ENERGY TRADING OF RENEWABLE ENERGY RESOURCES BY USING BLOCKCHAIN TECHNOLOGIES

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BILLY TU JIA FENG

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ABSTRACT

Blockchain is an emerging kind of technology that has the potential to revolutionise a wide range of organisations and businesses as well as the way people currently living. Most countries are more focused on centralised electric markets especially US. Traditional centralized energy trading systems suffer from numerous vulnerabilities, including single points of failure and privacy concerns. This thesis presents a comprehensive study on the design and implementation of a decentralized energy trading system using blockchain technology. A comparative analysis was conducted to assess the system's advantages over conventional centralized energy trading systems. The results showed that the blockchain-based approach offered better energy efficiency and higher user base compared to centralised system. For each deployed smart contracts in Hardhat, it consumes 10 computing units while Truffle uses 49 computing units. Thus, higher computing units lead to lower efficiency. Although implementation proved successfully, some challenges were identified including security in real time, and real time users deploying the smart contracts for energy trading. Suggestions for mitigating these challenges were proposed, emphasizing the need for collaboration with industry stakeholders and policymakers. In conclusion, this thesis contributes to the growing body of research on blockchain applications by presenting a decentralized energy trading system. The findings highlight the system's potential to increase the users' base and energy efficiency when it comes to smart contact deployment while offering a secure, transparent and traceable data shared across the business network. Further study and practical use are encouraged as the technology develops in order to address the difficulties and fully understand the revolution of blockchain-based energy trading systems.

ABSTRAK

Blockchain merupakan sejenis teknologi baru muncul yang berpotensi merevolusikan pelbagai organisasi dan perniagaan serta cara hidup orang ramai pada masa ini. Kebanyakan negaralebih tertumpu kepada pasaran elektrik berpusat terutamanya US. Sistem perdagangan tenaga berpusat tradisional mengalami pelbagai kelemahan, termasuk satu titik kegagalan dan kebimbangan privasi. Tesis ini membentangkan kajian komprehensif mengenai reka bentuk dan pelaksanaan sistem perdagangan tenaga terdesentralisasi menggunakan teknologi *blockchain*. Analisis perbandingan telah dijalankan untuk menilai kelebihan sistem berbanding sistem perdagangan tenaga berpusat konvensional. Keputusan menunjukkan bahawa pendekatan berasaskan blockchain menawarkan kecekapan tenaga yang lebih baik dan pangkalan pengguna yang lebih tinggi berbanding sistem berpusat. Bagi setiap *smart contract* yang digunakan dalam *Hardhat*, ia menggunakan 10 unit pengkomputeran manakala *Truffle* menggunakan 49 unit pengkomputeran. Oleh itu, unit pengkomputeran yang lebih tinggi membawa kepada kecekapan yang lebih rendah. Walaupun pelaksanaan terbukti berjaya, beberapa cabaran telah dikenal pasti termasuk keselamatan dalam masa nyata, dan pengguna masa nyata menggunakan smart contract untuk perdagangan tenaga. Cadangan untuk mengurangkan cabaran ini telah dicadangkan, menekankan keperluan untuk kerjasama dengan pihak berkepentingan industri dan penggubal dasar. Kesimpulannya, tesis ini menyumbang kepada badan penyelidikan yang semakin berkembang mengenai aplikasi *blockchain* dengan membentangkan sistem perdagangan tenaga terdesentralisasi. Penemuan ini menyerlahkan potensi sistem untuk meningkatkan asas pengguna dan kecekapan tenaga apabila melibatkan penggunaan hubungan pintar sambil menawarkan data yang selamat, telus dan boleh dikesan yang dikongsi merentasi rangkaian perniagaan. Kajian lanjut dan penggunaan praktikal digalakkan apabila teknologi berkembang untuk menangani kesukaran dan memahami sepenuhnya revolusi sistem perdagangan tenaga berasaskan *blockchain*.

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LIST OF ABBREVIATIONS

API	-	Alternative Current
BFT	-	Byzantine Fault Tolerance
CFT	-	Crash Fault Tolerance
DApps	-	Decentralised Applications
ETH	-	Ethereum
EVs	-	Electrical Vehicles
IEEE	-	Institute of Electrical and Electronics Engineers
IDE	-	Integrated Development Environment
IoE	-	Internet of Energy
MIT	-	Massachusetts Institute of Technology
NEM	-	Net Energy Metering
P2P	-	Peer-to-Peer
PoS	-	Proof-of-Stake
PoW	-	Proof-of-Work
RPC	-	Remote Procedure Call
SDK	-	Software development kits
SCE	-	Smart Contract Engineering
SMT	-	Satisfiability Modulo Theories
SPDX	-	Software Package Data Exchange
URL	-	Uniform Resource Locator
VS Code	-	Virtual Studio Code
WSL	-	Window Subsystem Linux

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CHAPTER 1

INTRODUCTION

1.1 Background

1.1.1 Renewable Energy

Renewable energy is seen to be a solution to save the Earth. The utilization of renewable energy resources can reduce the demand for fossil fuels, thus lowering the levels of carbon dioxide in the atmosphere. There are many types of renewable energy, such as solar, wind, and many more. These types of energy can produce high electrical energy for daily usage. It is suitable to concentrate on it in more detail. Solar energy is the type of energy generated by the sun. If the technology nowadays can tame them entirely, it will help to ensure the ecosystem around the Earth not be harmed further.

The primary purposes of renewable energy are to decrease the emissions from burning, reduce global warming, create economic development and jobs in industries [1]. This serves many advantages, especially when it comes to this new generation. The new generations can use mobile applications to get the latest renewable energy technologies and learn from them. Improving the efficiency of renewable energy will be a stable and reliable energy for all humans. Stable in terms of price and reliable in terms of an unlimited amount of energy.

Other than that, due to research and development in all the countries around the world, the amount and the efficiency of renewable energy are increasing daily. The potential of it replacing all the non-renewable energy is getting closer. According to Datuk Seri Takiyuddin Hassan, the Minister of Energy and Natural Resources [2], he stated that renewable energy will contribute 40 per cent to the country's energy supply in 2035. 31% of the renewable energy will be included in the Large Scale Solar (LSS) project. It is environmentally friendly by reducing carbon emissions and the sustainability of the raw materials to produce this energy.

1.1.2 Energy Trading

Energy trading is another trend for this generation. The idea of energy trading, which is meant to decentralise energy, is close to the theory of the Internet of Energy (IoE) [3]. Energy trading involves three main parties: generators, consumers, and suppliers. Taking the example of Sarawak,

the electricity supplier is Sarawak Energy, and the consumers are the Sarawakian and the generators, such as thermal power plants and energy storage sites[4]. The electricity is generated at power stations and then bought by suppliers to sell to consumers for daily usage. The energy trading between power generators that produce the electricity and the power supplies that sell it to the consumers.

There would be electricity contracts between the suppliers and the traders; electricity trading occurs in short and long-time frames. The generation and supply should meet an exact demand for every minute, and the traders should always be ready to buy or sell the power to fulfil the gaps between the time frames. Why is this energy trading important for the current generation?

Energy trading includes a method that is Peer-to-peer energy trading[5]. In Figure 1.1, this method is energy trading through grid-connected parties. It costs less than an off-grid solar energy system as an off-grid system requires more extensive storage, an inverter, and more solar panels[6].

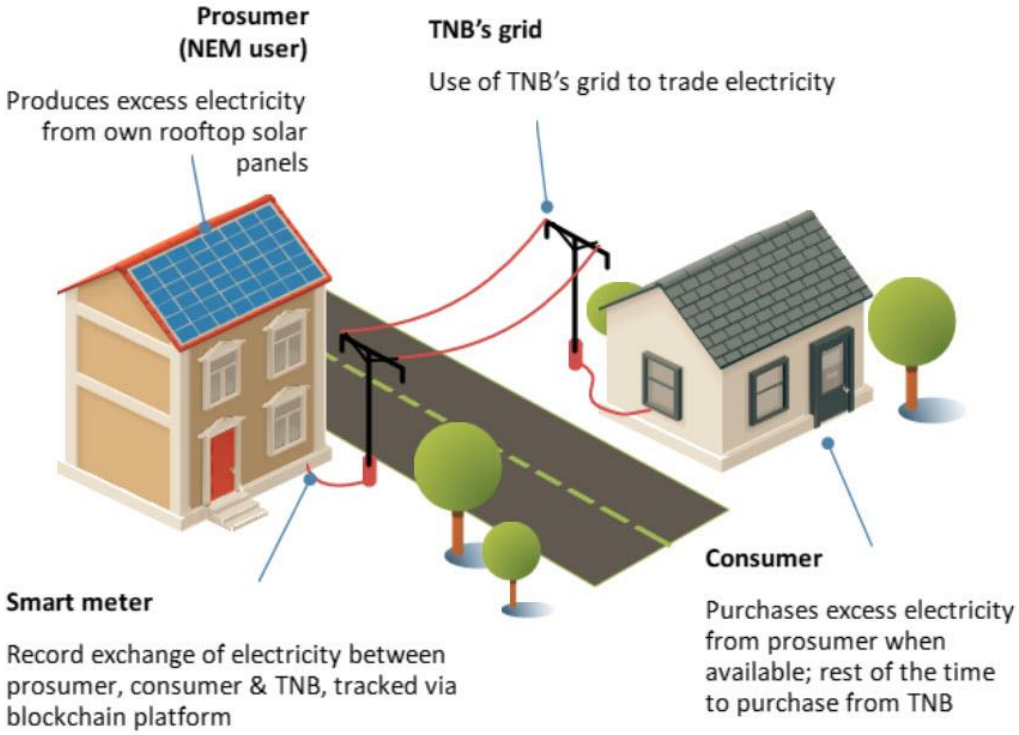

Figure 1.1: Peer-to-Peer (P2P) Energy Trading. [7]

This energy trading aims to make it possible for people without solar panels to obtain and use renewable energy from their neighbours at a fair price [8]. Other than that, people with excess electricity can sell it for more money than they would get from their retailer as a feed-in tariff. The energy does not have to come from the generator to the household or factories. This has

dramatically reduced the electric loss from the wire or the grid. By using the blockchain system, all the transactions can be publicly seen and cannot be altered in any way [9].

1.1.3 Blockchain

Bitcoin is released in the year 2019 [10]. Decentralised cryptocurrencies obtained so much attention from the surrounding. The number of coins and tokens is the primary host of bitcoin. But blockchain technology is exploited in the cryptocurrency to ensure it can secure transactions. There is a program called a smart contract. The smart contract is further explained in the next section of the Introduction. Other than smart contracts, other keys such as distributed ledger technology and immutable records are the key elements of a blockchain [9].

The blockchain is a shared ledger. It can facilitate transactions by recording and keeping track of it. The asset that is being tracked can either be tangible or intangible [9]. Through blockchain, each section has its function, and the values of the asset can be tracked and traded in this network. This is to reduce the risk further and cut the costs, for example, the transaction from bank to bank.

There are many benefits when it comes to using blockchain technology. It is not only a security enhancement but also increases the efficiency of the system speed as well. Blockchain helps create a record that cannot be altered to prevent unauthorized activity. Instead of being stored on a single server, the data is distributed throughout a network of computers. This has made it hackers challenging to view the data when hacking. Other than that, in terms of speed and efficiency, unlike traditional paper-heavy processes, which require third-party, the documentation that can be saved with transaction details in blockchain can eliminate the usage of paper, so the transaction is completed faster and more efficiently. As mentioned, blockchain technology must come with a smart contract. The intelligent contracts are pre-specified conditions that allow the following process to be automatically triggered in the blockchain. It is to reduce human intervention as it does not need third-party verification [11].

Based on Figure 1.2, The layers for the components of the Blockchain application. The working mechanism for this blockchain has five layers. The layers are the application layer, trust layer, Blockchain layer, Transaction layer, and Network layer. The application layer consists of innovative contract development, front-end applications, back-end applications, and Decentralised applications (dApps). This layer serves as the blockchain's front end and is crucial for users who generally come into contact with it when interacting with a blockchain network.

After that, the second layer is the trust layer. This layer protects the network's regulations. To keep the network uniform, these regulations are efficiently implemented. The transaction from one node is only allowed if all the other nodes agree. This can lower the transaction risk for the blockchain. The layer oversees the validation of a block. Then the third layer is the blockchain layer. This layer has four layers which are layers 0, 1, 2,3 and 4. Layer 0 has hardware, protocols and other foundational elements. Layer 2 maintains the blockchain's dispute resolution, consensus mechanism and programming. Layer 2 has better scaling than layer 0 due to its integration with a third-party solution.

Then layer three is used to host the dApps and other user-facing applications. The fourth layer is the transaction layer. As mentioned in the trust layer, when only one node agrees to have a transaction while the other node does not agree, the transaction cannot be done. Then the transaction can only be done if all the nodes agree. In addition, the network layer, which is a layer of the blockchain network, promotes communication between various nodes. Blocks can be created and can be added to this blockchain. This layer enables communication for the whole system.

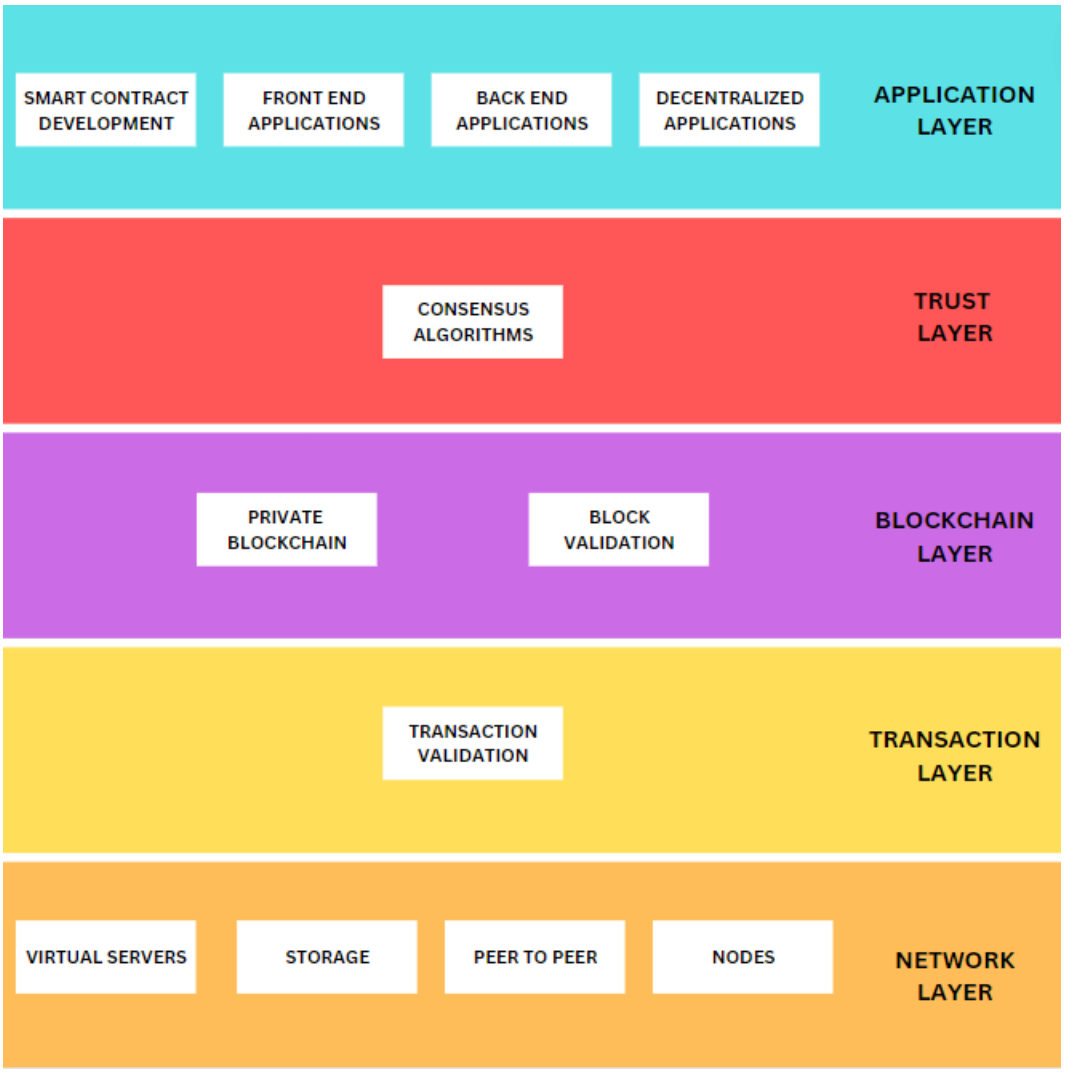

Figure 1.2: Blockchain layered architecture[12]

1.1.4 Smart Contract

The term smart contract is originally from legal contracts, which can be self-executing itself. Software is used to express and implement the contracts to run simultaneously on many distributed ledger nodes. It is a protocol that can ease the verification of an agreement and runs on the blockchain platform. It processes all the transactions in a contract and defines rules and penalties. Figure 1.3 shows the process of smart contracts.

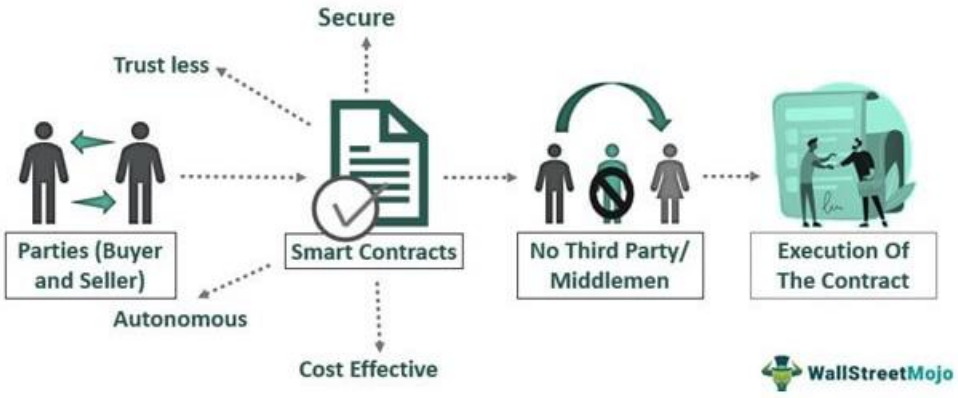

Figure 1.3: Process of smart contracts[13]

Smart contracts can be used in E-voting of the government, healthcare, supply chain, and financial services. Blockchain stores the required information with private keys only specific individuals can access. The stuff can be conducted confidentially and securely under smart contracts. [12]

An agreement that is stored in public databases can be executed more easily thanks to smart contracts. They offer a more efficient, quick, and secure method of managing these contracts. To handle these complex transactions, smart contracts must rectify mass adoption.[14]

The smart contract is a program inside a blockchain to ensure that the program runs when the conditions set in smart contracts are met. This automation of the implementation of an agreement without the involvement of a third party and without wasting time. They also can automatically trigger the following action after the conditions are met [15]. The smart contracts can implement a transactive energy auction that operates without the need for a trusted entity's oversight which is the third part. The smart contract used to carry out the auctions employed simulated building loads and energy from the PV array to show how the auctions worked. A research paper from the Washington University campus provided an example of how a Vickrey auction can be implemented in a smart contract and utilised for a transactive market with numerous users bidding for electricity from a PV array. Additional research is required to examine the scalability and performance of these strategies, and the work can only serve as proof-of-concept for Washington University Campus [16].

1.2 Problem Statement

Most countries have centralised wholesale electric markets, especially US. The market operator requires the producers to furnish specific cost information in the centralised marketplaces. This is because they have to decide how much to produce for each generator [17]. In the meantime, the decentralised markets rely on self-commitment, and the producers can provide the operator with less precise cost information because each area has different operators and generators. It is more effective, and the main problem is whether we should focus more on energy trading with a centralised or decentralised system. A peer-to-peer system can also be promoted by using the decentralised approach to enhance users' energy trading experience. In Peer-to-Peer trading, energy is sold and purchased between two or more grid-connected parties [18].

Besides that, when it comes to storage, the decentralised system is a better option than the centralised one. The storage for which node in the data for the decentralised system is not going down when the node for the server is done. The centralised system relies fully on the server. So, whenever the server is down, the amount of time and the energy trading of the system will be disabled. The decentralised storage platforms break the user's information in each node on the network.[19] The system can run even if certain components of it do not keep up with the system.

In addition, in terms of security, much software can be hacked easily. There are many stories of hacked crypto stock exchanges. In more than 20 thefts in 2022, a cyber thief stole computer-generated currencies worth more than $10 million from a cryptocurrency exchange. Data from NBC News indicates that hackers stole more than $100 million in at least six instances [20]. Therefore, personal information and data from customers, prosumers, suppliers, and generators will be leaked if the data is hacked. It is crucial to have a well-written program for this kind of security. Although with good security, there is only one layer of protection. A smart contract can improve the amount of this protective layer. The smart contract runs when the conditions for the blockchain are met. The existence of a smart contract is an automated flow of the program, and it will trigger the following action after the conditions are met. Smart contract technology has its immutability. It is an excellent security feature, making it hard to patch known bugs after deployment. Some common security flaws include reentrancy, over or underflows, frontrunning, and incorrect calculations [21].

To summarise this problem statement, blockchain technology and smart contracts address all issues relating to energy trade, security, and renewable technology development.

1.3 Objectives

- To investigate the application of blockchain technologies in renewable energy.
- To develop a smart contract for solar energy trading using Ethereum with Solidity.
- To analyze the performance of the smart contract in terms of scalability and security.

1.4 Summary

The introduction mainly discusses renewable energy, energy trading, and the blockchain technology ed in this project. The purpose of introducing these technologies are to ensure that the reader can understand this project's scope.

The objectives of this project are to apply blockchain technologies, create smart contracts for trading energy through a smart grid or microgrid, and improve the system's security.

This paper's purpose is to ensure that traditional energy trading can be eliminated and move on to the new generation, such as decentralizing energy trading. Decentralizing energy trading can help to expand energy trading through a platform. Energy trading can also give profit to consumers and provide money to the prosumers. But to make this a success, security is highly needed to prevent hackers from stealing electricity.

Chapter 2

LITERATURE REVIEW

2.1 Overview

The related studies include solar energy, blockchain technology, Ethereum and Hyperledger Fabrics applications and smart contract. To improve the effectiveness of their programmes and their works, industry and researchers have given blockchain much attention. Hence, some researchers also research how to improve the system's security and find new risks related to blockchain technology, especially regarding Ethereum.

2.2 Related Studies

There will be two studies. Study one covers theoretical and experimental, while study two covers solution or simulation. The related studies cover solar energy from the household, microgrids, blockchain technology, Ethereum and Hyperledger applications, and smart contract. The purpose of doing these related studies is to make sure that there is a discovery and comparison with the previous researchers' work to further develop blockchain technology, especially with the security or protection of smart contracts and the prevention of hacking.

2.2.1 Study one (Conceptual)

Inefficient charging and discharging are mentioned by the authors of [22], along with unsafe energy exchange between electric vehicles and EVs. As a result, they suggested a blockchain-based strategy for secure energy trade. The authors also suggested an alternative energy trading strategy for a blockchain-based system. [24] offers a billing guidance technique based on a consortium blockchain system. The proposed work addresses the taxi industry's need for charging. They employ a practical Byzantine fault tolerance (PBFT) technique to reach a consensus on the suggested system. The trust issue between various charging station operators is also addressed via PBFT. The presented work es multi-objective optimization to build the charge guidance model for taxis. The proposed work's simulation findings demonstrate an improvement in passenger satisfaction.

[25] covered various charging infrastructures and tactics ed in smart cities. The authors of [26] suggest a blockchain- and smart contract-based energy trading mechanism. They employed a reverse auction system and a dynamic pricing method during trading. The suggested work assists less competitive power vendors and lowers the cost of electricity. A blockchain-based decentralised trust management solution is suggested to address the trust difficulties among EVs. [27] s a different paper that addressed trust-related issues. EVs use a Bayesian inference model in this system to verify received messages. A comparable rating is generated for the message after it has been received. RSU determines trust value offsets for the EVs using these trust values. However, the proposed effort did not mention managing community trust or protecting privacy.

The authors also suggested a contract-based energy trading system in [28]. Authors in [29] describes the authors' work on consortia blockchain-based secure and effective data trade. The proposed system uses pre-selected nodes as the foundation for its consensus method. Although a double-auction method is utilised, it requires more energy due to the high number of iterations needed. The authors in [30] suggest an energy trading method for plug-in hybrid electric vehicles—the proposed plan calls for PHEVs to charge efficiently with lower energy costs. The writers also go over how well cars communicate. Energy balance needs to be considered in the suggested scenario, which makes it expensive to implement in real life.

As mentioned, big data plays a big part in blockchain. It stores the information needed for each chain to function. It explores big data analytics in electricity grids [31]. In [32], it presents a conceptual framework of blockchain-proxy demand resources. The blockchain application effectively ensures that information is processed within a second to ensure the risks of being hacked. The control of blockchain technology can be applied in the photovoltaic system by using the Hyperledger Fabric blockchain. [33] As mentioned in [34], trade distance and price model are needed to calculate depends on the station.

The application of electric power engineering projects can come in multiple types, links, parties and decentralised construction such as microgrids and smart grids [35]. The study of the distributed energy system design based on Smart contracts should be learnt [36]. Energy trading can be highly demanded sometimes, so prevention is better than cure. Using Ethereum or any other blockchain platform, such as Hyperledger Fabric, is one way to solve energy trading needs. The efficiency, scalability and cost are fully addressed. But security analysis needs to identify the drawback