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# Developing a Smart Implementation Framework for Blockchain-Based P2P Renewable Energy Trading in Indonesia: A Qualitative Analysis Approach

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### Abstract

The shift towards decentralized and sustainable energy frameworks is progressively propelled by innovations in technology and the imperative for energy democratization. Blockchain technology is a viable approach for facilitating peer-to-peer (P2P) energy trading, thereby diminishing dependence on intermediaries while augmenting transparency, security, and efficiency within energy transactions. Nevertheless, the application of blockchain-enabled energy trading continues to be constrained in Indonesia due to regulatory, technical, and economic challenges. This study aims to develop a smart implementation framework for integrating blockchain into P2P renewable energy trading in Indonesia. A qualitative research approach is employed, incorporating content analysis and thematic analysis of policy documents, technical reports, and stakeholder interviews. A blockchain simulation model is also designed to evaluate feasibility, efficiency, and scalability. The findings highlight that blockchain can significantly enhance renewable energy adoption by facilitating direct energy exchanges among prosumers, improving grid resilience, and reducing transaction costs. The proposed framework outlines essential components such as smart contracts, digital tokens, decentralized ledgers, and regulatory compliance mechanisms. Case studies from global implementations, including Power Ledger in Australia and LO3 Energy in the U.S., demonstrate the viability of blockchain-based energy trading. The study concludes that while blockchain has strong potential to transform Indonesia's energy landscape, successful implementation requires supportive policies, infrastructure investment, and public awareness. Future research should focus on optimizing smart contracts and developing consensus mechanisms tailored to Indonesia's regulatory and market conditions.



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## 1. Introduction

The global energy landscape is changing remarkably as nations move away from traditional, centralized fossil fuel-dependent systems toward more sustainable [1–4],

decentralized renewable energy frameworks [5]. This evolution is propelled by many factors, including the pressing need to confront the climate change challenge, the imperative reduction of greenhouse gas outputs, and the satisfaction of escalating energy requirements in an

environmentally conscientious manner [6–8]. Thanks to technological developments and economies of proportion, green energy sources—such as solar, wind, and hydropower—have gradually reached cost parity and established themselves as viable alternatives to conventional energy-producing techniques [5, 9–12]. However, there are several obstacles to integrate these decentralized and intermittent energy sources into the current power grids, especially when guaranteeing a steady and dependable energy supply [13, 14]. Decentralized energy systems, which facilitate community-level energy production and consumption, have become a viable strategy for addressing these issues, increasing grid failure resilience, lowering transmission losses, and improving efficiency [15, 16]. This transition towards decentralization is not solely a technical imperative but also a strategic initiative aimed at democratizing energy access and empowering local communities [17–19].

Concurrently with the ascendance of renewable energy, digital innovations such as blockchain technology have begun transforming energy trading and management [20, 21]. In 2008, Satoshi Nakamoto—an anonymous entity representing either an individual or a collective whose identity remains undisclosed—published a white paper outlining a framework for Peer-to-peer (P2P) trading of a digital currency known as bitcoin [22–24]. All Bitcoin transactions are recorded on the blockchain, which functions as a distributed, digital, decentralized, and publicly accessible ledger. Participants within the network can conduct transactions over the Internet without a central authority overseeing and validating each transaction [25]. Transactions on a decentralized blockchain network can be processed and authenticated with diminished dependence on intermediaries [26].

Operating as a decentralized technology, blockchain provides a digital ledger that secures, clarifies, and protects transactions from tampering, free from any central regulatory body. In the energy domain, blockchain tech promotes direct energy exchanges between users, empowering prosumers—those who generate and consume energy concurrently, such as residential or commercial entities—to offload their extra energy to fellow consumers [27]. This decentralized trading paradigm eradicates the necessity for intermediaries, including utility companies, thereby diminishing transaction costs [28]. Additionally, it fosters a more effective application of localized renewable energy assets by establishing microgrids and virtual power plants that can work independently of centralized power frameworks [29]. In summary, blockchain-powered P2P energy trading introduces a substantial

opportunity to advance more inclusive and sustainable energy models. By empowering local communities to generate, trade, and consume energy, P2P energy trading yields numerous advantages for all parties involved [30]. On the demand side, consumers can participate in a decentralized energy trading modality without intermediaries' intercession. For instance, they may assume the role of sellers when possessing surplus energy generated from photovoltaic panels, act as buyers to recharge their electric vehicles, or adopt both roles if they possess independent battery systems. At the community level, localized P2P energy trading can enhance the integration of renewable energy by incentivizing consumers to invest in local distributed energy resources or by motivating consumers to acquire green energy certificates—thereby ensuring their consumption of exclusively renewable energy—if they lack the financial capacity to invest in renewable energy assets [31]. Autonomously, Indonesia may surmount certain limitations inherent in its centralized energy grid and expedite the adoption of renewable energy technologies [32, 33].

The transformative potential of blockchain technology within energy markets has been substantiated through various pilot initiatives and scholarly investigations. Take Power Ledger, an enterprise from Australia, which has pioneered a blockchain-supported P2P energy trading platform that lets people buy and sell their extra solar energy [26, 34]. This initiative has illustrated that blockchain can mitigate transaction costs and facilitate more adaptable energy markets, wherein energy is traded in real-time according to supply and demand dynamics. In a comparable vein [35], LO3 Energy in the United States has instituted the Brooklyn Microgrid, a blockchain-enabled community microgrid that permits residents to trade solar energy produced locally [29, 36, 37]. These initiatives underscore the advantages of blockchain in promoting decentralized energy trading, enhancing transparency, and bolstering energy security. Empirical research corroborates these assertions: studies by Andoni et al. [26]. Despite the growing appeal of blockchain energy systems in many affluent nations, deploying this technology in developing countries, particularly throughout Southeast Asia, remains notably restricted. In Indonesia, where the availability of renewable energy resources is significant yet underexploited, an urgent need exists to investigate how blockchain can be amalgamated into the nation's energy framework to foster greater utilization of clean energy and decentralize energy markets.

Existing studies have demonstrated the transformative potential of blockchain-based P2P energy trading in

enhancing energy decentralization, reducing transaction costs, and improving transparency in energy markets [26, 30, 34]. Various pilot projects, such as Power Ledger in Australia and the Brooklyn Microgrid in the United States, have provided empirical evidence of blockchain's capability to facilitate local energy trading and integrate renewable energy resources [29, 36, 37]. However, despite increasing adoption in developed countries, research on blockchain-based P2P energy trading in developing countries, particularly Indonesia, is minimal. A unique regulatory landscape where no formal policy or strategy has been developed for P2P energy trading or blockchain. The absence of a track record of domestic blockchain utilization has hampered the formulation of appropriate policies and regulations, thus inhibiting the potential benefits of P2P energy trading and blockchain technology for the people of Indonesia. Infrastructure limitations, such as the lack of PLN (Perusahaan Listrik Negara) assets in distributing electricity in remote areas, such as in Eastern Indonesia, and socio-economic challenges, such as socialization about the advantages of using blockchain to gain energy benefits, in Indonesia, require a local framework considering these contextual obstacles [32].

Significant research gaps have been identified in several aspects. First, there are still limited studies that comprehensively analyze the implementation of blockchain for P2P energy trading in the Indonesian context, taking into account regulatory, infrastructural, and socio-economic aspects in an integrated manner. Second, no simulation model explicitly evaluates the technical and economic feasibility of a blockchain system for P2P energy trading according to the characteristics of the Indonesian electricity grid. Third, there is still a lack of research that develops an applicable implementation framework considering the strategic role of PLN as the national grid operator. To guide this research, some of the leading research questions asked are how blockchain technology can be effectively integrated into the P2P energy trading system in Indonesia, what are the technical, regulatory, and economic challenges faced in implementing blockchain for P2P energy trading in Indonesia, how a blockchain simulation model can be used to evaluate the feasibility, efficiency, and scalability of a P2P energy trading system in Indonesia, as well as what are the main components of a comprehensive framework for blockchain-based P2P energy trading that is suitable for the Indonesian context. The novelty of this research lies in the comprehensive framework that integrates blockchain technology with Indonesian energy policy, market structure, and the technological capability to create a sustainable and scalable P2P trading system, as well as the development of a blockchain simulation

model to evaluate the feasibility, efficiency, and scalability of a P2P energy trading system in Indonesia, where the two main aspects of novelty include a comprehensive framework that integrates blockchain with Indonesia's specific context and a blockchain simulation model for evaluating P2P trading systems in Indonesia. This study addresses this gap by proposing a tailored blockchain-based P2P renewable energy trading model suited for Indonesia's renewable energy sector. Ultimately, this study seeks to provide a strategic roadmap for policymakers, industry stakeholders, and researchers to accelerate the adoption of blockchain-enabled energy trading, thereby fostering a more decentralized and resilient energy system in Indonesia.

## 2. Materials and Methods

### 2.1. Research Methodological and Analysis Approach

This investigation applies a qualitative strategy to explore blockchain integration in P2P energy trading. The research design leverages content analysis and thematic analysis approaches to pinpoint, classify, and elucidate patterns and themes that arise from the data collected during the study.

Content analysis constitutes a rigorous methodological framework utilized in systematically and objectively evaluating textual, visual, or other media formats to elucidate patterns, themes, or significances embedded within the content being examined. The methodological structure for content evaluation encompasses the aggregation of data from diverse sources, including policy documents, technical reports, scholarly journals, and interviews with relevant stakeholders; categorizing this data into pertinent classifications or themes through a coding methodology; analyzing these categories to uncover patterns or trends, which may involve frequency analysis to ascertain the prevalence of specific themes; and interpreting the findings of the analysis to extract insights regarding the broader contextual landscape.

In contrast, thematic analysis represents a qualitative analytical methodology employed to identify, examine, and articulate the patterns (themes) intrinsic to the data, with procedural steps that involve an initial engagement with the data to achieve a comprehensive understanding, coding the data to emphasize significant segments relevant to the research question, delineating themes by consolidating codes into broader thematic constructs, reviewing themes to validate their relevance and representativeness, defining and labeling themes to clarify their meanings, and composing a report that articulates the identified themes, augmented by quotations from the data to substantiate the analytical narrative [38, 39].

**Table 1.** Method and research analysis

Method Research and Analysis	Components
Renewable Energy Regulation and Policies	Law No. 30 of 2007 concerning Energy Government Regulation No. 79 of 2014 concerning National Energy Policy MEMR Regulation No.49 of 2018 concerning the Use of Rooftop Solar Power Systems Regulations related to smart grids and electricity trading
Primary Data Collections	In-depth interviews with stakeholders like MEMR, PLN and blockchain technical practitioners
Secondary Data Collection	Scientific journals International case studies Energy regulatory documents
Blockchain Technical Analysis	Compliant blockchain architecture Consensus protocol Smart contract Data security and privacy
Economic Analysis	Business model Incentive scheme
Framework Analysis	Stakeholder mapping Implementation gap analysis Risk assessment Policy implementation proposal

Data collection was executed through diverse textual sources, including comprehensive interviews with stakeholders engaged in blockchain technology and renewable energy sectors, such as policymakers from the Ministry of Energy and Mineral Resources (MEMR), PLN, a state-owned electricity company in Indonesia, and blockchain technical practitioners. In addition, pertinent policy and regulatory documents, scholarly articles, technical reports, mass media outputs, and documentation about blockchain implementation projects related explicitly to P2P energy trading.

The qualitative analysis journey was carried out in various structured steps, encompassing (1) detailed data scrutiny to recognize essential themes regarding blockchain integration in P2P energy markets, (2) classifying data to assemble interconnected themes, (3) constructing themes to detect associations and dynamics among categories, and (4) analyzing data to foster a profound comprehension of the opportunities and obstacles of applying this innovation in the Indonesian environment.

This methodological approach facilitates a thorough technical, regulatory, and economic investigation and creates a framework for blockchain implementation in P2P renewable energy trading systems through an exhaustive analysis of the assorted textual data sources compiled [40]. By the method and analysis approach, [Table 1](#) and [Figure 1](#) are the author's steps to conduct research and analyze data divided into four detailed analysis components to obtain a framework for developing a P2P trading renewable energy system in Indonesia.

## 2.2. Data Collection and Sources

Data acquisition configuration is fundamentally important when considering the practicality of introducing blockchain technology for P2P energy transactions in Indonesia. Two primary datasets are employed: (1) technical information about the renewable energy potential in Indonesia, specifically the Target Renewable Energy Capacity Plant, and (2) blockchain-related data concerning the technical prerequisites necessary for the implementation of blockchain technology, encompassing aspects such as blockchain component and blockchain basic theory. Concerning the technical details, accessible public resources, including those supplied by Indonesia's MEMR and assorted regional renewable energy documents, are utilized. This data yields valuable insights into energy production and consumption patterns, grid accessibility, and the potential for renewable energy across diverse regions. Concerning the data specific to blockchain, platforms such as Ethereum, Hyperledger, and the Energy Web Foundation will undergo analysis to evaluate their relevance for energy trading uses. Moreover, through discussions with key stakeholders spanning the energy and blockchain fields, including utility firms, policymakers in energy, and blockchain specialists, we will collect qualitative insights on practical challenges and opportunities like [Table 2](#).

## 2.3. Framework Design for Blockchain-Based P2P Energy Trading

Data gathered from diverse sources indicate that Indonesia possesses substantial renewable energy potential, which serves as the foundation for the

**Table 2.** Research data collection

Data Type	Specific Metrics	Data Sources
Renewable energy data	Renewable energy potential in Indonesia	MEMR, National Renewable Energy Report
Blockchain data	Blockchain component, blockchain basic theory	Open-source blockchain platforms (Ethereum, Hyperledger, Energy Web Foundation)
Stakeholder interview	Utility companies, policymakers, blockchain expert	Direct interviews with stakeholders from the energy and blockchain sectors

**Table 3.** Key of component blockchain architecture

Component	Description	Examples in Practise
Blockchain Platform	Support decentralized energy trading and transparency	Ethereum, Hyperledger fabrics
Consensus Mechanism	Validates transactions with minimal energy consumption	Proof of Stakes, Proof of Authority, Proof of Work
Smart Contracts	Automates transaction execution	Energy sharing agreements
IoT Integration	Monitors and records energy data in real-time	Smart Meters
Energy tokens	Represents units of energy in digital form	Renewable energy credits (RECs)
Prosumers & Consumers	Participants in the energy market	Community, homeowners
Regulatory	Ensures alignment with national policies	Partnership with PLN, MEMR, National Energy Council
Incentive Mechanism	Reward for renewable energy	Feed-in tariffs, tax incentives

formulation of blockchain architecture to facilitate decentralized energy trading. This architecture is specifically engineered to accommodate elevated transaction volumes and enable real-time energy trading predicated on the availability of renewable energy resources.

Furthermore, prevailing regulations, such as Law No. 30 of 2007 regarding Energy and Government Regulation No. 79 of 2014 about National Energy Policy, underscore the necessity of regulatory compliance in energy trading; consequently, this architecture incorporates compliance mechanisms to guarantee that all transactions adhere to national regulations, encompassing the requisite reporting and auditing features that uphold transparency and legality. Stakeholder feedback has also revealed apprehensions regarding the intricacy of integrating blockchain technology with existing utility systems, prompting the proposed architecture to incorporate a user-friendly interface and integration points for current utility systems, such as PLN, thereby rendering the system accessible to all users, including individuals lacking extensive technological expertise.

Additionally, to stimulate engagement in renewable energy trading, this architecture implements an incentive mechanism that facilitates the tokenization of energy credits, thereby enabling prosumers to receive rewards for their contributions within the energy marketplace. Through a systematic analysis of this specific data, the proposed blockchain architecture for P2P renewable energy trading in Indonesia is meticulously designed to confront the distinctive challenges and opportunities present within the local context, thereby ensuring that this framework is not only technically robust but also

pragmatic and aligned with the requirements of stakeholders within the Indonesian energy sector.

The introductory segment of this inquiry involves crafting a conceptual scaffold for blockchain-oriented P2P energy trading in Indonesia. This framework considers Indonesia's distinctive geographical, regulatory, and technological characteristics, emphasizing how blockchain technology can facilitate decentralized energy distribution. Guided by an extensive evaluation of the dominant energy infrastructure, the potential for renewable energy sources, and the integration of blockchain technology in global energy markets, the framework's design emerges. Key features of the framework consist of the blockchain platform's framework, various consensus methods, including proof of stake or proof of authority, and the relationship dynamics between prosumers and consumers in a decentralized marketplace. This segment will elucidate the application of smart contracts in automating energy transactions, thereby ensuring transparency and reducing transaction costs [28, 34].

Furthermore, other components such as smart meters, energy tokens, community, and incentives are also important parts of a P2P trading architecture because they function as part of the technical framework in the blockchain, as in Table 3. Most importantly, the contribution of regulatory authorities and the prospective collaborations with local energy providers will be delineated, addressing how the framework is congruent with national energy policies and regulatory frameworks in Indonesia.

#### 2.4. Blockchain Simulation and Model Development

To analyze the effectiveness and practicality of energy trading facilitated by blockchain technology among peers, a simulation model will be developed employing blockchain simulation tools and platforms. This model emulates a decentralized energy marketplace wherein prosumers and consumers use blockchain technology to transact energy [41].

The framework will incorporate empirical data from Indonesian regions with significant potential for renewable energy, such as locales endowed with ample solar or wind resources. The simulation will investigate diverse scenarios or simulation, including PLN's role in the scenario as a blockchain developer, a renewable energy system framework using blockchain technology in a P2P trading scheme, and the dynamics of energy supply and demand. The blockchain simulation tool will facilitate an examination of parameters such as transaction throughput, latency, and energy cost per transaction. Moreover, the simulation will integrate distinct consensus algorithms, evaluating their energy efficiency and scalability to identify the most appropriate solution for Indonesia.

Smart contract capabilities will undergo thorough evaluation regarding the automation of the trading cycle, overseeing payments, and enforcing trading standards to decrease human participation while boosting system effectiveness [42]. Model validation was conducted by comparing operational data from the Brooklyn Microgrid and Power Ledger pilot projects. In these projects, smart contracts were implemented using Solidity v0.8.0, with features such as automated buy-sell order matching, real-time payment management, regulatory compliance verification, incentive and penalty management, and smart meter integration. Simulation results indicate that Hyperledger Fabric with PoA consensus is most suitable for the Indonesian context.

In selecting pertinent international blockchain implementation case studies, it is imperative to consider several critical criteria to ensure their relevance and applicability within the Indonesian milieu. Firstly, the pertinence of the technology emerges as the foremost criterion, whereby the chosen case studies must employ the same or analogous blockchain technology as that proposed, exemplified by the Brooklyn Microgrid and Higashi-Fuji P2P energy trading initiatives, thereby allowing the findings to be directly applicable or requiring minimal adaptation.

Secondly, the emphasis on the renewable energy sector is also of paramount importance, necessitating that the selected case studies concentrate on this domain, such

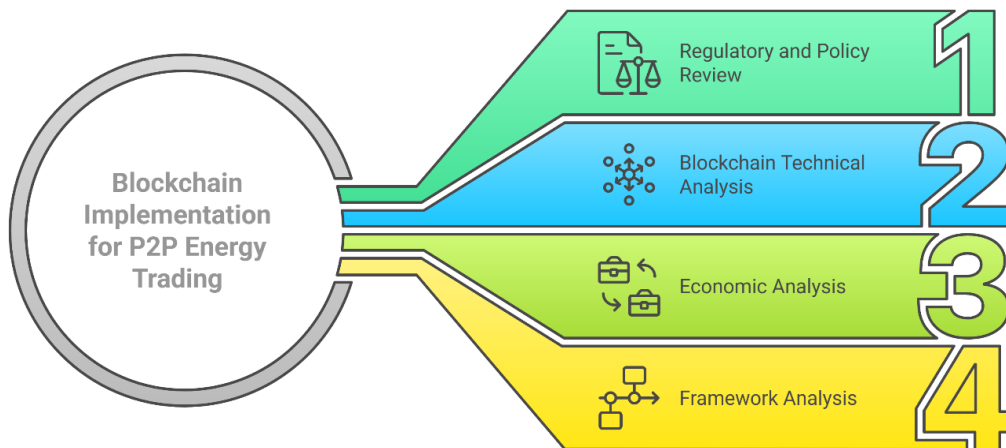
as energy trading systems or energy network management, with pertinent illustrations including Brooklyn Microgrid and Higashi-Fuji P2P energy trading that have effectively implemented blockchain solutions within this context, aligning with Indonesia's national energy policy objectives. Additionally, the scale and operational environment of the case study must accurately mirror the conditions prevalent in Indonesia, incorporating factors such as user demographics, the types of energy traded, and the existing regulatory framework to precisely represent the technological application in practice.

Moreover, the outcomes and insights derived from case studies that delineate precise results and the obstacles encountered will yield invaluable perspectives for implementation in Indonesia, which is crucial for identifying potential risks and opportunities. At last, the recognition of local and worldwide stakeholders in the case study should not be overlooked, as this partnership can furnish the fundamental guidance and resources essential for effective execution while reinforcing the project's authority in the community's view.

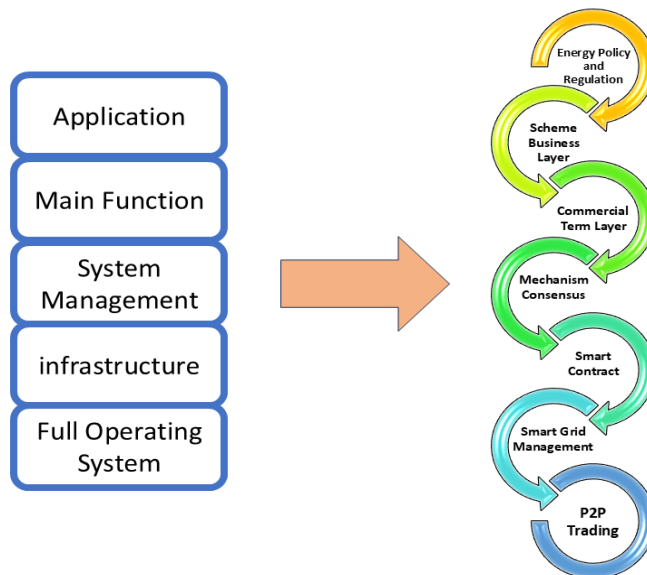
Considering these criteria, the relevance of international case studies to the Indonesian context can be ascertained, thereby establishing a robust foundation for analysis and recommendations within this study.

### 3. Results and Discussion

The proposed implementation of blockchain in a renewable energy system is illustrated in [Figure 1](#), showing key components and their interactions. The system comprises a Decentralized Energy Marketplace, Prosumers, Consumers, Smart Meters, Blockchain Network, Smart Contracts, and Regulatory Framework. Prosumers generate renewable energy and sell excess electrical energy allocated to consumers through a decentralized P2P trading platform facilitated by blockchain technology. Smart meters record energy generation and consumption, securely transmitting data to the blockchain network. The Blockchain Network acts as a decentralized ledger, ensuring transaction transparency, security, and traceability. Smart contracts automate energy transactions, verifying energy availability, pricing, and payments without intermediaries. These contracts facilitate real-time settlements, ensuring efficiency and cost reduction. The Regulatory Framework governs system operations, ensuring compliance with national energy policies while supporting incentives for blockchain adoption. Successful implementation requires infrastructure investment in smart grids, digital payment integration, and interoperability standards. Stakeholder collaboration,



**Figure 1.** Proposed implementation of blockchain in renewable energy system.



**Figure 2.** Proposed architecture model of blockchain technology in Indonesia.

including government agencies, energy providers, technology firms, and financial institutions, is crucial to overcoming regulatory and technical challenges. A phased approach, starting with pilot projects and continuous evaluation, will help refine the system before large-scale deployment. By leveraging blockchain, Indonesia can create a transparent, decentralized, and efficient renewable energy trading system, empowering communities and accelerating clean energy adoption.

Figure 2 shows the proposed architecture model of blockchain technology in Indonesia, outlining the key components and process flow for energy trading. At the foundation, Energy Policies and Regulations establish the legal framework for blockchain adoption in the energy sector. Once these policies are in place, an Energy

Business Scheme is developed, defining regulatory-compliant trading models. The next step involves setting the Consensus Mechanism, which determines transaction validation rules and establishes participant trust. This mechanism is then embedded in a Smart Contract System, which automates and enforces agreements without intermediaries. A Smart Grid infrastructure ensures efficient energy distribution, enabling P2P Trading where prosumers and consumers transact securely on a decentralized platform. The architecture eliminates the need for brokers, reducing costs while enhancing transparency and security. This structured approach ensures a seamless transition to blockchain-based energy trading, fostering Indonesia's more efficient and decentralized energy market.

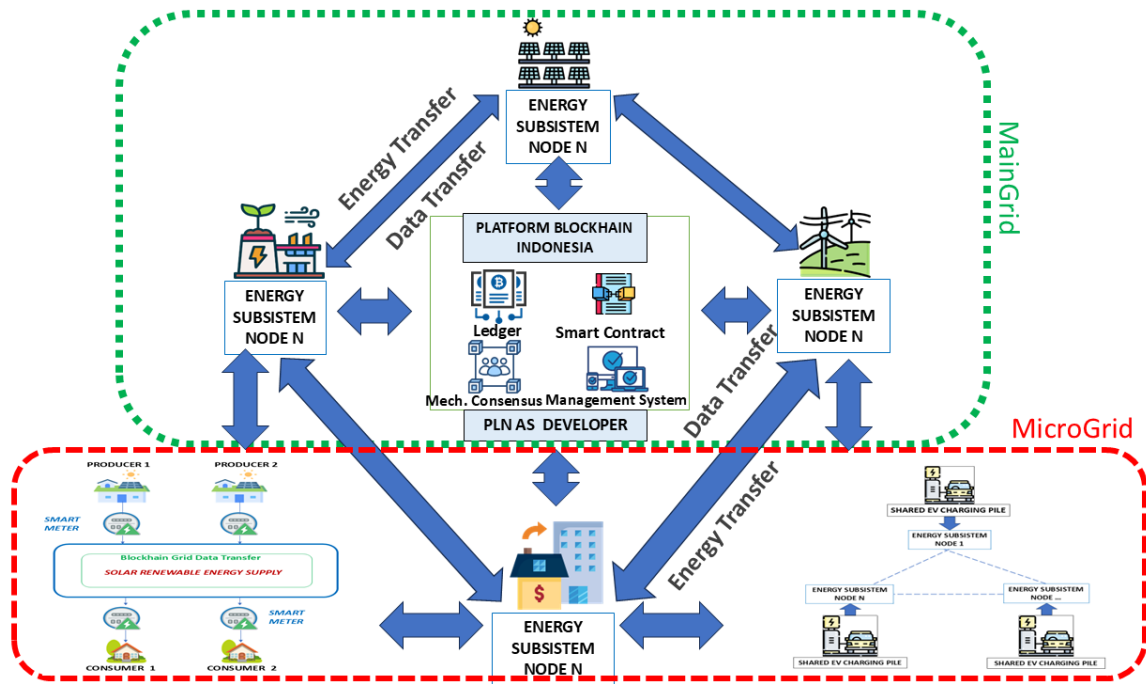


Figure 3. Proposed schematic diagram of concept PLN as blockchain developer.

Figure 3 shows the Implementation of the Blockchain Framework using the Framework Diagram. This diagram comprehensively overviews the key components and their interconnections in a blockchain-based P2P energy trading system. The framework is designed to ensure the seamless integration of blockchain technology in energy trading, focusing on security, transparency, and efficiency [43].

This diagram consists of several key elements that interact to facilitate energy trading. The framework's core is the blockchain network, which acts as a decentralized ledger that records all transactions securely and immutably. The network is powered by smart contracts, which automate trade agreements between prosumers and consumers, eliminating the need for intermediaries. In addition, smart meters play a vital role in collecting real-time energy consumption and production data, which is then sent to the blockchain for verification and transaction execution. The framework also incorporates an energy tokenization mechanism, which allows energy units to be represented as digital tokens that can be traded among participants. This feature enables efficient market transactions while ensuring transparency in energy exchange.

Furthermore, the consensus mechanism, which can be based on Proof-of-Stake (PoS) or Proof-of-Authority (PoA) [44], ensures transaction validation in a secure and decentralized manner. Another important component is the role of PLN, which is expected to be the developer and regulator of blockchain in the Indonesian energy market. PLN oversees the integration of blockchain

technology into the national energy infrastructure, ensures compliance with regulatory policies, and maintains grid stability. The framework also envisages implementing a decentralized energy market where prosumers and consumers can engage in energy transactions with greater flexibility and autonomy. To support the operational functionality of the framework, a secure data management system is integrated to maintain user information and transaction records. In addition, an incentive and reward system is established to encourage participation in the energy trading market, which promotes the integration of sustainable energy resources.

In summary, the Blockchain Framework Implementation depicted in Figure 3 is a structured and scalable approach to integrating blockchain technology into the Indonesian energy sector. The framework facilitates a secure, transparent, and efficient energy trading system by combining key elements such as smart contracts, tokenization, smart meters, and a decentralized trading platform. With PLN playing a leading role in blockchain governance, the model provides a viable path to increasing renewable energy adoption and optimizing energy distribution in Indonesia.

Figure 4 shows the proposed smart framework model of Indonesia's P2P trading renewable energy system. The framework includes key elements that ensure an efficient and secure energy trading system using blockchain technology. At its core, the blockchain platform acts as a decentralized ledger to facilitate transparent and tamper-proof energy transactions. Prosumers (energy producers

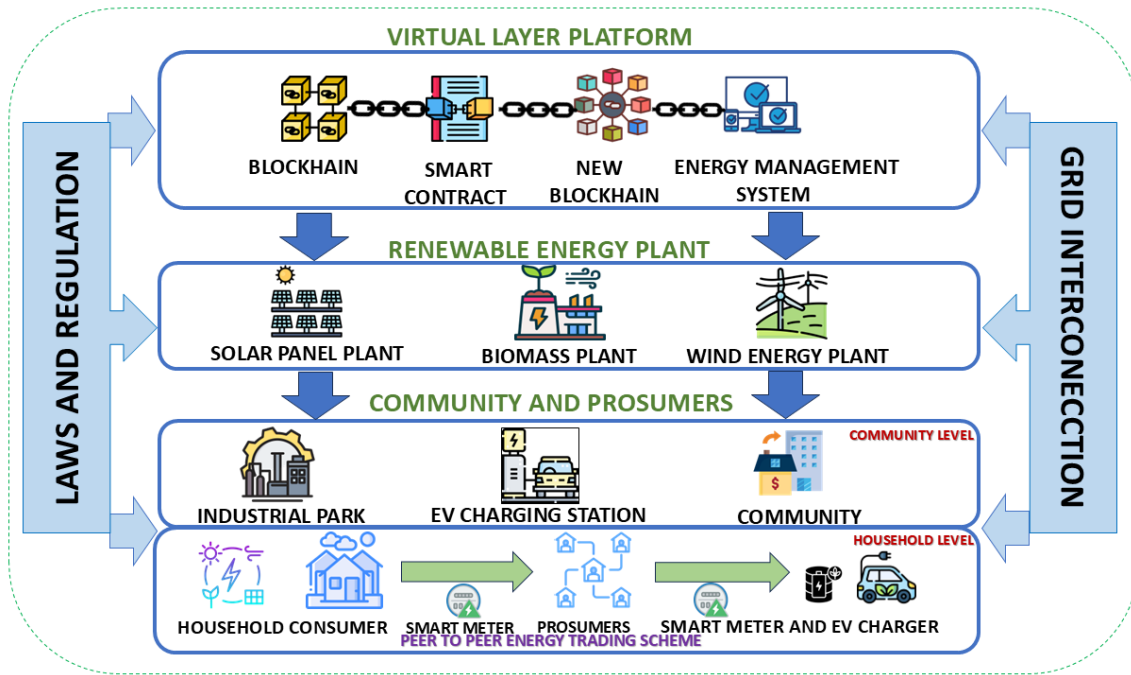


Figure 4. Proposed smart framework model of P2P trading renewable energy system in Indonesia.

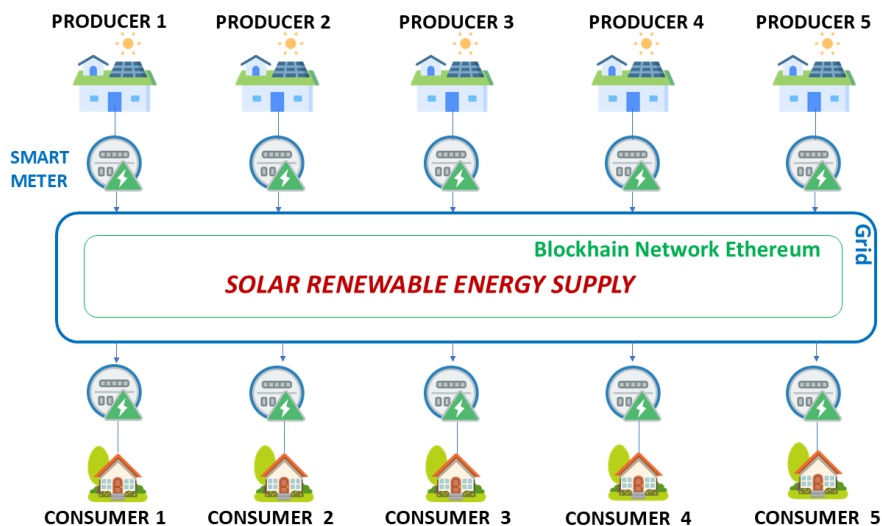


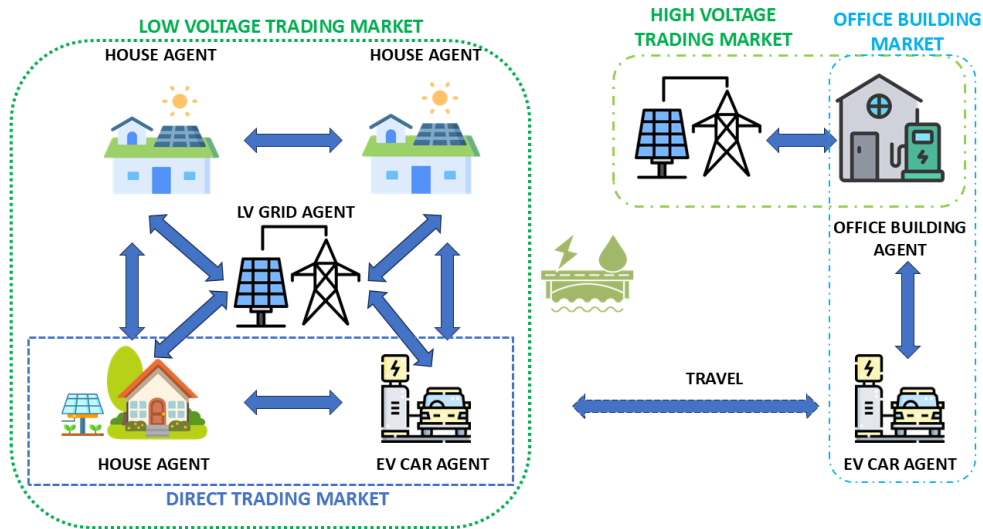
Figure 5. Schematic diagram of Brooklyn microgrid.

and consumers) generate renewable energy and trade it with consumers who require additional energy [45]. Smart contracts automate the trading process, defining transaction rules and ensuring compliance without intermediaries. Energy tokens serve as digital assets representing energy units exchanged within the system. Smart meters provide real-time energy production and consumption monitoring, enhancing data accuracy and system reliability. Additionally, the framework includes community-based microgrids, enabling localized energy exchange to optimize distribution efficiency. Integrating regulatory support and policy frameworks ensures compliance with national energy regulations [46], while stakeholder collaboration, including utility companies,

government agencies, and technology providers, fosters system adoption and scalability.

As shown in Figure 5, the implementation of this model is inspired by global case studies demonstrating the feasibility of blockchain-based P2P energy trading. In the United States, the Brooklyn Microgrid by LO3 Energy allows residents to exchange locally produced solar energy using blockchain technology [47]. Similarly, Canada has initiated Blockchain-enabled Transactive Energy Systems in Ontario to integrate renewable energy sources.

The Higashi-Fuji P2P Energy Trading Demonstration Experiment in Japan enables energy exchange between



**Figure 6.** Schematic diagram of the Higashi-Fuji P2P energy trading demonstration experiment.

communities to enhance grid efficiency, as shown in Figure 6. These case studies highlight the effectiveness of blockchain technology in decentralized energy markets, providing valuable insights into Indonesia's adoption of P2P trading [48].

Based on the results, there are interesting topics to discuss. The potential of blockchain-based P2P energy trading in Indonesia presents a transformative opportunity to decentralize energy markets and enhance the adoption of renewable energy. The study highlights Indonesia's significant renewable energy potential, including 207.8 GW of solar, 60.6 GW of wind, and 23.9 GW of geothermal energy [3, 49], which remains vastly underutilized. By leveraging blockchain technology, energy transactions can be securely and transparently conducted without intermediaries, allowing prosumers to sell excess electricity directly to consumers. This system can enhance the accessibility of energy resources in remote areas, reduce transmission losses, and empower local communities to participate in energy markets. However, the study emphasizes that the lack of a regulatory framework remains a significant barrier to widespread implementation.

The role of PLN as a potential blockchain developer in Indonesia is a crucial aspect of the proposed framework. As the state-owned electricity company, PLN controls the national grid and has the technical expertise and resources to integrate blockchain technology into Indonesia's energy infrastructure. The study suggests that PLN could develop a blockchain-based P2P trading platform to facilitate decentralized transactions while ensuring grid stability. This approach would allow PLN to maintain its central role in energy distribution while embracing innovative solutions for integrating renewable

energy sources. The challenge lies in regulatory alignment and the willingness of PLN to transition from a traditional centralized model to a more decentralized and consumer-driven energy market.

The economic and policy implications of blockchain-based P2P energy trading in Indonesia require thorough examination. The study outlines key legislative instruments, such as Law No. 30/2007 on Energy and Government Regulation No. 79/2014, which set targets for renewable energy development. However, specific regulations for blockchain applications in energy trading are still lacking; although regulatory frameworks are acknowledged as pivotal in executing a blockchain-based energy trading system, a comprehensive examination is imperative to ascertain the ramifications of specific regulations on the proposed model. Among the salient regulations worthy of consideration is Law No. 30 of 2007 on Energy, which establishes a legal infrastructure for energy governance; it is essential to guarantee that the proposed peer-to-peer trading system adheres to the tenets of energy autonomy and the optimal exploitation of national energy resources, as these factors can significantly influence the modalities of energy transactions and the sale of energy by prosumers to the grid. Furthermore, Government Regulation No. 79 of 2014 concerning National Energy Policy delineates objectives for the renewable energy mix and furnishes strategic guidance for the advancement of renewable energy; thus, the proposed framework must be congruent with objectives and necessitates a mechanism for the reporting and monitoring of target achievements through a blockchain system.

Additionally, the Regulation of the Minister of Energy and Mineral Resources No. 49 of 2018 regarding the

Utilization of Rooftop Solar Power Systems empowers consumers to produce their own electricity and market surplus energy to the PLN network [50], necessitating the integration of suitable net metering and smart contract schemes to ensure compliance with this regulation and to facilitate efficient transactional processes. Lastly, smart grids and electricity trading regulations must be incorporated into the framework, encompassing technical standards and licensing protocols requisite for the effective operation of blockchain systems within the prevailing regulatory landscape. Economic incentives, such as feed-in tariffs, tax exemptions, and carbon credit trading, are necessary to stimulate capital allocation in blockchain-based renewable energy markets.

Furthermore, the enduring viability of the framework will be contingent upon the capacity to adjust fluctuations in market conditions and advancements in technology; consequently, additional investigation is imperative to examine business models that possess the flexibility to respond to the evolving dynamics of the energy sector. The study emphasizes that a well-structured business model and regulatory support will be essential for successfully adopting this technology. Without clear policies and financial mechanisms, the transition to blockchain-powered energy trading may face significant hurdles in Indonesia.

This study provides a foundational framework for implementing blockchain-based P2P energy trading in Indonesia, offering practical applications for decentralized renewable energy markets. By leveraging blockchain, this system enables transparent, secure, and cost-effective transactions between prosumers and consumers, reducing reliance on traditional intermediaries and enhancing energy access, particularly in remote areas. The contributions of this research include a structured smart contract framework, consensus mechanisms, and regulatory insights tailored to Indonesia's unique energy landscape. Additionally, it highlights the economic and technological feasibility of blockchain adoption, emphasizing the role of stakeholders such as PLN, policymakers, and energy startups. Future research should optimize blockchain scalability and transaction efficiency, refine smart contract automation for energy trading, and develop a regulatory sandbox to test blockchain implementations in real-world settings. Further exploration into AI-driven demand forecasting and energy pricing within blockchain ecosystems could enhance system performance and market adoption.

Validation of the proposed framework was conducted through a multitude of rigorous methodologies, encompassing an examination of international case

studies that juxtaposed essential components of the suggested model with exemplary practices derived from case studies such as the Higashi-Fuji P2P Energy Trading initiative in Japan and the Brooklyn Microgrid project in the United States. This analysis entailed a thorough evaluation of the implementation of components such as smart contracts, consensus mechanisms, and incentive structures within diverse contexts, alongside the outcomes attained in terms of energy trading efficiency and transparency. Subsequently, a simulation framework will be established to assess the framework's efficacy by exploring various P2P energy trading scenarios utilizing empirical data from Indonesia, aimed at evaluating system performance under authentic conditions, including parameters such as transaction throughput, latency, and energy costs per transaction. Feedback regarding the responses elicited from this research framework simulation will be gathered from stakeholders through interviews and dialogues, which can provide valuable insights into practical challenges and opportunities that may remain unrecognized in the literature review or case analyses, along with a framework for national energy policy that guarantees the alignment of the framework with pertinent regulations in Indonesia, inclusive of an evaluation of the compliance of the framework components with existing laws and the formulation of policy recommendations necessary to bolster implementation. Through this exhaustive validation approach, the proposed framework emerges from theoretical foundations. It is also substantiated by empirical evidence and established best practices within the domain, affirming its pertinence and efficacy in the Indonesian context. The author is concentrating on case studies and developing a proposed model simulation framework.

The findings derived from interviews conducted with stakeholders, encompassing technology developers and regulatory authorities, yield significant insights regarding the impediments and prospects associated with the implementation of blockchain-based energy trading systems, wherein numerous stakeholders underscore the criticality of personal data safeguarding and transaction integrity, thereby advocating for the advancement of enhanced security features within the model, inclusive of data encryption and rigorous validation protocols; moreover, these interviews elucidate that a deficiency in public comprehension of blockchain technology may obstruct its adoption, thereby necessitating the incorporation of an educational initiative within the proposed model aimed at augmenting awareness and understanding of the advantages of the peer-to-peer energy trading system; furthermore, backing from governmental entities and the

presence of explicit regulatory frameworks are deemed exceedingly pivotal for efficacious implementation, which subsequently informs policy recommendations articulated within the proposed framework, including the imperative for a comprehensive regulatory schema to foster the adoption of this technology; lastly, numerous stakeholders accentuated the necessity for a robust infrastructure to underpin the energy trading system, encompassing an effective smart grid and monitoring apparatus, which are fundamental components of the proposed model. Consequently, this study offers a theoretical construct and mirrors the necessities and anticipations of stakeholders engaged in the energy sector, ensuring the proposed model is more pertinent and acceptable to the broader community.

The suggested framework shows significant potential for improving the exchange of renewable energy. Yet, it is crucial to recognize various limitations that need thoughtful attention, such as the insufficient infrastructure in Indonesia, especially in remote areas, which could hinder the implementation of blockchain technology and its connection with existing systems; the lack of understanding and knowledge among the public and key stakeholders about blockchain technology and its benefits in energy trading, which restricts the involvement of prosumers and consumers; along with the challenges related to the available data on renewable energy generation and usage in Indonesia, which is frequently partial and incorrect, thus possibly jeopardizing the accuracy of the model and the conclusions drawn from the evaluation. Furthermore, the execution of the blockchain framework for peer-to-peer renewable energy trading in Indonesia encounters obstacles, such as regulations and policies that may not entirely endorse the adoption of blockchain technology, necessitating regulatory modifications to facilitate this innovative trading model; system interoperability poses a challenge in aligning blockchain systems with the current energy infrastructure, inclusive of existing energy management and grid systems; as well as concerns regarding security and privacy, where, notwithstanding the enhanced security offered by blockchain, apprehensions persist regarding user data privacy and the susceptibility to cyberattacks, which necessitate supplementary measures to safeguard sensitive information. The proposed model also operates under specific boundary conditions that must be taken into account, such as economic conditions influenced by fluctuations in energy prices and investment costs associated with new technologies, which necessitate sensitivity analysis to comprehend the ramifications of changing economic circumstances, social and cultural conditions that may impact the acceptance and

participation in renewable energy trading systems, thereby making a nuanced approach to the local context indispensable; and environmental conditions that encompass the availability of renewable energy resources and the ramifications of climate change, necessitating environmental impact assessments to ensure the model's sustainability. Ultimately, the blockchain framework for trading renewable energy directly among users in Indonesia has considerable promise to boost efficiency and clarity in the energy domain; yet, to achieve effective execution, it is vital to confront the present barriers and difficulties, with proposals for ongoing investigation that involve policy creation to aid the use of blockchain technology, upgrades to infrastructure and access to data, alongside further explorations into the social and economic effects of implementing this framework.

#### 4. Conclusions

This inquiry uncovers the important prospects that blockchain technology can offer for facilitating (P2P) renewable energy trading within Indonesia. The principal findings of this research indicate that Indonesia possesses a plethora of renewable energy resources, which encompass solar (207.8 GW), wind (60.6 GW), biomass (32.6 GW), and geothermal (23.9 GW), all of which can be optimized through the integration of blockchain technology to enhance the efficiency and transparency of energy transactions. The proposed implementation framework underscores the critical necessity of robust regulatory support, sufficient technological infrastructure, and economic incentives to promote blockchain integration within the energy sector. Furthermore, a blockchain architecture model specifically designed for the Indonesian electricity market, with PLN identified as the primary stakeholder, is anticipated to facilitate the integration of this technology with the pre-existing network. Global case studies illustrate that blockchain can be effectively employed in decentralized energy trading, yielding insights into best practices pertinent to the Indonesian milieu. Despite the great benefits this technology provides related to decentralization and energy efficiency, hurdles like regulatory unification, technical standardization, and system compatibility need to be tackled. The results of this inquiry underscore that integrating blockchain in Indonesia's P2P renewable energy trading can lead to greater efficiency, improved transparency, and progress towards a sustainable energy solution. With appropriate policy support, infrastructure investment, and effective educational initiatives, blockchain can serve as a formidable instrument to foster the adoption of renewable energy and cultivate a more decentralized and

inclusive energy market. This investigation highlights the value of partnership among different stakeholders to effectively roll out these endeavors. Future inquiries should concentrate on optimizing smart contracts and developing consensus mechanisms that align with the renewable energy landscape in Indonesia, as well as validating the proposed implementation framework for P2P renewable energy trading in Indonesia as a crucial step towards realizing these objectives. Based on the results, there are interesting topics to discuss.

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