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A Blockchain Based Layered Architecture for Consensus Mechanism in Decentralized Energy Trading

Masters of Science in Electrical Engineering

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Dedication

I dedicate this MS thesis to my beloved parents, my better half, my siblings, and my grandparents. To my Dada Abu and Nanu Jaan, whose legacy of wisdom and unwavering strength has been my guiding light. Your loving guidance and steadfast support have provided me with comfort and courage, inspiring me to pursue my dreams with confidence. This work is likewise dedicated to my beautiful mother and my loving father, who have consistently loved and cherished me unconditionally and whose genuine models have trained me to work hard for the things that I aim to achieve. To my better half your steadfast support and belief in me have been my greatest motivation. Finally, to my siblings, your encouragement, support, and affection have given me the strength to persevere through tough times. Thank you all for believing in me more than I believe in myself.

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Publications

Conference

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Journal Paper

1. Khan, M. H. D., **Haider, A.**, Imtiaz, J., & Islam, M. N. U., “Blockchain Integration for a Secure Consensus Protocol in Decentralized Energy Trading.” PJETS, vol. 13.

Abstract

The utilization of renewable energy sources and the creation of a sustainable energy system can be greatly facilitated through platforms for decentralized energy trading. Multiple levels in the suggested architecture provide effective and safe consensus techniques for trustworthy transaction validation and verification. A blockchain-based framework that uses distributed ledger technology to guarantee transparency, immutability, and data integrity makes up the initial layer of the architecture. The second layer focuses primarily on the consensus process, which mixes evidence of work and evidence of stake algorithms to obtain consensus on transaction legality. The third layer uses a sharing method to increase scalability and efficiency. This mechanism splits the network into smaller, manageable parts known as shards, enabling parallel processing, and lowering the computational cost of consensus algorithms. Smart contracts are integrated at the fourth layer, automating the fulfilment of predetermined conditions and norms in energy transactions. Demand-response programmers and dynamic pricing models are made possible by smart contracts because they do away with middlemen, uphold trust, and simplify complicated energy trading systems. The last layer tackles privacy and data security through the use of privacy-enhancing tools like homomorphic encryption and zero-knowledge proofs. These solutions provide transparency for audits and legal compliance while protecting sensitive data. Decentralized energy trading systems can get around problems with scalability, efficiency, consensus, and privacy by utilizing this layered design. High throughput, low latency, and lower energy usage are all supported by the suggested hybrid consensus method, sharing strategy, integration of smart contracts, and privacy-enhancing technologies together, which promote market innovation and participation in decentralized energy trading.

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Acronyms and Abbreviations

CoAP - Constrained Application Protocol
CPU - Central Process Unit
DLL - Dynamic-link Library
DNS - Domain Name System
DSO – Distribution System Operator
EV – Electric Vehicle
HCI – Human-Computer Interaction
IoT – Internet-of-Things
P2P – Peer-to-peer
ID - Identity
P2P - Peer-to-peer
PoS - Proof of stake
TEM - Transactive Energy Market.
ToU - Time of Use Tariff
TRC - Total Revenue and Cost Saving.
PoW - Proof of work.
PTP - Prosumer-to-prosumer
PV - Photovoltaic
ICT - Information and Communication Technology
IoT - Internet of Things
JIT - Just in Time
PoC - Proof of Concept
PPA - Power Purchase Agreement
P2P - Peer to Peer
QoE - Quality of Experience
RCI - Relaxed Consensus+ Innovation
SA - Seller Agent
SBB - Strongly Budget Balanced
SESP - Smart Energy Service Provider
SSI - Seller Satisfaction Index
SW - Social Welfare.
TE - Transactive Energy.
Joul - Joule
LAGs - Load aggregators
DRBG - Deterministic Random Bit Generator
DSO - Distribution system operator

Chapter 1

Introduction

1.1 Background

A broad dependence on petroleum derivatives for the creation of energy has caused impressive mischief for the climate, causing issues such as ozone that damage substance outflows and air contamination[1]. Boosting the use of sustainable power has arisen as a basic objective. Given the capricious idea of environmentally friendly power age, the advancement of energy stockpiling innovations has become fundamental for store this energy and satisfy customers' needs. In this specific situation, the distributed (P2P) market has been presented as a stage for battery energy capacity frameworks to participate in direct energy exchange within their local area, eliminating the intermediary requirement. These members, frequently alluded to as "prosumers,"[2] both produce and consume energy. The execution of a compelling valuing instrument inside this decentralized exchanging construction can altogether lessen costs for members. Dealers can offer energy at more exorbitant costs, while purchasers can get energy at lower costs compared to conventional feed-in-levy rates.

The outcome of P2P energy exchange depends on a powerful programming stage that empowers consistent data trade among friends and enables framework administrators to screen and deal with the dissemination network. The particular exchanging rules laid out by the stage assume a vital part in directing the choices of friends during exchanges. Blockchain innovation assumes a urgent part in supporting energy exchanging by safely putting away exchange data blocks, approving exchanges across all organization hubs, and guaranteeing the security and protection of exchanges through encryption. The detailed analysis of exchanges and transient adjustment contracts in light of shrewd agreements is vital for working with energy exchange by means of blockchain innovation. Thus, a blockchain-upheld decentralized market stage empowers all individuals from a power organization to take part straightforwardly on the lookout, working with energy trade without the requirement for concentrated oversight.

Just legitimate exchanges can be remembered for blocks, which are then consecutively organized and connected through extraordinary hashes. Any endeavor to adjust an exchange would require changing hashes across all blocks in the blockchain, demonstrating the legitimacy of evidence and asset-concentrated task that likewise guarantees the security of friends' very own data.

Regardless of the benefits presented by blockchain innovation, as of now there is no secure technique to forestall cyberattacks from focusing on clients' cryptographic money put away in advanced wallets[3]. Thus, genuine money stays the favored vehicle for energy buys among prosumers talked about in this thesis. In any case, diggers keep on being compensated in light of PoW.

1.2 Decentralized Energy Trading

The ongoing power framework works within an incorporated market structure, yet the expansion of dispersed generators is ready to essentially influence the conveyance framework [4]. As disseminated age levels increase, there is a basic need to present market structures that work with nearby age and power utilization. Neighbourhood power markets advance a fair energy organic market at a nearby level, eliminating the need for expensive matrix extensions. In certain countries, states lay out power markets to empower more prominent support from retailers and proprietors of conveyed energy assets. Exchanges happen straightforwardly between members without middle person specialists in this shared (P2P) energy-exchanging model, setting aside both time and cash for members.

P2P exchanging is organized similar to microgrids inside the conveyance framework, requiring electrical associations between prosumers as well as data trade among. A middle energy dealer works with exchange data trade among these units and the utility framework, empowering units to buy required energy in view of the moderate energy merchant's data.

Current energy approaches in different nations center on advancing the self-utilization of photovoltaic (PV) energy according to the viewpoint of the consumers. Subsequently, a few investigations have investigated thoughts for planning energy exchanging market stages. In [5], a distributed framework configuration approach and a P2P-based exchange model are proposed. [6] Presents a detailing for dispersed energy assets (DERs) utilizing

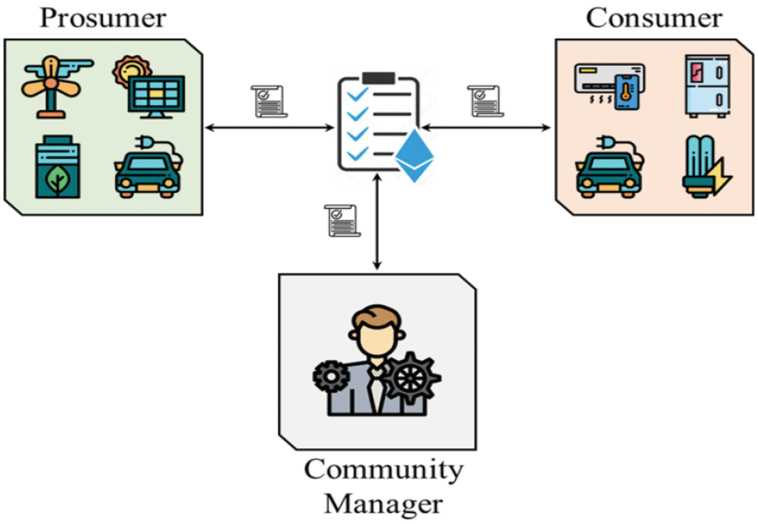

Figure 1.1: Decentralized Energy Trading System

a backpack closeout plan and market cleaning instruments off of the vendor's viewpoint. [7] applies a 34-transport test spiral conveyance framework to approve the model, leading broad tests to check streamlining.

Notwithstanding, P2P energy exchanging requires a product stage [8] for data trade among peers, supporting framework administrators in checking and controlling dispersion organizations. Different exchanging rules characterized by the stage altogether affect companions' choices during exchanging. Without appropriate programming stage support, client protection and exchange execution are unable to withstand cyberattacks. A P2P energy exchanging market requires a stage guaranteeing the security and straightforwardness of each exchanging interaction to get evaluating systems and administrative standards.

1.2.1 Distributed Ledger Technology

A cryptographic strategy to keep data [9][10]. In each opening of the schedule, peers keen to exchange share their exchange goals with different friends in the organization. When these exchanges are approved by any remaining friends, they are executed and closed within the time allocation. [11] All exchange subtleties are scrambled into a code set and put away in another block [12]. Anybody overall can contend in mining a block provided that their PCs can deal with it, yet ordinarily, those with more computational power have a higher possibility winning the chance to make another block. In stages like Bitcoin or Ethereum, the block maker acquires a specific measure of cryptographic money as a mining reward.

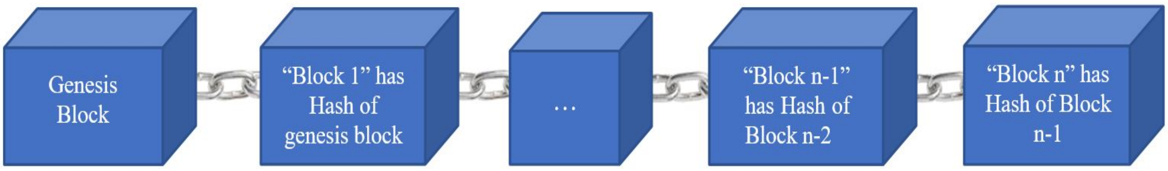

Figure 1.2: A basic "blockchain" (cryptographically linked n+1 blocks).

Blockchain innovation upholds P2P energy exchanging by putting away exchange data blocks, checking exchange legitimacy across all organization hubs, and guaranteeing exchange security and protection through encryption [13]. Since exchange records are exceptionally duplicated, blockchain-based energy exchange gives strong shields against alteration. These benefits make blockchain innovation a more viable help for P2P exchange. It diminishes defilement, improves straightforwardness, offers an installment stage for energy exchanging, and empowers consistent incorporation of various circulated generators, among different advantages. Thus, with blockchain's help, P2P exchanges can happen straightforwardly between peers without middle people. Be that as it may, blockchain innovation is still moderately new to the general population, and its maximum capacity presently can't seem to be completely understood.

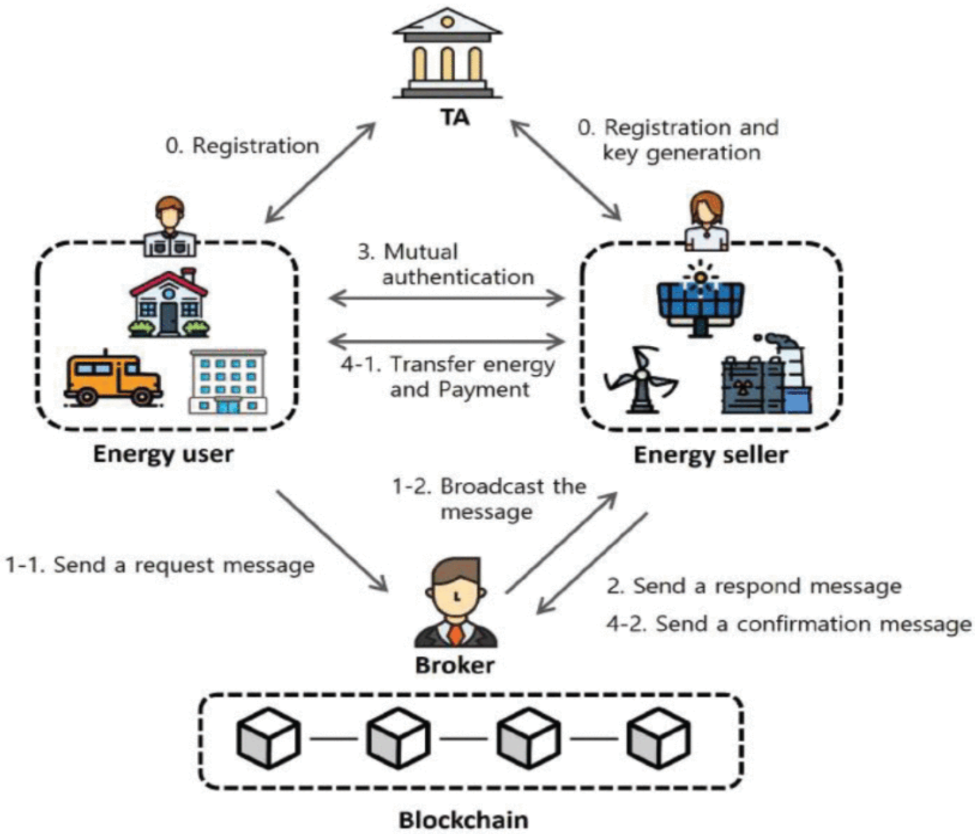

Figure 1.3: Energy Exchange market using blockchain

To fully utilize the benefits of blockchain development, a keen understanding is considered to build P2P trading. Continually, trading stock between untrusting companions presents challenges. To overcome this, an extremely durable code-based splendid understanding is familiar with work with trade execution. A splendid understanding fills in as PC code [14] on a blockchain, portraying a lot of concludes that get together agree to adhere to while teaming up. The splendid understanding code endorses and maintains understanding or trade conversation, making it an unmistakable sort of decentralized motorization.

1.2.2 Challenges in Data Transmission

The current distribution networks lack advanced communication mechanisms, but there's a growing trend toward implementing various communication techniques for smart grid applications. These infrastructural changes, along with their associated smart grid applications, are significantly increasing data transmission volumes within distribution networks.

Different pilot undertakings and research endeavors have examined this region, including the drawn out utility of blockchain development with clever arrangements. In [15], makers use flexible and lightweight contracts for flexible and lightweight trading, ensuring character check and trustworthiness through store portions during the contract game plan. In [16], a part of the scattered energy trade is proposed, which covers the contribution, the checking and obtaining of the capacities without knowledge arrangements. Regardless, unequivocal esteeming parts are not organized, and authentic world microgrid or power market execution models are lacking. Additionally, taking into account that savvy arrangements are fundamental to blockchain helpfulness, any dangerous improving could incite huge property mishaps. To avoid such issues, demanding substance creation and execution are essential [17].

Figure 1.4: A basic layout of "blockchain".

1.2.3 Consensus Mechanism

Consensus algorithms [18] are one of the core technologies of blockchain. In blockchain systems, data includes both transactions in blocks and the world state, and the transaction data is critical for recording legal blockchain operations [19]. Due to the high latency of peer-to-peer networks, the transaction order observed by each node is inconsistent. To address this issue, the consensus algorithm was proposed, which enables all nodes to reach consensus on the content and order of the created transactions within a certain period of time [20].

PoW is the consensus algorithm used in bitcoin. Its core idea is to allocate the accounting rights and rewards through the hashing power competition among the nodes. Based on the information of the previous block,the different nodes calculate the specific solution of a mathematical problem[21]. It's difficult to solve the math problem. The first node that solves this math problem can create the next block and get a certain amount of bitcoin reward.

1.2.4 Reputation Mechanism

Recent studies have introduced reputation systems to enhance efficiency and reliability in blockchain networks. One approach proposed a reputation-based consensus mechanism for peer-to-peer networks, where nodes with higher reputations are given the opportunity to publish new blocks. In this system, feedback from service requesters is broadcasted to the network, and once a threshold is met, nodes calculate a ranking list. The node with the highest reputation publishes the block, which is then verified by other nodes [22]. Another method incorporates reputation into the proof-of-work consensus algorithm, where a miner's voting power is based on its reputation, calculated from the amount and consistency of valid work contributed [23]. Additionally, the Blockchain Reputation-Based Consensus (BRBC) mechanism requires nodes to exceed a reputation threshold to publish new blocks, with a randomly selected judge updating reputation values. However, these systems generally do not address node behavior on a transactional level during interactions within the network [24].

1.2.5 Challenges of Consensus Mechanism without Reputation

Consensus systems that lack a reputation component face numerous challenges. These methodologies may suffer from diminished participant trust, a heightened risk of malicious activities, and inefficiencies in transaction validation if they lack a reputation mechanism. For instance, in proof-of-work systems, the absence of a reputation system may favor computationally powerful miners over those who consistently produce valid work, jeopardizing network security and equity [25]. If an efficient reputation system is not in place, proof-of-stake systems may favor individuals with more financial resources throughout the validation process over those who have a track record of dependable contributions. Furthermore, as nodes have no motivation to act morally, the lack of a reputation system may result in longer transaction processing times and a rise in fraudulent activity [26].

1.2.6 Challenges of Consensus Mechanism in Decentralized Energy Trading

Consensus mechanisms in decentralized energy trading face several big challenges. First, making sure transactions are validated and is crucial, given how complex and varied energy transactions can be. Regular consensus algorithms might have trouble scaling up, as energy trading networks can have a lot of transactions and participants. Also, reaching consensus in these systems often needs a lot of computing power [27], which can cost a lot and use up a lot of energy, going against what decentralized energy trading is trying to do for sustainability. Another issue is handling the spread-out nature of these networks where different participants from all over have to work together well. This makes balancing the system and ensuring fairness where everyone has a voice challenging [28]. Also, the absence of common rules and the incompatibility of various energy trading platforms can hinder smooth integration and operation. In the end, developing a well-functioning and fair consensus mechanism for decentralized energy trading remains a difficult task that needs fresh approaches to address these complex issues.

1.3 Motivation

Energy trading is introduced as a stage to create a business area within scattering associations, to execute energy sharing within organizations. This energy trading model tends to the hardships introduced by the increased entry of practical power, P2P energy trading might conceivably redesign the advantages for all individuals in the market through a thought of transactive energy. It similarly expects a section to balance closely by interest with broken RES age, in this way working on the overall strength of the scattering association.

Who are encouraged to make harmless to the ecosystem power energy and participate in P2P trading. Prosumers are enlivened by both financial inspirations, similar to cash-related benefits, and non-money-related factors, like their social commitment to reduce surges. Effective execution of P2P energy trading relies upon an item stage working with information exchange among friends and aiding system managers in network checking and control. Additionally, the trading rules spread out by this stage generally influence peer decisions during trades. Likewise, shrewd energy the load up organizations are crucial, engaging prosumers to seek after informed decisions concerning energy movement, recipients, timing, and assessing while simultaneously attracting with other market performers.

The improvement of a particularly made neighbourhood the chiefs structure (CEMS) is fundamental to manage the complexities of energy trades in the P2P energy trading stage, with an accentuation on tending to specific organization viewpoints. This study is driven by the fundamental goal of arranging a convincing CEMS to work with steady P2P energy trading without compromising association reliability.

1.4 Research Objectives

The solutions to the energy trading systems centralized issues could be realized through the many implementations that can be done. To begin, devising a blockchain-based energy trading system can be very transparent since it will provide immutable and verifiable transaction records that anyone can access and audit them to know for sure that the transaction details are correct[29]. Creating direct peer-to-peer transactions, free from intermediaries, will increase the trust among participants because of the safety of energy exchanges and their transparency. Besides, one can design a decentralized mechanism to improve reliability by removing single points of failure, consequently, making the system more resilient and fault tolerant. Finally, the use of optimized algorithms and protocols will ensure efficiency in matching energy supply with demand, thus, minimizing delays and the costs that are related to the transaction processing[30]. These actions, as a whole, lead to a better transparent, trustworthy, reliable, and efficient energy trading ecosystem.

1. Develop a blockchain-based energy trading system to ensure transparent and verifiable transactions.
2. Enable peer-to-peer energy exchanges without intermediaries to build trust and enhance transparency.
3. Design a decentralized mechanism to improve reliability and eliminate single points of failure.

1.5 Problem Statement

Centralized energy trading systems face significant issues that impact their overall effectiveness. These systems often lack transparency, which makes it difficult to view transaction details and operational processes. This opacity fosters distrust among users, as there is uncertainty regarding the fairness and integrity of transactions. Additionally, the involvement of intermediaries can lead to inefficiencies, causing delays and higher costs[9]. Recent reports have suggested that a big slice of energy transactions is challenged in the context of being transparent, for example, by the presence of intermediaries, facing trust issues too[31]. More importantly, still a relatively high number of transactions are late and more expensive than they ought to be. The centralized structure of these systems also poses challenges for scalability and adaptability, making it difficult to meet the growing and evolving demands of the energy market. Addressing these issues is crucial to improving the efficiency, security, and reliability of energy trading.

1.6 Scope

Approach could really offer a reasonable and capable response for trades within the spread system, given the proactive commitment of consumers and buyers in the energy market. Key thoughts for a blockchain-based energy trading model include:

1. Merging designs for PV age and weight interest of prosumers.
2. Surveying influence incident coming about in view of microgrid energy trades.
3. Doing canny agreements for trade execution and esteeming assessments.
4. Evaluating the costs or advantages related with trade mining or speculation.

1.7 Thesis Structure

This thesis is organized as follows:

Chapter 2: Literature Review discusses distributed energy trading, the application of blockchain technology in energy transactions, consensus protocols, methods of establishing blockchain, and the challenges associated with blockchain technology.

Chapter 3: Energy Trading with Blockchain-based Credit Ratings provides a summary of related literature and highlights major contributions, including the detailed system model, credit rating system, and a multi-layer trust architecture.

Chapter 4: Proposed System for Energy Trading offers an overview of the system architecture, underlying assumptions, problem definition, and market clearing methodology, along with practical applications and case studies.

Chapter 5: Conclusion concludes the thesis by outlining the key findings, analyzing their importance, and providing recommendations for further research. It unites the inputs of all the chapters into a whole to give a coherent view of the results of the research.

Chapter 2

Literature Review

2.1 Distributed Energy Trading

In recent years, energy storage systems have gained significant popularity. There is a growing need for innovative designs in distributed systems and solutions for peer-to-peer (P2P) electricity trading [32]. It operates as an autonomous grid capable of functioning in both grid-connected and isolated modes. Within the microgrid, a virtual entity known as the microgrid trader [33] is introduced. This entity establishes commercial agreements with prosumers and aggregators. An aggregator, in this context [34].

The following commercial relationships are established within this P2P trade model:

1. Relationships linking prosumers and the traders operating within their microgrid systems; Microgrid traders facilitate trade by connecting prosumers and facilitating the buying or selling of energy among them [35].

2. Relationships between microgrid traders on a business level; Although microgrids may need to trade with one another, microgrid merchants act as a middleman by transferring proposals and requests.

3. Relationships of commerce associating aggregators with market traders; Aggregators may enter into agreements with microgrid traders allowing them to take part in the whole-sell market [36]. In order to handle the strain, they may also negotiate commercial agreements.

4. Aggregators and distribution system operators (DSOs): Engage in business transactions whereby the aggregator provides services to the DSO [37]. They can use the resources of prosumers and microgrid merchants to carry out this function.

5. Prosumers from microgrids may enter into contracts with aggregators to participate [38] . These contracts are examples of the commercial relationships between prosumers and aggregators. Furthermore, they could provide services to their microgrid dealers by partnering with the aggregators.

6. These connections suggest that the core of the trading paradigm is microgrid traders. A distributed trading technique was created in, when microgrid merchants converse with one another to determine the price.

Distributed energy trading is a new process of buying and selling energy in a decentralized network. In sharp contrast to traditional models, this new approach makes use of blockchain technology and smart contracts to enable energy producers and consumers to do direct transactions. With the ability to allow peer-to-peer exchanges and minimize the need for intermediaries [39], distributed energy trading increases the efficiency of markets, fosters competitive pricing, and allows people and their respective communities to become very active players in the energy market. This Table 2.1 paradigm shift will further integrate renewable energies, enhancing the energy ecosystem to be resilient and sustainable.

Consensus Mechanism	**PoW**	**PoS**	**DPoS**	**PBFT**
Main Concept	Block addition is determined by computational power	Stakes in hand determine the chance of adding a block	Voting and stakes of nodes determine chance of adding a block	Based on Byzantine fault tolerance approach
Usage of energy	High	Low	Low	Low
Scalability	Best	Best	Best	Very Bad
Fault tolerance	51%	51%	50%	34%
Centralization level	Low	Medium	Medium	High
Application	Open	Open	Open	Closed

Table 2.1: Comparison of Consensus Mechanisms

2.2 Reputation in Decentralized Energy Trading

For the world of decentralized energy trading, it is less likely that a competent reputation mechanism will be turned out to keep trust and secure transactions among participants. Decentralised energy trading is unlike traditional central systems where a single point of control monitors and ensures the integrity of transactions, with no need to trust one another [40]. This change calls for a strong set of expertise mechanisms, actually able to reflect the behavior and results from historical transactions that caused participants their reputations. These mechanisms can score many such kinds of metrics like its transaction success rates, the efficiency in delivering predefined level energy etc. and combine them into a full reputation model for each participant [41]. Reputation mechanisms, by offering an open and verifiable way of assessing the reliability of market players can effectively reduce risks associated with decentralised trading which offers a means to make energy trade system safer more so efficient.

The content of the ILUA was registered at the time the system scores the reputation of all users to midway, in order to ensure that each of its users is provided with an equivalent value. This will be later no need to change because maintain its state upon successful completion each transaction, using the relevant data [42]. Real-time electricity prices for P2P are determined using prosumer and consumer reputation scores electricity trading. Meanwhile, the recruitment of DSOs that may be viable for supply-demand balancing include the DSO reputation score.

2.3 Consensus Mechanism in Decentralized Energy Trading

The consensus mechanism is the basic technology and at the same time the bottleneck of the blockchain systems. It is a pivotal element that makes it possible for the nodes to agree on the new blocks that are added to the chain, therefore, ensuring data validation and fault tolerance in the network. The Byzantine problem is still one of the most difficult problems that have to be solved in the distributed consensus protocols [43] . Consensus protocols that are popular and based on Byzantine Fault Tolerance (BFT) include Proof-of-Work (PoW), Proof-of-Stake (PoS), and Practical Byzantine Fault Tolerance (PBFT) [44] . Although PoW and PoS are the most widely used for digital currencies, they are not suitable for Internet of Things (IoT) applications like energy trading. A lot of research has been done on using PBFT or its upgraded versions as the consensus mechanism in energy trading; nevertheless, the communication complexity of PBFT is too high for direct application in this field.

Mechanisms	Decentralization	Scalability	Throughput	Latency	Computing
PoW	High	Low	Low	High	High
PoS	High	Low	Low	Medium	Medium
DAG	High	Medium	High	Low	Medium
Hashgraph	Medium	Medium	High	Low	Low
BAC	Medium	High	High	Low	Low

Table 2.2: Different Trading Methods for Sharing Energy Among Peer

Studies often perceive the consensus mechanism as minor in their research and rather opt for traditional blockchain consensus methods. These methods, on the other hand, have their own limitations in terms of throughput and scalability. To solve this,we have come up with a novel method using sharding. This method sharding is a technique that allows infinite scalability(scale-out, i.e., unbounded throughput). In the case of energy trading, we have already gone through blockchain's impossible triangle(security, decentralization, and scalability) by prioritizing security and unlimited scalability over decentralization [45] . However, some decentralization is sacrificed, but having a certain degree of centralization is reasonable to allow government regulation of the energy economy. The importance as shown in Table no 2.3 of decentralization is that it helps to ensure security and to improve efficiency.

Objective	How Blockchain can Achieve
Confidentiality	Generally, in public ledgers, the records are not encrypted; the use of cryptographic techniques
Integrity	Data structured by cryptographic techniques through hash function, Merkle tree, nonce (numbers used once) and time-stamps;Manipulated records can be detected and prevented decentralized access
Authentication	Authenticated transactions are done within the blocks by the users' private keys, confirming the validity of the user of the respective transaction.
Auditability	Records of all the transactions in a public blockchain are available for everyone to see.
Authorization and Access Control	User-defined authorization and access control relied on smart contract; Attribute certificates
Privacy	Pseudo-anonymization through applying hash functions to keep secret identities, Zero-knowledge proof
Trust	Consensus algorithms, In such a system, trust is not centralized but rather distributed among the peers in the network.
Transparency	Total transparency by holding an unchangeable distributed ledger making it possible to incorporate every record, transaction, event, and log.

Table 2.3: Objectives and the Descriptions of How Blockchain Can Address Them

2.4 Blockchain Applications in Energy Exchange

When consumers wish to exchange their spare energy with others.

1. The transaction model: Requires each generator producing energy to verify how much electricity needs to be associated with a particular transaction. [46] By transferring their electrical energy to the virtual power system (VPS) [47], which compiles all generated energy produced, generators certify their output. Using a re-partition rule, the VPP divides the electrical energy and approves the transaction.

2. The consensus model: Preventing the negative effects of malicious nodes is the goal of developing a consensus model. [48] Each node creates a block containing all of the legitimate transactions. A random node is selected at each time interval, and its block is then broadcast. In addition, if they do, that will allow them to extend their chains. [49] Only when the majority of the nodes approve of this block can it be approved. Measures are meant to assure the origin of the energy and fair transactions.

	Category of Blockchain		
Properties	**Public**	**Consortium**	**Private**
Nature	Open and Decentralized	Controlled and Restricted	Controlled and Restricted
Participants	Anonymous and resilient	Identified and Trusted	Identified and Trusted
Consensus Procedures	PoW, PoS, DPoS	PBFT	PBFT, RAFT
Read/Write Permission	Permissionless	Permissioned	Permissioned
Immutability	Infeasible to tamper	Could be tampered	Controlled and Could be tampered
Efficiency	Low	High	High
Scalability	High	Low	High
Transparency	Low	High	High
Example	Bitcoin, Ethereum, Litecoin, Factom, Blockstream, Dash	Ripple, R3, Hyperledger	Multichain, Blockstack, Bankchain

Table 2.4: Comparison among different blockchain infrastructures

Every person's right to privacy should be protected, indicating that pinpointing an individual's electricity statement is not feasible. Only this community is the owner of what is permitted there. [50] However, as their primary identity is derived from their transactions, every member of a microgrid or community is acquainted with one another. [51] Each participant drafts a contract promising not to disclose this information to outside parties. Participants' personal information should be secure via anonymity, and the DSO system will guard against cyberattacks.

2.5 Consensus Protocols in Blockchain

The consensus mechanism of a blockchain application defines its operation as a distributed, immutable ledger [52]. Numerous studies have been conducted to identify the best consensus protocol to withstand Byzantine faults [53] or to create a platform that can be used to execute several consensus algorithms.

The consensus functions as a vital feature :

1. Sybil attacks: These criminals can create fake accounts or people to attest to their dishonest and self-serving acts. The "proof-of-work" method used by the blockchain technology in the case of bitcoin involved completing cryptography puzzles in order to validate transactions [54]. This protocol has a high computing cost, which makes it difficult for the false peers to validate and calculate transactions.

2. Consensus algorithms are agreements or decision-making techniques used by the decentralized network. They guarantee authentication, byzantine fault tolerance, integrity, regulation, and quorum structure [55]. Other consensus algorithm concepts, such as "proof-of-stake," "proof-of-authority," and "proof-of-existence," are all commonly used in the blockchain area, with the exception of the "proof-of-work" employed by bitcoin. In particular, a novel consensus mechanism called Stellar [56] is developed to address the byzantine fault tolerance problem and preserve the blockchain system's low latency, flexible trust, and asymptotic security.

3. Consensus procedures also aid in transaction validation and prevent forking issues, which arise when separate mining groups mine separate blocks containing the identical transactions. The "longest chain rule" is used to handle this problem [57]. As a result, the protocols control a blockchain's architectural design.

2.6 Summary

This chapter is a qualitative study that gives a detailed examination of diverse features of distributed energy trading. It focuses on the complex nature of reputation systems in decentralized electricity markets and discusses the consensus mechanisms that make sure energy transactions are safe and reliable. Apart from these, it also studies the blockchain applications in energy exchanges, illustrating the case of how blockchain contributes to transparency and efficiency. The review also highlights the various consensus protocols applied in blockchain, pinpointing their significance to energy trading systems. It is the literature review this time that lays out the perfect basis for understanding how blockchain will absolutely change the energy market.

Chapter 3

Energy Trading with Blockchain-based Trust Ratings

3.1 Overview

"Prosumers" are terms in the energy industry that refer to units that both make and consume energy under the energy exchange. Power is typically distributed through utility systems in many countries, and exchanging energy directly among prosumers is less expensive. In the P2P energy market, a fair trading price for each transaction is therefore important. The public can participate in Singapore's power market, which was established by the government. With so many players in the market, a fair price structure could allow the market to close agreements and encourage prosumers to participate in P2P trading[58]. The trading costs for distributed energy resources (DER) and other players will be reduced by this functionality.

3.2 Related Works

Many methods have been suggested by earlier research to improve the effectiveness of distributed apps and increase the range of applications that blockchain technology can be used for. Reference [59] examines how blockchain is used and uses Predix as an example of a green certificate to demonstrate how it might be used as a potential asset monitoring system for energy-related assets. The authors of look at a micro-grid energy sharing paradigm and develop an internal prosumer pricing system. The authors of suggest a peer-to-peer (P2P) electricity trading system that moves the maximum load using plug-in hybrid electric cars. Furthermore, it presents blockchain technology to facilitate vehicle-to-vehicle transactions and do away with the necessity for a middleman. Apart from energy transactions, examines the application of blockchain technology in grid operations with consideration for energy losses. The authors of look at a blockchain application that the wholesale electricity market has accepted. These earlier studies all demonstrate the blockchain's stability, openness, and decentralization. However, in order to further the community's social welfare, optimization techniques must be integrated with the blockchain architecture. In addition, every transaction should be free from malicious operations by the fair market management[60].

In this thesis, we implement a blockchain architecture to ensure the security and openness of every transaction on the peer-to-peer trading market. Blocks are only able to include valid transactions since they are stored in sequential time and uniquely hashed (coded) to identify them from one another. One benefit of the blockchain is that in order for a peer to modify a transaction.

3.3 Key Contributions

The contributions are as follows.

1. The development of a credit rating system [61] aims to deter harmful activity. Regarding the trading market, reduced market priority should be applied to prosumers who have a history of deregulation. A credit rating system is used to accomplish this goal by rewarding prosumers for their great behavior and raising the caliber of the market. To this effect, a decentralized credit system on the basis of blockchain technology may be constructed so as to eliminate the issue of the fraud in this P2P market.

2. To ensure participant security and transparency, a blockchain architecture is used. In the P2P market, these tactics play a variety of functions that result in prosumers' savings and best management. [62] This idea can theoretically accommodate future modifications by the application of more advanced technology in place of these methods.

3.4 System Model

3.4.1 Blockchain Framework

Prosumer in the market then records and acknowledges the news. A smart contract's content could not be changed or broken during a transaction[63]. Before getting on the blockchain, the data concerning this deal will be posted in a new block after the trade.

The one-of-a-kind information of a piece of data is used to generate a cryptographic output that is connected to a specific data unit; this hash is then further used as an entry to link to the previous block in the next one. Any unexpected alteration in the hash due to modification of the block content will result in all the following blocks displaying such a change thus rendering them to be invalid. To be acknowledged as a bonafide transaction, a transaction must have the approval of the majority of prosumers in a certain region. The kind of format the blockchain has makes it possible for transaction data to be so secure that it is virtually impossible for malicious actors to alter any information in such a way that they are not detected[64]. Furthermore, the decentralized structure of blockchain increases its security and reliability by preventing any one person from controlling the entire chain. Figure 3.1 illustrates the structure of a blockchain involving smart contracts and block hashes. A block consists of a smart contract, the hash of the prior block, and a sequence of transactions. The arrows show that every block's hash has a link to the one before it, thus forming a secured chain. This structure guarantees that all transactions are verifiable and tamper-proof, since each block relies on the integrity of its predecessor. Bad operations could be halted, and monitoring and tracking of all transactions is made simple by the blockchain's transparency.

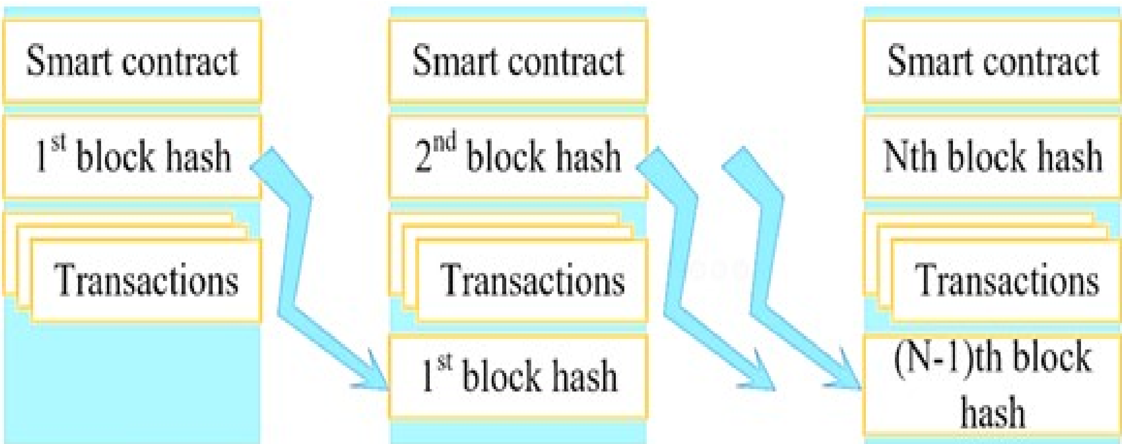

Figure 3.1: Blockchain Structure and Components illustration

3.4.2 Blockchain Creation

A series of blocks together form a blockchain. A block is represented by a collection of codes, suggesting that each code is a piece of DNA that expresses every element found in this block. The term "Hashing" [65] refers to this computation process, and a hash number is what the DNA code is described as. Figure 3.2 the information of the transactions within a specified time period is used to create each letter and number of a hash number.

The hashing process is more difficult because multiple transactions are typically carried out on the market during a specific time frame. To create a new block.

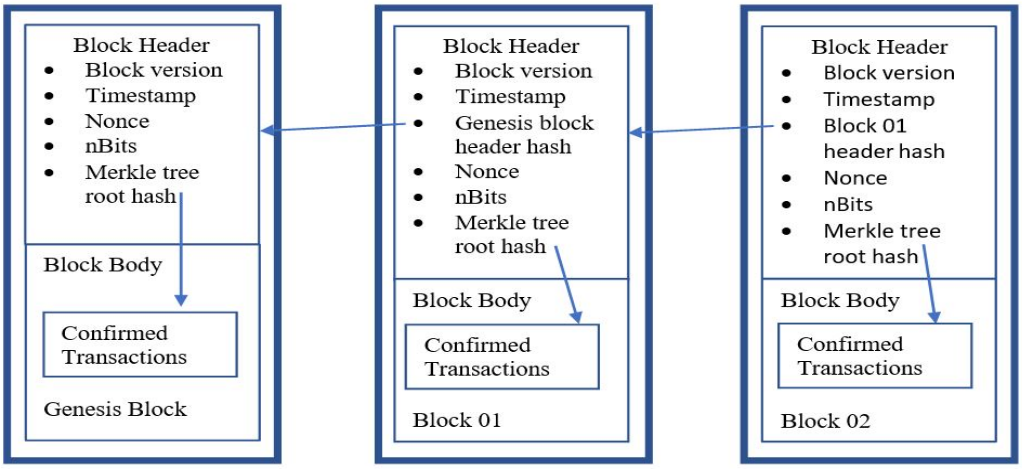

Figure 3.2: Structure of blockchain "Block".

A line of code (hash number) represents a large transaction derived from the previously mentioned hashing process. This encryption method's structure is known as a merkle tree . The topology of a merkle tree when eight transactions (A through H) occur inside a time slot is shown in Figure 3.3. The transactions inside a pair are gathered and hashed in this image. To represent these eight transactions, their codes are grouped and hashed once more, leading to the final code, or Root.

The P2P market receives the introduction of a trading token. Since Ethereum served as the foundational framework for building the blockchain, we used a type of cryptocurrency called Ether in this study. Ether has a unit of measurement called wei.

Figure 3.3 the Prosumer A sends two identical tokens that travel in opposing directions around the network circle. In conclusion, the details of the trade procedure are recorded in a new block that is uploaded to the microgrid blockchain upon the completion of this authorized transaction[66].

The smart contract automatically completes all of the transactions in the previously described manner. The need for starting the smart contract is not satisfied during this period if the token sender is unable to get any responses from other parties, and no block will be created. The multi-microgrid system's blockchain structure operates essentially in the same way as it does inside each individual microgrid[67].

However, the solar photovoltaic system's energy output is limited by the state of the weather. Therefore, network users would have to abide by a few fundamental guidelines, and our suggested model could only function in the following situations:

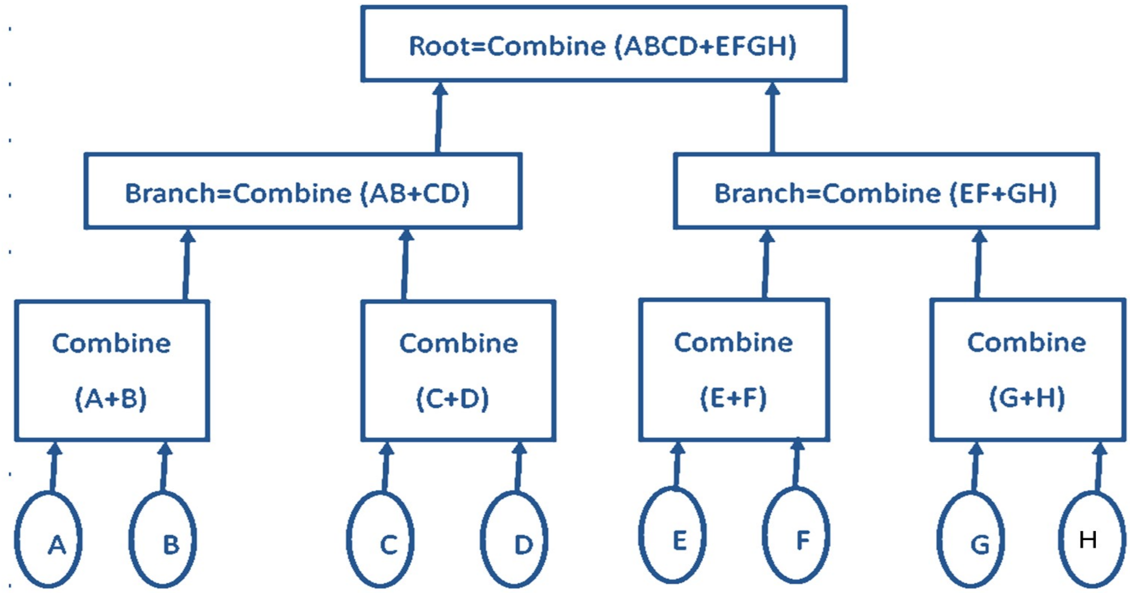

Figure 3.3: Merkle Tree Architecture

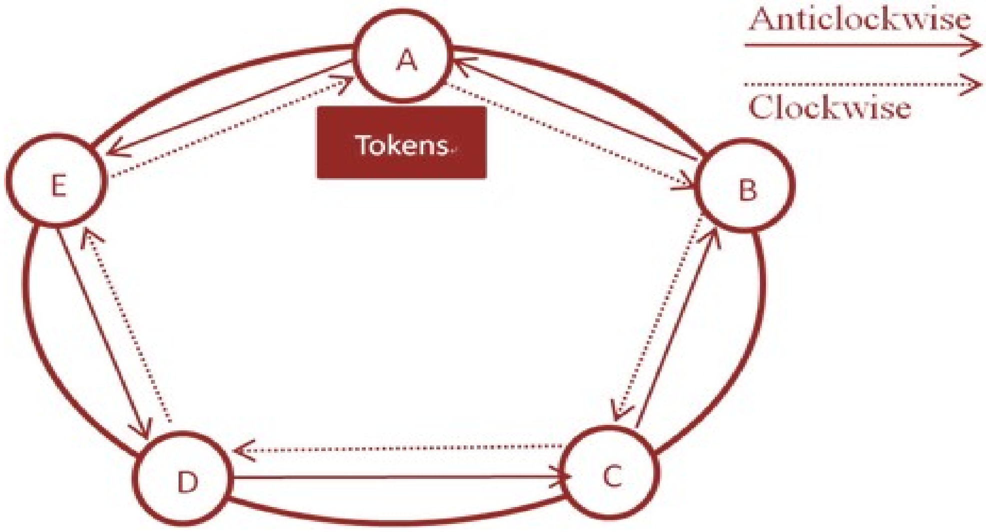

Figure 3.4: Token-Passing Mechanism within a Microgrid

1. Most of the time, prosumers' output of renewable energy is less than their consumption of power. The power plant would close the gap in availability and stabilize the grid.

2. Smart contracts determine the current price of electricity, which fluctuates based on supply and demand. As a result, individuals are unable to conduct private personal bidding without using the blockchain technology.

In a post-paid system, energy transfers that don't flow via the blockchain might result in unpleasant issues. Since every consumer belongs to the same group of electricity contributors, it is only fair to charge each user the same amount.

The effectiveness of the P2P architecture built on the blockchain technology relies on the fact that the newly added blocks need to be validated by the existing peers of the system and also the rate of prices at different times should be based on the load demands and power generation output of all peers[68]. As a result, the various advantages that distributed ledger technologies provide, such as their highly secure, decentralized, and traceable characteristics, can be used in a very advantageous way.

3.4.3 Development and Execution of Smart Contracts

With blockchain technology, smart contracts are central to its success. Energy trading on the blockchain, on the other hand, requires transaction design and short-term balancing contracts which are both coupled and realized through smart contracts. By reviewing existing blockchain ideas and the restrictions posed by computations and communication infrastructure, a low-requirements and sufficient security model is obtained. Transaction flows are done in cryptocurrency, and the data of dealings is reliably encrypted in a blockchain. On a market platform, decentralized clients schedule individual power flows based on transactions and negotiate contracts using bidding algorithms. Short-term contracts are set up or the manager of the balancing group makes sure that there is enough power provided in the event of unplanned deviations. Customers, owners of electric vehicles, and grid operators/utilities all benefit from cooperating with the pricing process[41]. Energy auctions could be done as smart contracts that are visible to all parties involved in the energy transaction and follow transparent regulations. The smart contracts are implemented on blockchain and written in Solidity, a language used to create smart contracts. It eliminates the need for any middlemen in transaction processing and permits distributed applications to use decentralized computation. In Figure 3.5, No middleman is required for the execution of energy transactions since, once a smart contract's pay-and-take condition is satisfied, the transaction will be carried out automatically.

A transaction can be finished if and only if all of the smart contract's requirements are met. This method uses a smart contract to make energy transfers easier to implement.

Through the buyers' broadcasting of trading demand to the P2P network in each time slot, sellers were given the opportunity to respond to every original participant by stating the size of their energy and price at the instant they were given the trade tokens. Meanwhile, all of the network's peers will be verifying the market participants' TRP values in accordance

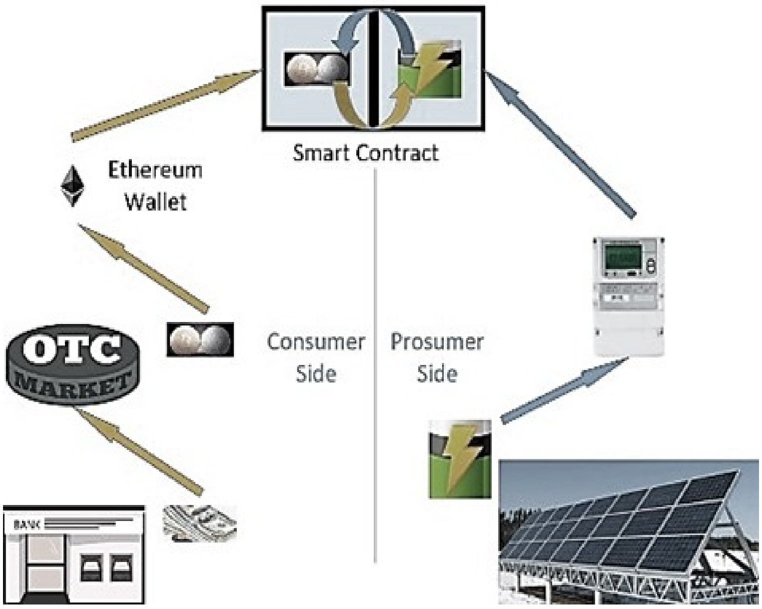

Figure 3.5: Smart Contract Operation Process

with the specifications of the credit rating system[42]. Transactions between traders can be conducted and ended only after the identification of the best sellers and buyers.

Remix is the platform used to design and run smart contracts, and it is the technology used to develop the Solidity language. For example, the load demand and generation profile of a prosumer are taken to illustrate the functions of the smart contract.

Since each new block on the Ethereum platform may only be constructed within 15 minutes, the length of each time slot has been shortened to 15 minutes in this blockchain. In order to complete the consensus using Blockchain technology, the time period is changed[42]. Each participant's identification (Power station, Prosumer, or Consumer), account number, and transaction details for a specific time period are displayed in this graphic. The Joule (Joul) is the unit of energy. The cost and amount of energy used are converted into the Ethereum network token "wei." During the transaction execution process, information is dynamically displayed in this interface. Another benefit of blockchain technology is demonstrated by this chart; transaction details are visible despite each participant's account name being anonymous[69]. This implies that while each transaction's openness is still guaranteed, the client's security and privacy are greatly preserved. In Fig 3.6, This characteristic makes blockchain technology a reliable platform for peer-to-peer energy trade.

Along with the previously described information, this interface displays the trading price as well as the energy production (generation power) and consumption (load demand) of participants[70]. Because the BESS is not taken into account in this study, all of

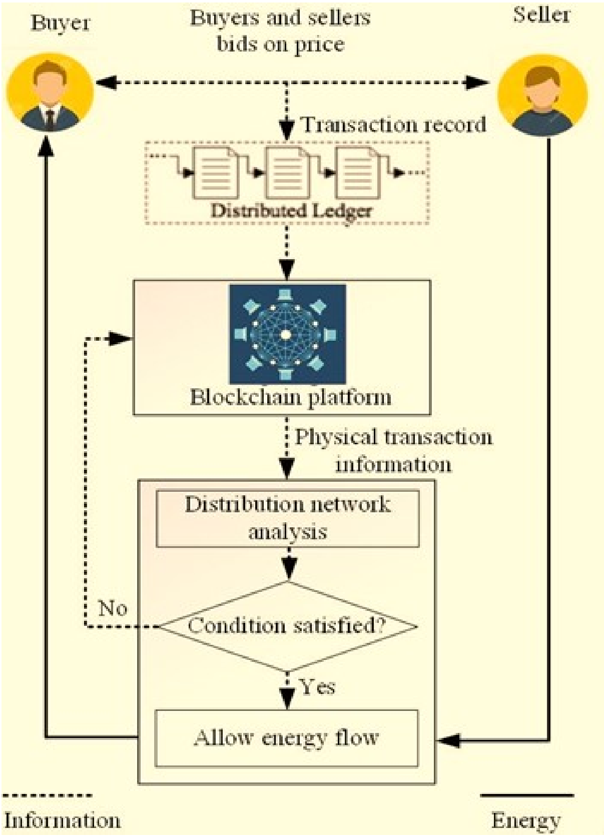

Figure 3.6: Blockchain Implementation in Peer-to-Peer Trading

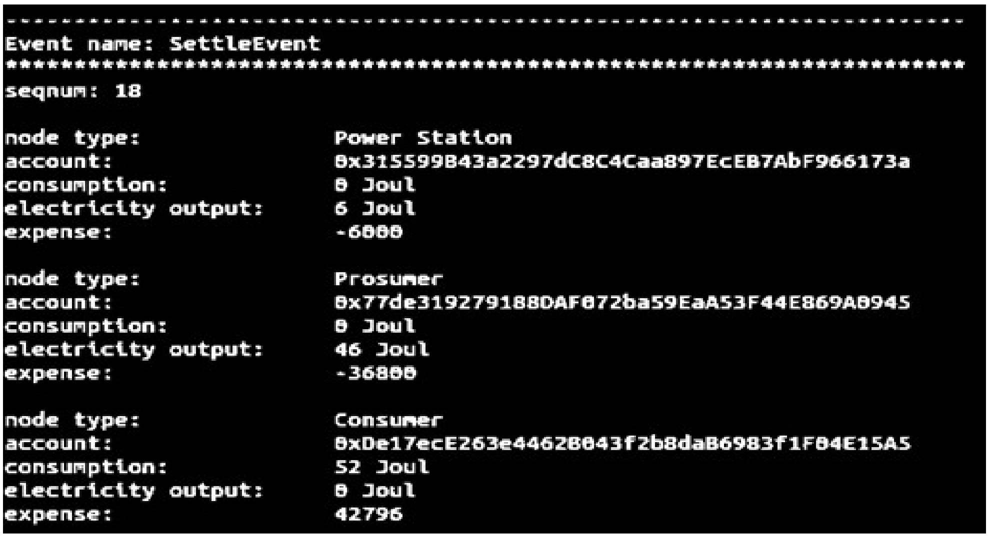

Figure 3.7: Blockchain Participant Information

the battery station's contents are zero or "the battery station did nothing." In this study, blockchain technology serves as a framework to ensure participant security and privacy while showcasing transaction transparency. As a result, it has no bearing on the outcome of the two-level pricing procedure. Using blockchain technology is intended to protect and promote peer-to-peer energy trading.

3.4.4 Dual-Level Pricing Strategy

A two-level pricing system is developed to address the pricing issue and enable the P2P market's transaction execution [44]. PV panels are installed on every prosumer in a microgrid, and multiple microgrids are networked together to form a multi-microgrid system. For trading in a peer-to-peer market, a two-tier pricing scheme is offered. The microgrid's prosumers are the focus of the first level, while the system's several microgrids are the focus of the second.

3.4.5 Microgrid to Microgrid

Interactions between microgrids are used for operations on the second level. We disregard the power loss during power supply because we presume that these microgrids are close to one another in their region. The total load and consumer generation on the microgrid j is equal to the demand for load and the energy generated by it. The total energy sold (TES_m) and total energy purchased (TEP_m) for the time period t are computed in the same manner as at the first level.

$$TESm^t = -\sum_{j=1}^{n} (L_j^t - E_j^t), \quad NP_j^t < 0 \tag{3.1}$$

$$\text{TEPmt}^k = \sum_{j=1}^{n} (U_j^t - E_j^i), \quad NF_j^t \geq 0 \tag{3.2}$$

$$\gamma_m^t = \frac{TESm^t}{TEPm^t} \tag{3.3}$$

$$P_{m\_sell}^t = \begin{cases} \frac{P_{sell}^t - \frac{P_{buy}^t}{P_{buy}^t})}{\gamma_m^t P_{sell}} & 0 \leq \gamma_m^t \leq 1 \\ P_{sell}^t & \gamma_m^t > 1 \end{cases} \tag{3.4}$$

Within each microgrid, consumers' primary objective under this two-tier price structure is to exchange energy.

3.4.6 Decentralization Contributions

Below is an explanation of an intriguing part of this pricing procedure. Due to the unpredictable nature of PV power generation, load demand has an impact on prosumers' selling prices. Thus, by making agreements to meet their energy needs, the prosumers might modify the market price.

The price of renewable energy is always guaranteed to be less than that of energy traded with the utility grid according to this pricing structure. Peers are prevented from arbitraging by this feature. One can continue to store and resell electricity later on, claiming that it is renewable, if the cost of conventional energy is less than that of renewable energy.

Furthermore, the load demand of each participant and the generation profile determine the price of power for each time interval. With the help of this feature, blockchain technology can reach consensus because each transaction must be approved by all network nodes before a new block can be created. Thus, the operating of the two-tiered pricing system could be advantageous in a decentralized P2P marketplace utilizing blockchain technology.

3.5 Trust Rating System in P2P Energy Markets

It's possible that those with lower rating points will not be able to trade with others who have higher offers or bids. It implies that a price agreement between buyers and sellers is not sufficient to form a transaction. The quantity of bids or offers that a prosumer can obtain upon entering the market is ascertained by this approach[71]. Traders' trust rating points (TRPs) can rise with good behavior, but their TRPs might fall with poor behavior. Choosing the best item for traders in the P2P market based on the TRP results - which are based on assumptions - is crucial. TRP readings are broken down into 1, 2, 3, and 4 points. Prosumers are granted up to 50%, 75%, 90%, and 100% respectively, under these four value standards [72]. Buyers must evaluate sellers' offers first since sellers with the greatest TRPs have to be at the top of the list.

If the buyer's TRP is too low to trade with them, those with lower TRPs may not be able to participate in the market during this time frame. Depending on the seller's offer price, buyers may be limited in the vendors they can choose from due to their TRPs. Only the most costly price that is still available in the market is available to buyers with the lowest TRPs.

Energy trading between various microgrids operates in a way similar to the processes described above. Every microgrid participates in the two-level pricing process as a trader. The prosumers of a microgrid receive the energy it has acquired in decreasing order according on their individual TRP values, and they are also responsible for paying the price based on the quantity of energy they have accepted. In reality, these transactions take place between several purchaser groups. Figure 3.8 shows how transactions are carried out.

Lower TRP traders have higher trading costs and have fewer options for completing trades. Thus, this approach can effectively guarantee traders' legal behaviors.

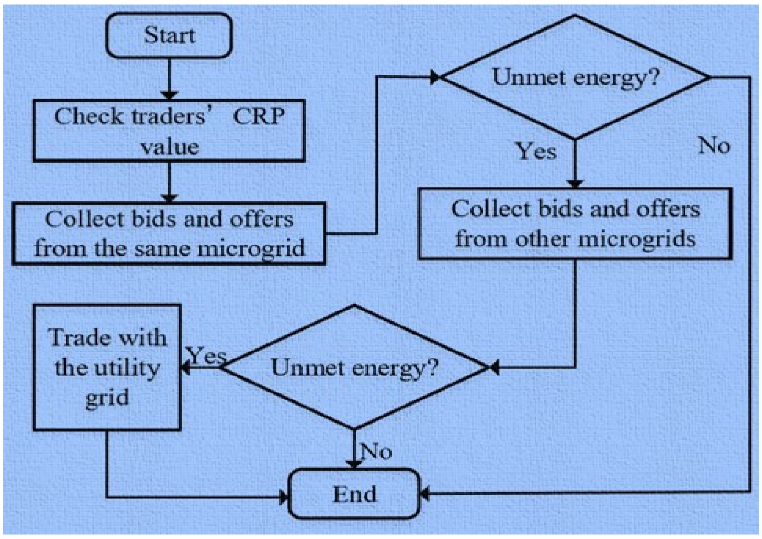

Figure 3.8: Buyer Trading Process Workflow

As a result, the quality of the market improves. Moreover, this mechanism also determines the sequence in which transactions are executed, meaning that traders with higher TRPs may benefit from the market's trading energy first.

In this report, all participants in this peer-to-peer trading network have verified all of the transactions that are secured by the blockchain and recorded in blocks, using the 16th hour as an example. In the Figure 3.8, The prosumers' income, excess energy values, and selling price are indicated by a "+." "-" reflects the cost to the consumers as well as the energy deficit and purchase price.

Entities	Power (kW)	Rate (cents/kW)	Reserve Cost	Prosumer Rates
Grid Unit 1	+50.1234	+10	3.5	(3,3,2,3,4)
Grid Unit 2	-150.5678	-18.2500	3.8	(1,2,2)
Grid Unit 3	-120.9876	+9.1122	2.7	(1,4,2,2)
Grid Unit 4	+7.2345	+12.4500	4.0	(3,6,2)
Grid Unit 5	+90.5678	+7.5	3.1	(3,3,3,2,1,2)
Grid Unit 6	-30.4567	-9.8765	3.4	(2,3,1,3,1,2)

Table 3.1: Summary of Power Transactions

Power transactions and the cost analysis of grid units are the ones that of which the conclusion is solved by Tables 3.1 and 3.2. Technology 3.1 focuses on the extracted power, rate, reserve cost, and prosumer rate of various grid units The variations in energy supplies are presented. Technology 3.2 relates the energy deficits, the prices, the total costs, and the

Entity	Energy Deficit (kW)	Price (cents/kW)	Total Cost	Grid Interaction Cost
GU1	0	+650.87	+650.87	+650.87
GU2	0	-4800.45	-4800.45	-4800.45
GU3	+75.1234	+1200.56	+2000.45	+1300.67
GU4	0	+60.89	+60.89	+45.23
GU5	0	+800.22	+800.22	+800.22
GU6	0	-250.44	-250.44	-450.90

Table 3.2: Cost Analysis of Grid Units vs. Grid Interaction

grid interaction costs for the grid units, which then exposes the renewable energy trading financial implications among them.

3.6 Multi-Layer Trust Architecture

The multi-layer trust architecture is a comprehensive framework designed to bolster security and minimize risks within complex technological ecosystems. It consists of multiple layers of defense mechanisms, each contributing to a robust and layered security approach. These layers encompass various components such as identity and access management, encryption, intrusion detection systems, and secure communication channels. By employing multiple layers, the architecture creates multiple barriers that potential attackers must overcome, thereby reducing the impact of breaches or vulnerabilities. It follows a defense-in-depth strategy, implementing security measures at different levels to protect critical assets and data. We offer a higher-level system overview and suggest a multi-layer design coupled with a fundamental consensus technique. The digital ledger technology consists of multiple components that are responsible for various tasks, including block propagation, transaction collection, mining, crypto-currency ledger maintenance, consensus establishment, and more [73].

In this article, we propose an extension of the existing four-layer architecture to a multi-layer trust architecture. While initially designed for energy trading, this multi-layer architecture can be adapted for various other applications as well. In the context of an energy trading system, the platform connects energy prosumers (such as those with solar panels installed on their rooftops) using the network as a channel, they can sell their surplus of power to the users who in turn are the consumers. Through our energy trading platform, consumers have the option to directly purchase energy from prosumers, facilitating a streamlined and efficient trading process[74].

This mechanism utilizes a stable crypto-currency called “trust coin,” linked to the paper currency of the deployment country. Trust coins are essential for participation in the system and the consensus process, and can be obtained through designated exchanges. The trust scores of consumers, prosumers, and validators contribute to the application layer, along with values from upper and lower layers, creating a multi-layer protocol. The consensus algorithm's internal mechanisms are then explained across the different layers.

3.6.1 Physical Layer

In our system, the physical layer connects the energy users with the microgrid using smart meters. Each of the energy user is equipped with smart meters, that are responsible for measuring and recording the energy usage and to perform bi-directional communication with the other microgrid entities. The infrastructure layer belongs to the physical layer of decentralized energy trading system[29]. It only contains the energy prosumers, energy consumers and agents, while other allied entities are in physical layer of the automated system for exchanging energy[75].

3.6.2 Infrastructure Layer

They create digital identities with private-public key pairs and engage in electricity trading. Two transaction types exist[76]: ETH coin transactions and trust transactions. ETH coin transactions involve transferring trust ETH coin from the buyer to the seller upon acceptance of an offer[77]. These transactions are propagated, included in blocks, and added to the blockchain for finality.

3.6.3 Virtual Layer

The virtual layer stands to be a crucial component in our system in order to make a more transparent[78], efficient, and resilient energy market using the digital technologies to directly trade energy between peers and optimize the decentralized energy system. The network layer and the consensus layer composes the virtual layer of a decentralized energy trading system[79].

3.6.4 Application Layer

This layer's digital contract maintains and controls the credibility scores of the entities that were retrieved from blocks. These credibility scores are retrieved through the connection between the user interface (UI) and the smart contract[80]. Acting as an internal trust score Oracle, the smart contract provides a reliable source of trust information within the system. Agents who create blocks are rewarded with trust ETH coin as an incentive for their participation[81].

3.7 Blockchain consensus mechanisms

In our system, the Proof-of-Stake (PoS) and Proof-of-Burn (PoB) concepts serve as the foundation for the proposed[82] consensus algorithms. Under our algorithm, validators from the Proof-of-Stake (PoS) consensus model delegate a certain degree of trust in ETH to a smart contract, and are then selected according to the size of their stake and the trust score given to them. Agents are rewarded for creating blocks, but their deposit is confiscated if they misbehave. In the Proof-of-Burn (PoB) approach, miners burn crypto-currency to participate in block creation and receive rewards. Multi-layer consensus mechanism, a certain number of validators stake unrecoverable trust ETH coin and meet a minimum trust score threshold. Agents' base trust scores increase over time as they create blocks[83]. After a certain interval, a transaction block is generated even if there are less number of transactions. The validators for the next trading are selected based on deposited trust coins.

3.8 Summary

This Chapter is about blockchain technology and trust ratings in the energy trading arena. It gives a brief overview of the topic at hand, and then Related Works are discussed to provide the basis by a comprehensive review of existing studies and practices. The section on Key Contributions presents the novel aspects of this research with the introduction of the detailed System Model that will follow.

In the System Model, the core of the Blockchain Framework is described and then more on the topic of Blockchain Creation is provided to demonstrate the practicality of such technology in the real-world. The chapter then covers the Development and Execution of Smart Contracts, which is the key to securing and automating the transactions. The Dual-Level Pricing Strategy provides suggestions for setting the price either at the upper or lower level, the case of Microgrid to Microgrid is about the relation of the smaller energy systems among themselves. The Decentralization Contributions area stresses the fact that a decentralized way of doing things makes the system more resilient. This chapter moreover, extends into examining the Trust Rating System in P2P Energy Markets, which is a critical designation for keeping the reliability of the participants in the market. Ultimately, the Multi-Layer Trust Architecture is the last to be presented. It describes the different layers such as the Physical, Infrastructure, Virtual, and Application Layers and the use of Blockchain Consensus Mechanisms in making trust and efficiency.

Chapter 4

Proposed System for Energy Trading

When we analyze and observe a system from a higher perspective, we present how the system operates by exploring the architecture and detailed consensus technology used by the system. A typical blockchain system has its different components that are involved in various activities such as sending blocks, receiving, transmitting and keeping records of transactions, mining and validating the authenticity of new blocks hence enhancing the overall security of a blockchain network, and determining the transactions accepted in a consensus mechanism, and so on[84]. Each of these components together in the system to form different layers which perform specific tasks, and this concept has its similarities with the model in the majorly used TCP/IP layer software [85]. This allows the system to guarantee the desired results and satisfy the needs and expectations of the enterprise while ensuring that the architecture is stable and resilient and that the system remains efficient.

4.1 Cross Layer Architecture

We propose a cross-layer mechanism for the model of trust which is used for the presence of different layers' elements and assigned trustworthiness scores, as well as so-called logic values that describe the trust of different features in different layers that belong to the meta-system the application and Agreement layers[86]. The pivotal element of our consensus scheme is the application of a peculiarly designed cryptocurrency which we call the trust coin, a type of money whose value is not prone to wild fluctuations and which, as per the cryptography community, its issue is tied to the national currency which is the one it is issued.

Each considered a major contributing factor of the inclusive mechanism of the whole arrangement. The stakeholders can buy as well as dispose of trust coins as desired from the officially earmarked purchasing centers[87]. The marks of good faith for both vendors and purchasers are included in the algorithmic formula used to determine the credit quotas. Secret rating assessments of an attacker besides the validating node are also found on the application layer. Conversely, elements of the top layer and those of the lower layer contribute to the application layer [88]. This is called the cross-layer protocol as the impact of trust scores determined from one layer influence the working of adjacent layers which shows that layers are interdependent. We present here the inner mechanisms of the consent protocol.

4.1.1 Consensus Architecture

In our system the one that is put forward is PoS and PoB the two main algorithms that have been implemented in the consensus mechanism. With the PoS system, validators have a minimum deposit (in this case, cryptocurrency) that serves as collateral to ensure they are the ones who create the block. Validators are chosen based on the size of the deposit they make to the blockchain[89]. The validator's acts when he/it successfully creates a block yield him a reward. However, the deposit is withheld if it is found that the deposit was a result of a bad act. In PoB, a miner has to burn a fixed amount of crypto for the sake of being part of the block creation and getting a reward. The cryptography community claims that this is linked to the national currency in which it is issued[90].

The consensus protocol is the basis of the algorithm whereby the so-called validators participate. A node can become a validator based on the following criteria: it has to stake some non-reversible trust to the smart contract and its credibility rating must be above a certain threshold. The validators deposit the necessary trust funds into the smart contract that assigns them the baseline trust rating. The validator is then given a trust score which is adjusted as the validator remains active in block creation over time. A block is produced each minute even if there is at least one transaction. In the case of no transaction for a minute, a block is not produced[30].

A well-defined epoch would be a set of ten blocks that are explicitly signed by ten validators. The smart contract function of the next epoch is initiated by the validators and ranks them according to the trust coins they have deposited. The selected validators then reconfigure themselves randomly in the next ten blocks for validation[91]. The validators are irrevocably chosen and the deposits are not recoverable. Thus, we have the same PoB situation of burning coins. The protocol then picks 10 additional validators from the rest of the pool, omitting the current epoch's validators, for the subsequent epoch during the fifth block generation of the current cycle. This procedure is continued[92].

4.2 Trust Model

This segment provides a thorough elaboration of the numerical basis and the procedural steps of the proposed multi-layer consensus method.

4.3 Metaapplication Layer

The energy buyers and sellers weigh the reliability of the counterparty transactions based on the past mutual exchanges they have had. At the meta-application layer, energy trading is assessed using a variety of criteria, which can be modeled as a tuple $\langle \alpha, \beta, \gamma, \delta, \varepsilon \rangle$ where α is the trader's rating, β is all time that the trader has spent on the network, γ is the number of coins that the trader exchanged, δ is the human experience, i.e., the satisfaction with energy trading service[93], and ε is the service experience of the energy trading platform. One of the main reasons for the trust score being so high for the traders is α, β, and γ, while the trust score of the platform is defined by δ and ε.

Trust Score of Traders: Traders, who pose as both purchasers and vendors within the system, have their credibility scores recalibrated after each deal. These scores create perfect trust between individuals and the whole network[94]. Trust score of a trader is given based on the following factors:

Rating of Traders(α): Traders are based on each other with a Likert-type scale, where 1 denotes the lowest and 5 symbolizing the highest information quality of the particular aspect. The rating of a trader is represented as $\alpha = \{\alpha_1, \alpha_2, \alpha_3, \ldots, \alpha_n\}$, where $\alpha_1, \alpha_2, \ldots,$ are the ratings obtained after transactions 1, 2, and so on.

Total Time Spent (β): This factor captures the total time a trader has spent in the system. Generally,the more time a trader has been active in the network, the higher their trustworthiness. To compute the β trader time registration is subtracted from the current time and an infinite value is created[95].

Total Coins Traded (γ): This metric indicates the total amount of trust coins that have been traded by the traders. The original value being unbounded is thus it is mapped to a bounded range of 0 to 5 using Equation (4.1).

$$\xi = \frac{5}{1 + e^{-0.5x}} \tag{4.1}$$

4.4 Trust Score Calculation

The value of confidence for the traders as well as for the platform is computed by the use of Algorithms 1 and 2 with appropriate notations[96].

Algorithm 1 is applied for measuring the reliability of the trader u only after the corresponding currency and trust transactions have been recorded and confirmed in the block which ensures the finality of the transactions. At first, β_u' and $\beta_{u'}'$ Score are fixed, and then the calculation of $u \cdot \gamma_u$ Score (the scoring of all currencies traded for u and the score they got) as shown in Algorithm is done. The latest reliability score for u, which is represented as $NT'S_{u'}$, is calculated using the weighted arithmetic mean method. This technique factors in the number of u's historical transactions and their reliability scores, as well as the reliability score that is gotten from transaction[97].

Likewise, the reliability score of the platform is determined by Algorithm 2. This algorithm includes a weighted arithmetic mean formula, which takes into account the count of past reliability scores along with the current human experience[98].

Algorithm 1 Trust score calculation for u after t

Input: α_u^t, RT_u, γ_u^t, PTS_u^t
Output:NTS_u^t *New trust score for u*

currentTime =time();
$\beta_u^t = \text{currentTime} - RT_u$;
$\beta_u^t.\text{Score} = \frac{1}{1+e^{-0.5\beta_u^t}} \times \frac{5}{1}$;
$u.\gamma_u^t = \text{totalCoinTraded}(u)$;
$u.\gamma_u^t.\text{Score} = \frac{1}{1+e^{-0.5(u.\gamma_u^t)}}$;
temp = $\alpha_u^t + \beta_u^t.\text{Score} + u.\gamma_u^t.\text{Score}$;
oldTransList = listOfTrans(u);
$NTS_u^t = \frac{|oldTransList| \times PTS_u^t + \text{temp}}{|oldTransList|+1}$;
function TOTALCOINTRADED(u)
    totalCoin := NULL;
    transList =listOfTrans(u);
    while $l \in$ transList **do**
        Extract traded coin c from l;
        totalCoin += c;
    end while
    return totalCoin;
end function
function LISTOFTRANS(u) := NULL; L, all transactions minus t from the blockchain;
    while $l \in L$ **do**
        if l involves u **then**
            LIST := LIST $\cup l$;
        end if
    end while
    return LIST;
end function

Algorithm 2 Calculating Platform Trust Score After$t$

Input: δ^t, ε^t, $PTSP^t$, FN^t

Output: $NTSP^t$ *// New trust score for platform*

1: temp = $\frac{\delta^t+\varepsilon^t}{2}$;

2: $NTSP^t = \frac{FN^t \times PTSP^t + \text{temp}}{FN^t+1}$;

4.5 Application Layer

At this level of trust, it is measured by means of a digital currency called trust coin. The smart contract executes the trust ratings of all the traders and validators within the system. The trust coin system is intended to dissuade the validators who act unethically[99]. It helps energy traders and validators to take part in a trust-based incentive scheme. This incentive which is a transaction fee charged to the buyers, is distributed to the traders not only according to their trust ratings but also adjusted based on the proportion they have in the network. This strategy is wooed the down or even the erroneously completely the control of outlier nodes. The trust coin is a big economic carrot for the validators to do their work and be in the system.

4.5.0.1 Trust Coin Attributes

The suggested system is made up of the basic components which determine the number of awarded (trust) coins. Since those elements can be evaluated on different scales, we brought them all to a common scale from 0 to 5 so that we can estimate the number of coins for block creation[100].

Notation	Description
θ_b	Total money transacted for block b
λ_b	Trust fees for block b
ρ_b	Total calculated trust coin for block b
mt_i	Money transacted for transaction i
tf_i	Trust fees for transaction i
ts_i	Trust score of the buyer for transaction i
R_b	Block reward for block b
TL_b	Transaction list in the current block b
TS_u	Trust score for trader u
TT	$\lvert TL_b \rvert$, number of total transactions in b

Table 4.1: Notations Used in Application Layer

Block Reward (R_b): The validator who successfully generates block b gets a fixed compensation of five coins. The mechanism is closely aligned with the block reward system utilized in Bitcoin.

Algorithm 3 Trust coin calculation for block b

Require: TL_b, tv_b
Ensure: ρ_b ▷ Trust coin for b

$R_b = 5;$
$\lambda_b = 0;$
$\theta_b = 0;$
for all $i \in TL_b$ **do**
    $buyer \leftarrow i.\text{buyer}();$
    $ts_i \leftarrow \text{trustScoreVal}(buyer);$
    $tf_i \leftarrow i.\text{trustFee}();$
    $\lambda_b \leftarrow \lambda_b + tf_i \times ts_i;$
end for
for all $i \in TL_b$ **do**
    $mt_i \leftarrow i.\text{amount}();$
    $\theta_b \leftarrow \theta_b + mt_i;$
end for
$\omega_b \leftarrow \frac{5}{1+e^{-0.5\theta_b}};$
$\rho_b \leftarrow R_b + \lambda_b + \omega_b + tv_b;$
function TRUSTSCOREVAL(v)
    $trustScore \leftarrow NULL;$
    Retrieve $trustScore$ for v from the smart-contract;
    return $trustScore$;
end function

4.6 Agreement Layer

The consensus layer is the part that defines how agreement is managed described. This component is responsible for computing the trust rate, which is the process the validator goes through when it gets the block validated. The trust rating is affected by different factors, which are given below according to the notations defined[101].

Trust Score Assigned by Other Validate: When a validator successfully adds a block to its chain, it is then sent across the network to be verified by the other validators. These validators then assign a trust value to the validator who proposed the block. This trust score is a key element in the process of filtering out validators who are either untrusted or do not have a high degree of trustworthiness from participation in all subsequent consensus procedures. The trust value is automatically calculated based on the following parameters:

Total Number of Transactions: This indicates the count involved in the proposed block transactions.

Total Money Transacted: It is the total sum of money paid for each transaction in the block which is calculated.

Time Spent in the Network: This describes the aggregate time the chosen validator has been operating in the net, denoted by β_v^t. The time is then normalized using the following formula:

$$\beta_v^t.\text{Score} = \frac{5}{1+e^{-0.5\beta_v^t}} \quad (4.2)$$

Trust Score Calculation: A validator v is assigned a trust score which is determined using Algorithm 4. In this process, the values of β_v^t and β_v^t.score are computed first. After this, it is established first there are the total coins assigned to the block and the number of transactions. These values are then utilized to compute the trust score (tv_b)[102].

Elapsed Time: In the first phase, we analyzed the proposed system in terms of elapsed time. As shown in Figure 3, it is evident that our trust-enhancing consensus mechanism outperforms the traditional PoS and PoW algorithms. The bar graph demonstrates that the performance of our system remains stable even as the number of energy users increases. This indicates that the elapsed time for our proposed scheme increases gradually, unlike PoS and PoW, where the elapsed time grows more rapidly[103].

4.6.0.1 Selfish Mining Attack

In this attack, a malicious user with the help of other dishonest helpers mine transaction blocks with the purpose of undermining the efforts of the honest users[31]. Our proposed mechanism is resistant against this attack since we have defined a two stage threshold. First, the transaction verifiers are selected from a set of agents with high trust score than the other agents. Secondly, for a particular transaction, the agent with the highest trust score at that moment will be selected.

Notation	Description
β_v^t	Total time spent by validator v up to t
$\beta_v^t.Score$	Total time spent score for v
tv_b	Calculated trust value for b
NTS_v	New average trust score for v
PTS_v	Previous average trust score for v
PB_v	Set of proposed blocks by v
RT_v	Registration time for v
TC_b	Total coin traded in b
$TC_b.Score$	Total coin traded score in b
$TT.Score$	Total transaction score in b
V	Set of validators
$v \in V$	Current validator
$V \setminus v'$	$V \setminus v$, Set of other validators

Table 4.2: Notations Used in Consensus Layer

In a typical decentralized energy trading system, we have a prosumer, a consumer and an agent. Here, based on the layered architecture defined earlier, the energy users (prosumers/consumers) belong to the infrastructure layer, while the agents which perform transaction verification and block validation belong to consensus layer. These energy users can also take the role of an agent (which facilitates the trading process and performs transaction verification and block validation in the consensus layer)[104]. This section provides a detailed implementation of our proposed multi-layer trust mechanism that enhances the trust of the participating energy users.

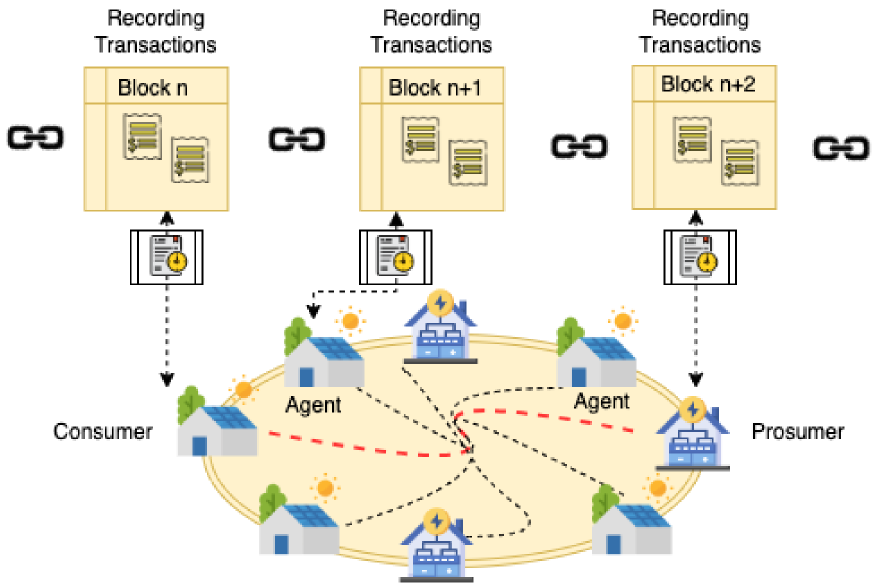

Figure 4.1: Decentralized Energy Trading

4.7 Performance Evaluation

In order to verify and measure the effectiveness of our new approach, we used a simulator for blockchain called SimBlock. SimBlock is devoted to imitating the various blockchain operations, including block creation, block advertising, node administering, and different consensus methods such as PoW (Proof of Work)and PoS (Proof of Stake). The main SimBlock who is a software does not have the function of transaction. To meet the above requirements, we included the function of transactions in SimBlock, thus enabling us to simulate both coin and trust transactions. The communication protocol was amended by adding SimBlock implementation. With this addition of the capabilities, we could measure and compare the three agreement protocols PoW, PoS, and our own in exactly the same network configuration[105]. Furthermore, the fact that SimBlock lacks the advantages of automated contracts and meta-application capabilities, we mapped the functional elements of these two to the SimBlock platform[106].

Algorithm 4 Trust score calculation for validator v

Require: RT_v, V', PTS_v, TL_b
Ensure: NTS_v ▷ New trust score for v

$currentTime = time()$
$\beta_v = currentTime - RT_v$
$\beta_v.Score = \frac{5}{1+e^{-0.5\beta_v}}$
$TC_b = totalCoinTraded(TL_b)$
$TC_b.Score = \frac{5}{1+e^{-0.5TC_b}}$
$TT = |TL_b|$
$TT.Score = \frac{5}{1+e^{-0.5TT}}$
$avgTrust = \frac{\beta_v.Score+TC_b.Score+TT.Score}{3}$
$temp = 0$
for all $i \in V'$ **do**
    $temp+ = \frac{avgTrust \times trustScoreVal(i)}{5}$
end for
$tv_b = \frac{temp}{|V'|}$
$NTS_v = \frac{PTS_v \times |PB_v| + tv_b}{|PB_v|+1}$
function TOTALCOINTRADED(TL_b)
    $totalCoin := 0$
    for all $i \in TL_b$ **do**
        Extract traded coin c from l
        $totalCoin+ = c$
    end for
    return $totalCoin$
end function
function TRUSTSCOREVAL(v)
    $trustScore = 0$ $trustScore$ for v from the smart-contract;
    return $trustScore$
end function

In the simulation that has started out, two kinds of users, a buyer or a seller, were given 100 trust coins of 100 units of time each. The validators on the other hand, were given a range of 2,000-5,000 trust coins starting with a base trust core of 3. We have used these settings along with performance assessments like the time to finish one round of the simulation (execution time), memory, and processor utilization during each iteration. Besides, we were examining how trust calculations were influenced by the number of transactions and blocks produced inside the system. The total execution time for each simulation round gave us the ability to determine which agreement protocol was the fastest in terms of performing a single simulation round.

For each algorithm to be evaluated in a manner that is as close to the real scenario as possible, the transactions per second (TPS) metric could be useful. Nevertheless, one of the challenges of SimBlock is implementing transactions and blocks at a set speed, which should be predetermined as a configuration parameter before running any simulation. This drawback limits the applicability of the TPS measure as a valid performance metric for

Parameter	**Value**
Number of Energy Prosumers	50
Number of Energy Consumers	50
Number of Malicious Users	30
Simulation Duration	1- 24 Hours
Computational Power of Honest Energy Users	0-100%
Computational Power of Malicious Users	0-100%
Average Block Creation Time (Approx)	250s

Table 4.3: Simulation Parameters

SimBlock. Therefore, we selected the duration of time that elapses as the main indicator of the performance of our solution. On the other hand, the CPU and memory usage showed us the differences of the resource consumption among the consensus algorithms. Finally, trust score updates monitored the evolution of trust levels among entities as they interacted with each other in the system, thereby providing a visual map of this evolution[107].

From the above mentioned observations, it is reasonable to assert that the prosumers and consumers with lower trust scores are at a serious disadvantage. Since they are being forced to buy and sell expensive energy units, as compared to the prosumers and consumers who have significantly higher trust scores. In Table 4.4, implemented technique will discourage all participating energy consumers and prosumers to perform any malicious activity.

Other than this, the implemented trust mechanism has also been analyzed from a graphical point of view. Here, the trust scores of the consumers and prosumers have been presented against the specific transactions. It can be clearly seen that there is an upward trend when it comes to the trust scores[108]. Meaning for each subsequent transaction, the selected prosumer and consumer have higher trust score than the last transaction.

A decentralized energy trading mechanism designed to facilitate direct communication between buyers and other party in the electricity market. Under the suggested approach, market participants engage in bilateral energy trading in the forward market in an effort to maximize their welfare. A brand-new algorithm that makes use of the primal-dual gradient technique is created to completely decentralize market clearing. The algorithm's convergence time is shortened when local optimization issues are solved using the first-order approach rather than the interior-point method. In bilateral energy trading, line flow restrictions are modeled by creating price signals to prevent overflowing or clogged lines in the system. This market structure permits bilateral energy trade with product differentiation, respecting the preferences of the market participants[109].

Energy Requests	**Energy Units**	**Prosumer's Pseudo Ids**	**Prosumer's TrustScore($UpdTS_i$)**
Tx21	18	Prosumer A	4.279
Tx22	32	Prosumer D	1.929
Tx23	60	Prosumer E	3.146
Tx24	26	Prosumer F	3.938
Tx25	35	Prosumer H	2.183
Tx26	33	Prosumer J	2.812
Tx27	38	Prosumer K	2.716
Tx28	40	Prosumer Q	4.265
Tx29	59	Prosumer R	2.538
Tx30	35	Prosumer S	3.482
Tx31	40	Prosumer Q	1.010
Tx32	59	Prosumer R	1.238
Tx33	35	Prosumer S	1.182

Table 4.4: Energy Prosumer's Requests with Trust Score

Peer-to-Peer (P2P) energy trading has garnered significant attention from the scientific community over the past decade and a half. With the growing concern for climate change and advancements in technologies such as sensors, wireless networks, and blockchain, a suitable platform for P2P energy trading has emerged[110]. Establishing trust in such platforms remains a major challenge for regulators. In this research, we have used a complete multi-layered strategy to embed trust in the whole blockchain-based energy trading system. Our system has also introduced different User-driven factors into the computation of trust values for energy users as shown in Figure 4.2 . In the course of our design process, we thoroughly took into account the main security threats that are common in blockchain-based systems. Moreover, we performed bench marking experiments to assess our system against two most popular blockchain consensus models, Proof of Work (PoW) and Proof of Stake (PoS). These experiments' results indicate that our proposed protocol provides superior trust levels without incurring significant overhead when compared to these mechanisms.

Agent's Pseudo Ids/ TrustScore($UpdTS_j$)	**Consumers' Pseudo Ids**	**Prosumers' Pseudo Ids**	**Unit Cost ($/kWh)**
Agent M/ 1.83	Consumer G	Prosumer H	1.57
Agent L/ 1.53	Consumer P	Prosumer R	1.81
Agent B/ 1.34	Consumer N	Prosumer R	2.19
Agent L/ 2.99	Consumer N	Prosumer K	2.06
Agent M/ 2.17	Consumer C	Prosumer K	2.19
Agent B/ 2.78	Consumer C	Prosumer J	1.91
Agent L/ 3.52	Consumer Z	Prosumer J	1.97
Agent M/ 3.91	Consumer Z	Prosumer S	2.15
Agent V/ 3.89	Consumer I	Prosumer E	1.99
Agent L/ 4.68	Consumer B	Prosumer E	1.73
Agent B/ 3.46	Consumer V	Prosumer S	1.52
Agent M/ 4.55	Consumer V	Prosumer F	1.76
Agent V/ 4.97	Consumer L	Prosumer Q	1.94
Agent C/ 5.21	Consumer M	Prosumer Q	2.08
Agent L/ 6.62	Consumer M	Prosumer A	2.29
Agent M/ 5.76	Consumer O	Grid	3.55
Agent V/ 5.93	Consumer W	Grid	3.55
Agent L/ 7.25	Consumer X	Grid	3.55
Agent B/ 8.13	Grid	Prosumer T	1.25
Agent L/ 8.74	Grid	Prosumer U	1.25
Agent M/ 9.12	Grid	Prosumer Y	1.25

Table 4.5: Energy trading with Agent's Trust Score

We tested the consensus algorithms between 250 and 8000 nodes and gathered the information on time consumption, memory consumption, and the trust scores of different nodes. The tests were done on a PC with Ubuntu 18.04 operating system, 2.50-GHz Intel Core-i7 CPU,8-GB DDR4 RAM, 1-TB hard disk and Intel HD 520 GPU[111].

4.8 System Framework

The incorporation of blockchain features in distribution systems within a richer trading environment demanded an intelligent trading engine to implement the energy trading framework. This blockchain-based energy trading engine (B-ET-engine) has been developed by making the blockchain and energy market as one. The proposed engine's model entails the physical layer of the power system and applies it in the transactions to tie the financial cash flow to the actual power flow. The initial form of blockchain was birthed by the P2P transfer's thought. The great contradiction is that this is not in line with the way the power actually behaves in the physical structure. In P2P, the cash only goes one way from the person sending to the person receiving, but in a physical system, the power

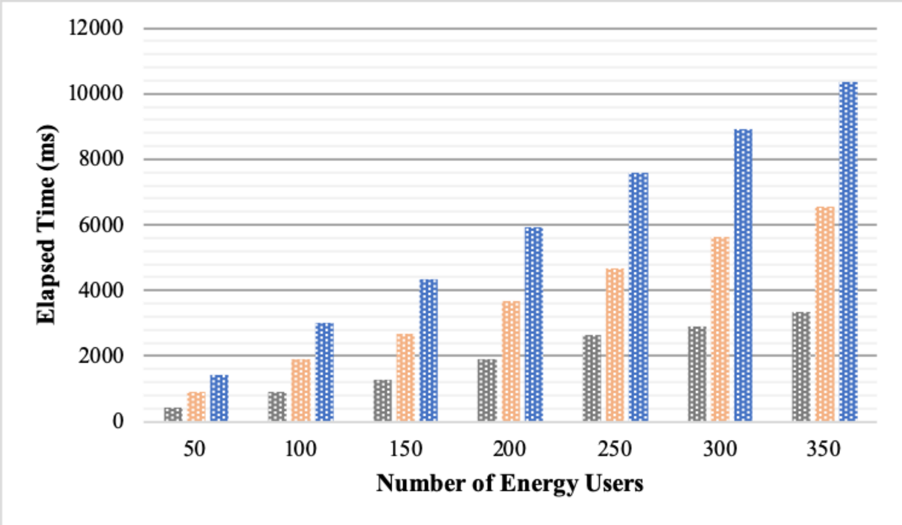

Figure 4.2: Elapsed Time Vs Energy Users

gets to the power system only if the recipient of the cash pays the transmitter of the cash. Nevertheless, one cannot be certain that all the power forwarded will be collected as the network is in control of the power flow.

On the flip side,in the case of P2P paradigm, the envoy and the receivers are supposed to have come to an agreement on the transaction and accordingly the system is not required to be updated for the optimization of social welfare. The major advantage of implementing this P2S2P system is the embedding of a market model that will allow the participants to gain the most profit that leads to the highest social welfare of them during the trading of the energy[61]. Furthermore, inside the blockchain the chain structure is changed so that securing is done in two blocks combined instead of one single as it is in the traditional blockchains. The first block includes a list of expected candidate energy transactions that were obtained from the solution of the market model while the real-time transactions collected through smart meters are communicated, stored and secured in the second block[112]. The ledger confirms the success of the energy commitment of the participant and the real-time energy transactions by user (fulfillment). It should be mentioned that merely the participants' wallets are added in the second block.

In the case of P2P paradigm, the envoy and the receivers have to decide on a transaction and therefore the system will not be updated for the optimization of social welfare. The most important advantage of the implementation of the P2S2P system is the embedding of a market model that will enable the participants to achieve the maximum profit that will be the highest social welfare of them during the trading of the energy[113]. Moreover, the blockchain's chain structure is modified in such a way that the securing is done in two blocks combined instead of one single as it is in the traditional blockchains[87]. The first block has a list of expected candidate energy transactions that were obtained from the solution of the market model while the real-time transactions collected through smart meters are communicated, stored and secured in the second. The ledger confirms the success of the energy commitment of the participant and the real-time energy transactions by user (fulfillment). It should be mentioned that merely the participants' wallets are added in the second block.

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4.9 Summary

In Chapter 4, the pillar of the energy trading system is built through a thorough discussion of its architecture layers and components. The chapter starts off with the Cross Layer Architecture, which is the first element of the system's structure and is crucial for the system's functionality. Inside this architecture, the Consensus Architecture is extremely important for the reliability and security of the network, which is crucial in the case of energy trading.

Then the chapter moves on to the Trust Model, which is an important aspect that creates trust among the participants by introducing some mechanisms that make sure the transactions are fair and transparent. The Meta application Layer is also talked about, as it shows how this layer brings the different applications together to form a unified space for the energy trading. Also, the Trust Score Calculation section provides information on how the trustworthiness of the system is measured, which is one of the crucial aspects for integrity in trades. The Application Layer focuses on the user interaction and trade execution, while the Agreement Layer describes the procedures for forming and managing trade agreements. The last part of the chapter is a Performance Evaluation, which measures the system's total effectiveness and efficiency in real-world scenarios.

Chapter 5

Conclusion

5.1 Conclusion

This chapter's focus on decentralized energy trading is newly created for the purpose of establishing a route for electricity market buyers to directly communicate with the other party. The planned strategy gives the market participants the window to negotiate on energy trading with one another in the forward market in order to maximize their welfare. A totally distinct decentralized clearing market algorithm that employs primal-dual gradient techniques has been developed. The time of convergence of the algorithm was reduced when the local optimization problem was solved using the first-order method instead of the interior-point method. In bilateral energy trading, line flow restrictions are modeled by the means of price signals so as to avoid overflowing or getting clogged lines in the system. This market setup permits bilateral energy trade along with product differentiation, that is, the preferences of the market participants are to be respected.

There is no doubt that a transition towards more sustainable energy sources needs to happen in the nearest future. Governments are now forced to apply new strategies to offset the complete disaster, with the climate crisis and the global concerns about the diminishing natural resources being the driving force. The current energy system as we know it is a major cause of this worldwide situation and therefore a deep change needs to be done. Technological growth is currently on the steepest curve in human history. The solutions are being developed so often and so fast that it is difficult to keep track. Things that were previously impossible are now possible, for example generating your own energy and being self-sufficient. Distributed Energy Resources such as distributed generation stand as a great opportunity for a sustainable energy transition. However, present-day requires the re-conceptualization of the existing energy infrastructure.

Peer-to-Peer (P2P) energy trading has garnered significant attention from the scientific community over the past decade and a half. With the growing concern for climate change and advancements in technologies such as sensors, wireless networks, and blockchain, a suitable platform for P2P energy trading has emerged. However, establishing trust in these platforms poses a significant challenge. The confidence of all involved in a blockchain-based energy trading platform has been holistically integrated with a multi-layered approach in this study. The different User-driven factors have been added as well to calculate the trust values for the energy customers.

Taken altogether, these will set the world towards the sought-after and expected development program. Many organizations are trying to find new business models for their modern technologies. One is the growing importance of blockchain technology in the energy sector. Blockchain provides a wide spectrum of novel approaches to assist the evolution to decentralized energy systems with the example of peer-to-peer energy trading which is tackled in this work.

Our future objective involves deploying and assessing the performance of our proposed consensus protocol in an actual real-life environment, utilizing an existing blockchain system. The applied case studies confirm that, despite requiring less information transmission, the suggested approach can optimize market participants' welfare and produce results that are as good as those of other distributed methods. Furthermore, imposing a line usage fee guarantees that each individual transaction respects line flow restrictions. Since each participant only needs to exchange a little amount of information and a central organizer is not required, the suggested system is simple to put into practice.

Blockchain technologies have come a long way in terms of regulatory, technological, and institutional adaptations, yet little is known about the transaction's and systems' social aspects that inevitable hinder or enable the adoption of such systems. To cope and even try to surpass those, PowerShare project has been launched under wider international consortium devoted to the development of sustainable solutions for islands (SMILE).

5.2 Future Work

In general, blockchain technology has to win the issue of scalability if it is to provide the services and to meet the demand in the various fields. As per the research the question of scalability is a challenging one. However, consensus algorithm is the central building block of blockchain. Thus, this thesis has focused on the two main protocols Proof-of-Work (PoW) and Proof-of-Stake(PoS). Both of them consider to be having the same basic idea of the use of the cryptographic puzzle to get access to the network. However, the idea of PoW finding a cryptographic nonce on an infinite space and PoS only people holding cryptocurrency stake proving their stake ownership are the main differences that make the whole situation different. Thus, the slashing of expenses at the base consensus protocol level can help fix one of the biggest obstacles in the path of the expansion of blockchain-based applications.

There is still the possibility of reducing energy demand through PoS improvement. Therefore, other consensus protocols were proposed such as Tendermint and Ripple which are even do not consume mining, instead, they use energy efficiently. Thru, they are saving off the energy consumption, however, further studies are needed to check their applicability to be used as an appropriate consensus mechanism.

A hypothesis emerged that rewards for active participation in community challenges should be based on individual contribution as per findings of research. The respondents expressed that it would be a stimulating part of the process to know that the more effort one puts in, the more interesting incentives are offered. A redesign of the platform in this direction may lead to a greater response from the participants in the next experiment. Another potential improvement of the system could be by means of challenges, i.e. making them non-mandatory and more flexible. For example, the application could suggest a larger amount of tasks that will be completed in a shorter period of time, in this way it will be appropriate for those who have not much time to interact with the application.

A proposed prototype was missing for the experiment, as it was stated in the previous subchapter. To properly respond to the hypotheses and research questions related to PSv2, it must be a pilot test for a longer period (e.g. a months) with prosumers and consumers. Hence, they could start to grasp the main concepts of the platform and submit an all-in-all evaluation of each of its features. At present, the collected data is about system usability and a general idea of how collective challenges work. Allowing to actively participate and trade energy (even in a simulation) can greatly influence the views, participants have on the system. The creation of a functional prototype for Power Share future tests might result in much better and more accurate findings. The following trial should also involve a more diversified sample so that the platform is able to get feedback from a wider number of people and, thus, will be able to adjust to a wider range of users.

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