# Real-Time Home Energy Management with IoT and Blockchain

## Balancing Consumption and Peer-to-Peer Trading

**Eissa Jaber Al-Reshidi**
Department of Information and Computer Science, College of Computer Science and Engineering, University of Ha'il, 81481, Ha'il, Saudi Arabia
e.alreshidi@uoh.edu.sa

**Rabie A. Ramadan**
College of Economics, Management, and Information Systems, Department of Information Systems,University of Nizwa, Oman | Computer Engineering Department, College of Computer Science and Engineering, University of Ha'il, 81481, Ha'il, Saudi Arabia | Computer Engineering Department, Faculty of Engineering, Cairo University, Egypt
rabie@rabieramadan.org (corresponding author)

**Bassam W. Aboshosha**
Department of Communication and Computer Engineering, Higher Institute of Engineering, El Shorouk Academy, Egypt
bassam.ahmed32@gmail.com

**Marwa Salem**
Computer Engineering Department, College of Computer Science and Engineering, University of Ha'il, 81481, Ha'il, Saudi Arabia
marwa_asu@yahoo.com

**Abdulaziz Mohammed Alayba**
Department of Information and Computer Science, College of Computer Science and Engineering, University of Ha'il, Ha'il, 81481, Saudi Arabia
a.alayba@uoh.edu.sa

*Received: 2 March 2024 | Revised: 18 March 2024 | Accepted: 21 March 2024*

 *DOI: https://doi.org/10.48084/etasr.7188*

**ABSTRACT**

**As a result of the exponential increase in energy consumption, energy shortages, and augmented energy costs have become a significant problem for households. Solar cells are used in many homes and/or buildings to address these problems. However, managing renewable energy sources in homes can be difficult due to the irregular nature of renewable energy production. Internet of Things (IoT) devices can provide real-time data on energy production and consumption, offering a promising solution to this issue. The current study proposes a framework based on IoT and blockchain technology for home energy management by predicting future energy consumption patterns and optimizing energy use in real time. The blockchain module facilitates peer-to-peer energy trading between renewable energy-generating homeowners and consumers. The proposed framework was tested employing a dataset based on smart homes with solar panels and wind turbines. The results manifest a reduction in energy costs and a possible 30% increase in their traditional gain.**

***Keywords-energy consumption; smart homes; peer-to-peer; energy trading; prediction***

## I. INTRODUCTION

The energy crisis is one of the most important issues in the world. Global energy consumption has increased in recent years due to industrial development and population growth. As the energy cost has significantly raised, users may be required to sacrifice their level of comfort. Energy production, energy preservation, renewable energy sources, etc., are considered possible solutions to this problem [1]. A Building Energy Management System (BEMS) can reduce energy consumption, save money, and maximize consumer satisfaction. A BEMS is an effective strategy to eliminate electricity costs and prevent energy shortages by diminishing power loss. It is a smart and energy-efficient technology that deploys smart devices, such as smart meters, Area Energy Management Servers (AEMS), etc. Some BEMSs also include Dynamic Pricing (DP) and various cost systems for peak- and off-peak-hour scheduling [1-4]. A BEMS is a system or service that can monitor, regulate, or analyze energy use in homes. This definition includes residential utility applications, home automation, personal energy management, data analysis and visualization, auditing, and related security services. The Internet of Things (IoT) refers to the interconnection of devices and things, involving cars, electrical or mechanical equipment, and homes. Figure 1 presents an example of a smart home. As time passes, many objects in buildings are transformed into Internet-connected smart devices. Furthermore, Renewable Energy (RE) is broadly defined as energy derived from naturally replenishing resources on a humane timescale, such as sunlight, wind, rain, tides, waves, and geothermal heat. The rapid adoption of RE yields increased energy security and economic benefits. However, an energy crisis has resulted from the recent exponential rise in energy consumption and cost for various home and building appliances, whereas residential areas are the most affected ones.

Fig. 1. Smart homes setup.

Historically, in many countries, grid operations have not met user expectations owing to energy shortages, violating user comfort constraints. RE is recognized as the most efficient out of the many available energy sources and has established itself as a necessary alternative energy resource. The prevalent technologies are wind energy, hydropower, solar energy, geothermal energy, bioenergy, and heat pumps. Due to the fluctuating energy output from RE sources [3-4], a BEMS must buy or sell energy during energy shortages or surplus periods. When making these decisions, it is crucial to have precise estimates of the energy output of numerous RE sources and the consumption of various home appliances. Once there is surplus energy generated by RE sources, it accumulates in fixed-capacity storage. Consequently, determining the optimal amount of energy to purchase or sell at a given time is a complex issue, as it must ensure that the demands of home users are met with high levels of satisfaction while simultaneously reducing energy costs. Since energy prices fluctuate throughout the day, establishing an energy management strategy for IoT devices in the real world is very difficult. Energy prices fluctuate throughout the day as energy demand and supply change. Developing an energy production system and putting it into practice, implementing energy conservation mechanisms, distributing energy to household appliances, and ensuring the greates user satisfaction may be challenging. It is difficult to determine the optimal scheduling procedure, entailing how much energy is required to operate the appliance, which appliance will receive the highest priority, and how much energy must be conserved in anticipation of future zero-energy output situations. Consequently, minimizing energy costs through Energy Time-of-Use (ToU) pricing is crucial to an effective energy management strategy.

This study evaluates a BEMS connected to an AEMS. BEMS predicts the total energy and consumption for each period using the Exponential Weighted Moving Average (EWMA) and determines energy surplus or shortage based on these projections. This system employs a maximum-minimum fairness distribution to allocate the total cost over time. Load shifting occurs when purchasing energy, considering customer satisfaction and purchase rate. This study aimed to:

- Generate more realistic datasets to manage large home energy production and consumption as well as trading.
- Use a weighted average of previous time-slot data to predict how much energy might be produced in real time.
- Propose a self-learning home energy management system for smart homes.
- Predicate how much energy will be required to complete everyday tasks in real time.
- Estimate the level of stored energy.
- Determine the optimum energy threshold by calculating a weighted average of the previous time-slot data.
- Utilize the max-min fairness method to distribute the monetary budget across various time frames.
- Propose a blockchain model for energy management and trading systems.

## II. RELATED WORKS

In [5], a smart building infrastructure was established with the smart meter receiving the energy cost of the appliances. In [3-4], smart meters reduced energy costs and minimized power loss, helping to distribute electricity and energy supply that meet consumers' requirements. In [1], the Heat Ventilation and Air Conditioning (HVAC) systems were examined for various home loads. A new Traversal-and-Pruning (TP) method was adopted to discover optimal day-ahead plans for thermostatically controlled home loads. In [2], timetables were developed taking into account consumer payments and comfort requirements. In [6], a realistic optimization model was proposed to schedule household appliances in the context of Time of Use (ToU) energy costs. In [7], a new energy management method for smart buildings, which combined a low-energy Bluetooth wireless network for communication between domestic appliances with the development of a HEMS, was presented. In [8], a new smart home design, based on the Resource Name Service (RES), was proposed. However, none of the previous works considered a renewable energy-based system. In [9], a green home power control system that can show and compare energy use in domestic appliances was recommended. In [10], a renewable power control system that uses a complex and broad-based optimization technique to reduce energy costs while maintaining user comfort was introduced. In [11], a smart building was designed with BEMS and enabled load models. In [1], PLC-based BEMS capable of monitoring and providing information on energy usage trends and intelligent control of appliances were discussed. These studies did not fully integrate renewable energy sources and did not propose models to trade between energy generation, purchasing, and user convenience.

In [12], a Dynamic Pricing (DP) mechanism was employed for both traditional and smart home agent systems, comparing the efficiency gain. This study presented an agent-based model to evaluate BEMS in the deployment of residential demand response. Several price schemes have been implemented to encourage customers to program their home appliances, conserve power, reduce costs, and support grid operation during periods with a low buying rate. In [5, 7], the response to demand was addressed including renewable energy. In [13], SEDMS, which works via the interaction between an intelligent energy distribution system and an intelligent monitoring and control system, was proposed. This study aimed to integrate a new renewable energy system with an intelligent dynamic pattern service as well as to analyze energy usage, user situations, and the environment. An architecture based on ZigBee and PLC was presented without a mathematical model to predict the amount of production and spending in a time plan. This study simply mentioned the connection between energy production and weather but did not explain this correlation to forecast energy output. Additionally, this system had a Remote Energy Management Server (REMS) to calculate energy consumption for home appliances and create patterns for subscribers. However, this system ignored the energy-saving limits of storage devices and trading processes.

BEMSs are developed to address the issues of demand response, energy scarcity, and user satisfaction and have gained popularity due to their low cost and unique features. Modern smart homes include sustainable energy sources, including solar, wind, and biogas [14, 15]. This study assumes that a building has a set of renewable energy sources. On a typical sunny day, solar energy production peaks around 11 am and gradually decreases after 1 pm. One can also assume that energy production from other renewable sources follows a similar trend, gradually increasing and decreasing. The 24-hour day is divided into equal-length time slots. As conventional meters are still on the market, most energy suppliers still charge their consumers based on fixed prices per kWh. However, replacing old meters with smart ones is a continuous process, allowing greater production and fewer mistakes. ToU, real-time pricing, and critical peak pricing are extremely popular for residential customers. The ToU pricing model divides each day into $n$ fixed time slots. Customers may set their electrical appliances to run during specific time slots to reduce costs. For example, if power consumption is very high from 6 to 10 pm, customers can switch off unnecessary loads during this period to eliminate their energy costs. The distinction between ToU and Day-Ahead Planning (DAP) is seen in DAP energy costs, which are set just for that day, and rates for various time slots are also known in advance. Electricity costs change hourly under real-time pricing. As a result, power prices will be low during low energy demand hours and high during high energy demand hours. Another pricing system known as critical peak price utilizes preset pricing rates in which users are charged based on a pace. This plan encourages consumers to consume less energy during peak hours.

## III. METHODOLOGY

Each smart home has a home server that controls intelligent energy management [13]. The energy management server components, described below, help intelligently manage inter- and intra-smart home components.

- System Architecture: The system includes intelligent devices, such as smart meters and appliances, along with a data collection and analysis module, an energy management module, and a blockchain module. Smart devices collect immediate energy production and usage data, which are then transmitted to the module responsible for collecting and analyzing data. The data collection and analysis module follows the EWMA technique to forecast energy consumption trends. The predicted energy consumption is subsequently transmitted to the energy management module, which is designed to optimize energy consumption in real time according to the foreseen energy consumption. Blockchain technology facilitates distributed energy trading among households that produce sustainable energy.
- Data collection and analysis methods: Real-time data are collected from a smart home equipped with both solar panels and wind turbines. The dataset consists of energy production and consumption information obtained from smart meters and appliance data collected from smart appliances. The data were evaluated employing EWMA analysis to predict energy consumption patterns.
- Blockchain platform and smart contract development: A decentralized platform for energy trading among homeowners who generate renewable energy was developed implementing a blockchain platform such as Ethereum. Automated execution of agreements was made easier by using smart contracts.
- Energy management system: An energy management system was developed to dynamically control energy consumption following anticipated energy use. This system consists of a control module that affects the energy

consumption of appliances and devices in accordance with the predicted energy consumption.

- Communication protocol and data transmission methods: This protocol facilitates real-time data transmission between smart devices and the module that handles data collection and analysis. Data transfer is carried out through a reliable and safe protocol, like HTTPS or MQTT.
- Testing and evaluation methods: The proposed system was evaluated deploying real-time data collected from smart homes with solar panels and wind turbines. Compared to the baseline, the system's performance was evaluated through a reduction in energy costs and carbon emissions. The performance of the blockchain module was assessed for the efficacy and safety of energy trading transactions.

This method facilitates collecting and evaluating immediate data from smart devices, predicting future energy consumption via EWMA, and controlling energy consumption in real time to improve energy use. The architecture of the system and the communication protocol guarantee a secure and reliable data transmission between the smart devices and the module that handles data collection and analysis. The proposed energy management system can achieve price reductions for homeowners and reduce their carbon footprint. Additionally, including a blockchain module allows peer-to-peer energy trading among homeowners who generate renewable energy. The blockchain part also ensures the efficiency and security of energy exchange. Figure 2 presents a diagram of the proposed method.

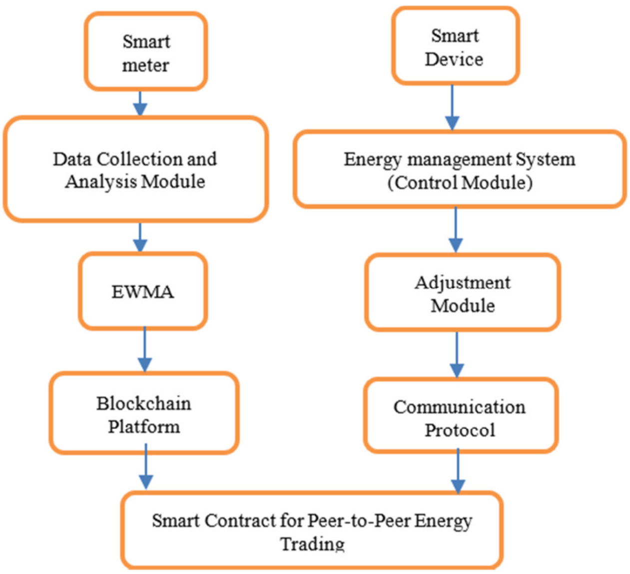


Fig. 2. The proposed method.

The system collects real-time energy production and consumption data through smart meters and devices, which are then transmitted to a dedicated module responsible for data collection and analysis. This module deploys the EWMA method to predict energy consumption patterns. The results of these predictions are then transmitted to the energy management system. The energy management system consists of a control module that governs the energy use of appliances and devices employing projected energy consumption. Blockchain technology is utilized to facilitate distributed energy trading among homeowners who generate renewable energy. Smart contracts are put into service to automatically execute the terms of agreements between the participating parties. Additionally, a communication protocol is in place to ensure secure and reliable data transmission between smart devices and the data collection and analysis module. These components allow homeowners to reduce energy costs and minimize their environmental impact. Simultaneously, this system facilitates peer-to-peer energy exchange, benefiting from the security and efficacy provided by the blockchain module.

### *A. Peep-to-Peer Energy Model*

This model enables homeowners who generate renewable energy to sell their excess energy to others or exchange it with the energy grid. The former operates as follows:

- Homeowners install renewable energy systems on their properties, such as solar panels, wind turbines, or hydropower. These systems generate surplus energy that can be fed back to the energy grid or stored in batteries.
- Transactions are recorded in a decentralized and immutable ledger, ensuring transparency and eliminating the need for intermediaries like banks or energy suppliers. Homes with surplus energy can sell it to other homes in need or feed it back to the grid.
- Smart contracts are used to execute the terms of agreements between the parties involved, ensuring secure and efficient transactions.
- A communication protocol ascertains the privacy and security of data exchange between entities involved in the energy trading process.
- By purchasing surplus energy from fellow homeowners, the dependence on traditional energy suppliers can be eliminated while simultaneously promoting the adoption of renewable energy alternatives.

The peer-to-peer energy trading model, as shown in Figure 3, offers several benefits, including cost reduction, increased adoption of renewable energy sources, and the establishment of a more sustainable and decentralized energy system. Blockchain technology provides improved security, transparency, and efficiency to transactions, while smart contracts enable the automatic execution of agreement terms.

### *B. Exponentially Weighted Moving Average (EWMA)*

The EWMA is a statistical technique commonly utilized in the analysis of time series data, particularly in the fields of technical analysis and volatility modeling, often in the domain of finance. It involves constructing a moving average by assigning relatively smaller weights to older data points compared to the more recent ones. This weight decay follows an exponential pattern. The choice of the alpha parameter is the only decision required when engaging EWMA. This parameter determines the importance of the current observation in the computation of the EWMA. Generally, a higher alpha value results in a closer fit of the EWMA to the original time series. EWMA can be expressed as:

$$E_{s,t}^{*d} = \propto_s E_{s,t}^{*d-1} + (1 - \propto_s) E_{s,t}^{d-1} \quad (1)$$

where $E_{s,t}^{*d}$ is the current energy for slot *s* at time slot *t* in day *d*, and $\propto_s$ is the weight. $\propto_s$ is computed based on the production behavior of the energy source and the weather. Different values will be examined for estimating $\propto_s$. The average sum of the energy from different sources is given by:

$$E_t^{*d} = \sum_1^S E_{s,t}^{*d} \quad (2)$$

At the same time, the energy consumption by each source can be calculated by:

$$C_{s,t}^{*d} = \beta_s C_{s,t}^{*d-1} + (1 - \beta_s) C_{s,t}^{d-1} \quad (3)$$

where $\beta$ is the weight parameter computed based on the usage energy pattern.

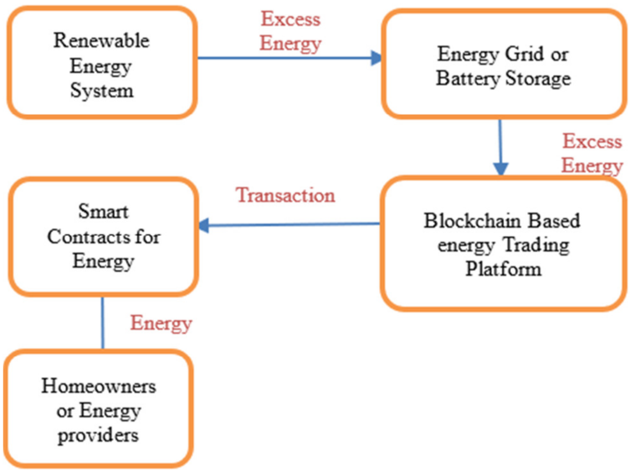


Fig. 3. Peer-to-peer energy trading model.

## *C. Blockchain-based Energy Trading System*

Blockchain is a form of distributed ledger technology that offers a secure and transparent framework to conduct peer-to-peer transactions without the need for intermediaries. In the realm of renewable energy management, blockchain can be used to establish a decentralized system for energy exchange among individuals who generate renewable energy. By allowing homeowners to sell their surplus energy to other homeowners or the grid, this system encourages the adoption of renewable energy sources while reducing the reliance on traditional power suppliers. The implementation of a blockchain-based energy trading system involves recording transactions on a decentralized and immutable ledger, ensuring transparency and eliminating the need for intermediaries such as banks or energy providers. Smart contracts play a crucial role in automating the execution of agreements between the parties involved, enhancing the security and efficiency of transactions. Figure 4 provides a visual representation of two smart contracts for energy exchange between Homes A and B. The decentralized ledger records transactions, thereby certifying transparency and eliminating the need for intermediaries. Smart contracts are employed to automate the execution of contractual terms between the parties involved, ensuring the security and effectiveness of transactions.

- Blockchain Network: The hosting environment of the decentralized ledger comprises a distributed network of nodes. In this decentralized system, the ledger is maintained and updated by multiple nodes, with each node storing its own copy of the ledger.

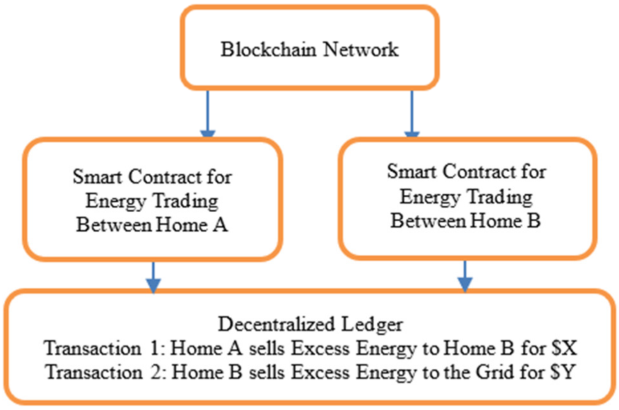


Fig. 4. Blockchain-based energy trading system.

- Smart Contract for Energy Trading: The self-executing contract stipulates the terms of the agreement between Homes A and B regarding energy exchange. It includes details, such as the amount of energy, the unit price, and the transaction time, all of which are recorded within the smart contract. Once the conditions specified in the smart contract are fulfilled, the transaction is automatically executed without the involvement of intermediaries.
- Decentralized Ledger: The digital ledger serves as a comprehensive record of transactions between Homes A and B. Within the blockchain network, each participant maintains their own synchronized copy of the ledger, fostering trust and obviating the need for intermediaries. Completed transactions are recorded as new blocks in the ledger, cryptographically linked to the preceding one. Once a block is added to the blockchain, it becomes immutable and cannot be altered or removed.
- Transaction 1: Home A sells excess energy to Home B for $X: This case exemplifies an energy exchange scenario between Home A and Home B. In this scenario, Home A possesses excess energy and enters into a transaction with Home B to sell a portion of it at a predetermined price $X. To guarantee transparency and traceability, each transaction is meticulously recorded in a distributed ledger, and a unique hash is assigned to it for accurate identification and tracking.
- Transaction 2: Home B sells excess energy to the grid for $Y: This case presents an energy trading arrangement between Home B and the larger power grid. The transaction details, including the energy quantity and financial terms,

are securely stored in the distributed ledger using a unique hash for efficient data management and traceability.

The diagram illustrates the establishment of a peer-to-peer network for energy trading between homes that generate renewable energy deploying blockchain technology. Through the implementation of smart contracts and a distributed ledger, transactions are carried out securely, efficiently, and transparently, eliminating the need for intermediaries.

## IV. EXPERIMENTS AND DISCUSSION

### *A. Performance Measure*

The following steps were taken to comprehensively evaluate the proposed model integrating blockchain and EWMA for IoT-based home renewable energy management with peer-to-peer energy trading:

- EWMA predictions: Use EWMA to predict future energy consumption patterns based on the given dataset. This enables real-time adjustments to optimize energy consumption across various appliances and devices.
- Blockchain-based energy trading simulation: Implement a blockchain-based energy trading platform and smart contracts to simulate peer-to-peer energy trading. Generate transaction examples to buy and sell excess energy between the smart home and neighboring homeowners or energy providers.
- Performance evaluation: Evaluate the effectiveness of the proposed model by analyzing energy consumption patterns, associated costs, and income generated from peer-to-peer energy exchange. Perform a comparative analysis against conventional energy management systems that lack blockchain integration and peer-to-peer trading capabilities.
- Model optimization: Fine-tune the model by modifying parameters related to the EWMA algorithm, smart contracts, and communication protocol. Evaluate the performance of the optimized model to determine if it improves overall system competence.
- Resilience and scalability testing: Validate the model's resilience and scalability by repeating the testing and optimization process using diverse real-world datasets and scenarios. This will ensure the model's ability to adapt and perform reliably across different contexts.

This rigorous evaluation process can thoroughly assess the proposed system, providing valuable insights into its feasibility, effectiveness, and potential benefits. The specific procedure ensures the accuracy, efficiency, and reliability of the model, contributing to the wider acceptance of renewable energy and fostering sustainability within the community.

### *B. Dataset Description*

Five datasets with different numbers of houses were utilized: 20, 50, 100, and 200, spanning 365 days [16]. The fifth dataset was generated for 50 houses as a case study based on initial realistic data collected from weather information in Saudi Arabia.

### *C. EWMA Prediction*

The main objective is to evaluate the accuracy of the EWMA algorithm in predicting future energy consumption patterns. EWMA is applied to the collected energy consumption data and compared with the actual energy consumption patterns. Figure 5 depicts the values for consumption and production along with the corresponding average values for each day for 200 houses. The importance of EWMA in prediction can be emphasized by observing the differences between the average and the EWMA values. For example, let us consider the following:

On day 1, the average consumption and EWMA consumption are the same, which is 3749.974933. On subsequent days, the average consumption fluctuates, while the EWMA consumption gradually adjusts to the changing trend. EWMA consumption tends to smooth out fluctuations and provides a more stable estimate of future consumption.

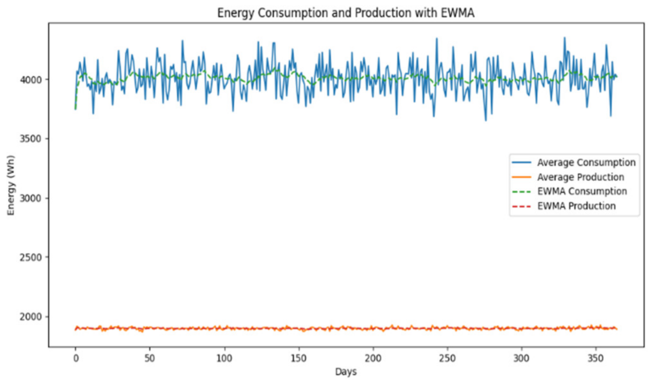


Fig. 5. EWMA prediction for 200 houses.

### *D. Peer-to-Peer Energy Trading*

Peer-to-peer energy trading is a way of exchanging the produced energy between houses, where some houses at certain times could have produced extra energy, and thus they can trade it. The cost could be computed based on the time and amount of energy to be traded. The blockchain concept is deployed to secure trading information and transactions in an attempt to avoid attacks and privacy violations. The main objective of this experiment is to evaluate the performance of the blockchain-based energy trading platform and smart contracts in enabling peer-to-peer energy trading. This method is based on simulating peer-to-peer energy trading engaging the blockchain-based energy trading platform and smart contracts. This generates sample transactions to buy and sell excess energy between smart homes. Then, it measures the transaction processing time, transaction confirmation time, and throughput. The transactions, including the blockchain algorithm, are extensive in evaluating the overall system. Figure 6 portrays daily transactions between the sellers and buyers, where the arrows indicate that there is a transaction between these two houses, whereas Figure 7 presents the number of transactions per day. The red nodes in Figure 6 refer to the nodes that experience the maximum transactions.

The simulation environment is designed to mimic the real-world deployment of energy trading systems within a localized area, such as a residential neighborhood or a business district. The Zigbee communication protocol was used to facilitate efficient communication between participants. Zigbee is a low-power wireless communication protocol that is well-suited for local area networks and supports reliable data transmission. The simulation environment encompasses key components, including a simulation platform tailored for local implementation, Zigbee-enabled smart meters and HEMS installed in participating households, a centralized energy market platform, a blockchain model, and a data management infrastructure. The simulation platform provides a flexible and scalable framework for modeling and simulating the energy trading dynamics within the local community. Zigbee-enabled smart meters and HEMS devices qualify the collection and exchange of real-time energy consumption and data generation, ensuring accurate and timely information for trading decisions. The centralized energy market platform serves as the coordination hub, matching energy buyers and sellers according to their preferences, prices, and available energy resources. Additionally, the simulation environment incorporates a robust data management infrastructure to store, process, and analyze energy data for performance evaluation and optimization purposes. By simulating the energy trading dynamics in a localized setting and leveraging the Zigbee communication protocol, the proposed simulation environment offers a realistic and scalable platform to study the feasibility, efficiency, and potential benefits of local energy trading implementations in smart cities. This results in secure and efficient peer-to-peer energy trading. The transaction processing time is within an acceptable range, on average 1 second per transaction, while the transaction confirmation time is immediate, and the transaction throughput, is up to 95% on average, which is high enough to support a large number of transactions.

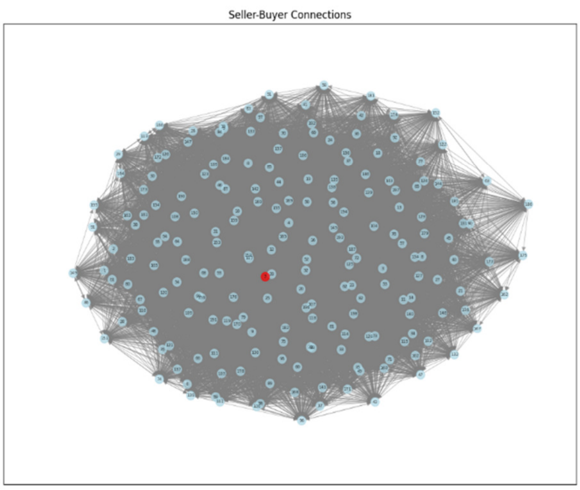


Fig. 6. Transactions between sellers and buyers.

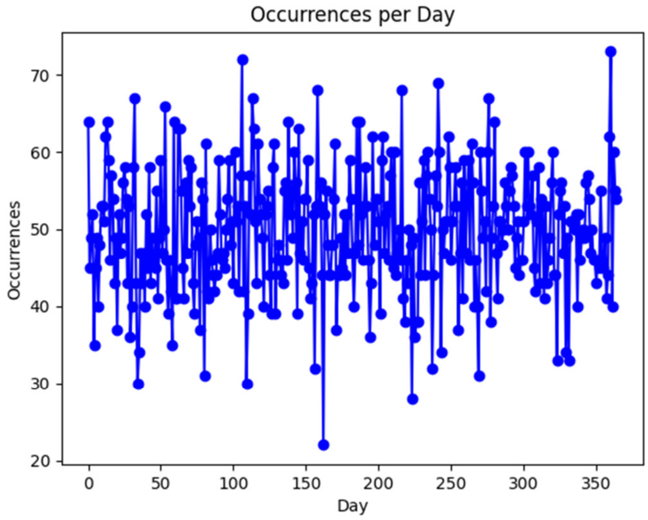


Fig. 7. Number of transactions per day.

## *E. P2P Performance Evaluation*

Figure 8 exhibits the total revenue and costs generated from peer-to-peer energy trading based on traditional grid management and trading rules. Trading revenue refers to the income or revenue generated from trading energy between participating smart homes within a localized energy market. Smart home energy trading facilitates homeowners to produce and consume their renewable energy and trade any surplus with other homes in the same energy ecosystem. Trading revenue in this scenario represents the monetary value earned by homeowners when they sell excess energy to other participants in the smart home energy trading network. It is calculated based on the agreed-upon pricing mechanism and the quantity of energy traded. Revenue earned for consumption can contribute to offset energy costs, increase the overall efficiency of energy consumption, and promote the use of renewable energy sources. The additional revenue refers to the net revenue generated from energy trading activities after accounting for the additional costs incurred. This represents the difference between the revenue earned from selling excess energy and the costs associated with purchasing energy when needed.

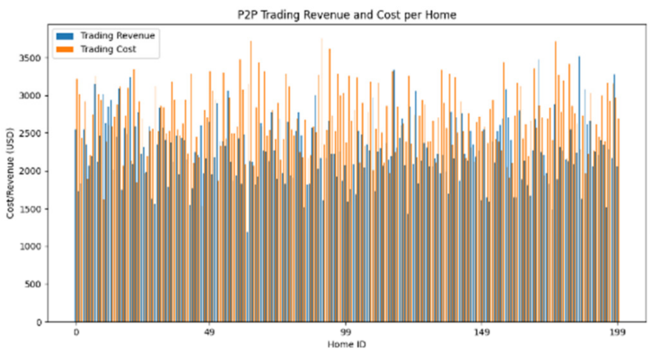


Fig. 8. P2P trading revenue and cost per traditional grids.

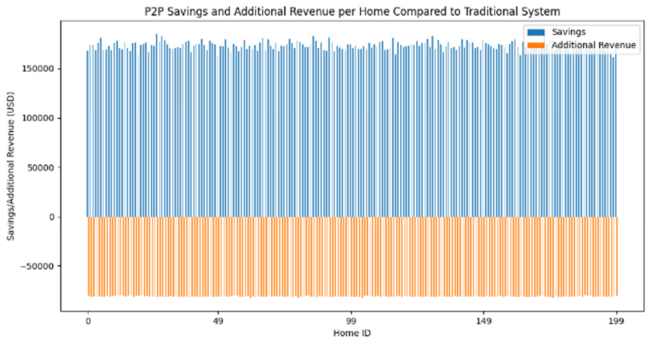


Fig. 9. Savings and additional revenue after applying the proposed model.

As observed in Figure 8, some houses gained revenue due to the trading cost of a large amount of energy. Figure 9 demonstrates that the proposed model was able to make a profit for almost all homes and that the savings were greater than the additional revenue (negative section). These data reveal that homes have achieved significant savings through energy trading up to 30% over their original expenses. Although the additional revenue is negative, the net values remain positive, indicating that homes are still financially benefiting from their participation in the energy trading system. These findings highlight the effectiveness of the system in reducing energy costs for participating homes.

## V. CONCLUSION

This study addressed the challenge of managing renewable energy sources in homes by proposing an IoT-based home energy management system. This system followed the EWMA method to predict future energy consumption patterns and optimize real-time energy use. Additionally, the integration of a blockchain module facilitated peer-to-peer energy trading among renewable electricity-generating homeowners. The system was evaluated using an energy dataset collected from a smart home with solar panels and wind turbines, demonstrating reduced energy costs and a potential 30% increase in traditional gains. Future research should focus on data scalability, user adoption, and AI techniques to further improve the system's efficacy.

## ACKNOWLEDGMENT

This research was funded by Scientific Research at the University of Hail, Saudi Arabia through project number RD-21 011.

## REFERENCES

[1] D. Han and J. Lim, "Smart home energy management system using IEEE 802.15.4 and zigbee," *IEEE Transactions on Consumer Electronics*, vol. 56, no. 3, pp. 1403–1410, Aug. 2010, https://doi.org/10.1109/TCE.2010.5606276.

[2] C. Wang, Y. Zhou, J. Wang, and P. Peng, "A novel Traversal-and-Pruning algorithm for household load scheduling," *Applied Energy*, vol. 102, pp. 1430–1438, Feb. 2013, https://doi.org/10.1016/j.apenergy.2012.09.010.

[3] H. Ghazzai, H. Menouar, A. Kadri, and Y. Massoud, "Future UAV-Based ITS: A Comprehensive Scheduling Framework," *IEEE Access*, vol. 7, pp. 75678–75695, 2019, https://doi.org/10.1109/ACCESS.2019.2921269.

[4] S. S. Ali, M. Maroof, and S. Hanif, "Smart energy meters for energy conservation & minimizing errors," in *2010 Joint International Conference on Power Electronics, Drives and Energy Systems & 2010 Power India*, New Delhi, India, Dec. 2010, pp. 1–7, https://doi.org/10.1109/PEDES.2010.5712393.

[5] L. Liu, Y. Liu, L. Wang, A. Zomaya, and S. Hu, "Economical and Balanced Energy Usage in the Smart Home Infrastructure: A Tutorial and New Results," *IEEE Transactions on Emerging Topics in Computing*, vol. 3, no. 4, pp. 556–570, Oct.. 2015, https://doi.org/10.1109/TETC.2015.2484839.

[6] A. Rezaee Jordehi, "Enhanced leader particle swarm optimisation (ELPSO): a new algorithm for optimal scheduling of home appliances in demand response programs," *Artificial Intelligence Review*, vol. 53, no. 3, pp. 2043–2073, Mar. 2020, https://doi.org/10.1007/s10462-019-09726-3.

[7] R. Balakrishnan and V. Geetha, "Review on home energy management system," *Materials Today: Proceedings*, vol. 47, pp. 144–150, Jan. 2021, https://doi.org/10.1016/j.matpr.2021.04.029.

[8] N. Staifi and M. Belguidoum, "Adapted smart home services based on smart contracts and service level agreements," *Concurrency and Computation: Practice and Experience*, vol. 33, no. 23, 2021, Art. no. e6208, https://doi.org/10.1002/cpe.6208.

[9] J. Han, C. S. Choi, W. K. Park, and I. Lee, "Green Home Energy Management System through comparison of energy usage between the same kinds of home appliances," in *2011 IEEE 15th International Symposium on Consumer Electronics (ISCE)*, Singapore, Jun. 2011, pp. 1–4, https://doi.org/10.1109/ISCE.2011.5973168.

[10] A. Amer, K. Shaban, A. Gaouda, and A. Massoud, "Home Energy Management System Embedded with a Multi-Objective Demand Response Optimization Model to Benefit Customers and Operators," *Energies*, vol. 14, no. 2, Jan. 2021, Art. no. 257, https://doi.org/10.3390/en14020257.

[11] S. Davarzani, I. Pisica, G. A. Taylor, and K. J. Munisami, "Residential Demand Response Strategies and Applications in Active Distribution Network Management," *Renewable and Sustainable Energy Reviews*, vol. 138, Mar. 2021, Art. no. 110567, https://doi.org/10.1016/j.rser.2020.110567.

[12] S. Xu *et al.*, "Agent-based modeling and simulation for the electricity market with residential demand response," *CSEE Journal of Power and Energy Systems*, vol. 7, no. 2, pp. 368–380, Mar. 2021, https://doi.org/10.17775/CSEEJPES.2019.01750.

[13] T. Molla, "Smart Home Energy Management System," in *Research Anthology on Smart Grid and Microgrid Development*, IGI Global, 2022, pp. 1132–1147.

[14] A. M. S. Saleh, "A Power-Aware Method for IoT Networks with Mobile Stations and Dynamic Power Management Strategy," *Engineering, Technology & Applied Science Research*, vol. 13, no. 6, pp. 12108–12114, Dec. 2023, https://doi.org/10.48084/etasr.6352.

[15] M. Sojoudi, R. Madatov, T. Sojoudi, and P. Farhadi, "Achieving Steady and Stable Energy from AlGaAsGaAs Solar Cells," *Engineering, Technology & Applied Science Research*, vol. 1, no. 6, pp. 151–154, Dec. 2011, https://doi.org/10.48084/etasr.93.

[16] R. A. Ramadan, "Internet of things dataset for home renewable energy management," *Data in Brief*, vol. 53, Apr. 2024, Art. no. 110166, https://doi.org/10.1016/j.dib.2024.110166.