Energy tracing using blockchain technology: current state-of-art

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Abstract. Reducing greenhouse emission is a mission for many organizations. Since road transportation is a major contributor of CO2 emission, there is a shift towards electric vehicles rather than fuel vehicles due to zero CO2 emission during operation stage. With the gradual shift towards EV, the demand for electricity would also increase. Thus, it is important to move our attention on how electricity is generated because the provenance of electricity supply is closely linked to climate change. Energy system is complex resulting in difficulty to truly verify the claims of "only using 100% green energy" by many buildings and charging stations. Blockchain technology caught the attention of researchers to adapt this technology to track and trace the end-to-end off products. The purpose of this paper is to identify the current state-of-art focusing in energy tracing using blockchain in academic and commercial sector. From our search, we identified one literature and one commercial project that focus on energy tracing. There are 8 comprehensive systematic literature reviews published, but none of their work focus on energy tracing. One of the reasons is the electricity is a non-physical attribute matter which makes tracing of the source challenging. The volatility of renewable energy source (RES) such as wind and solar power farms, along with complex energy distribution system, makes tracing harder. Current work on energy tracing remain scarce and more work should focus on this section to prevent rebound effect of carbon emission due to the lack of a transparent carbon footprint.

Keywords: Energy tracing, blockchain, rebound effect, electric vehicle.

1 Introduction

1.1 Background

Moving towards greener energy is a part of the strategy in reducing greenhouse gas emission. This has been a challenge for various international bodies. The European Union commission has put in place legislation to reduce emissions by at least 40% by 2030, as part of the EU's 2030 climate and energy framework. [1]. Nations outside of EU also committed to bring down the greenhouse emission to a pledge target. For

example, the Norwegian government pledges to be a carbon neutral country by 2050 and Canada pledges to cut carbon emissions by 30 per cent by 2030 [2, 3].

Road transportation contributed of greenhouse gas emission up to 70% compared to other mode of transportation [4]. Similarly, the energy demand for road transportation is the highest compared to other types. To combat climate change, there is now a gradual shift towards electric vehicles (EV) from fossil fuels types because fossil fuels-based vehicles inevitably emits CO_2. EV is a greener mode of transportation because of the zero-carbon emission during the operation phase. Therefore, it is now important to move our attention to production stage on how electricity is generated.

With the current trend of shifting towards a greener world, the reliance of non-renewable energy, particularly fossil fuel, is reducing. Offices, residential area, manufacturing plant and soon, more vehicles rely on electricity. Electricity is generated from different types of energy source to sustain our daily lives. Different types of energy source have different impact on climate change. For example, renewable energy sources like solar power has less negative impact on climate change than fossil fuels.

Currently, there are many claims by buildings and EV charging station that they only utilize 100% green energy. Owing to the complex distribution of electricity generated from different energy sources, it is challenging to truly verify the provenance of the electricity. There is an extensive research on using blockchain as a digital tool to track the provenance of product and food throughout the entire supply chain. However, the focus on the provenance of the electricity remains little. This paper is to draw a clearer picture of the current state-of-art the electricity tracing in the energy sector. To answer this, a systematic literature review is executed to answer the following two research tasks (RT).

RT1 : What is the state-of-art?
RT2 : What are the barriers and potential future work?

2 Related work

2.1 Electricity

Since things are now more electrified then before such as the shift to EV and electrified heater from fuel cars and wood-based heater respectively, it is important to understand how electricity is generated because it is closely related to climate change. Electricity is the delivery of energy resulted from a series of transmission across multiple grid levels and the interplay of numerous entities across several connected infrastructures [5].

Electricity can be generated from two types of sources: (1) Renewable sources such as solar, wind and Hydro and (2) Non-renewable sources like fossil fuels. For example, in a fossil fuel plant, electricity is generated through the conversion of heat energy to

electricity while hydropower converts kinetic energy to electricity. The generated electricity is then transmitted through a series grid then to final consumer as shown in Fig 1. Both these energy sources generate electricity to support daily lives, but each have different impact on the climate. A life cycle assessment done by Siddiqui and Dincer [6], they encouraged electricity derived from hydropower power plant to be heavily utilized because the generation stage does not use utilize fossil fuel and emits CO2.

Energy markets is already highly complex and with the increasing share of renewable energy sources such as wind and solar power plants only serve to amplify this complexity [5]. In short, electricity is generated from a mixed from different energy sources and varies from a country to another. Today, there are firms that claims to be utilizing only green energy. The deeper question is how we can know the source and trace or track the greenness of our electricity. A lot work has mentioned how blockchain can enhance the traceability of product within a complex supply chain [7].

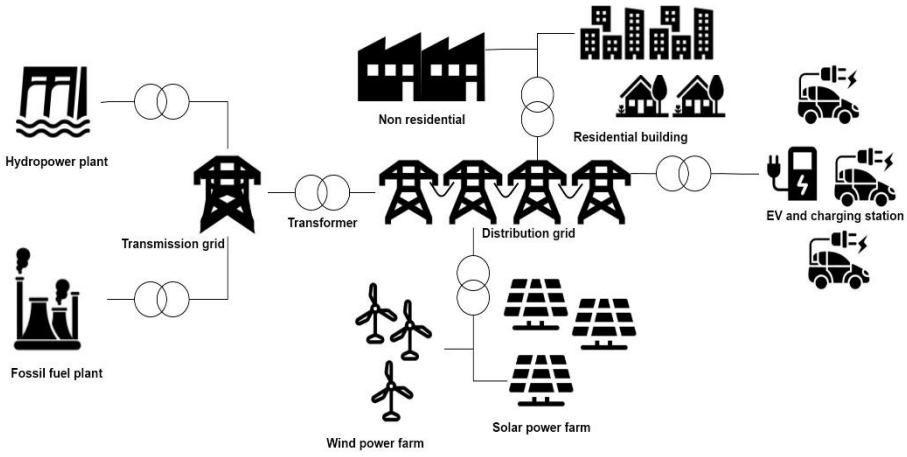

Fig. 1. Layout of general electricity network

2.2 Blockchain

Blockchain technology is a distributed ledger that contains replicated and synchronized digital data. This technology has the potential in enhancing traceability and transparency owing to how blockchain stores data structure. All valid transactions are recorded in a block format, and each block is linked with a time stamp and hash references forming a chain of blocks [8]. The data storage structure ensures that information and data are stored in a tamper-evident environment [9] because any attempt to alter information breaks the hash reference and thus makes it obvious to the other members of the network. This way, a hash reference creates a tamper-evident environment that maintains and ensures data integrity. Blockchain technology can store events chronologically which enhance the traceability.

Blockchain has caught the attention of sectors like food [10] and pharmaceutical [11] sectors to ensure the to ensure end-to-end traceability and the product Integrity. With the similar interest, this technology can potentially shed some light in energy tracing. However, the current focus in tracing the provenance of electricity using blockchain remain unclear. This is an important key as things are electrified, it is crucial to for user to know the degree of "greenness" of the electricity source. To answer this, we will perform a systematic literature review on blockchain and energy tracing to have a clearer picture of the current state-of-art.

3 Methodology

3.1 Search requirement

In our search, we include academic, commercial and startup projects. Literature included mainly literature from: published work reports and application descriptions of a commercial project, revealing the core idea of the project from both private and public sectors are collected.

The review of material starts as early as in 2008, since the term blockchain was firstly introduced, until May 2021 prior to the submission of this paper. Material collection was carried out through various databases (Scopus, IEEE Xplorer digital library and Web of science) to gather widest possible samples. Only English papers were included, with no restrictions on the year or country of publication. We excluded general views, no full paper, and conference abstracts.

In order to capture blockchain technology specifically within the energy tracing, and to be as comprehensive as possible, generic keywords we used the following:

- (blockchain) AND ("Energy tracing")
- (blockchain) AND ("Energy tracking")

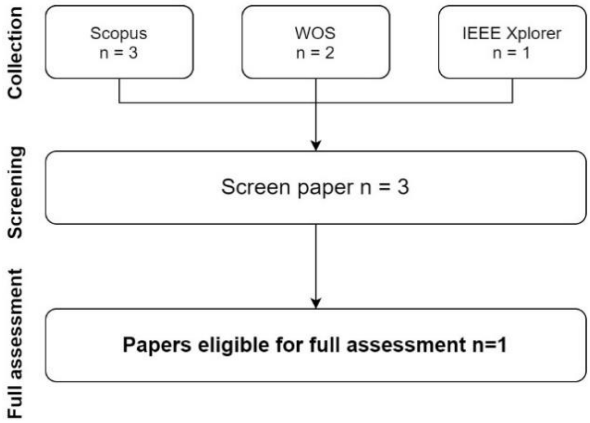

Fig. 2. Summary flow of systematic literature review

3.2 Material collection and analysis

We initially collected a total of 6 papers (3 from Scopus, 2 from Web-of-Science and 1from IEEE Xplorer Library). After a thorough screening based on our systematic literature flow as shown in Figure 2, there is only 1 paper that fits our criteria. Similar, from our search in the commercial sphere, there is only one commercial project focusing in energy tracing using blockchain technology.

Table 1. Table captions should be placed above the tables.

Author	Type	Scope	Approach	Comments
Yang, et al. [12]	Academic	Electric vehicle	Display Green Pass and checking Green Pass on the blockchain.	Certification is difficult to justify the source of electricity generation
Iberdrola Group	Commercial project	Green energy certificate	to guarantee, in real time, that the energy supplied and consumed is 100 % renewable	The framework is not explained

Table 1 gives a summary of the collected material. There is one published literature which focused on blockchain-based energy tracing in electric vehicles (EV). Yang et al. [12] published their work on energy tracing method for electric vehicles charging consumption in relation to the type and source of energy. They designed a platform which integrates the power trading centre, power dispatching centre, local power operators and EV user using blockchain. Green pass is stored on blockchain for checking to ensure to check the renewable transaction. However, electricity generation is from a mix of different energy source; therefore, a certified green pass may be difficult to justify the origin of energy source.

Iberdrola Group [13], a company in Spain, is working on to certify the source of green energy generated wind farms in Spain. They have begun a pilot project based on using blockchain to guarantee, in real time, that the energy supplied and consumed is 100% renewable. Using this technology, they have managed to link plants where electricity is produced to specific points of consumption, allowing the source of the energy to be traced. This increases transparency and ultimately encourages the use of renewable energy. However, the framework is not disclosed much. Current work effort on energy tracing using blockchain remains limited.

4 Finding and discussion

4.1 RT1: What is the state-of-art

After internet of Energy (IoE), blockchain has emerged as a popular technology in the energy sector by integrating blockchain to can result in a more secure, fast, transparent and low-cost operation solution [14]. There are eight [5, 14-20] systematic literature review published on blockchain-based within the energy sector. Andoni, et al. [16] reviewed and mapped out 140 blockchain commercial and research initiatives on the challenges and opportunities of the applications of blockchain for energy industries. They pointed some of the potential impacts are sharing resources for EV charging and significantly improve auditing and regulatory compliance. However, they did not mention on the tracing of the electricity and the energy source in most their work.

Ante, et al. [5] pointed out in their literature review that energy management in smart grids such as peer-to-peer trading is the potential emerging fields within the energy sector using blockchain. This is due to what blockchain can offer; immutable timestamped transaction which makes trading easier and less complex. Private oil and gas company like Shell [21] also envision the potential of blockchain in renewable energy source tracking which could change relationship between how energy is produced and consumed and transform the way companies collaborate and interact to accelerate the development of low-carbon energy.

Energy tracing is important because without a transparent energy footprint, rebound effect of carbon emission may occur. The increase in the use of electricity, particularly EV. This is important for user to know what types of energy source generated electricity. Since the operation stage are now relying on electricity, the generation stage becomes the main focus in order to meet the energy demand. When the user have the impression of that they are utilizing of green electricity and with the increasing demand, it could potentially result in increasing production of energy source which leads to increase of rebound effect of CO_2 [22], if the energy source are not generated from renewable energy source like hydropower and solar energy.

Digitalization can help to decarbonise future energy system for example in both tracing EV consumption and energy management system. Becour is private firm that focuses on tracking of renewable energy with the goal of increasing transparency of the energy market accelerate the shift away from fossil-based production [23]. Petrusic and Janjic [24] proposed a novel charging system to track the origin of the energy for the charging of EV in multiples systems using multicriteria algorithm. However, both the work did not mention blockchain technology as digital tool to enhance tracking. This could due to the nature of electricity is difficult to trace.

4.2 RT2: What are the barriers and potential future work

Unlike physical object tracking like food and diamond, electricity is a non-physical attribute making it challenging to trace the origin. The concept of tracking the provenance of food is easier as current approach is assigned unique identifier to the physical product but that is not for the case for electricity tracing. The fact that, energy flow is highly dynamic, which makes electricity more challenging to trace from energy source of the electricity then to final consumer. The current approach in ensuring the use of green energy source is by trading of green certificate. Owing to the immutable nature of blockchain, researchers have suggested this technology can store and trace the green certificate which guarantees the electricity is generated from green energy. However, electricity is highly dynamic which make green certificate difficult to truly reflect the origin of the energy source.

Another barrier in tracing electricity is because electricity is generated from a mix of different energy sources in order to provide sufficient electricity. Unlike Norway almost 100 % of the electricity production come from renewable energy sources (RES) [25], most of the other countries have a diverse energy mix to generate electricity. For example, in the US about 80% of the electricity is produced from fossil fuels and about 11% is from RES [26]. RES is a better alternative compared to fossil fuels when it comes the greenhouse emission, but its volatile supply of energy only serves to amplify this complexity which in turns makes tracing of energy harder. Batteries can be an alternative to store energy from RES during good weather condition, but it faces issues such as reduction in power quality and increased of energy loses during charging [27].

Apart from electricity consumption in EV, the electricity consumption in building sector dominates approximately 30% of the global annual greenhouse gases emission [28]. And in the entire life span of a building, the operational stage has the largest share of carbon emission [29, 30]. Agency [31] reported that in the operational stage, up to approximately 50% of the energy supplied is utilized for space heating and cooling purposes in the OECD countries. The types of energy supply to the both residential and non-residential building for activities like heating and cooling is important to prevent greenwashing and rebound effect because many has claimed their buildings only utilize 100% green energy.

5 Conclusion

Blockchain has emerged as a popular technology in the energy sector due to various benefits such as secure, transparent, and low-cost operation solution offered by blockchain. However, the focus on the energy tracing remains very limited. The energy source for electricity generation is closely connected to carbon emission. It is important to place a strong focus in tracing the energy source since things are more electrified then before. From our search, only 2 work focus on energy tracing. Current method of trading green energy certificate may not truly reflect how the energy source since electricity is highly dynamic. This work highlight the need to focus on energy tracing. With

the benefits offer by blockchain, particularly in terms of traceability, it potentially can reduce some complexity and open up new types of services in the energy market for a more transparent green energy trading. Although from our search, there are not many relevant literature and commercial project focusing on energy tracing at this stage, yet. Nonetheless, it is vital to understand the entire end-to-end of electricity generation to consumption in order to have a positive impact on climate change.

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