Peer to Peer Solar Energy Trading Demonstrator Blockchain-enabled

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Abstract— **By combining distributed generation, battery storage, and smart meters, microgrid performance can be enhanced. As a result, distributed energy resources (DER) can be intelligently controlled via online platforms. Through integration, prosumers that use decentralized resources like wind power have replaced conventional power customers. Due to the growth and digitalization of the power distribution infrastructure, a new method of exchanging electricity in community microgrids called peer-to-peer (P2P) intra-trading has emerged. Blockchain technology is used because it is transparent, secure, and completes transactions quickly. Prosumers, consumers, and owners of renewable energy sources may now trade energy more easily amongst one another. This study develops the P2P paradigm to create a self-sufficient community microgrid system for trading energy. Incorporating peer-to-peer energy trades and a battery backup system, the suggested technique uses blockchain to simulate a decentralized microgrid energy market. The microgrid P2P market's clearing price is established by taking into account customers' expected reactions to price changes, incentivizing consumers and prosumers to alter their patterns of energy usage. A cryptocurrency called Cosmos that is mined and distributed using blockchain technology is also included in the P2P market idea. The results show how automated P2P commerce and adjustable energy storage enable end users to save energy and become more independent. This paper provides a sustainable microgrid energy market model and suggests an approach to improve security by incorporating blockchain technology into current energy management systems. In summary, the paper offers a design paradigm for an independent microgrid system that makes use of distributed energy sources. It demonstrates how end users may gain from energy efficiency and independence while highlighting the possibilities of P2P energy trade and storage variety offered by blockchain. This thorough method provides information on creating a sustainable microgrid energy market and illustrates how blockchain technology can be used to increase the safety of energy management systems.**

Keywords—Blockchain; Data Forecasting; Smart Buildings; Solar PV; Artificial Intelligence; Energy Efficiency, Sustainability.

I. INTRODUCTION

As a reaction to expanding urbanization and environmental concerns, nations throughout the globe are aggressively investigating renewable energy options [1]. As governments work to lessen their reliance on fossil fuels, microgrids and distributed energy sources are becoming more and more popular in this context. Governments were urged to provide aggressive plans for reducing emissions at the COP-26 session in 2021. By the middle of the century, net-zero carbon emissions are what we want to achieve [2]. The provision of consistent access to clean electricity is essential for the accomplishment of these goals [2].

Peer-to-peer (P2P) energy investment inside an open microgrid system using distributed ledger technology is one suggested strategy to allow the integration of renewable energy sources and support local autonomy, as shown in Figure 1 [2]. In the next years, it is anticipated that microgrids, which may run independently or in cooperation with the main grid, would be widely used. However, several obstacles must be overcome for their effective implementation, including integrating market concepts into low- and medium-voltage systems, organizing distribution operators, and creating accessible platforms [3]. Prosumers—clients who both use and create energy—are projected to rise because of the establishment of a community-level market. The implementation of a self-regulated market system, however, has technical challenges that must be solved.

During peak generating times, mismatches between supply and demand may produce voltage and frequency variations inside the microgrid. To store extra energy for future use or to offer it back to the electric grid, a self-regulating system is necessary. However, curtailment may reduce the profitability of prosumers' generating capacity, deterring their investment in distributed generation. In addition, grid integration concerns may make it difficult for the current feed-in tariffs to accommodate the rising number of prosumers [3].

To solve these problems, the employment of optimization algorithms in microgrids for demand-side management has generated interest. Numerous optimization strategies are being researched, such as evolutionary algorithms, game theory, and hybrid approaches like dynamic programming in combination with mixed-integer linear programming. According to this research, a larger proportion of active prosumers must be incorporated into the microgrid system for it to be self-sufficient in satisfying the local community's electricity needs [4].

Therefore, the move toward renewable energy on a worldwide scale calls for the investigation of cutting-edge technologies like microgrids and distributed energy sources. These systems' integration must overcome difficulties about technology, coordination, and market principles. To overcome these challenges and pave the path for an environmentally friendly and autonomous energy future, P2P energy investment inside an open microgrid system, together with optimization algorithms and increasing prosumer involvement, has the potential.

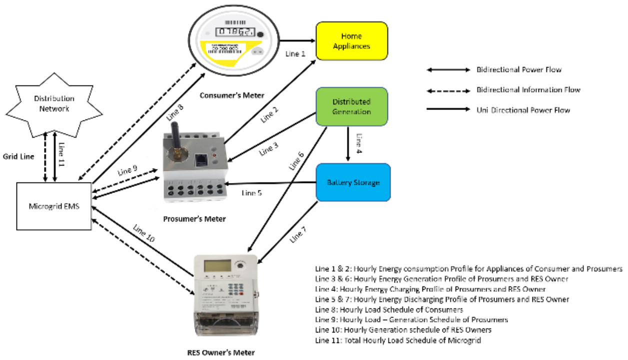


Figure 1 – A community microgrid system using blockchain to facilitate P2P energy trading.

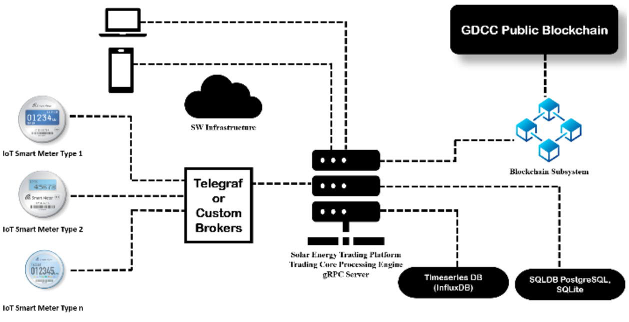
Table 1 provides a list of the terminology used in this paper.

Table 1: Nomenclature used in the paper.

Nomenclature	Referred To
DER	Distributed Energy Resources
P2P	Peer-to-Peer
PV	Photovoltaic
COP	Conference of the Parties
LV	Low Voltage
MV	Medium Voltage
GT	Game Theory
MEMS	Microgrid Energy Management System
RES	Renewable Energy Sources
SOC	State Of Charge
EMS	Energy Management System
MMR	Mid-Market Rate
SDR	Supply Demand Ratio
ABM	Agent Based Model
ECCH	Education City Community Housing
GIS	Geographic Information System
DER	Distributed Energy Resources
CHP	Cooling/Heat and Power
NA	Network Administrator
PoW	Proof of Work
PoS	Proof of Stake
TE	Transactive Energy
EBCE	Energy Blockchain Community System
IoT	Internet Of Things
G/D	Generation/Demand

II. MANAGEMENT OF ENERGY IN MICROGRID SYSTEMS

Providing a micro-array energy scheme prototype, a complete system is shown that combines blockchain technology, peer-to-peer transaction pricing utilizing smart contracts, and producers, consumers, and prosumers of Renewable Energy Sources (RES) (see Figure 2). This idea's main objective is to create a self-contained micro-array energy management system that efficiently controls load distribution by leveraging prosumers, RES storage, as well as distributed ledger smart contracts [9]. In the suggested method, smart meters are used to link households and prosumers to the Microgrid Energy Management System (MEMS). Using communication gateways, these smart meters gather data and send it to blockchain software operating on personal PCs.



Users can trade energy either through the Solar-Trade app or Solar-Trade's website using browsers like Microsoft Edge, Firefox, Google Chrome, etc. These user include buyers or sellers such as residential units, C&Is, or utility companies.

Figure 2 – Intra-Peer Energy Trade in Grid-linked Microgrid Energy Management Systems.

Data from a variety of sources is gathered by the central controller in the Microgrid Energy Management System (MEMS) and sent to both the local controller and the data cloud. The system runs on a microgrid paradigm with p prosumers, m consumers, and r owners of Renewable Energy Sources (RES) as its constituent parts. To ease connection and information sharing, a network of smart meters, Internet of Things (IoT) devices, and sensors is deployed. RES owners and the microgrid's main server (central controller) may now exchange data in both directions [9].

A strong mathematical framework and underlying assumptions support the idea [10].

$$n \;=\; \sum An\ a = 1\ xh\ n, a \qquad \text{(Eqn 1)}$$

The equation (1) given may be applied by all consumers and prosumers as it is a generic equation. Equation (1) in this case describes the appliance 'a's' hourly load consumption profile in kW. Each appliance's individual hourly load consumption profiles are added up to create the overall hourly load schedule for all consumers [9]. Equation (2) places restrictions on the energy production profile for the first sixty minutes to make sure it corresponds to the resources that are available. The term g(max)n refers to the amount of energy output that is best for users to produce within the given time period 'h'. The usage of a limited number of appliances is subject to specific restrictions described by equation (3) for each user.

$$0 \leqslant gh\ n', b \leqslant g(max)\ n' \qquad (Eqn\ 2)$$

The total number of Renewable Energy Source (RES) generating contributions made by RES accumulators and prosumers is represented by g(max)n'. In further detail, the 60-minute energy storage profile is defined as stated in reference [10] for the battery storage of consumers expressed as n' within the range of (p_i, r_i).

$$sh\,n',c \;=\; sh\,n',c(+) - sh\,n',c(-), where\; sh\,n',c(+), sh\,n',c(-) \;\geq\; 0$$

are the sixty-minute charging and discharging outline, in that sequence

$$Pmin \ll\; xh\,n \;\ll Pmax \qquad \text{(Eqn 3)}$$

Pmin and Pmax are the microgrid's prosumers' and customers' minimum and maximum power needs, respectively.

Users of battery storage have the choice of charging their batteries or selling any unused energy to neighboring neighbors or the power grid after their energy needs have been met. The State of Charge (SOC) of the batteries comprises time-dependent storage states represented as h(n). The suggested strategy uses a smart contract set up on a blockchain platform to guarantee accuracy and transparency. For all peer-to-peer (P2P) transactions occurring between prosumers/RES holders and consumers, this smart contract stores relevant information, such as the amount of energy traded (measured in Energy Units) and the accompanying price (in USD/kWh).

Equation 4:

$$0 \ll s\;0\;init,n' \;+\; \sum H\;h = 1\;s\;h\;n',c \ll\; E(max)\;n'$$

However, SOC is ultimately explained by Eqn (5).

$$\sum H\;h = 1\;s\;h\;n',c \;=\; \rho storage$$

Ultimately, perspectives on the value of battery storage differ, hence its estimation is a subject of debate. The utility grid's pricing range for the microgrid system covers an hour to promote competition. Compared to selling electricity to the main grid, the modeling strategy is intended to provide sellers more rewards. In addition, it gives customers access to power at prices that are lower than those paid by the main grid.

III. P2P ENERGY INTRA-TRADING WITH MICROGRID-PRICED INTERNALS

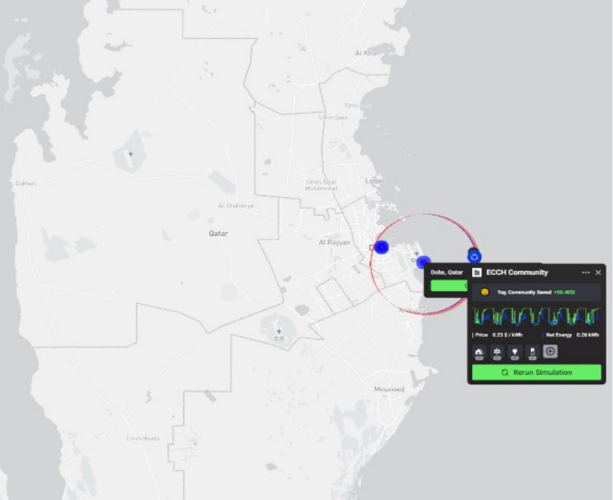
The peer-to-peer (P2P) energy market trading architecture is shown in Figure 5 inside a microgrid energy management system (EMS) that is linked to the main grid. The diagram illustrates the Pth number of prosumers, the Rth number of RES owners, and the Mth number of market participants. Dotted lines represent the flow of information, while solid lines represent the flow of power. The existence of distributed energy resources (DERs) makes it possible for prosumers and the energy grid to trade electricity in both directions.

IV. ENERGY MANAGEMENT IN MICROGRIDS USING DISTRIBUTED-LEDGER-PROPOSED SIMULATION

Blockchain technology is used to manage microgrid electricity. Peer-to-peer (P2P) energy trade is possible inside the system thanks to the use of blockchain smart contracts. Participants construct mutually acceptable rules using Solidity-written smart contracts. Network nodes validate and broadcast participant transactions on the blockchain once the smart contract processes them. Simulated prosumers and owners of Renewable Energy Sources (RES) may bid or request energy using a blockchain-based microgrid energy management system depending on demand, availability, and battery levels. The simulation includes a number of features, including user registration, approval or rejection of participants, modeling of the optimal power flow (OPF) to set system limitations, broadcasting of transaction requests to the P2P network, and verification of consensus techniques. Solc and Ganache Network are two examples of the software used to create and implement smart contracts. As shown in Figure 7, contracts that include crucial techniques and criteria guarantee the market's openness.

V. RESULTS AND DISCUSSIONS

An agent-based model (ABM) trade model created using Hyperledger Fabric was used in this research to analyze peer-to-peer (P2P) energy trading inside Qatar's power market. The foundation of this model is the ECCH compound, which condenses the complexity of Qatar's electrical market (see Figure 3). The study focuses on a market of 295 prosumers who have rooftop photovoltaic (PV) installations. The ABM model was first filled with home agents, and the data they corresponded with, such as hourly generation and demand profiles, was simulated for a whole day.



Yay, Community Saved +50.40$!

Price 0.23 $ / kWh

Net Energy 0.26 kWh

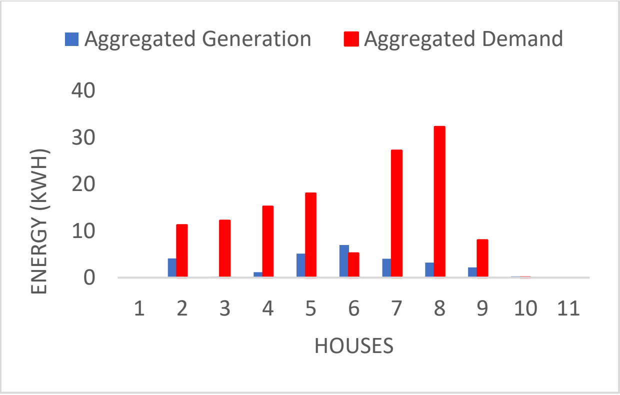
Figure. 3 – (a) ECCH Community Housing project testbed. The data used in this project is for Qatar Foundation housing compound (#lot1 and #lot2). This compound contains 623 homes from different types (villas and flats). The #lot1 is adjacent #lot2.

The research examined P2P energy trading using an agent-based model (ABM) created using Hyperledger Fabric inside Qatar's power market. As seen in Figure 4, the simulation showed that trade transactions happened when the generation-to-demand ratio (G/D) was equal to or higher than 1. Each agent's utility function was calculated after being categorized as either a "seller" or a "buyer" based on the G/D ratio. 10% of the total demand was made up of the flexible and nonflexible requests of all prosumers in the model. Different energy offerings from different sellers pitted them against one another in competition. The starting prices were equal, and sellers competed to make a discount within the [E(buy), E(sell)] range. Prices fell as energy output rose, and vice versa. Because of increasing competition, prices fell as PV energy became more widely available. For a specified hour, each home competed to give the best price and sell the most excess energy. The price of the transaction rose as purchasers competed. The cheapest alternative, self-generation using solar energy, satisfied the initial need. Prosumers might sell their surplus energy to the market at a little higher but still below-market price to deter consumers from buying it straight from the market. With a 10% fluctuating demand, the excess energy in lithium-ion batteries might potentially be used.

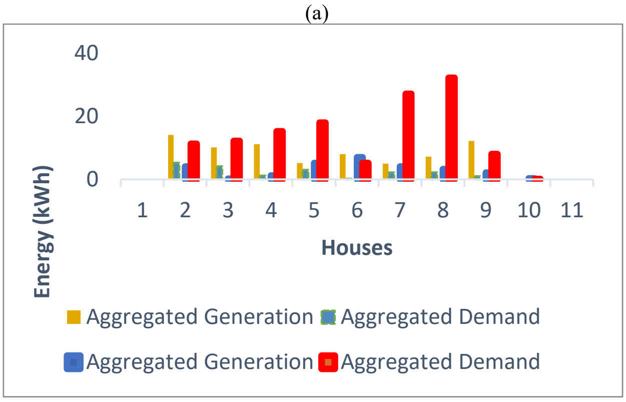
Using information from ECCH lot#2 homes, Hyperledger Fabric created a model of a microgrid with 10 distinct customer accounts, as illustrated in Figure 4. Accounts with more energy made requests, whilst those with less bid. Based on the dynamic grid price (grid selling and buying prices), the fixed marketing clearance price was calculated using the SDR approach. Wei was traded between the bidder and the seller when the bids and requests met. The central grid put rejected bids into its account at a set price set by the government. The simulation information was exported and displayed for examination after 48 hours.

The ECCH lot#2 microgrid community's 10 dwellings' energy requirements were calculated by the research. This is done by using ECCH data on the production of solar and wind energy, battery storage, energy profiles, loads, demands, grid power requirements, and overall utility costs. Due to its ideal capacity (5 kWh), charging efficiency (98%), appropriate charging and discharging rate (2.5 kW), and discharging effectiveness (99.99%), battery storage was chosen by solar prosumers. The study of these factors revealed that P2P trading and battery storage cut costs, avoided curtailment due to battery depletion, decreased grid demand, and preserved the microgrid's capacity to support itself using renewable energy. As shown in Figure 9, the energy balances of all ten homes within a centralized/decentralized framework were made available to the public, and market indicators highlighted P2P transmission losses by showing energy transfers between homes.

The research concluded by showing how battery storage facilitates the exchange of energy shortages and surpluses within a community microgrid at specified intervals. Figure 4's results illustrated how energy storage lowers peak grid demand by maximizing the use of distributed energy resources. To address a community's energy needs, market architecture combined with blockchain technology may create a microgrid that is dependable, effective, and self-sufficient [15, 16].



(a)



(b)

Figure. 4 – (a) Microgrid's total generation and demand, (b) Aggregated Demand/Microgrid Generation Without (Continuous Lines)/With Peer to Peer Energy Trading (Dashed Lines).

Following the implementation of smart contracts, the Network Administrator (NA) informs members within the blockchain network of the availability of the market, as shown in Figure 6. Energy services offered by prosumers and RES owners are up for bid by customers. Up until a mutually agreeable offer is reached, talks between buyers and sellers sometimes go through many revisions. The chosen provider then moves on with supplying power to the clients when the NA ends the market.

By automating tedious tasks, the use of smart contract software on the blockchain streamlines business processes. Every transaction made on the blockchain is irreversible, transparent to everyone, secure, and auditable. The community microgrid's overall demand and the demand profiles for various prosumer groups are shown in Figure 7 for 48-hour periods. Initial energy use is modest, rising progressively during the day until reaching its peak in the late afternoon. During this period, the net load is significantly lower than the total load request since a part of the demand is provided by renewable sources, as represented by the blue line. The graphs show the total volume of requests as well as the time profiles for each. The biggest amounts of excess power production occur during these periods. This cumulative control era is used to regulate peak stack demands in the near term as the control era rises during the morning, triggered by a surge in solar radiation in the late afternoon.

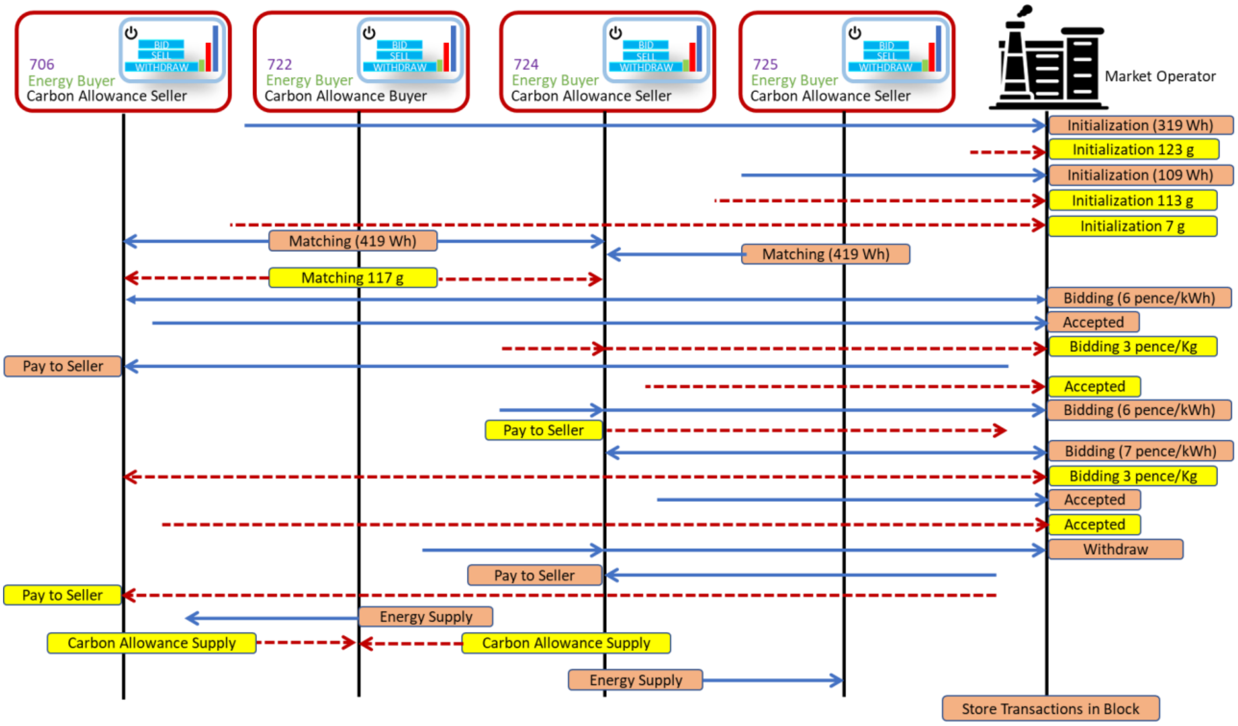
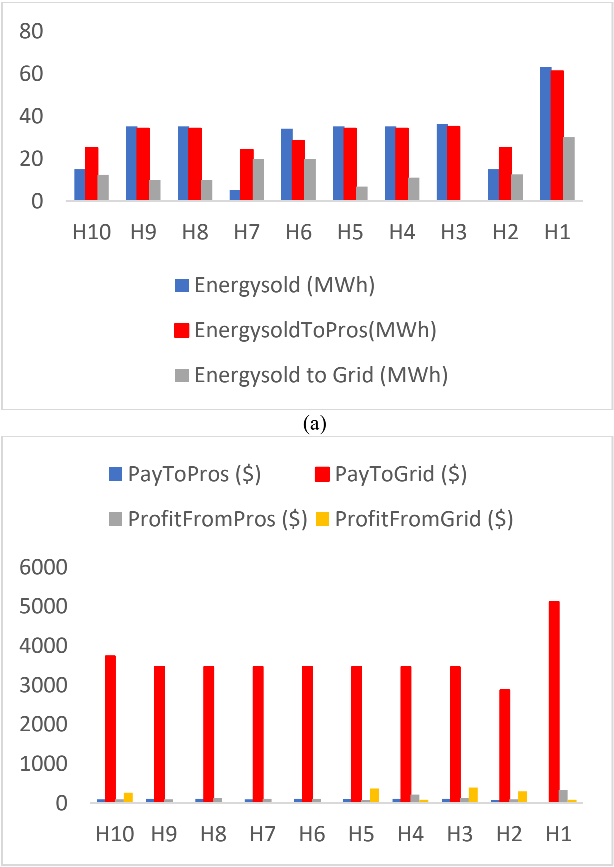


Figure. 5 - Diagram illustrates the peer-to-peer trading process allowed by blockchain.



(a)

(b)

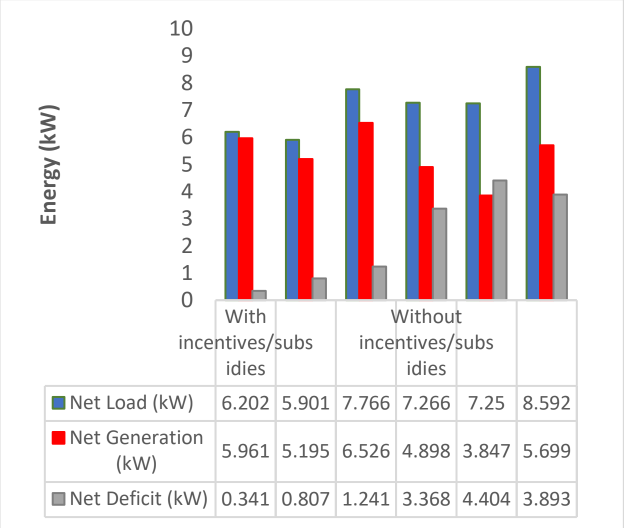
Figure. 6 – (a) Aggregated demand and generation of the microgrid without peer-to-peer energy trading, and (b) Aggregated demand and generation of the microgrid with peer-to-peer energy trading.

As shown in Table 1, we ran market simulations for three different scenarios, and the results are presented in this section. The baseline or point of reference for the "business as usual" condition is represented by the first scenario, or S1. The second instance, S2, shows a situation in which no energy was returned to the grid, but more energy was sold to other prosumers than in the first baseline case, S1. This emphasizes how crucial it is to include battery storage in market models so that extra energy may be kept for possible sales in the future. The photovoltaic (PV) system's capacity was raised to 10 kW in scenario S3, allowing for the trading of a larger amount of electricity. In comparison to S1 and S2, the improved PV potential made it possible to meet a greater percentage of household demand, which led to a greater quantity of electricity being sold back to the grid. On the other hand, in S3, less grid electricity was required. Energy trading in S2 was made easier by battery storage, which increased the amount of energy sold to prosumers and the grid. The aggregate income from trade increased because of prosumers buying more energy from one another. Even though the amount of energy that was available for trading did not rise in S3 compared to S2, the utility's higher price per unit of energy delivered led to an increase in trading income.

Table 1. Energy "Bought" and "Sold" per Household H_i $(0<i<9)$, Profit per Household H_i $(0<i<9)$ for 3 scenarios S_j $(1<j<4)$.

Variable/Houses	*H_1*	*H_2*	*H_3*	*H_4*	*H_5*	*H_6*	*H_7*	*H_8*	*H_9*	*H_{10}*
S_1: $Energy_{sold}$ (MWh)	63.104	15	36.174	35.165	35.165	34.165	5.165	35.165	35.165	*15.0073*
S_2: $Energy_{soldToPros}$(MWh)	61.174	25.1	35.103	34.197	34.197	28.197	24.197	34.197	34.197	*25.127*
S_3: $Energy_{sold\ to\ Grid}$ (MWh)	30.108	12.5	0	11.06	6.77	19.83	19.83	9.83	9.83	*12.4953*
S_2: $Energy_{boughtFromPros}$ (MWh)	67.940	25.1	35.103	34.197	34.197	14.197	24.197	34.197	34.197	*25.127*
S_2: $Energy_{boughtFromGrid}$ (MWh)	52.1916	61.7	72.3834	70.17	74.4817	54.4817	64.4817	74.4817	74.4817	*61.6741*
S_2: Pay_{ToPros} ($)	33.704	82	115.18	111.75	104.225	111.75	100.75	111.75	111.75	*95.05*
S_3: Pay_{ToGrid} ($)	5114.78	2868	3458.83	3463.4	3463.4	3463.4	3463.4	3463.4	3463.4	*3731.28*
S_2: $Profit_{FromPros}$ ($)	337.04	95.1	132.27	216.68	82.03	115.18	111.75	131.75	98.75	*95.05*
S_3: $Profit_{FromGrid}$ ($)	90.38	298.76	401.64	90.38	374.86	0	2.94	3.78	12.94	*265.98*

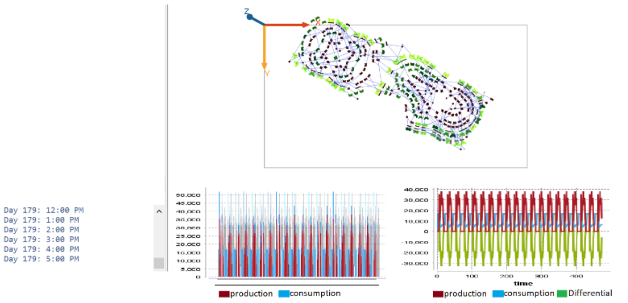
According to scenario S1 (which is represented in the "without incentives" scenario in Figure 7, the installation of a carbon price raises the cost of energy. Therefore, compared to scenario S2, trading results in much bigger earnings. Battery use in scenario S1 lowers the quantity of energy sold to the grid, which lowers the amount of money collected from the grid. The income from prosumers in scenario S1 nevertheless amounts to more than three times more than that in scenario S2 owing to the higher energy costs and the use of battery storage (as indicated in the "with incentives" scenario in Figure 7). This is mostly attributable to scenario S1's greater supply of energy available for purchase.



🟦 Net Load (kW)	6.202	5.901	7.766	7.266	7.25	8.592
🟥 Net Generation (kW)	5.961	5.195	6.526	4.898	3.847	5.699
⬜ Net Deficit (kW)	0.341	0.807	1.241	3.368	4.404	3.893

Figure. 7 - Microgrid Net Deficit Managed by Price Based Demand Response Program without (S_1) and withs Incentives (S_2).

The trading platform and its components are available as a web application that replicates the trading behavior between 623 participants/agents, who stand in for the 623 homes in ECCH #lot1 and #lot2. A screenshot of the platform, showing its user interface and capabilities, is shown in Figure 8.



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Day 179: 12:00 PM
Day 179: 1:00 PM
Day 179: 2:00 PM
Day 179: 3:00 PM
Day 179: 4:00 PM
Day 179: 5:00 PM
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Figure 8. A snapshot of the energy trading platform simulating 623 houses in ECHH #lot1&#lot2. We can anticipate each household's consumption and production profile throughout the energy exchange process with this program, which also allows us to follow the trading activity between agents.

VI. CONCLUSION

This paper suggests a microgrid market model that uses blockchain technology to make it easier to coordinate dispersed power production, delivery, and consumption. In the context of a community microgrid, the recommended strategy works well. Electricity producers and customers are able to agree on a price by using a mid-market strategy and an SDR-based pricing mechanism. Because of its responsiveness to the generation-load balance, the SDR-based strategy performs better. Additionally, the research investigates how the P2P pricing system is affected by load cost, incentive responsiveness, and battery storage, all of which may lower P2P energy purchase costs. The research also emphasizes the significance of reducing the gap between production and load while considering the impact of incentives and prices on load dynamics. Crowd consumers in local microgrids can efficiently control their output and load balancing by merging microgrid Energy Management Systems (EMS) with blockchain architecture. Participant registration is made easier by using public blockchain network addresses that are interfaced with Ganache. All players participate in P2P energy trading by implementing smart contracts that guarantee capacity and cost exchanges are completed within a sixty-minute period and make use of the functions specified in the smart contract. Within the distributed ledger network, peers exchange data. Using distributed ledger transactions, a systematic integration of peer-to-peer price settlement and energy capacity is described. Blockchain-based microgrids provide more flexibility, automation, and security in load-generation balancing.

Following thorough testing inside the emulation environment, the energy blockchain platform will be made available to ECCH homes via a subscription drive designed to sign up as many families as possible and encourage realistic involvement through a reward system. By using this strategy, the platform will be validated with actual users and with actual trade activity before being implemented with physical PV systems and digital money in the context of ECCH. The energy blockchain platform will undergo any required modifications to guarantee its proper implementation in a practical context, serving as a last test before deployment with actual PV systems and digital money.

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REFERENCES

[1] https://climate.nasa.gov/news/2865/a-degree-of-concern-why-global-temperatures-matter/.

[2] https://unfccc.int/conference/glasgow-climate change-conference-october-november-2021

[3] Rosario, Felix Santos-García, Miguel Euclides Aybar-Mejía, Patricio Mendoza-Araya, Angel Molina-García, "Coordinated ancillary services, market participation and communication of multi microgrids: A review, Applied Energy vol. 308, pp.118332, 2022.

[4] Bayram IS, Shakir MZ, Abdallah M, and Qaraqe K. A survey on energy trading in smart grid. In: Proc. IEEE Global Conf. Signal Inf. Process. (Global SIP); 2014. p. 258-262.

[5] Jin X, Wu J, Mu Y, Wang M, Xu X, Jia H. Hierarchical microgrid energy management in an office building. Apple Energy 2017; 208:480–94.

[6] Farhangi H. The path of the smart grid. IEEE Power Energy Mag 2010; 8(1):18–28.

[7] Niknam T, Azizipanah-Abarghooee R, Narimani MR. An efficient scenario-based stochastic programming framework for multi-objective optimal micro-grid operation. Apple Energy 2012; 99:455–70.

[8] Jin M, Feng W, Liu P, Marnay C, Spanos C. MOD-DR: Microgrid optimal dispatch with demand response. Apple Energy 2017; 187:758–76.

[9] "Principles of Internet of Things (IoT) Ecosystem: Insight Paradigm", Springer Science and Business Media LLC, 2020.

[10] Abdullah Umar, Deepak Kumar, Tirthadip Ghose,Blockchain-based decentralized energy intra-trading with battery storage flexibility in a community microgrid system, Applied Energy, Volume 322, 2022, 119544, ISSN 0306-2619.

[11] Italo Atzeni, Luiz G. Ordonez , Gesualdo Scutari, Daniel P. Palomar, Javier Rodriguez Fonollosa, "Demand- Side Management via Distributed Energy Generation and Storage Optimization" IEEE Transactions on Smart Grid, Vol. 4, No.2, June 2013.

[12] Anak Agung Gde Agung, Rini Handayani. Blockchain for smart grid. J King Saud Univ. Comput Inform Sci; 2020.

[13] Wen Y, Feng Yuan Lu, Liu Y, Huang X. Attacks and countermeasures on blockchains: A survey from layering perspective. Comput Netw 2021; 191:107978.

[14] Ameni Boumaiza, Mazhar Sajjad, Antonio Sanfilippo, Nassma Mohandes, "Designing an Agent-based Energy Exchange Simulation Framework for Modeling Blockchain Systems," International Conference on Sustainable Energy-Water-Environment Nexus In Desert Climate, Doha, Qatar", 2-5 Dec 2019.

[15] A. Boumaiza, M. Z. C. Wanik and A. Sanfilippo, "Modeling a Blockchain-enabled Transactive Energy System for Community Microgrids," *2022 IEEE 16th International Conference on Compatibility, Power Electronics, and Power Engineering (CPE-POWERENG)*, Birmingham, United Kingdom, 2022, pp. 1-6, doi: 10.1109/CPE-POWERENG54966.2022.9880874.

[16] Boumaiza, Ameni et al. "Innovation diffusion for renewable energy technologies." *2018 IEEE 12th International Conference on Compatibility, Power Electronics and Power Engineering (CPE-POWERENG 2018)* (2018): 1-6.

[17] Boumaiza, Ameni et al. "Modeling a Blockchain-enabled Transactive Energy System for Community Microgrids." *2022 IEEE 16th International Conference on Compatibility, Power Electronics, and Power Engineering (CPE-POWERENG)* (2022): 1-6.

[18] Gai K, Wu Y, Zhu L, Qiu M, Shen M. Privacy-preserving energy trading using consortium blockchain in smart grid. In: IEEE Trans. Ind. Inf. 2019.

[19] Olivier Van Cutsem, David Ho Dac, Pol Boudou, Maher Kayal,

[20] Cooperative energy management of a community of smart-buildings: A Blockchain approach, International Journal of Electrical Power & Energy Systems, Volume 117, 2020, 105643, ISSN 0142-0615, https://doi.org/10.1016/j.ijepes.2019.105643.

[21] J. Gao *et al*., "GridMonitoring: Secured Sovereign Blockchain Based Monitoring on Smart Grid," in *IEEE Access*, vol. 6, pp. 9917-9925, 2018, doi: 10.1109/ACCESS.2018.2806303.