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Energy Trading of Renewable Energy Resources by using Blockchain Technologies

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ABSTRACT

This article explores the utilisation of blockchain technologies to improve renewable energy, having an emphasis on Sarawak. In Sarawak, solar power presents a viable option for generating sustainable electricity. This article seeks to demonstrate the capability of blockchain technologies to offer transparency, effectiveness and verifiability in energy transactions. The study explores the execution of an energy trading smart contract on the Sepolia Network, facilitating the involvement of energy buyers and sellers in trade on the Ethereum blockchain explorer Etherscan through a user interface. The smart contract oversees the trade process, ensuring that both parties comply with the set quantity and price of energy. The study emphasises the significance of gas pricing and MetaMask in guaranteeing the prompt and reliable implementation of the energy trading smart contract. The experimental results derived from the energy trading smart contract are demonstrated, accompanied by an elaborate exposition of each function and its significance inside the smart contract architecture. In conclusion, the article showcases the efficiency, clarity, and security necessary for successful energy trading in the Sarawak context.

1. Introduction

Within the region of Sarawak, characterised by its ample sunlight and tropical climate, solar energy presents itself as a promising solution for the production of sustainable electricity. Sarawak Energy Berhad (SEB)[1], a leading energy provider in the region, has undertaken an ambitious initiative to capture the abundant solar resource available. SEB has set an ambitious objective of deploying a minimum of 400 megawatts (MW) of floating solar energy capacity on its dams by 2030[2]. The magnitude of this effort highlights the importance of solar energy within the region; nonetheless, it does not lack of complications. Nevertheless, underneath the potential of solar energy lies a complex network of problems, intricately linked throughout the journey towards efficiently harnessing the power of the sun.

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The incorporation of solar electricity into the energy system poses distinct challenges. The generation of solar power is subject to intrinsic unpredictability due to the dynamic interplay between daylight and climatic conditions[3]. This variability introduces complexity in the administration of power grids and the dynamics of energy trading. The achievement of precision, openness, and reliability in solar energy transactions is a complex task within the context of this entire framework. The procedure is further complicated by administrative overheads, settlements that need a significant amount of resources, and complex contractual commitments[3]. The problems at hand pertain to the establishment of confidence among participants, protecting of sensitive data, and attaining scalability in energy trading operations.

However, amidst these myriad problems, a glimmer of optimism arises in the manifestation of blockchain technology. The blockchain technology is widely recognised for its decentralised nature, transparency, and high level of security[4], [5]. These attributes make it well-suited to tackle the complex difficulties that arise in the context of solar energy trade. The aforementioned framework offers the essential components required for addressing concerns pertaining to the integration of grids, promoting transparency, enhancing administrative efficiency, fostering trust, ensuring data security, and facilitating scalability[6], [7].

The utilisation of blockchain technologies has the potential to substantially revolutionise the generation, trading, and utilisation of solar energy within the specific setting of Sarawak. This shift is centred on the core concepts of decentralisation and transparency, which serve as the fundamental components of blockchain technology. The main objectives of this study are:

i. The article explores the utilization of blockchain technologies to improve renewable energy, with an emphasis on Sarawak.
ii. The study demonstrates the capability of blockchain technologies to offer transparency, effectiveness, and verifiability in energy transactions.

The study explores the execution of an energy trading smart contract on the Sepolia Network, facilitating the involvement of energy buyers and sellers in trade on the Ethereum blockchain explorer Etherscan through a user interface.

1.1 Empowering Solar Energy through Blockchain Technologies

The integration of solar energy generation in Sarawak with blockchain technology presents an optimistic potential of alignment; nonetheless, there exist possibilities for further improvement to improve transparency and effectiveness.

The solar energy generation in Sarawak intrinsically represents the decentralised nature that forms the basis of blockchain technologies. The integration of blockchain technologies facilitates the efficient exchange of energy between peers, known as peer-to-peer (P2P) energy trading [8], [9], which aligns with the decentralised nature of solar power. This innovation streamlines energy exchanges economically, removing the need for intermediaries.

1.1.1 The Empowerment of Local Consumption

The utilisation of solar energy often takes place in close proximity to its source, thereby efficiently reducing transmission losses[10], [11]. The utilisation of blockchain technology facilitates the establishment of decentralised energy trading platforms, thereby empowering communities to engage in the exchange of excess energy resources. This not only enhances operating efficiency but also decreases reliance on long-distance transmission, so further improving the feasibility of solar power.

The solar energy system in Sarawak has the capability to function alone as well as when combined with the larger power grid. Blockchain technology effectively integrates both microgrids and broader grid networks, hence enabling flexibility in diverse energy generation contexts [12]–[14].

1.1.2 Advantages of decentralisation

Decentralisation, an essential principle of blockchain technology[15], [16], brings out a number of advantages for the solar energy industry in Sarawak. The introduction of decentralised energy trading contributes to a reduction in dependence on centralised utilities, hence facilitating consumer autonomy and fostering an effective energy environment.

Decentralised systems demonstrate enhanced resilience when confronted with grid disruptions and unanticipated disasters. Ensuring continuous electrical supply to critical places is of paramount importance.

Through the removal of intermediaries in decentralised energy trading, there is a significant reduction in administrative costs [9], [17]. The integration of smart contracts optimises operational procedures, resulting in improved operational effectiveness and reduced obstacles within the energy trading process[18].

The utilisation of blockchain technology promotes trust and confidence among participants by virtue of its transparent ledger, which facilitates the independent verification of transactions. This practise not only improves the level of transparency, but also mitigates the occurrence of fraudulent activities and conflicts, thereby establishing a just and responsible environment for energy trading[19].

The practise of decentralised solar energy trading promotes localised sustainability, fosters the uptake of solar power, mitigates emissions, and supports environmental preservation, which is an important issue in modern society.

The integration of blockchain's decentralised attributes with the inherent dispersed nature of solar power signifies a paradigm shift in the energy landscape of Sarawak. The integration being discussed possesses the capacity to bring about a substantial transformation within the energy trading industry. This transformation would result in improved efficiency, transparency, and adaptability, enabling the industry to effectively respond to the changing demands of both consumers and producers. As the exploration of blockchain technology progresses, the anticipated benefits discussed in theory will begin to appear in practical and significant outcomes for the solar energy sector in Sarawak [20].

1.2 Smart Contract

The concepts of smart contracts originate from the fundamental principles of legal contracts and its inherent ability to execute autonomously. In the environment of the digital domain, software is used to express and implement these contracts, operating concurrently on several distributed ledger nodes. Smart contracts serve as technologies that ease the verification of agreements and function within the blockchain platform. The individuals in this role are responsible for supervising and managing all financial transactions associated with a contractual agreement. Additionally, they establish and enforce regulations and penalties related to any violations of the contract's terms and conditions. Figure 1 illustrates the process of smart contracts.

Applications of smart contracts are numerous across various sectors, encompassing government systems for e-voting, healthcare, supply chain management, and financial services [22]–[24]. The blockchain technology effectively safeguards critical data by restricting access solely to authorised individuals through the use of private keys, thereby guaranteeing the confidentiality and security of sensitive processes [14].

Smart contracts enhance operational efficiency and bolster the security of executing agreements that are maintained in publicly accessible databases. These contracts provide a more efficient, expedited, and reliable approach to contract management [25]. Nevertheless, it is imperative to acknowledge that the wide acceptance and utilisation of smart contracts are indispensable for efficiently managing intricate transactions.

One characteristic that distinguishes smart contracts is its capacity to automatically execute agreements upon the fulfilment of predetermined circumstances. The implementation of this automation removes the necessity of involving other parties, resulting in time savings and guaranteeing the automatic execution of actions upon the fulfilment of predetermined conditions[22], [25].

Smart contracts have a transformational function within the field of solar energy trading. This technology facilitates a direct connection between solar producers and customers, hence optimising the process of exchanging surplus solar energy. The integration of the decentralised features of solar energy trade and the decentralised characteristics of smart contracts represents an essential step towards the facilitation of efficient and economically viable energy tradingeliminating the necessity for intermediaries.

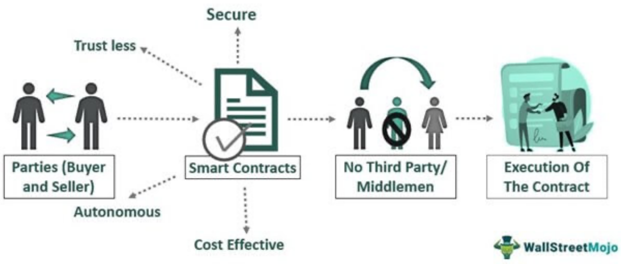

Fig.1. Process of smart contracts [21]

1.3 Related Work

A study in [26] highlights the inefficiencies in the charging and discharging operations within the electric vehicles (EVs) ecosystem. The authors also emphasise problems regarding hazardous energy transfers among EVs. To address these issues, the authors suggest adopting a blockchain-based strategy to guarantee the safety of energy trade. Moreover, they propose an alternate energy trading strategy specifically tailored for blockchain systems.

A different study [27] presents a billing guidance method based on a consortium blockchain system, particularly tailored to fulfil the requirements of the taxi business. The researchers utilise the Practical Byzantine Fault Tolerance (PBFT) technique to establish consensus in the suggested system. Furthermore, they tackle trust concerns among different charging station operators by employing the PBFT algorithm. The study utilizes multi-objective optimization to enhance the charge model for taxis. Their modelling results show significant enhancements in passenger pleasure.

The authors in [28] examine various charging infrastructures and techniques employed in smart cities. The research highlights the necessity of a proficient and safeguarded energy trading mechanism in metropolitan environments.

The authors of [29] suggest a model for energy trade that utilises blockchain technology and smart contracts. The implementation of a reverse auction system and dynamic pricing tactics during trading aims to assist less competitive power vendors and mitigate electricity expenses. In addition, their strategy integrates a decentralised trust management solution based on blockchain technology to tackle trust-related concerns within the realm of electric vehicles.

The authors of another study [30] examine trust management for electric vehicles (EVs) in depth. They employ a Bayesian inference model to validate incoming communications and produce trust ratings that may be compared. The ratings are utilised to calculate trust value adjustments for electric vehicles (EVs). Nevertheless, the study does not explore the topics of community trust management or privacy protection.

Authors of [31] suggest a contract-based energy trading system, offering a fresh approach in the sector. While, the authors in [32] outline their research on a consortia blockchain-based methodology aimed at ensuring secure and efficient data exchange. This system utilises pre-determined nodes as the foundation for its consensus mechanism. Nevertheless, it is important to mention that the implementation of a double-auction approach in this particular situation necessitates a greater amount of energy because of the substantial numbers of iterations required.

The article [33] introduces a specialised energy trading approach tailored for plug-in hybrid electric vehicles (PHEVs). The objective of the strategy is to facilitate the effective charging of PHEVs while minimising energy expenses. In this context, the writers also examine the communicative characteristics of automobiles.

A conceptual framework in [34] proposes the utilisation of blockchain-proxy demand resources, emphasising the significance of processing information within one second to reduce security threats. The debate highlights the potential use of blockchain technology in solar systems using Hyperledger Fabric [35]. Additionally, it is crucial to take into account the trading distance and price models, which may vary based on the station [36].

The utilisation of blockchain technology in energy trade, namely in the area of electric vehicles and smart grids, is steadily progressing. It provides the potential for improved productivity, clarity, and cost-efficiency. Nevertheless, as the area advances, it is essential to carry out rigorous security evaluations to detect and resolve any possible limitations. Furthermore, the success and general acceptance of these novel solutions [37] heavily depend on energy efficiency. The significant influence of blockchain technology on energy trade is clear, and as these subject advances, it will continue to attract attention and bring about transformative changes in the energy sector [20].

Sarawak's shift towards a sustainable and renewable energy environment relies on the effective administration of energy resources, minimising expenses, and fostering transparent energy transactions through the utilisation of blockchain technologies. As the area advances, it is essential to perform comprehensive security evaluations, although the revolutionary capacity of blockchain in energy trade is certain. The studies' innovative methodologies have the potential to significantly influence the energy situation in Sarawak, aligning with the region's objectives of enhancing the utilisation of sustainable energy for extending the availability of environmentally friendly electricity to its residents. This transformation has the potential to result in a more sustainable and resilient energy ecosystem, which would have positive impacts on both the environment and the residents of Sarawak.

2. Methodology

This section focuses on the applications and technical standards that support our energy trading initiative in the Ethereum blockchain platform.

2.1 Applications in the Project

Our work employs many applications and tools to enhance energy trade through smart contracts on the Ethereum network. The following items are included:

i. Ethereum: Our concept relies on Ethereum, which offers a decentralised and secure platform for interacting with digital assets and executing programmable agreements. It utilises a distributed network of computers to authenticate and execute transactions, guaranteeing dependability and safeguarding against breaches.

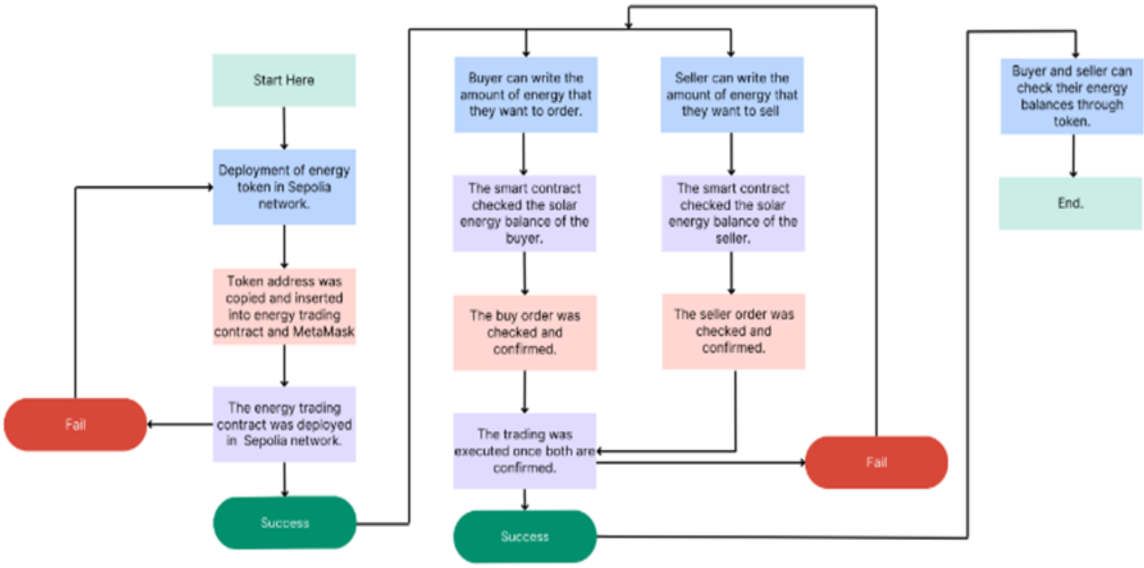

Fig. 2. Overview of the smart contract flow

ii. Virtual Studio Code: This integrated development environment streamlines the management and installation of diverse development tools and components, accelerating the configuration of our development environemnt. It simplifies the process of installing essentioal dependencies, libraries and sofware packages, hence improving the productivity of developers.

iii. The programming language known as JavaScript: JavaScript is a versatile and extensively utilised programming language that is mainly used on the client-side of online applications. It permits web designers to endow webpages with interactive and dynamic behaviour, a vital aspect for our project's user interface and functioning.

iv. Hardhat: Hardhat is a widely used programming framework that plays a crucial role in developing Ethereum smart contracts and decentralised apps (DApps). It offers a wide range of utilities and tools that accelerate the development, testing, and deployment processes.

v. Alchemy: Alchemy provides a comprehensive framework and set of tools for constructing and utilising Ethereum applications. Developers are given a dashboard that facilitates project management, encompassing features such as deployment automation, analytics, and debugging. In addition, Alchemy improves the scalability, stability, and performance of Ethereum applications.

vi. The Sepolia Testnet is a crucial tool for our project, facilitating fast progress in the development, implementation, and evaluation of blockchain applications. Developers are provided with comprehensive documentation, code samples, and debugging tools.

Furthermore, its ability to work along with well recognised blockchain systems guarantees smooth integration and compatibility across different chains.

2.2 Simulation

The simulation of our project entails the implementation and interaction of energy tokens and energy trade contracts on the Sepolia Network, which is an essential element of our smart contract workflow. Figure 2 depicted the overview of the smart contract flow. The sequence of events is as follows:

i. To initiate the deployment of the energy token, the initial action entails utilising VS Code to deploy it onto the Sepolia Network. This deployment involves executing the required code to create the energy token and enable its availability on the network. After a successful deployment, the energy token is assigned a distinct token address.
ii. The energy trade contract is implemented on the Sepolia Network, and the token address is specified in the deploy.js file. The deployment is begun by executing the command "npx hardhat scripts/deploy.js --network Sepolia." Following that, the Sepolia Network creates and initiates the energy trading agreement.
iii. Energy Trading: After implementing the energy trading contract, energy buyers and sellers participate in trading on the Ethereum blockchain explorer Etherscan using a user interface. The smart contract monitors the trade process, guaranteeing that both parties comply with the predetermined amount and price of energy. This bilateral agreement ensures the transaction's legality and honesty.
iv. Energy Balance Verification: Once the transaction is finalised, the energy token allows participants to authenticate their resource levels within the decentralised system. Blockchain’s transparency and immutability guarantee the precise recording of energy balances, allowing for audits to be conducted at any given moment.

The demonstration of energy token and energy trading contract implementation on the Sepolia Network highlights the capacity of blockchain technology to provide transparency, effectiveness, and verifiability in energy transactions.

Ultimately, our project's strong technical foundation is demonstrated through our methodical implementation and utilisation of applications and tools, as well as the simulation of energy token and contract deployment. This complete strategy guarantees the effectiveness, clarity, and protection required for prosperous energy trading within the Sarawak context.

3. Results

3.1 Experimental Settings

This part provides detailed information about the experimental settings and deployment procedures, focusing on the technical complexities of the project. The following topics are covered: Energy Token Deployment: To begin with, the precise function of the energy token is established in this particular setting. The energy token plays a vital role in enabling transfers inside the system. It serves as a digital embodiment of energy units and is essential to the operation of the smart contract system.

Minting vs. Mining: It is crucial to comprehend the rationale behind the project's decision to choose minting over mining for energy tokens. In this way, minting relates to the act of creating tokens once, without the possibility of additional mining.

The energy token complies with the ERC20 standard, which is a widely recognised foundation for generating tokens on the Ethereum blockchain. This standard guarantees the capacity of different systems to work together smoothly and effectively, while also minimising expenses.

The price of gas and the deployment of smart contracts are closely related in Ethereum. Gas units play a crucial role in measuring the computing effort needed for transactions and executing contracts. To illustrate the influence of gas prices on smart contract deployment, here are examples to. emphasise the importance of optimal gas prices in order to boost the success of deployment.

Setting gas prices: Prior to deploying the smart contract, we must establish gas pricing. Gas is a metric that quantifies the computing workload required to execute transactions on the Ethereum network. The gas price represents the specific quantity of Ether (ETH) that we have prepared to offer for each unit of gas, with the intention of motivating miner to include our transaction in distributed ledger. If the gas prices decrease, miners may give preference to transactions with higher petrol costs, perhaps leading to a delay or failure in the deployment of our smart contract.

i. Scenario 1 - Suboptimal Gas Price: In an effort to reduce expenses, we choose to establish a comparatively low price for gas. Although this approach may appear cost-effective, it has the potential to result in time delays. Miners might give priority to transactions that offer greater petrol prices, resulting in the deployment being delayed. Over a span of time, our deployment transactions are processed, although it takes a considerable duration, and we were notified of the successful deployment. Nevertheless, the delay has adversely affected the overall efficiency of her application.
ii. Scenario 2 - Optimal Gas Fee: In an alternate situation, we, having gained knowledge from our prior encounter, chooses to establish an ideal gas charge for the implementation of the smart contract. The elevated petrol fee renders our transaction more appealing to miners. Consequently, our deployment transaction is promptly recognised and incorporated into the blockchain.

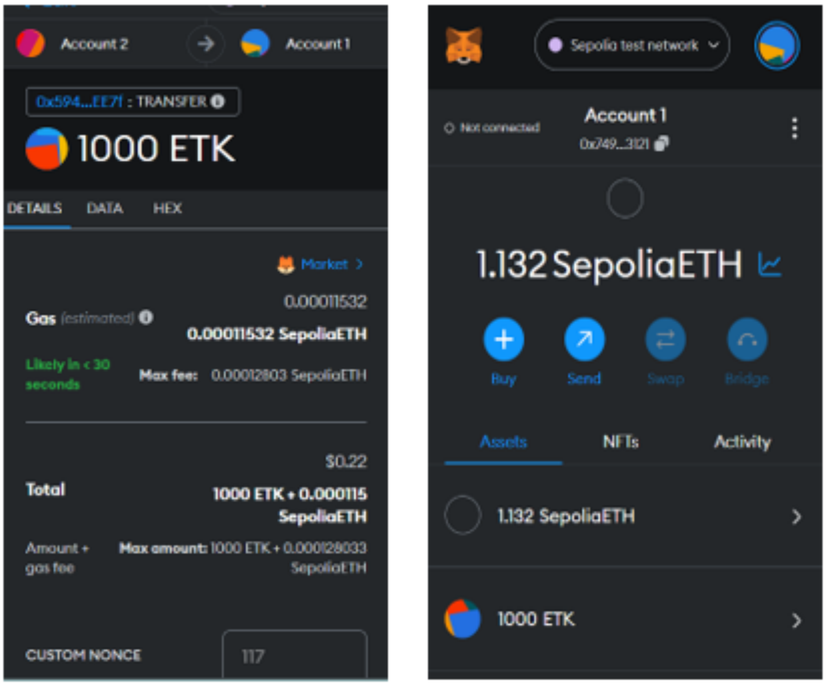

Fig. 3. Confirmation of Transfer of Token in MetaMask

We promptly receive a notification confirming the successful execution of the deployment process in a matter of minutes. This example demonstrates the need of establishing optimal gas pricing while implementing smart contracts. The first situation had a gas price that was not ideal, causing delays that had a negative influence on the system's operation and might potentially result in user unhappiness. In the second scenario, the use of an appropriate gas fee facilitated a seamless and timely deployment, hence enhancing the effectiveness and dependability of the energy trading systems.

Within the context of the project, it is important to have suitable gas prices in order to guarantee the fast and dependable execution of the energy trading smart contract. An efficiently optimised gas fee not only accelerates the process of deployment but also improves the entire user experience by minimising delays and guaranteeing the smooth completion of transactions within the energy trading ecosystem. Hence, it is crucial to thoroughly evaluate and establish the gas price in order to synchronise it with the project's objectives of efficiency and efficacy.

Verification Process: Ensuring the integrity and security of the smart contract necessitates a verification process.

MetaMask Connection: Establishing a connection between MetaMask and the project is crucial. Its crucial function is in allowing users to safely engage with Decentralised Applications (DApps) and authorise transactions. Figure 3 shows an example of the confirmation of token transfer in MetaMask.

Etherscan's capacity to scan JavaScript codes is pertinent to the project and the particular types of JavaScript codes being examined.

Transactions are deemed necessary for every function in VS Code, as stated in the concluding paragraph.

3.2 Real-time Implementation

The experimental findings obtained from the energy trading smart contract is presented here. A detailed description of each function and its importance within the framework of the smart contract is explained here:

i. buyEnergy Function: This function triggers the process of acquiring energy from the smart contract. The user stipulates the preferred quantity of energy and solicits it from the smart contract. Afterwards, the smart contract proceeds to hunt for a seller who is able to provide the exact quantity of energy tokens that was requested. Subsequently, the purchaser proceeds to finalise the deal by providing the necessary information and remitting the corresponding petrol cost. Following this stage, the purchaser can confirm the effective implementation of the intelligent agreement. For example, if a user wishes to purchase 1000 energy tokens from a merchant, the transaction particulars would encompass the quantity of energy needed and its corresponding cost. Furthermore, every order is allocated a distinct order number, such as "numBuyOrderofCustomers," which increases in value as additional orders are made.

ii. The sellEnergy function involves a seller selling energy to another user. The seller designates the quantity of energy offered for purchase, such as 1000 energy tokens, and establishes the associated price, for example, 12000. It is crucial to clarify that the indicated price is not directly linked to the petrol fee, which functions as an essential transaction cost inside the Sepolia network. The details regarding this transaction are documented in the smart contract, just like the purchase order.

iii. deal Execution: After the smart contract identifies matching buy and sell orders, the deal is executed. It is crucial that the quantities of energy tokens from both parties align perfectly, such as 1000 energy tokens each. In the event that the quantities do not correspond, the smart contract will not carry out the order. After the task is completed successfully, the specified recipient, in this instance, "account 1," will be granted 1000 energy tokens (ETK). ETK indicates the digital value of energy within the contract. The smart contract is crucial in guaranteeing the integrity and security of token transactions between buyers and sellers.

4. Future Recommendations

In order to optimize the effectiveness of the energy trading smart contract, it is necessary to overcome certain restrictions it now possesses. Several of these limitations include:

i. Scalability: The existing energy trading smart contract may lack the capacity to efficiently process high volumes of energy transactions. The smart contract may experience a decrease in speed and effectiveness with the increasing numbers of players of the energy trading ecosystem.
ii. Security: It is the most important in maintaining the integrity of energy trading smart contracts. Nevertheless, the smart contract is prone to hacking and other security breaches, potentially leading to substantial losses for the parties.
iii. Interoperability: Lack of interoperability may hinder the general adoption of the energy trade smart contract by limiting its compatibility with other blockchain networks.
iv. Complexity: The energy trading smart contract is a sophisticated system that necessitates specialised knowledge for its development and maintenance. The complicated nature of this could potentially hinder its usability for anyone without technological expertise.

In order to overcome these constraints, there are various potential avenues for enhancement, which include:

i. Possible improvements for the energy trade smart contract include the integration of scalability methods such as sharding, sidechains, or state channels. These methods could enhance the smart contract's capabilities to manage substantial quantities of energy transactions.
ii. Upgrading security measures: The security of the energy trading smart contract could be strengthened by incorporating advanced security features like multi-factor authentication, encryption, and routine security audits.
iii. Enhancing the interoperability of the energy trading smart contract can be achieved by incorporating protocols that facilitate communication with different blockchain networks.
iv. User-friendly interfaces: Enhancing the accessibility of the energy trading smart contract for non-technical users can be achieved through the creation of user-friendly interfaces that streamline the interaction process with the smart contract.

To summarise, the energy trading smart contract possesses various restrictions that require attention in order to enhance its efficacy. By employing solutions to overcome these constraints, the energy trading smart contract has the potential to evolve into a more streamlined, protected, and user-friendly platform for energy trading.

5. Conclusions

This paper has demonstrated the capability of blockchain technology to offer transparency, efficiency, and authenticity in energy transactions. The paper provides a comprehensive examination of the implementation of energy trading smart contracts, covering the development environment, modelling, and experimental findings. The study emphasises the significance of gas pricing and MetaMask in guaranteeing the prompt and reliable implementation of the energy trading smart contract. The empirical results derived from the energy trading smart contract are showcased, accompanied by a comprehensive explanation of each function and its significance inside the smart contract framework. The study also examines the constraints of the energy trading smart contract and possible avenues for enhancement, including scalability, security, interoperability, and complexity. The report concludes by highlighting the capacity of blockchain technology to revolutionise the process of purchasing and selling renewable energy, leading to a more environmentally friendly and robust energy ecosystem. The studies' novel approaches have the potential to greatly impact the energy situation in Sarawak, aligning with the region's goals of improving the use of renewable energy and expanding access to eco-friendly electricity for its users.

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