
	Multi level Optimization

TABLE I
Types of Local Energy Market Clearing Mechanisms

Table I explains the various market clearing methods used in local energy markets. These methods are typically not used independently, and a combination of them will be used for market clearing to improve the accuracy and efficiency of system. Selecting market clearing methods is influenced by a variety of factors like [3],

Assumptions
Market structure
Behaviour of market player
Market rules

The distributed optimisation algorithms are divided into four categories: decomposition, networked optimisation, game-theoretic, and agent-based methods. The majority of the local energy market focus on using distributed optimisation methods because they are effective in markets with fewer players, on contrast to auction and multi-level optimisation methods, which are better suited to large markets with many market participants.

The decomposition method is the common approach for distributed optimisation, in which a large-scale complex problem is divided into several small problems depending on the structure and constraints of the objective function. After decomposition, each small problems can be solved independently, but a coordinator is required to ensure that local decisions converge to the global optimum [10].

When a problem needs to be decomposed based on its original structure, networked optimization is used. The interaction of decision markers is based on the communication structure, and decomposition is required to match this structure. The complete distribution network is illustrated by a graph in this method, the graph's vertices represents market participants like buyer/seller/agents. To model a local market in a distribution network, various graphs such as random graphs, directed and undirected graphs, weighted and unweighted graphs, can be used. This method is used in a market where players can only exchange information with their immediate players [11].

Game theory is defined as the study of a statistical model of several decision-making players with potential cooperation and conflicting objectives. A cooperative game is a competition between groups of cooperative players, whereas a non-cooperative game is one in which players make their own decisions. Typically, game theory is used to counteract selfish behavior in LEMs. Game theory can be applied in situations where information exchange is impractical for market participants, and thus agents prefer to optimize their local or private objectives while reacting to limited network information [12].

This method is applicable to large-scale systems involving various types of interactions. Each market player in this method is considered an agent (Buyer/Seller), and this method can be as simple as a single variable or as complex as with infinite actions and decisions. Markets designed based on this model are highly adaptable, scalable, and highly reliable. But this method suits for large market participants [13].

The formulation of a decentralised electricity markets explained by authors in [14]. The energy market is designed in such a way that communication links among market stakeholders (Buyer, Seller, and Agent) are the only variables defining the type of market architecture: from community-based to peer-to-peer, pool markets, and any hybrid combination of all of these architectures. As a result, the negotiation process is transformed into a decentralized consensus problem, for which various optimisation techniques such as game theoretical algorithms and distributed control strategies can be used [15].

The authors in [16] identifies that the centralised market has high understanding among the market participants, high flexibility within the communities and high aid in services related to grid. But the author's also addresses the challenges like impartialities in energy sharing and struggle to maintain participants interactions in market balance. These shows the current market lacks in customer centric values.

While [15] and [14] describes the market mechanism and negotiation techniques, it fails to address the uncertainties in performing game theoretical algorithms. The authors in [17] address this uncertainty and heterogeneity in market participants on decentralised electricity markets by defining cost and utility curves. These cost and utility curves are based on risk attitudes, which aids in the recovery of market fairness and efficiency. Human error in including risk attributes and challenges in financial transactions continues to be a significant disadvantage in overall performance.

The advancement of technologies such as Internet of Things, Blockchain, and Machine learning has removed the majority of the obstacles in the LEM. [18] focuses on a blockchain-enabled predictive energy trading platform built on the combination of machine learning and blockchain model. This advancement in technologies improved the local energy market operation and creates a better control comparing to the previous model.

However, technological advancements have failed to address the issues raised in section I, regarding maintenance costs and transmission loss. The authors in [19] focus on including transmission and maintenance cost through network charges, by including electrical distance between agents in a LEM. Using incentives, they accounted the grid-related costs. This mechanism encourages encourages market participants to sell the energy to the buyers near by avoiding network overload. If network charges are not chosen wisely, this approach may result in inefficient or unfeasible solutions.

Authors in [20] explains various models for consumer-centric markets. Market evolution from pool-based structures at the micro-grid level to full peer-to-peer network described in [21]. The degree of centralisation is important in implementing these peer-to-peer models because it tells us whether the market requires an external agent [21] and [22]. A market framework that allows all agents to express their preferences is critical; because electricity is priced uniformly in forward markets, expressing preferences should have a significant impact on market performance [23]. The implementation of such novel market structures in which user preferences play a critical role in trading decisions is a cornerstone for behavioural change among electricity consumers [24].

According to the literature review, technological advancement focuses on improving overall system modelling while struggling to improve social aspects and participant motivation. Taking this into account, this thesis focuses on improving social aspects by incorporating participant-specific product differentiation in the Local Energy Market. Since the proposed work is centered on small-scale community-based markets, a simple market clearing mechanism based on a merit order list can be used. Unlike the game theory model mentioned in paper [12], distance and price play an important role in creating trading pairs in this work. The result obtained from proposed solution is compared with the market result obtained from Pymarket, which is a significant enabler of ongoing research in the Local Energy Markets [25].

VI. Methodology

There are two main types of stakeholders in the proposed LEM mechanism: the buyer and the seller. Each seller has at least one unit of energy for sale, and each buyer has the ability to buy at least one unit of energy. To bid in the market, the user must first register and provide the required information. In the proposed local market, the necessary informations are listed below.

- Quantity - The quantity of electricity in kW that the user wishes to sell or buy in the local energy market.
- Location - The user's distance from the community center in kilometers.
- Price - The price in € at which the user wishes to sell or buy energy in the local energy market .
- Buying - True - if the user chooses to purchase energy from the market; False - if the user chooses to sell energy in the market.

The proposed LEM is designed based on the following mentioned conditions. Conditions 2 and 3 are presented in [12].

1) To exchange energy among neighbours in a community, with interaction based on full peer-to-peer topology.
2) Agents are informed about the value of the traded good in an asymmetrically manner.
3) Once the market is open, no new buyers or sellers are permitted.
4) Sellers and buyers are ranked based on the price and distance.
5) The merit order list is used to create trading pairs.

VII. Local Energy Market - Mathematical Model

The mathematical model of the proposed LEM structure is adapted from [12] and is formulated as following,

In Equation 1, P_n is the net active power injection by each agent n and is equal to the sum of traded quantities with set of nearby agents in the community $m \in \omega_n$.

$$P_n = \sum_{m \in \omega_n} P_{nm} \tag{1}$$

The power boundaries of each agents n participating in the LEM are defined by the below mention equation 2

$$\underline{P_n} \leq P_n \leq \overline{P_n} \tag{2}$$

Each agent n in the LEM can play the roles of producer, consumer, and prosumer. The agent's market role is determined by the agent's need for energy consumption or available excess energy energy in a specific period t. In the case of the prosumer, where the agent can be either a seller or a buyer, the sign of the decision variable determines the agent's role.

1) The agent n is a producer, when $(P_{nm} \geq 0)$.
2) The agent n is a consumer, when $(P_{nm} \leq 0)$.
3) In Prosumer case, the agent n acts as seller when $(P^+_{nm} \geq 0)$, and buyer when $(P^-_{nm} \leq 0)$.

The supply-demand equilibrium is represented below by a set of reciprocity constraints involving all agents $n \in \omega$ and $m \in \Omega$

$$P_{nm} + P_{mn} = 0$$

The equation 3 maximize the social welfare of the agents n, participating in the local energy market, under the constraints mention from $(3b \ and \ 3d)$.

1) Time t - The agent participates in the local energy market on an hourly basis.
2) The total cost of the model is denoted by $C_{n,t}$
3) $\tilde{C}_{n,t}$ represents the product differentiation function, which includes additional preferences.
4) $P_{n,t}$ is the net power of n agents at time t, and it is positive for producers but negative for consumers.
5) The sets of producers and consumers are denoted by Ω_p and Ω_c.

$$\min_{D} \sum_{n \in \Omega} C_{n,t}(P_{n,t}) + \tilde{C}_{n,t}(P_{n,t}) \tag{3}$$

$$s.t. P_{n,t} = \sum_{m \in \omega_n} P_{n,m,t} \ n \in \Omega, t \in T \tag{3a}$$

$$\underline{P}_{n,t} \leq P_{n,t} \leq \overline{P}_{n,t} \ n \in \Omega, \ t \in T \tag{3b}$$

$$P_{n,m,t} + P_{m,n,t} = 0 \ n \in \Omega, m \in \omega_n, t \in T \tag{3c}$$

Equation 4 describes the overall trading coefficient of the agent n, can include various preferences under criterion g. Distance, energy source, economic status, emissions, and other environmental factors belongs to criteria g. Each agent's criteria are denoted by γ^g_{nm}.

$$c_{nm} = \sum_{g \in \mathcal{G}} c^g_n \gamma^g_{nm} \tag{4}$$

In the proposed solution takes distance as a preference. In this case, γ^g_n would contain the distance between the agents n and m in kilometer. The main goal of the proposed solution is to create a simple trading mechanism. Given this, we will replace equation 4 by generating a merit order list based on the agent's price and preferences. A penalty will be included in the agent's bidding price to cover the transmission losses between agents using equation 5 and 6.

$$Buyer \ price = Bidding \ Price_{buyer} - \frac{Distance_{buyer}}{Quantity_{buyer}} \times 0.1 \tag{5}$$

$$Seller\ price = Bidding\ Price_{seller} + \frac{Distance_{seller}}{Quantity_{seller}} \times 0.1 \quad (6)$$

VIII. Proposed Mechanism - Algorithm

Algorithm 1 Local Energy Market

1: function $bids$
2: $buying = bids[bids.buying]$
3: $selling = bids[bids.buying == False]$ $buying['price'] = np.round(bids['price'] - (bids['Distance']/bids['quantity'] * 0.1), 3)$
4: $selling['price'] = np.round(bids['price'] + (bids['Distance']/bids['quantity'] * 0.1), 3)$
5: $Seller\ list = selling.sort\ values(['price','Distance'])$
6: $Buyer\ list = buying.sort\ values(['price','Distance'])$
7: **for** `User ID in buyer list` **do**
8:   **for** `User ID in seller list` **do**
9:     `Create trading list(user ID from buyer list , user ID from seller list)`
10:   **end for**
11: **end for**
12: **for** `Available trading pair from trading list` **do**
13:   **if** $Price_{Buyer} \geq Price_{Buyer}\ \&\ Quantity_{Buyer/seller} > 0$ **then**
14:     Traded Quantity = $min(\ quantities[buyer]\ ,\ quantities[seller]\ )$
15:     Traded Price = $price[buyer]$
16:     $trans.add\ (*\ Transaction\ _{buyer})$
17:     $trans.add\ (*\ Transaction\ _{seller})$
18:   **end if**
19: **end for**
20: **return** $Transaction$
21: *Profit calculation*

Algorithm 1 takes the bids output from Python Bid Module. The main goal of this proposed methodology is to include social aspects (product differenciation) in LEM. Taking this into account, equation 5 & 6 are used to update the bidding price. This updated price is determined by the user's location - the distance from the community center / market hosting area. After updating the price, the algorithm generates the buyer and seller merit order list by ranking them based on their price and nearest distance.

The sample raw bid output from the *Python bid module* is described in Table II. In Tables III and IV, the price is updated based on the user's distance, and user's are ranked based on their distance and price. The sample merit order list generated by algorithm 1 is shown in Tables III and IV.
Following the creation of a merit order list, possible trading pairs are generated by mapping users from the buyers' merit order list to users from the sellers' merit order list. For example, the first user in Table III is **User 12**, will be mapped to the first user in Table IV which is **User 1** and then with next user from Table IV, **User 13** and so on. This process is repeated until **User 12** is paired with all of the available sellers in Table IV.

Quantity in kW	Price in euro	User ID	Buying	Distance in KM
69	0.74	1	FALSE	1
53	0.81	2	FALSE	9
150	0.76	3	FALSE	2
80	0.95	4	TRUE	3
100	0.99	5	TRUE	7
59	1.01	6	TRUE	2
72	0.79	7	FALSE	0
82	0.85	8	FALSE	2
110	0.97	9	TRUE	6
58	0.74	10	FALSE	7
60	0.82	11	TRUE	4
50	1.06	12	TRUE	2
113	0.74	13	FALSE	9
53	0.76	14	FALSE	3

TABLE II
Example of Bids from the Python bid module

Quantity in kW	Price in euro	User ID	Buying	Distance in KM
50	1.056	12	TRUE	2
59	1.007	6	TRUE	2
100	0.983	5	TRUE	7
110	0.965	9	TRUE	6
80	0.946	4	TRUE	3
60	0.813	11	TRUE	4

TABLE III
Buyers' merit order list

Quantity in kW	Price in euro	User ID	Buying	Distance in KM
69	0.741	1	FALSE	1
113	0.748	13	FALSE	9
58	0.752	10	FALSE	7
150	0.761	3	FALSE	2
53	0.766	14	FALSE	3
72	0.79	7	FALSE	0
53	0.827	2	FALSE	9
82	0.852	8	FALSE	2

TABLE IV
Sellers' merit order list

Line 12 receives the potential trading pairs generated by algorithm 1. In round 1, all potential sellers will try to trade with highest ranked user in buyers merit order list. The buyer and seller will reach an agreement based on the condition mentioned in Line 13, if the trading pair meets the required condition, the buyer and seller will reach an agreement, and the transaction will take place. The quantity traded will be determined by the conditions listed below.

$$Traded\,Quantity = min(quantities\_buyer,\ quantities\_seller)$$

The trading price will be determined by the buyer's price, which is updated in Line 15. Line 16 and 17, update the transaction details; this is more like a ledger-based information, where details such as traded quantity, trading price, buyer and seller ID, and whether the buyer/seller is available for the next round are stored.

IX. Case Study

Several Local Energy Markets (LEMs) have been proposed in order to align energy consumption with excess supply of renewable generation. This is implemented in the python library *Pymarket* [25], which is an essential element of ongoing research in LEMs [25]. To validate the proposed trading mechanism, we will compare the market results with those from the *Pymarket* [25]. Different scenarios will be simulated and results will be compared. The bids serves as an input for the proposed mechanism designed in python as well as for the *Pymarket* [25]. The result obtained from proposed mechanism and *Pymarket* [25] will be compared. These results will help us to understand the impact of distance and price in Local Energy Market. The *Pymarket* [25] was designed considering the following conditions,

- Agents are asymmetrically informed about the value of the traded good.
- No new entrants are allowed once the market is open.
- Trading pair generation is based on game theory [12].

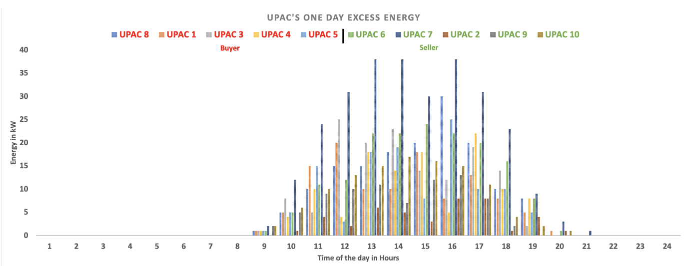

Fig. 6. UPAC One Day Excess Energy

This section makes use of a full day's worth of UPAC data from the SMILE project. Since the installed capacity of the UPACs is low, the excess energy of each UPAC is scaled to maintain the market equilibrium. In this simulation, ten UPAC from the SMILE project act as market participants. They are classified as buyers or sellers based on the balance between their production and concumption. The following are the assumptions that were used in this simulation: The following are the assumptions that were used in this simulation:

1) Market Participants
    1) **Buyer** - Consumption > Production.
    2) **Seller** - Consumption < Production.
2) The buyer's or seller's distance from the community center / market hosted area is assumed to be within a 10 km radius..
3) In the simulation, the prices in € used are the average market prices obtained from existing peer-to-peer markets. [**?**].
4) There is no involvement of an outside agent.

The buying and selling prices and distance of the UPACs are fixed in this simulation, and the bidding quantity varies based on UPAC consumption and production. The Table V describes UPAC's market role, distance, and bidding price.

User	Distance in Km	Price in €	Role
UPAC 1	0	0.81	BUYER
UPAC 2	7	0.74	SELLER
UPAC 3	4	0.83	BUYER
UPAC 4	10	0.91	BUYER
UPAC 5	3	0.89	BUYER
UPAC 6	5	0.76	SELLER
UPAC 7	2	0.79	SELLER
UPAC 8	1	0.85	BUYER
UPAC 9	9	0.76	SELLER
UPAC 10	6	0.74	SELLER

TABLE V
UPAC DETAILS FOR MARKET SIMULATION

The obtained result from the proposed solution is validated by comparing market results to *Pymarket* [25].

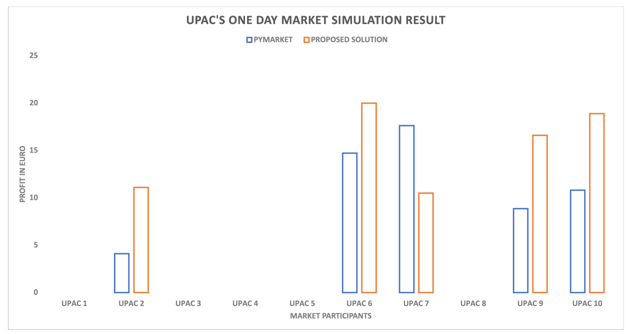

Fig. 7. UPAC one day market simulation result

Figure 7, represents UPACs one-day profit from participating in the proposed local energy market and PYmarket. The results show that all the UPAC has a higher profit in proposed solution than the pymarket, with the exception of UPAC 7. This is primarily due to the fact that UPAC 7 has the highest bidding price when compared to the other UPACs. Because the proposed solution generates a merit order list based on price and distance, other UPACs are preferred over UPAC 7.

The same is true for UPAC 2 and UPAC 6. UPAC 2 has a distance of 7 kilometers and the lowest bidding price compared to the other UPACs, but he receives less profit than UPAC 6, who has a higher bidding price than UPAC 2. This is due to the proposed solution favouring users with the shortest transmission distance.

The below mention Figure 8 and 9 describes the UPAC profit in hourly basis.

X. Conclusions

This thesis proposes a simple and direct trading mechanism for people who participate in a community-based LEM. The proposed method bases its trading decision on a simple merit order list generated by the market after taking into account the price at which the buyer/seller bids in the market as well as the transmission distance based on the location from which the buyer/seller participates. In contrast to the other methods mentioned in the literature, this solution is extremely simple

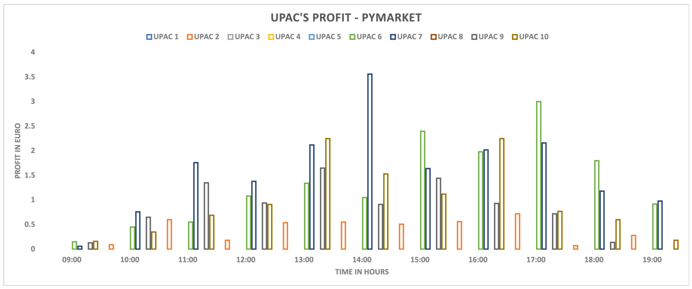

Fig. 8. UPAC Result PYmarket

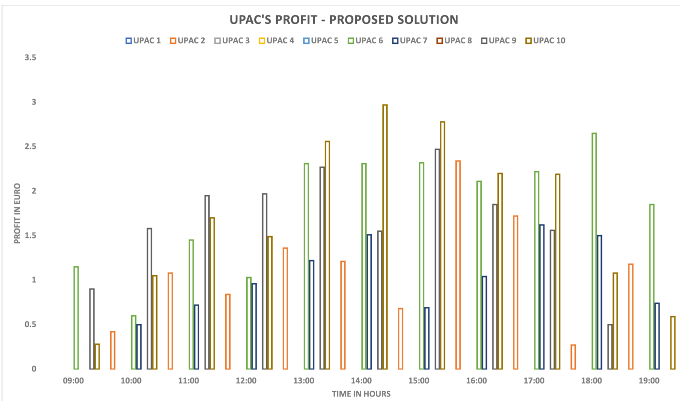

Fig. 9. UPAC Result Proposed Solution

to implement. Most market clearing mechanisms are designed for large or medium-sized market participants. However, this method can be used for small communities with fewer than ten participants.

The results of the six different cases show that the participants in the proposed solution make more profit than the participants in the LEM, which is based on a non-cooperative game theory model. To maintain trading fairness in a non-cooperative game theory model, trading pairs are formed by random pairing, but the proposed solution involves environmental factors such as transmission distance in determining trading pairs. As a result, the user who participates in the market from the shortest distance earns a higher profit than the user who participates from a longer distance. This encourages user participation in the local energy market. However, the impact of this mechanism in a sustainable community must be thoroughly validated.

XI. Recommendation

The proposed mechanism has some limitations and assumptions; the recommendations for a sustainable community-based LEM are listed below,

- The proposed mechanism includes a penalty of 0.1 € for transmission losses; this value must be validated in light of various economic factors and government regulations.
- This thesis focuses on distance as an environmental factor, and the merit order list is formed by taking into account the market participants' bidding price and transmission distance. Taking into account more environmental factors such as energy source (renewable/non-renewable), income, type of organisation (private, government, non-profit), and so on, and developing a decision-making mechanism that assesses user weights based on more environmental factors will add further value to the market.
- The proposed system includes a penalty-based mechanism to address transmission loss, which may result in a reduced profit for the seller. To address this, a different type of incentive-based system could be proposed, or user participation in the market may suffer.

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