Ethereum Blockchain Network-based Electrical Vehicle Charging Platform with Multi-Criteria Decision Support System

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***Abstract*—Recent developments in electric vehicle technology have lead to an increase in the use of electric vehicles. With the increase in the use of electric vehicles, it is necessary to secure the information and money flow in the process from production to consumption. In this study, an energy ecosystem in the Ethereum Blockchain network, which records all processes from the generation of electricity to the end user, is designed. Furthermore, this study includes energy producers, consumers, distributors, dealers, electric charge station and electric vehicle users. Transactions between users are provided using smart contracts. Smart contracts eliminate third-party contacts and all transactions with the decentralized application created are recorded on the Blockchain network. Recorded transactions are maintained in accordance with the principles of confidentiality, integrity and availability through Blockchain and smart contracts. In the application developed with the use of smart contracts, the user can access information such as location, price list, payment type, charging mode, charging type and plug types of the related charging stations. PROMETHEE, which is a multi-criteria decision-making method, is used in case there is more than one offer suitable for a user request. In this method, the weights required for the criteria are determined according to the profile of a user.**

Keywords— Electric Vehicle, Ethereum Blockchain Network, Multi criteria decision, Smart Contract

I. Introduction

Greenhouse gases, which arise from the use of petroleum-based fuels, cause problems that may affect the whole world such as global warming. Europe is undergoing a wide-scale energy transition, replacing fossil fuels and nuclear power with low carbon, renewable energy sources such as wind and solar power [1]. The quantity of CO_2 emissions of electric vehicles can be very low depending on the way in which electricity is obtained. Electric vehicles that supply with electricity need by using a renewable energy source can have zero emissions [2]. Electric vehicles are becoming widespread with low emissions, fuel economy, quiet operation and the development of existing technology. This spread increases the need for electricity and the need for charging stations. These needs provide academic and industrial researchers in the literature with a field of research on the use of Blockchain and smart contracts technologies in the energy sector.

Products developed in the energy sector can be categorized for commercial and research purposes. In the literature, there are many commercial applications about Blockchain and electric vehicle charging systems [3] [4] [5] [6] [7] which is used for various purposes. In research [3], smart contracts are designed for gas stations. Smart contracts in the Ethereum blockchain network minimize security effort. A single smart contract can be used by many different vehicles and gas stations. The Open Charging Network [4] provides an uninterrupted, safe and smart charging system for the end customers of the electric vehicle charging community developed by the Share and Charge Foundation. The Open Charging Network is a system that concerns the end customers and there is no monitoring of the energy from the producer to the end consumer. Exergy [5] is a distributed accounting system that combines layers of software and hardware designed to solve management problems caused by renewable energy sources operating in local distributed energy networks developed by LO3 Energy. Exergy is not developed for electric vehicles and smart grids. Furthermore, there are no smart contracts in the Exergy development phase. Power Ledger [6] is a software-based process layer that communicates with existing smart meters and a tool that acts as a server computer. Power Ledger introduces renewable energy sources based on Blockchain to the market. Power Ledger is not developed for electric vehicles. In addition, there are no smart contracts during the development of Power Ledger. Bittwatt [7] is a platform that connects producers, energy suppliers and consumers. Bittwatt develops integrated measurement services that enable new and existing suppliers to communicate quickly and securely exchange energy. However, although Bittwatt is Ethereum-based, credit card information is required for processing. It could have been safer for Bittwatt to use cryptocurrency for payment.

Another category is the development of Blockchain energy sector products for academic use [8] [9]. In study [8], examines the selection of the most appropriate charging station. There are many variables in the selection process. These variables are determined as station location, price, charging power and plug types. In the article [8], after the selection process, the communication of the station and the electric vehicle is provided by smart contracts. In research [9], Blockchain-oriented energy market application is being

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developed. To realize developed application, Blockchain and smart contracts are used. Developed application contains only sellers and energy buyers. Unlike all the above-mentioned articles, this article provides a multi-criteria decision-making mechanism is included in the end-user section.

The aim of this study is to secure the flow of information and money in the process of energy from production to consumption. This study includes energy producers, consumers, distributors, dealers, electric charge station and electric vehicle users. Transactions between users are provided using smart contracts. Smart contracts eliminate third-party contacts and all transactions with the decentralized application created are recorded on the Blockchain network. Recorded transactions are maintained in accordance with the principles of confidentiality, integrity and availability through Blockchain and smart contracts. In the application developed with the use of smart contracts, the user can access information such as location, price list, payment type, charging mode, charging type and plug types of the related charging stations. PROMETHEE, which is a multi-criteria decision-making method, is used in case there is more than one offer suitable for user request. The weights of the criteria required for this method are determined in the order of profile of the user. Weights are used with profile functions to list the most appropriate offers for the user's profiles. After the user request, transactions are automated according to user profiles. Demo video could be watched from YouTube [10].

This paper is organized as follows. In section 2, the technologies used in the system are introduced. Section 3 describes the proposed system. Section 4 describes the proposed method. Conclusion and future work are outlined in section 5.

II. SYSTEM OVERVIEW

In the developed study, all transactions made by users are stored to Ethereum Blockchain network using with smart contracts. Smart contracts are software which conducts a commercial transaction without third parties. By eliminating third parties, transaction costs were reduced and the trust problem with these third parties was eliminated. Another advantage of smart contracts is the autonomous execution of commercial transactions. Since smart contracts are written on the Blockchain network, they cannot be altered in any way and these contracts are undeniable. If the parties agree to the terms of the agreement, the accuracy of this agreement cannot be questioned. Also, applications created by using smart contracts and Blockchain network together are called decentralized applications. In order to interact with this decentralized application, web interfaces have been developed. These interfaces were developed using JavaScript, HTML and CSS. For the interaction of these interfaces and the smart contract on the Ethereum network, the JavaScript library web3.js is used. This library is performed by the npm package manager. During the creation of interfaces and smart contracts, Ganache application was used to simulate the Ethereum Blockchain Network. This application provides wallets and ethers contained in these wallets. By using these wallets in the application, smart contracts can be deployed or transactions in created smart contracts can be triggered. The tools used to improve the system are shown in Figure 1.

Fig. 1. Development Tools

A. Ethereum Blockchain Network

Ethereum is an open source, blockchain-based operating system that is capable of developing applications using smart contracts. Thanks to the distributed architecture of the Blockchain network, the storage of data is carried out securely without being affected by any interference. The reason that the Blockchain network provides us with security is that all data in the Blockchain network is kept on all nodes and has a consensus algorithm. According to the consensus algorithm, in order to change or delete a data stored in the network, 51% of all the nodes in the network need to be replaced. One of the major reasons for selecting Ethereum as the Blockchain network is that it is one of the most nodes in the Blockchain networks that support smart contracts. The Ethereum Blockchain network operates on the Ethereum virtual machine on each node. Figure 2 shows the Ethereum Blockchain Network and the Ethereum virtual machine. This creates a programmable Blockchain network. Ethereum developed the gas mechanism to prevent attackers from unnecessarily busy the network. With this mechanism, each transaction has a transaction fee. Therefore, users should code the gas price of their transactions to be low. With the solidity programming language developed by Ethereum, smart contracts running on the Ethereum network are written. These codes are converted to byte code by the Ethereum virtual machine and processed on the network. In this way, the environment was created for the creation of smart contracts in the Ethereum network.

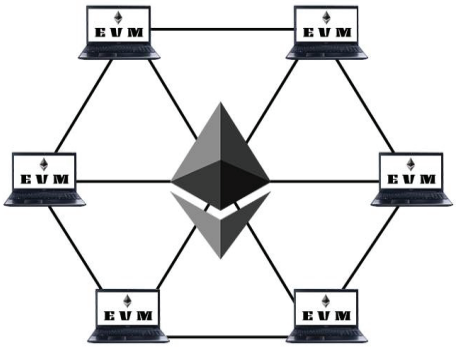

Fig. 2. Ethereum Blockchain Network Distributed System

III. PROPOSED SYSTEM

There are 5 different types of users in this study. Users must fill in all required form information such as username, password and Ethereum wallet address to register. The user entering the system with the username and password is directed to the interface designed for user type. This page displays all offers received, all purchase / sale transactions and wallet information for users.

The first user type in the project flow is the electric producer. This type of user is the first type of user in the generation and transmission of energy. The generated energy is put on the market at the unit price determined by this user. The offer placed on the market is forwarded to all grid operators. In case the bid is accepted by the grid operators, the bid price is transferred to the producer's wallet address registered in the system. Producer's web page is shown in Figure 3. The user types in the second and third stages in the flow are the grid operator and the trader. Most of the work they do is similar, the only difference is that the grid operator receives offers from the producer and bids to the electric trader. Similarly, the electric trader receives an offer from the grid operator and makes an offer to the station. In case the bids are accepted, the bid price is transferred to the wallet address of the users registered in the system. The station is the fourth type of user in the energy flow. It is the type of user that interacts directly with the electric vehicle user. In this type of user, an offer is received from the electric trader and an offer is made to the user of the electric vehicle user. During the bidding phase, bidding is made according to the characteristics of the charge unit in available.

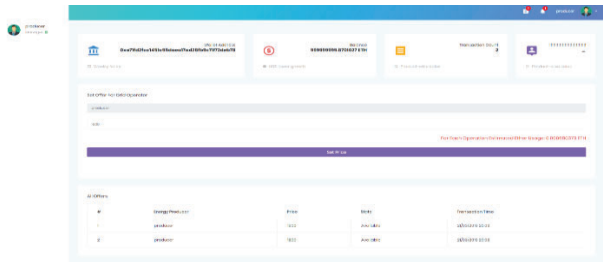

Fig. 3. Sample Producer User Interface

The electric vehicle user is the fifth and final stage of the energy flow in this study. When registering in the system, as in other user types, in addition to all the form information, the charging features (plug type, charging mode, charging type) appropriate to the vehicle of the user are registered to the system. On this page, the electric vehicle user can view the station offers, all their purchase / sale transactions and wallet information in accordance with the charging characteristics of his vehicle. Electric vehicle user's web page is shown in Figure 4.

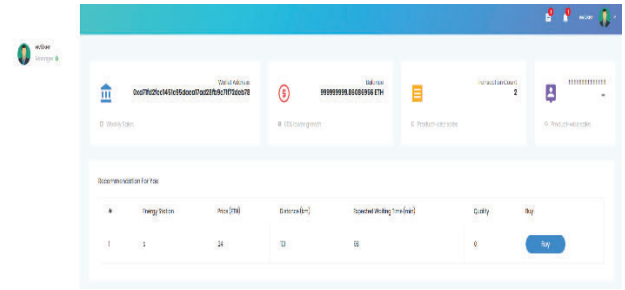

Fig. 4. Sample Electric Vehicle User Interface

In addition to this information, the most suitable stations are sorted. This sorting process is performed by PROMETHEE method which is a multi-criteria decision-making method. In the sorting process, the name and bid price of the bidding stations, as well as the service quality value of the station, the estimated waiting time of the relevant unit and the distance of the vehicle to the station are shown. These values are also the criteria used in the PROMETHEE method. The interaction of all user types in the system is shown in Figure 5.

IV. PROPOSED METHOD

One of the most widely used multi-criteria decision-making methods, PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations) method, was developed based on the difficulties arising from the implementation of existing prioritization methods in the literature. The most important feature of this method is that it allows more detailed analysis. In addition, this method allows analysis of both partial and full priorities of alternatives. Before using this method, the criteria data determined is collected and made suitable for the process. These criteria were determined as product price, station quality, station distance and estimated waiting time. The operation steps of the method are as follows;

The decision matrix is created with the product price of the stations, station quality, station distance and estimated waiting time. R refers to the decision matrix, R_{ij} refers to the values of the decision matrix. The criteria are divided into beneficial and non-beneficial. Beneficial criteria refer to criteria where higher values indicate better status in achieving the objective. As shown in equation (1), the minimum of the relevant criteria values $\left(min(x_{ij})\right)$ is subtracted from the relevant criteria value $(x_{ij})$and the result is divided by the difference between the maximum $\left(max(x_{ij})\right)$and the minimum $\left(min(x_{ij})\right)$ of the relevant criteria values. Non-beneficial criteria refer to criteria where lower values indicate better status in achieving the objective. As shown in the equation (2), the relevant criteria value (x_{ij}) is subtracted from the maximum criteria value$\left(max(x_{ij})\right)$ and the result is divided by the difference between the maximum $\left(max(x_{ij})\right)$ and the minimum $\left(min(x_{ij})\right)$ of the criterion values.

$$R_{ij} = \frac{x_{ij} - min(x_{ij})}{max(x_{ij}) - min(x_{ij})} \quad (1)$$

$$R_{ij} = \frac{max(x_{ij}) - x_{ij}}{max(x_{ij}) - min(x_{ij})} \quad (2)$$

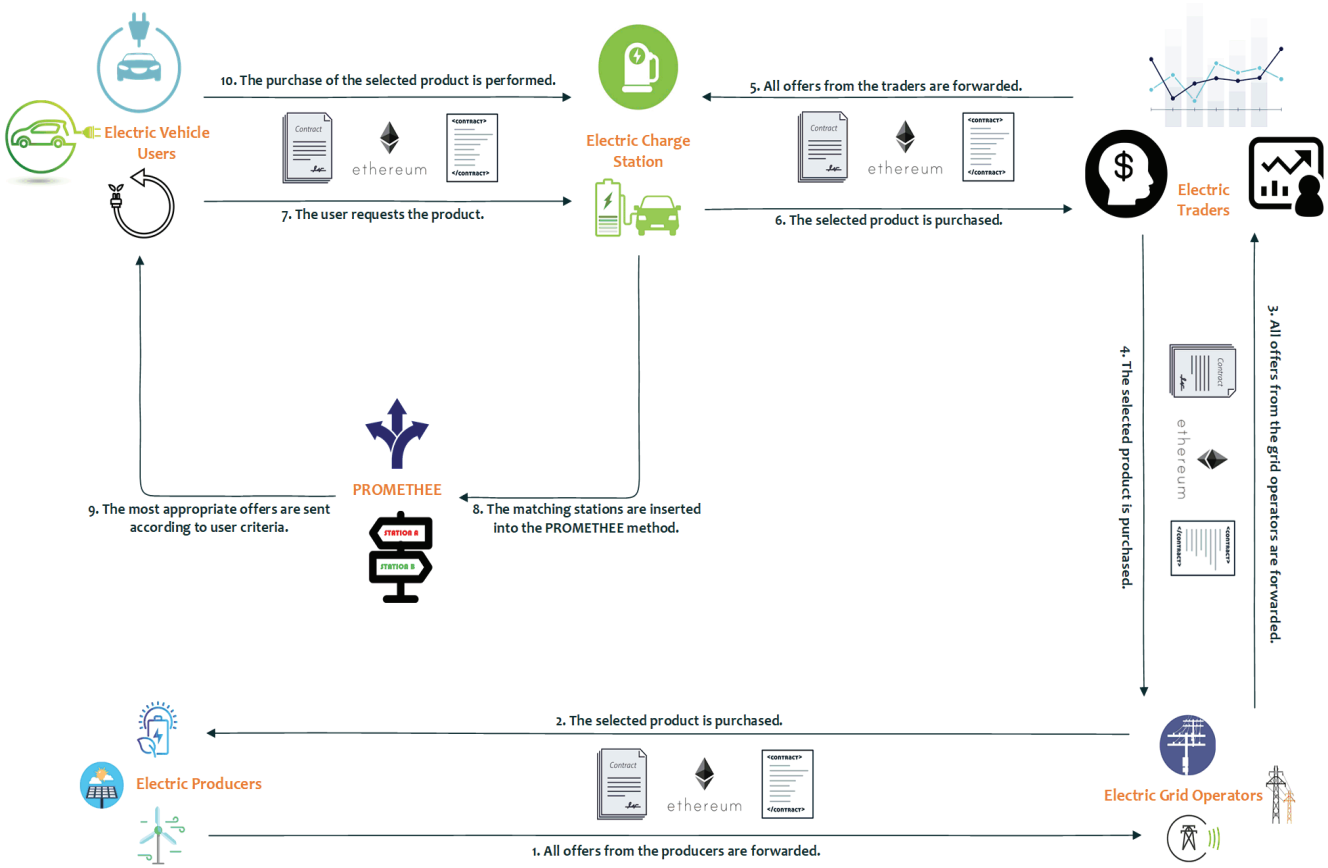

Fig. 5. System Diagram

The difference matrix is created for each row. Calculations are made according to the determined preference function ($P_j(a,b)$). Equation (3) shows the preference function. In this function, operations with line values are performed (R_{aj}, R_{bj}).

$$P_j(a,b) = \begin{cases} 0, R_{aj} \leq R_{bj} \\ R_{aj} - R_{bj}, R_{aj} > R_{bj} \end{cases} \quad (3)$$

Each column is multiplied by the specified criterion weights (w_j) and the aggregated matrix ($\pi(a,b)$) is obtained by adding the rows as shown in equation (4).

$$\pi(a,b) = \frac{\sum_{j=1}^{n} w_j \cdot P_j(a,b)}{\sum_{j=1}^{n} w_j} \quad (4)$$

Each row and column are collected within itself as shown in equation (5), (6).

$$\varphi^+ = \frac{1}{m-1} \sum_{b=1}^{m} \pi(a,b) \qquad a \neq b \quad (5)$$

$$\varphi^- = \frac{1}{m-1} \sum_{b=1}^{m} \pi(b,a) \qquad a \neq b \quad (6)$$

The exact priorities for the alternatives are calculated using equation (7). With the calculated full priority values, all alternatives are evaluated in the same plane and exact order is determined.

$$\varphi(a) = \varphi^{+(a)} - \varphi^{-(a)} \quad (7)$$

The bids are sorted according to the found results. After the steps have been completed, the offers are presented to the user of the electric vehicle.

V. CONCLUSION & FUTURE WORK

In this paper, the data was successfully saved to the Blockchain data structure. Therefore, it was understood that the Blockchain system could be integrated into such an application. Because the data is stored on the Blockchain, the data is fully secured. In addition, the application is now fully protected against all access restriction attacks (DDoS, etc.) that threaten centralized applications. Money transfer transactions were carried out safely and successfully through Ethereum Network. The PROMETHEE method, which was decided to be applied in order to make suggestions to the electric vehicle user, was applied successfully and the appropriate proposals were presented to the user. User interfaces have been prepared with a user-centric approach to the user through the prepared web pages. In this way, a comfortable and easy-to-use service is provided to the user.

As a result, a completely free application was developed that was born out of the industry's secure data storage needs working on the Ethereum Blockchain Network. The outputs of this application were specifically observed on the charge management system of electric vehicles, and it was found that Blockchain and smart contracts provide a secure environment for data storage.

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