Framework for User-Centered Access to Electric Charging Facilities via Energy-Trading Blockchain

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***Abstract*— In recent years, trends towards user-centered technology are increasing due to various social, economic, and environmental aspects. Concurrently, the success of electromobility is highly dependent on how we provide the charging facility and the security of energy-trading gateways. In this paper, we propose a modeling framework that would address all these challenges and would be ready for real-life implementation when data becomes available. The proposed model works on a two-charging station methodology, which allows us to examine the mutual benefits of vehicle users and electricity supply entities. In addition, the massive data revolutions and blockchain technology are providing enough impetus for the success of the given framework. Undoubtedly, this study is unique and should be considered a milestone to reveal directions for further studies.**

Keywords—Blockchain technology, Energy trading, Electromobility, Infrastructure, Smart city, Transportation, User-centered access

I. INTRODUCTION

Using data is prominent in the 21st century, and as everything becomes digitized, we are in a season of unprecedented societal and technological change. Digitization enhances various services through efficient data management, rapid sharing of data between various stakeholders, and knowledge exchange at all levels [1]. With the use of digitization, we can use a collaborative approach with all players, for example, humans, machines (electro-mobility devices), and energy grids. Digitization has forced us to think about future mobility solutions. One of these solutions is electro mobility (e-mobility or e-vehicles), as they have numerous advantages over current traditional vehicles, such as: a) the reduction of CO_2 emission which reduces health-related problems, b) an improvement of air and noise quality, c) the provision of sustainable transportation in all areas of mobility, which are economically more accessible as the numbers of e-vehicles being used increase, and d) significant time saving as e-vehicles can be recharged while shopping for example[2].

Digitization has significantly influenced the mobility sector due to customers' travel needs and personalized services. To manage the increased flow of data requires a robust high-tech solution. Blockchain is one of the proposed solutions for managing these large data transactions [3]. As mentioned earlier, electro mobility (including all modes of electric transportation) is a viable mobility solution for citizens in the future [4], as it provides sustainable transport for everyone. As various benefits have been highlighted, the original equipment manufacturers (OEMs) are now planning to increase their fleets on the road. Simultaneously, governments across the globe are promoting e-vehicles for their prime mode of transport to benefit from its advantages [5]-[8]. In 2009, the introducing of distributed ledger technology (DLT) known as blockchain with Bitcoin as a cryptocurrency [9], the direction and scale of transactions changed. The growth of digitization paved the way for the use of DLTs in every mode of mobility, e.g., future vehicular infrastructure development, multi-modal transportation, vehicle-to-vehicle communication, and the provision of a distributive infrastructure for charging electric vehicles [10][11]. Similar impact has been noticed in the energy sector, as the energy grid is highly centralized with complex transactions at all levels. Blockchain will stabilize the grid operations by providing more data information and generate security for the grid against external attacks [12]. The key advantages of blockchain include: a) a cost reduction as more and more information is provided, b) unlocking of new possibilities of integration between different energy resource devices, c) a significant reduction of transaction costs, and d) the acquisition of new users by offering affordable energy via local and decentralized grids [13]-[16].

We are currently building cities for the future known as "smart cities". The success of this venture depends on many parameters, but the most influential factor is the provision of a sustainable and resilient infrastructure. Future cities must meet both the demands of mobility and energy, which will ensure an improved quality of life [17]-[19]. However, there are still many challenges related to the charging infrastructure and energy-trading for charging the vehicles, including the management of the charging stations [20]-[24], and the pricing strategy of energy-trading [25]-[27]. Potential users are looking for flexible, affordable, secure, and connected charging facilities for their electro mobility. All the previously mentioned points lead us toward user-centered access for the charging stations with viable energy-trading. Considering this, the main goal of the paper is to:

1. Provide a user-centered access to the charging of electro mobility through a two-charging station (TCS) methodology.

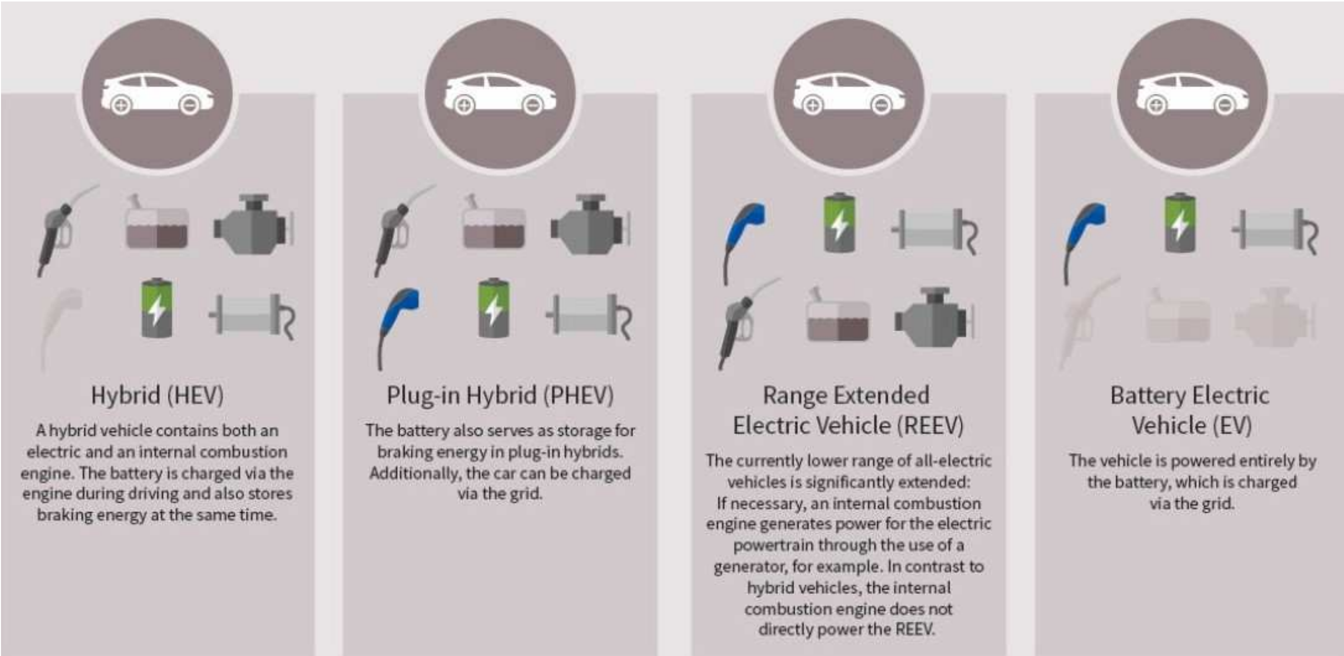

Fig. 1 Comparison of various electromobility [31]

2. Ensure secure payment gateways (in this case, energy-trading through blockchain) for the charging infrastructure.

This will enable the user to prioritize their needs and be provided with flexible energy-charging (for example, a user can charge their vehicle with conventional or non-conventional energy source-based supply), along with secure energy-trading through blockchain (e.g., households, private partners, government-owned entities, and public-private partnership-based utilities).

The rest of the paper is organized as follows. In Section II, the key discussion on how an electro mobility emerged as a one solution for sustainable transportation. The idea and infrastructure layout for the future charging stations is presented in Section III. Section IV contains the blockchain-based energy-trading concept in the supervision of charging the electric-vehicles. Finally, we conclude the paper in Section V along with future directions.

II. Electromobility-as-a-Service (EaaS)

Recently, there have been several mobility-based services developed as a response to different needs of transportation networks around the globe. Electro mobility has been built on three key pillars in relation to diverse features: efficiency, eco-friendliness, and quiet technology [28]-[30]. Electric-vehicles (EVs) are flexible and robust and can utilize energy directly from the grid with no major modifications. This ensures a user-centric mobility option for future transportation. One of the core concepts of smart cities is the inclusion of a smarter, and cleaner transportation mode, which will provide an efficient, intelligent, and faster societal service. A comparison of different electro mobilities is shown in Fig. 1. It is further divided into various types of operations, and user-demands: (a) personalized e-vehicles, (b) e-scooter, (c) hydrogen-based mobility, and possibly (d) shared and connected EVs (SCEVs) [31].

However, there are many obstacles to the successful deployment of EVs for all users and services. Apart from the cost and efficiency of the vehicles, user demands and expectations are also a major challenge. It is still unclear whether electro mobility will overcome these obstacles and become a key player in future smart cities, as the success of this venture largely depends on the policymakers and how efficiently charging stations accommodate the users [32].

III. Two-Charging Station (TCS) Based Methodology As A Future Charging Stations

As the population of cities grows, we need to think about strategic planning of sustainable transportation as it is forecasted that by 2050, almost 2.5 billion additional inhabitants will be added to the cities [33]. To meet the demands of the future, the challenge is to develop a new infrastructure to enhance the existing infrastructure framework. As the success of electro mobility depends on the performance of batteries and charging facilities, it is vital to provide ease-of-use charging facilities. The locations of the charging stations should be in the most convenient places for the users [34][35] where they can best utilise their time [36]. User comfort during charging should be a priority [37], as it plays a vital role in the success of the charging infrastructure (specifically, location-based infrastructure), and thus the overall encouragement of the use of electro mobility.

There are multiple players involved in providing affordable and efficient charging. These players can be divided into home utilities, private utilities, government-owned utilities, and public-private partnership utilities. In this paper we propose a TCS based method (in which conventional energy, and non-conventional energy-based charging facilities are available) which is presented in Fig. 2. The main feature of a TCS is to view the whole ecosystem as a dynamic and multi-agent environment, where human-centered access is a point of interest. For example, if an EV user wants to charge their vehicle, the following would be their concerns: size and proximity of the nearest charging station [38]-[40], the cost of charging [41]-[45], and the security of the energy-trading gateway [46]-[48]. All these concerns are addressed with a TCS-based method by the following actions: i) the user asks to charge their vehicle; ii) on this request, information is passed to the nearest charging station (which is based on queue waiting time, service time of the station, users' effective time

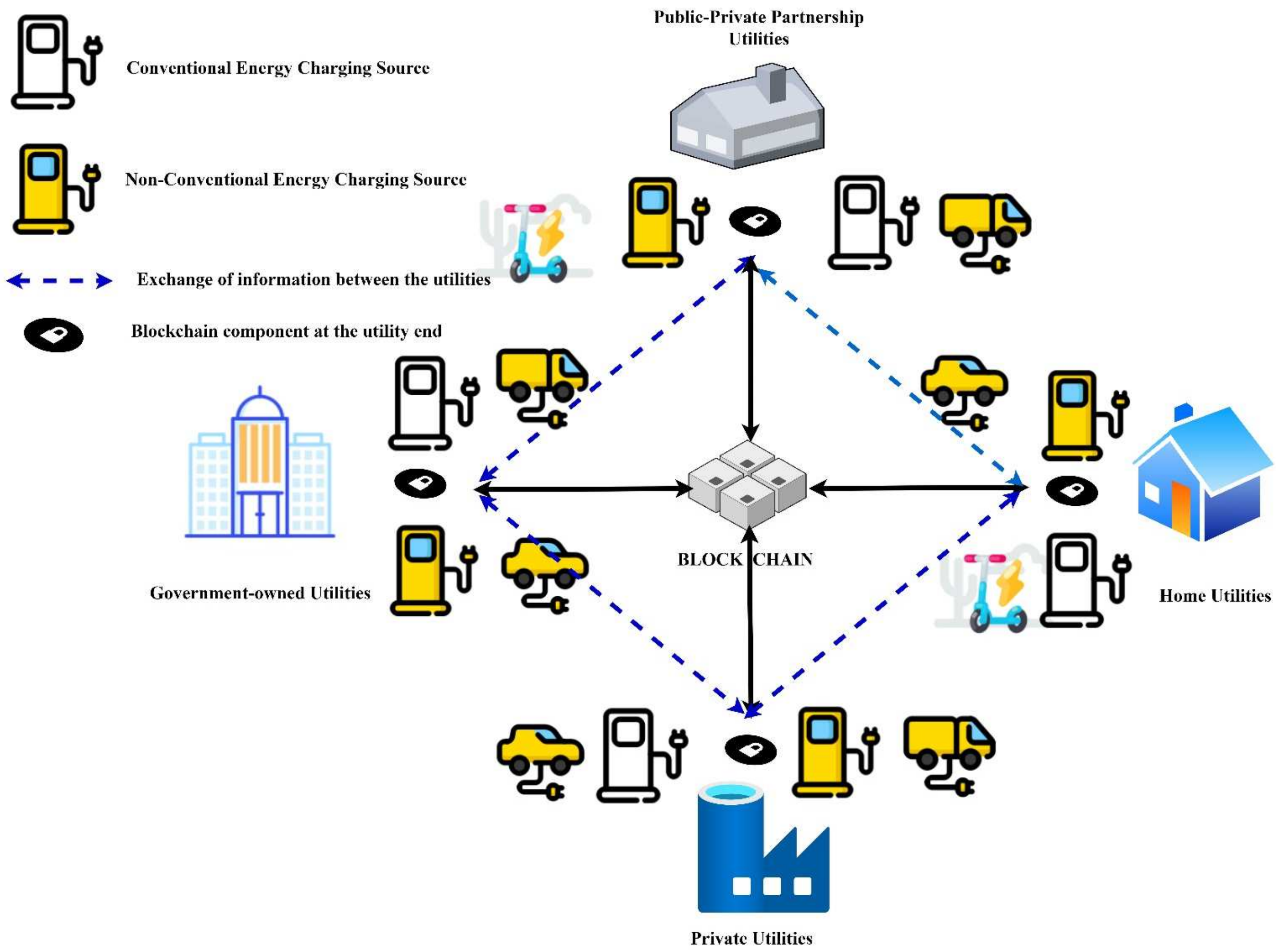

Fig. 2 Proposed framework for electromobility charging and energy-trading through blockchain

to be spend at EV station, and battery's initial state of charge, are among others); iii) the nearest charging station then contacts the user enquiring how much charging is needed; iv) upon confirmation, once the user arrives at the charging-station, there is an optional charging facility, either conventional energy charging (for example, fossil-fuel based electricity) or non-conventional energy (for example, energy generated from photo-voltaic, solar, wind, etc.) charging; this is important in sustainable transportation, where both pricing and energy sustainability are vital. The payment of energy-trading is secured with blockchain technology at all the utilities and will be discussed in detail in the next section.

Despite all the advantages of TCS, there are still many obstacles to overcome, prior to its successful implementation in real-time for all users. These obstacles include: the overall cost of the charging infrastructure increases due to two-charging options, resulting in some utility-owners not being ready for the increase in cost; issues with allocation of the charging stations, especially home utility-based stations, where the utility owner can use solar PV-based and diesel-generator based electricity generation; the speed of the charging at various utilities and the impact on the grid stability; the requirement for future users to be ready to pay different charges with conventional and non-conventional energy based charging facilities; social implications need to be addressed especially in the business, environment, and financial market sectors, as energy-trading can only be carried out with cryptocurrency [49][50]; government policies need to support this kind of exchange in which payment gateways are operated with cryptocurrency; and the impact of digital payment gateways on climate change, as recently Tesla refused to accept Bitcoin over climate concerns [51].

IV. Energy-Trading through Blockchain Technology

Digitization of the current energy grid is a necessary for using smart and sustainable technology. Distributed energy resources (DERs), like a photo voltaic (PV) panel, electric vehicles (EVs), or an energy storage device, play a major role in the digitization of the energy grid. DERs are used by consumers for household and/or industrial purposes, as well as by the energy producers in the market. Penetration of the DERs can cause a steady and secure energy supply with low-cost and low emission [52]. The digitization process has changed the energy market scenario and has allowed various market players to be involved. Consumers are now also becoming prosumers (producer and consumer) by producing their own energy as a source of income. This process needs real-time monitoring and control, for which real-time data needs to be auto-updated. To make this happen, the system needs to be advanced enough to make secure communication with all the players in the market. In order to make the system smart, secure, and communicative, one need access to a higher computational intelligence. Optimization techniques are used for real-time data management, cyber security, etc. while cryptocurrency, like Bitcoins and Ethereum make the transactions easy and secure [53]. The blockchain as depicted in Fig. 3 is a decentralized, distributed, and immutable technology for the peer-to-peer (P2P) energy trading [54]. It

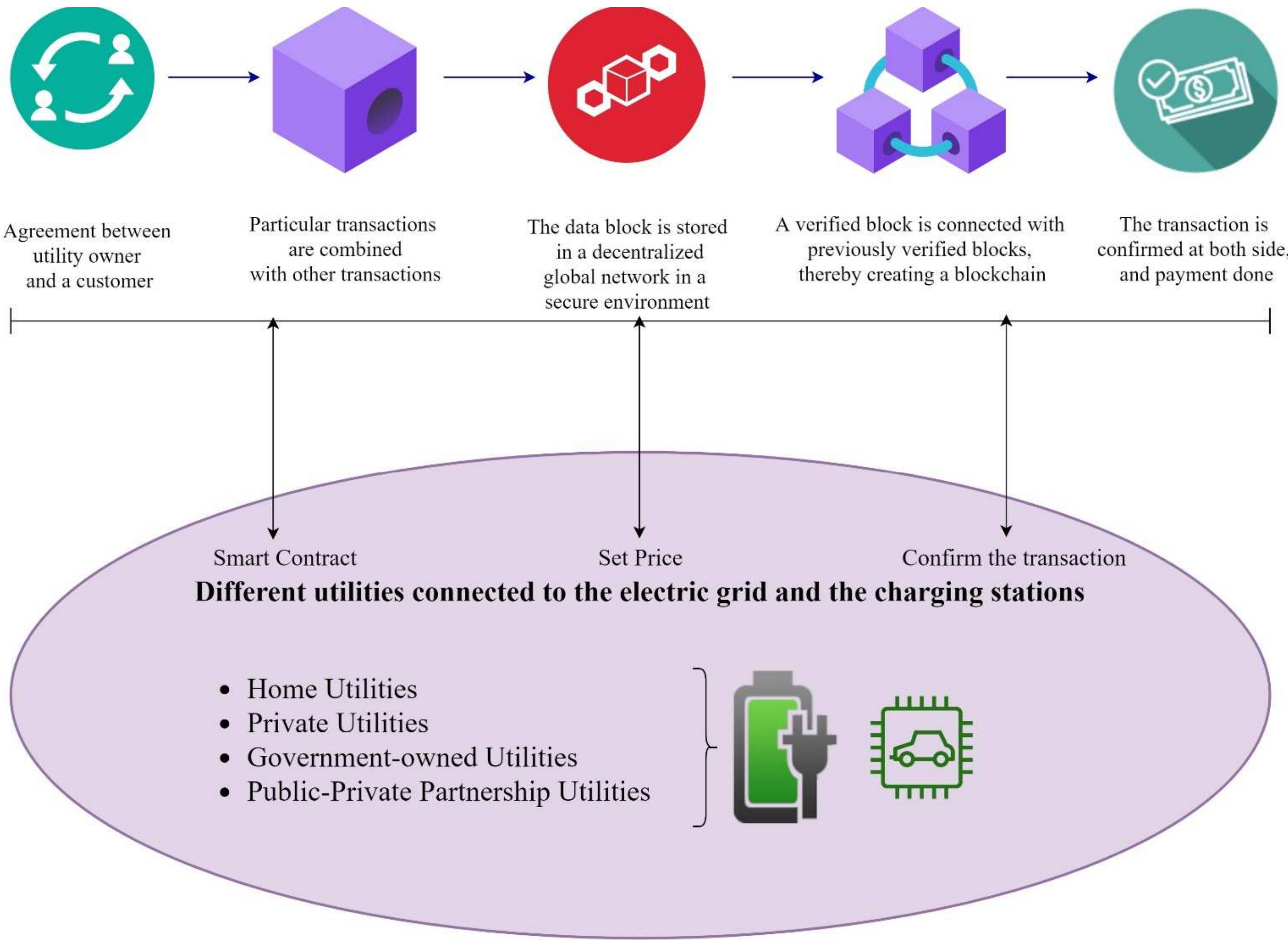

Fig. 3 Process of energy-trading in the realm of blockchain technology

facilitates with advantages for consumers and utility-owners by increasing the satisfaction of service [55], lowering the operational and maintenance costs, and improving the system performance especially in the case of DERs [56]. TCS-based methodology using blockchain is challenging as the use of non-conventional energy-based charging is also taken into consideration. Blockchain is used for the communication between vehicles, charging stations, and utilities [57]. This communication is secure and done by the unique code at different points in time. Once the data enters the blockchain it is then immutable, and it is done by using cryptographic algorithms. The working principle of a blockchain is such that it will provide the best peers among all, especially, in the energy-trading perspective. In other words, users will get the details about the charging station which is the most suitable for their demand. This matching result can be in terms of energy and money. Due to the distributed network, if some of the peers are not working, then the other peers will remain unaffected and that is why the blockchain is the fault tolerant. The trading will be very transparent as both the utility and the user will be having the same copy of the ledger; therefore, if any error or fault occurs with one peer it can be restored in the form of a sub-set database inside the ledger. So that the user will at least get the data of the charging station which fulfils the need. The money transaction is digital and therefore very secure and trusted, as there is no need of a third-party involvement. Even in the third world countries the use of cryptocurrencies and digital transactions is available easily so the concept of TCS using blockchain will be suitable worldwide [58]. The smart contract also plays a vital role when there is a presence of more than one player interested in the same deal. It is the identical contract with visibility to all the members involved, so that any of them cannot try to buy the deal unethically. Also, the smart contract in blockchain does not allow the user to pay directly to the utilities; it only pays to the utilities when the demand of the user is fulfilled.

There are several key benefits of the utilisation of blockchain technology, yet it has some low points which can resist the real-time implementation. This includes:

- Once the data is recorded by the blockchain, it is practically impossible to alter or modify this data.
- The usage of cryptocurrencies in exchange of real money is challenging and vice versa; the theft of crypto funds is not possible.
- Distributed networks can be the reason of slow processing because as the number of users and/or utility players increases, the constant run of peers goes slow for all the users and/or utilities as they may not facilitate all of them.
- Slow processing can affect the results in supply and demand scenarios for real-time monitoring and affects the best result for the user in terms of transactions [59].
- Transparency can be harmful as the blockchain will have public and private utilities data which can lead to the loss of the cryptocurrencies by the third party involved.
- As the currency exchange is online, there is a possibility of various cyber-attacks in blockchain technology [60].

V. Conclusions and Future Directions

The success of future electro mobility highly depends on the charging environment. Future users are more aware of the usage of charging facilities, including their location and the delivery facility provided. To overcome these factors, we propose the implementation and usage of a TCS-based methodology in the interest of users' choices and preferences. The method itself is unique and facilitates decisions to be made by the user, e.g., where to charge the vehicles and how to pay for it through secure energy-trading gateways via blockchain. Users are guided by the information gateways concerning the nearest charging station and the charging facility available (conventional energy-based and non-conventional energy-based).

Future work should include the implementation and effective monitorization of the utilities. This could be done by massive investments in infrastructure facilities for the charging stations as well as making new cyber-space driven policies on energy-trading. It is important to ensure that the system works robustly to provide efficient services to the daily users. As many stakeholders are involved in the TCS-based operational methodology, it is essential to manage the charging speed at the charging-stations. Fast-charging plugs should be considered, and a detailed analytical investigation should be carried out in each city adopting such technology for estimating the impact of current and future EV demand not only on the grid electrical consumption, but also on the capacity of available EV stations. Future predictions for both energy consumption, EV penetration rates and traffic congestion increase should be considered with regards to demand impact on the system performance under daily operations.

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