Framework Development for Energy Trading

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***Abstract*—Blockchain usage is becoming more and more common across a range of businesses, particularly in the energy sector. As distributed energy resources (DER) proliferate, energy Users have the ability to create, store, and exchange resources with one another. Peer-to-peer (P2P) energy trading marketplaces based on blockchain have an impact on utility corporations and energy consumers. Blockchain gives the associated transactions more immutability and transparency. When the requirements are satisfied, blockchain smart contracts run automatically and without the need for outside intervention. Inspired by these advantages, an Ethereum smart contract-based energy trading system is built in this study. Energy consumers may utilise the smart contract features to buy energy or exchange their excess energy. Remix with an inserted metamask provider is used to compile and deploy a solidity smart contract. Accounts are created with Ganache and then imported into Metamask to sign transactions. We also go over several approaches of deploying smart contracts. Evaluating the gas consumption analysis for the smart contract functionalities is how computational cost analysis is carried out.**

***Index Terms*—blockchain, peer to peer energy trading, transaction, contracts, decentralized**

I. Introduction

The conventional, centralised energy infrastructure is facing problems from the growing use of renewable energy sources like solar and wind power. These scattered and variable energy supplies are not well adapted for integration with the one-way flow of energy from power plants to consumers.

Peer-to-peer (P2P) energy trading shows promise in addressing these issues. Prosumers can directly sell extra energy to neighbours or other community members using peer-to-peer (P2P) frameworks if they have rooftop solar panels or other renewable energy sources. This localised energy exchange can empower prosumers, encourage the integration of renewable energy sources, and increase grid efficiency [1].

The idea of peer-to-peer energy trading mechanisms is examined in this research. We provide a unique framework architecture that makes use of blockchain technology to guarantee safe and open energy transactions. The potential advantages of P2P trading for prosumers and the energy sector as a whole are further examined in the research. Lastly, we go over the difficulties and factors to be taken into account for P2P energy trading to become widely used.

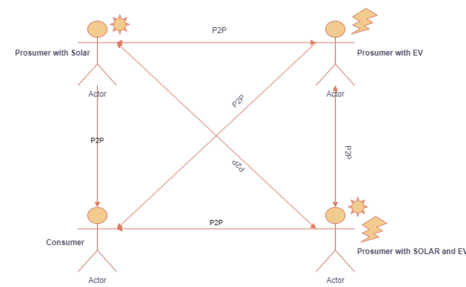

Fig. 1. Illustration of P2P energy trading

II. Background

A. Centralised Energy Systems' Drawbacks

There are some inherent shortcomings with the old paradigm of centralised energy systems:

- **Consumer Disempowerment:** With little influence over their energy sources or price structures, consumers typically act as passive receivers of energy.
- **Transmission losses and inefficiencies:** Since centralised generating frequently necessitates significant power transmission across large distances, greater infrastructure costs and energy losses result.
- **Environmental Impact:** Greenhouse gas emissions and worries about climate change are greatly increased by reliance on fossil fuel-based power plants.
- **Vulnerabilities:** Widespread blackouts may result from disturbances to centralised infrastructure, such as natural catastrophes or deliberate assaults.

B. The Rise of P2P Trading and Decentralised Energy

The pursuit of new paradigms for energy distribution has been spurred by the convergence of environmental concerns and technology breakthroughs. Important advancements consist of [3]:

- **Renewable Energy Boom:** Localised generation is becoming more and more practical due to the maturity and declining prices of distributed renewable energy sources, such as solar and wind power.
- **Smart Grid Initiatives:** By combining sensors, communication networks, and smart metres, the electrical grid is

gradually changing to allow for real-time data collecting and two-way energy flows.
- **The Rise of the Prosumer:** As more people and small groups become able to generate their own energy in addition to consuming it, the idea of the "prosumer" is fostered.

C. Peer-to-Peer (P2P) Energy Trading: A Revolutionary Framework

In a localised marketplace, prosumers and those looking to buy energy are directly connected through peer-to-peer energy trading. This particular model can [2]

- **Open Up New Markets:** By extending consumer access to energy, customers have the chance to sell excess energy and earn income.
- **Democratise Energy:** Peer-to-peer (P2P) trade fosters a more participative and decentralised energy economy by reducing reliance on middlemen.
- **Boost Choice:** Customers have the freedom to select the energy sources that best suit their needs, maybe gravitating towards renewable options.

D. Blockchain: The Foundation for Trust and Efficiency

P2P energy trading is powered by blockchain technology, which provides a certain set of characteristics that are vital to its success:

- **Decentralisation and the Elimination of Middlemen:** Blockchain technology does away with the necessity for centralised authority or big energy businesses in a peer-to-peer energy market. Direct transactions allow consumers and producers to maintain control over data and transactions.
- **Immutability and Transparency:** A transaction (such as the production, trading, or consumption of energy) is unchangeable once it is recorded on the blockchain. This promotes confidence, lowers fraud, and streamlines regulatory compliance by offering a clear, tamper-proof audit trail that all parties can verify.
- **Smart Contract Functionality:** Smart contracts are arguably the most revolutionary feature of blockchain for peer-to-peer energy trade. The agreed-upon guidelines, conditions, and sanctions governing energy transactions are contained in these self-executing contracts. Without human participation and the related overhead expenses, they may automate pricing based on pre-established criteria, start transactions when conditions are satisfied, and guarantee safe money transfers.
- **Types of Blockchains:** A variety of blockchain technologies may be utilised by P2P energy trading systems. Maximum decentralisation is provided by public blockchains, such as Ethereum, although permissioned or consortium-based blockchains may be chosen where regulatory frameworks need a certain degree of control and participant identity [4].

Though still a nascent field, P2P energy trading holds immense promise for the future of energy. It could fundamentally restructure traditional electricity markets and catalyze a more sustainable and equitable energy landscape.

III. Proposed Solution

The proposed platform leverages a community-driven model with an auction-based mechanism to facilitate transparent and secure energy trading. Smart contracts and tokenization (ERC-20) form the backbone of the system, ensuring trust and traceability Addressing the needs of electricity grid operators, this application enhances grid efficiency and encourages the adoption of distributed energy resources.

A. Technology Stack

- Frontend: React.Js, Redux, MaterialUI
- Backend: Node.js, Firebase Authentication, Firestore DB
- Blockchain Integration: Solidity, Ethers.js, Metamask

B. System Architecture

Figure 2 shows the architecture of entire system

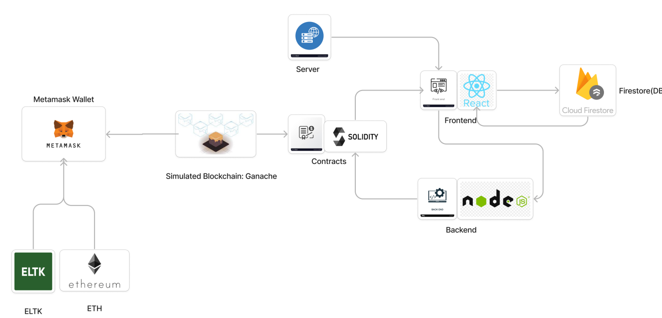

Fig. 2. System Architecture Diagram

C. Key Features & Implementation

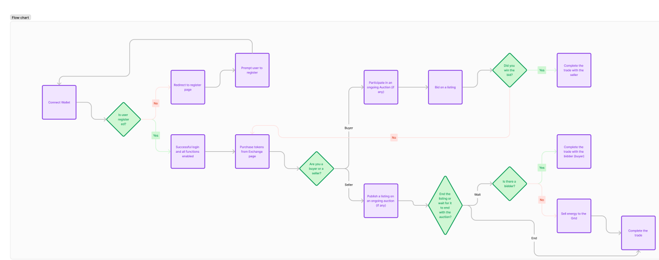

Fig. 3. System workflow diagram

- **User Management:**
Community.sol - This contract establishes the core elements for enabling users to register, participate in a tokenized energy market, and interact with an administrative entity within a community-based energy trading system.
- **Auction Mechanism:**
Auction.sol - This auction contract introduces a market-driven element to your P2P energy trading platform.

Rather than fixed prices, buyers and sellers engage in bidding, allowing supply and demand to determine the value of energy certificates. This can lead to more efficient pricing and potentially incentivize further renewable energy generation.

- **Community Grid:**
  GridInteraction.sol - This contract acts as a bridge between P2P energy trading system and the internal grid. It enables bidirectional energy flow:
  - **Grid to P2P:** Grid buys energy certificates from P2P sellers implicitly if they do not get bidders.
  - **P2P to Grid:** P2P buyers purchase energy directly from the grid in times of need.
- **Tokenomics:**
  - Token Symbol: ELTK
  - Total Tokens: 10000
  - Token Price: 0.0017 ETH

  ElectricityToken.sol - This contract provides a basic but customizable token designed to represent and manage electricity units within a blockchain-based energy marketplace. It enforces administrative control over token supply, likely linked to a larger system where the token is traded between users.
- **Energy Certificates:**
  EnergyCertificate.sol - This contract establishes a mechanism to create, manage, and redeem certificates representing renewable energy units. It integrates with custom electricity token, likely playing a key role in rewarding renewable energy producers within P2P trading marketplace.

D. User Experience (UX) Design

Figure 4 to Figure 10 shows the UI of entire framework for different stages.

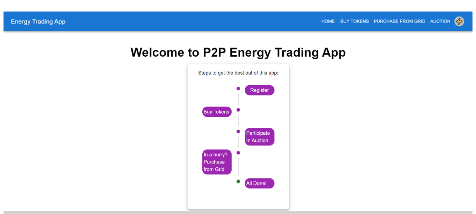

Fig. 4. Home page of energy trading framework

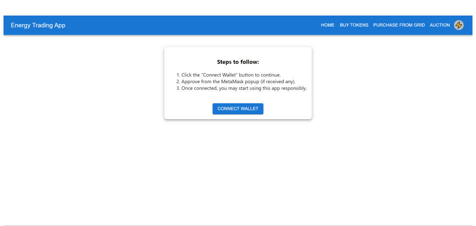

Fig. 5. Admin need to connect to metamask wallet

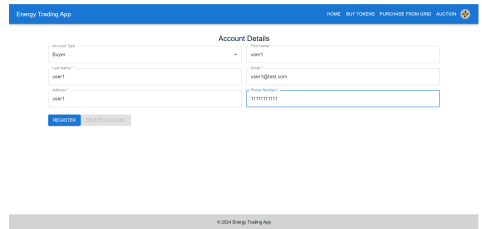

Fig. 6. User Registration page

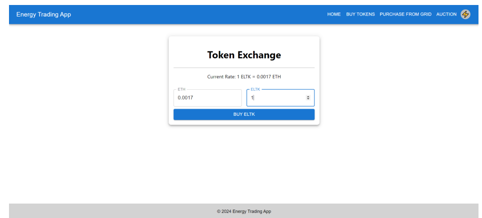

Fig. 7. Purchase token to participate in trading

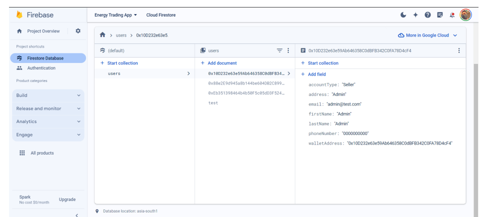

Fig. 8. Database for storing details

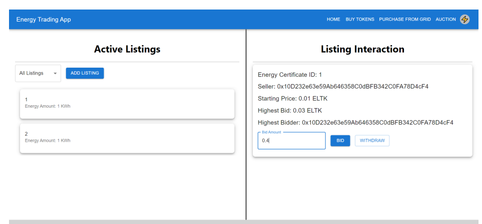

Fig. 9. Auction Listing selected for bidding

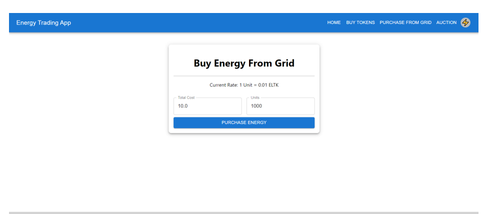

Fig. 10. Purchase energy from grid

E. Testing and Evaluation

- Smart contract security audits
- Usability testing

IV. Potential Benefits and Challenges associated with P2P Energy trading framework

A. Potential Benefits:

Compared to conventional energy models, our decentralised energy trading platform, which is based on blockchain technology, has the following benefits:

- **Enhanced Prosumer Empowerment:** By enabling individuals or small groups with the ability to generate energy (referred to as ”prosumers”), our platform enables them to take an active role in the market. In order to avoid middlemen, producers might sell extra energy to customers directly. This improves control over energy resources and opens up possible new revenue streams.
- **Encouragement of Renewable Energy:** A special method for exchanging energy certificates, which stand for units of energy, is incorporated into our system. This can also be used for renewable energy sources with little tweaks. This supports the shift to a more sustainable energy environment by directly encouraging the production and consumption of renewable energy.
- **Choice and Openness for Customers:** Customers now have the power to select the energy sources they use. The blockchain records transactions, increasing openness about the source of energy that is purchased. Customers are now better equipped to encourage the production of energy in line with their environmental values.
- **Dynamic Pricing Models:** By including an auction-based trading system, energy pricing is subject to market forces. As a result, pricing may now accurately represent supply and demand, which may increase efficiency and help customers choose more affordable options.
- **Potential Grid Resilience:** During power outages, a P2P energy network equipped with a microgrid can increase local resilience. As a result, reliance on centralised grid infrastructure is decreased.
- **Potential Cost Savings:** Participants may see a total decrease in energy expenses by eschewing conventional middlemen and taking advantage of smart contracts’ efficiency for transactions.
- **Encouraging Innovation:** P2P energy trading facilitated by blockchain creates opportunities for innovation in the energy markets. New pricing methods, demand response tactics, and value-added energy-related services are some examples of this.

B. Challeges

1) *Technical Challenges:*

- **Scalability:** Blockchain systems must be able to effectively manage a high volume of transactions, particularly as the user base expands. For the market to remain viable, low transaction costs and quick settlement times must be maintained.
- **Interoperability:** Our solution must be able to interact with legacy energy systems and maybe other blockchains in an efficient manner. Ensuring the steady flow of energy and data is crucial for precise market operation.
- **Security:** In order to safeguard user information, stop fraudulent transactions, and fend off future cyberattacks, blockchain systems need to have strong security.

2) *Regulatory Challenges:*

- **Existing Frameworks:** P2P energy models may challenge current regulations designed around centralized energy systems. Navigating legal requirements and potentially advocating for policy updates will be important for long-term success.
- **Grid Integration:** Balancing decentralized energy flows with the stability needs of the larger grid requires close coordination with grid operators and potentially new regulatory mechanisms.

3) *Market related Challenges:*

- **Adoption by Consumers and Producers:** It is crucial to draw a sufficient number of energy producers and consumers to a new market. This might entail offering incentives, launching information efforts, and showcasing distinct benefits above conventional approaches.
- **Market Maturity:** The area of peer-to-peer energy trading is still in its infancy. It takes time to establish best practices, gain the trust of customers, and create generally recognised standards.
- **Pricing Volatility:** Energy prices may fluctuate in response to dynamic market conditions, particularly when using auction-based methods. There’s a chance that this will make the system less certain.

4) *Strategies for Mitigation:*

I am aware of these difficulties and am proactively formulating plans to deal with them:

- **Scalability and Performance:** To make sure our system can accommodate rising demand, we are investigating blockchain scaling options and streamlining smart contract interactions.
- **Security Focus:** To safeguard user assets, prioritise security audits, put best practices into effect, and maybe use insurance mechanisms.
- **Regulatory Engagement:** Working together with decision-makers to create laws that support peer-to-peer energy innovation.
- **User-Centric Design:** To promote adoption, make sure our interfaces are easy to use, offer clear instructional materials, and highlight the advantages for prosumers and consumers alike.

V. Conclusion

The goal of this study project was to design a framework for peer-to-peer (P2P) energy trading, a cutting-edge idea that has the potential to completely transform the energy industry. The creation of a blockchain-based infrastructure to enable safe and open energy transactions between prosumers and consumers was the project’s ultimate result.

The suggested approach combines an inventive auction mechanism with a community-driven concept. By allowing buyers and sellers to compete through bids, this mechanism brings vitality to the energy market and promotes price discovery based on current supply and demand. Compared to conventional fixed-rate energy models, this strategy may result in more cost-effective pricing and encourage the production of additional renewable energy.

The self-executing programmes called smart contracts that live on the blockchain are what enable the platform to work. Important P2P marketplace operations including user registration, energy token administration, and auction execution are automated by these contracts. By doing away with the need for middlemen, this automation lowers transaction costs and lowers the possibility of manipulation or human mistake. The platform also makes use of an energy token that is compatible with ERC-20, which makes value transaction inside the P2P ecosystem safe and traceable.

VI. Learning Outcomes

A. Technical Learning Outcomes

- **Blockchain Fundamentals:** Comprehensive knowledge of consensus procedures, transaction validation procedures, and decentralised ledger ideas.
- familiarity with programming tools and a particular blockchain platform (such as Ethereum, Hyperledger Fabric, etc.).
- **Smart Contract Development:** The ability to codify the logic of agreements and transactions using a smart contract language, such as Solidity.
- comprehensive understanding of testing procedures and secure smart contract design ideas.
- **Web3 Interaction:** Have knowledge of utilising front-end interface frameworks like as Web3.js and Ethers.js to communicate with the blockchain.
- proficiency with integrating wallets like as MetaMask.

B. Beyond Technical: Problem Solving and Project Development

- **Research and Analysis:** Proven capacity to look up pertinent legal frameworks and current energy trading platforms. aptitude for data analysis in the energy sector.
- **System Design:** Hands-on experience creating a P2P system's architecture, taking into account factors like user roles, price structures, and security measures.
- **Troubleshooting and Debugging:** Developed methodical techniques to solve issues when smart contracts or blockchains have flaws.

C. Broader Understanding: Energy and Innovation

- **Integration of Renewable Energy:** Acquired knowledge on how blockchain enables dispersed integration of renewable energy sources and possible microgrid development.
- **Impact on the Environment:** A greater comprehension of the possible advantages P2P energy trading models may have over conventional systems in terms of the environment.
- **Innovation in the Energy Markets:** A greater understanding of how new business models may be fueled by blockchain technology and how it can disrupt established energy markets.

VII. Contributions

This project is an extensive personal investigation into the conception and development of a peer-to-peer energy trading network based on blockchain technology. At each phase of project development my mentor guided me in correct direction. I was the only one who contributed the following:

- **Conceptualization:** Developed the system architecture, incorporating the fundamental smart contracts and how they work in a peer-to-peer marketplace. To help with the choice to incorporate one, the function of auction systems was investigated.
- **Implementation of Smart Contracts:** Created the Solidity codebase, which included user interface design, auction features, and token administration. modified the current ERC20 token specifications to meet the needs of the project.
- Acquired expertise in Solidity programming, blockchain development concepts, and the particular use of smart contracts in the energy trading industry.

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