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The blockchain in the renewable energy sector: a tool for sustainability promotion

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Abstract. Energy transition and companies' commitment to sustainability can be supported by integrating innovative technologies into the renewable energy (RE) sector. Blockchain technology (BT) represents one such technology. This paper explores how BT can support RE consumption as an answer to energy sector companies' technological, transparency and traceability needs. We conducted a literature review on blockchain's ability to adapt to the energy sector, focusing on RE applications. In addition, we qualitatively analysed two projects pursued by energy sector companies in Europe. Although there is an abundance of research on the application of BT in the energy sector, there are only a few operational studies on this theme. Therefore, we combined the theoretical analysis with an exploration of the practical application of BT in two actual developments that highlight its positive implications for the transition to RE. BT applications for RE are at an early stage and require time for development. The analysis invites interactions among academics, energy sector operators and legislators. The findings contribute to facilitate the RE adoption and greenhouse gas emissions reduction in compliance with 2030 and 2050 goals.

Keywords: Blockchain, renewable energies, circular economy, multi-utilities, energy transition.

1. INTRODUCTION

Various sectors are adopting blockchain technology (BT). For example, the financial, agriculture, waste and energy sectors have been heavily influenced by their adoption of this technology, with several projects under development (Baralla et al., 2023; Centobelli et al., 2022; Wang & Su, 2020). The energy sector has been implementing novel technologies to update and support different functions and

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processes. Its structure is undergoing profound changes and attracting interest. Energy transition goals identified before the Covid-19 pandemic and reinforced during it are deeply connected to the adoption of digital solutions. In addition, the conflict between Ukraine and Russia has highlighted the need to diversify energy supplies by strengthening the promotion of a new energy mix, including renewable sources.

In this context, the strategic value of the energy sector has been demonstrated by international and local policies moving it away from production using fossil resources and leading it towards renewable energy (RE) resources. However, the growth of the RE sector requires sustainable decisions involving businesses and communities. International agreements and European directives have targeted sustainable development and twin transition. These include the n. 7 of the United Nations Goals, which concerns moving energy production towards clean sources and thus the adoption of RE, thereby reducing greenhouse gas (GHG) emissions (United Nations (UN) General Assembly, 2015). The Paris Agreement and the European Green Deal have also defined a path towards carbon neutrality supported by the RE sector (European Commission, 2019; Paris Agreement, 2015). A further push to accelerate the achievement of these goals has come with the European initiative ‘Fit for 55%’, which is intended to increase RE adoption as part of the energy mix (European Commission, 2021). These policies affect a plurality of countries that share the same goals.

From a practical standpoint, objectives have been transformed into policies and regulations that promote the use of RE and the reduction of carbon emissions through interventions such as taxes, subsidies and renewable energy certificates (RECs) (Yamaguchi et al., 2021). In terms of RECs, these have been applied in the European Union under the guise of guarantees of origin (GOs), which are supposed to encourage RE consumption by providing important information to consumers about the energy they consume (European Parliament, 2009). These tools should enable companies to account for their actions by encouraging clean energy consumption and reducing CO_2 emissions into the atmosphere. In this scenario, the energy sector has radically changed its structure towards the decentralisation of energy production facilities, driven by the adoption of new technologies that have digitised systems. Among these technologies, blockchain, due to its decentralised nature and distributed ledger, enables the information recorded on it to be immutable and secure and to have a high level of transparency.

As will be shown later in this paper, and according to Khezami et al. (2022), BT in the energy sector may have implications for carbon emissions, and evidence will be provided for its use in the transition to RE. Moreover, the ability to communicate reliable information to consumers and stakeholders more generally can be seen as a positive element of BT in terms of its value to businesses (Xu et al., 2023).

This paper explores how RE management can be supported by BT as an answer to the technological, transparency and traceability needs of companies in Europe's energy sector. Hence, we provide an analysis of the literature on RE, focusing on RE developments and the features, functions and applications of BT in the RE sector. We pay particular attention to how technology can facilitate the consumption and promotion of RE. The literature analysis highlights the state of BT applications in this field, most of which are at the proof-of-concept stage. In the European context, to the best of our knowledge, only a few studies have investigated actual applications of BT in the energy sector by major operators to achieve and promote energy transition towards RE.

Having engaged in two exploratory projects developed by a transmission system operator (TSO) and a multi-utility company, we examine their use and opinion on BT applications, exploring whether BT can support RE usage and promotion.

The paper is structured as follows. In the following section, we provide the theoretical background. We then present the methodology, followed by a description of the analysed projects and a discussion of the findings. In the final section, we highlight the conclusions and detail further research.

2. THEORETICAL BACKGROUND

A multi-perspective approach is required when considering the characteristics of BT use in the energy sector to encourage the adoption of RE. Thus, the literature review examines various aspects of the topic and considers how BT can be applied to improve transparency and traceability features specific to the energy sector. It then focuses on the integration of BT into RE in balancing and flexibility services and its promotion and use in the circular economy.

2.1. The energy sector, blockchain and renewable energy

2.1.1. The energy sector’s move to renewable energy

For the 2030 and 2050 goals for reducing GHG emissions, based on global warming targets and RE resource adoption, to be reached, there must be a decrease in the use of fossil fuels (Gacitua et al., 2018; UN General Assembly, 2015; Zhao et al., 2020). Adapting its energy production system in response to environmental needs, the energy sector has been decentralising its structure, realising a progressive energy transition. In this context, distributed energy may be an answer to growing energy demands and achievement of the RE transition. For this reason, the integration of RE in the energy system is taking place (Gacitua et al., 2018; Juszczyk et al., 2023).

Several countries have tried to boost development of the RE sector by adopting regulations (Gacitua et al., 2018), including those belonging to the European Union. As Gacitua et al. (2018) reported, the tools and incentives frequently adopted include funding R&D with tax credits and grants, renewable portfolio standards, cap-and-trade systems, feed-in tariffs, RECs and carbon taxes. These measures can lead to energy transition and are based on four principal elements: decarbonisation, decentralisation, digitalisation and democratisation (Andoni et al., 2019).

Decarbonisation is related to the transition from fossil fuel energy production to RE. This is an important element that underlies carbon accounting and disclosure policies.

Decentralisation refers to the widespread adoption of small-scale energy production plants. This phenomenon has given energy production systems a local dimension by potentially reducing the distance to the point of consumption.

Democratisation concerns a revolution in the energy system, which has seen a move from a few large, centralised companies to small prosumers, consumers and producers. Over the years, this concept has moved from extending access to different services to participating in energy policy decisions. With the increased number of stakeholders, a new idea of energy democratisation has manifested, linked to ‘energy communities’ (Szulecki & Overland, 2020). The concept has also been supported by the creation of peer-to-peer (P2P) platforms for the direct exchange of energy without the involvement of third parties between the stages of energy production and consumption.

Digitalisation is related to adopting information and communication technologies (ICT) (Nour et al., 2022). According to Wang et al. (2022), the integration of energy technology and ICT is inevitable; in this context, blockchain plays such a fundamental role that it can be defined as the 'energy blockchain'.

These elements require digitised management of energy exchanges involving multiple actors (Juszczyk et al., 2023). As reported by Friedman and Ormiston (2022), BT is useful as a data recording system in environments where technological innovation is a sustainability tool, and technologies such as artificial intelligence (AI) and the Internet of Things (IoT) are fundamental elements of data trustworthiness.

2.1.2. Blockchain technology

BT made its debut in 2008 during a financial crisis, when it was used as a P2P platform to support the bitcoin system, allowing the creation and exchange of the most famous cryptocurrency (Friedman & Ormiston, 2022). This disruptive technology enabled P2P value exchanges without the need for a third party to guarantee transactions, overcoming the double-spending problem (Nakamoto, 2008). According to Wang and Su (2020), bitcoin was created as the first safe and reliable decentralised digital currency mechanism, and it became popular as a means to solve problems related to value guarantee, transaction anonymity and the absence of a third-party guarantor.

Blockchain is a distributed and decentralised ledger with a distinct architecture composed of a chain of blocks that follow a chronological order. All transactions are recorded inside the blocks through a consensus mechanism. Cryptography and hash functions attribute immutability to the recorded information, ensuring the safety of network operations. Every participant in a P2P network owns a copy of the ledger (Friedman & Ormiston, 2022). This system facilitates real-time communication between participants and does not require identity verification (Abas & Reynaldo, 2022).

Three kinds of BT have been identified that relate to different types of participation in the network. Permissionless blockchains, also known as public blockchain, are open access, allowing everyone to participate in the network and own a ledger copy. Bitcoin and Ethereum are examples of permissionless blockchains. Permissioned blockchains restrict the network and access to a defined group of participants by a validator (Kouhizadeh & Sarkis, 2018). Between permissionless and permissioned blockchains, there are consortium blockchains, which are hybrid blockchains with a semi-decentralised structure whereby the network is one part private and one part public (Llamas Covarrubias & Llamas Covarrubias, 2021).

Smart contracts have played an essential role in the development path of blockchain in the energy sector. A smart contract is a computerised transaction protocol that verifies and executes the terms of an agreement (Zheng et al., 2020). According to Wang and Su (2020), it is helpful in automatically allowing trusted transactions to occur with no third party as a guarantor.

Since 2008, blockchain has evolved in terms of its applications. Pimentel and Boulianne (2020) reported many case studies of BT being applied in different sectors according to its various characteristics and highlighted how 'actual blockchains exist on a continuum across these many characteristics'.

The relevance of BT development away from the financial sector is determined by its characteristics. The supply chain, for example, offers potential applications that could benefit in terms of effectiveness and efficiency thanks to BT's ability to verify, share, program and trace (Al-Zaqeba et al., 2022). Interest in BT among the supply chain and its actors emerged in the cases we analysed.

The growing importance of BT has drawn the attention of important operators in the technology sector and strategic consultancies such as Gartner Inc., which has predicted the development and adoption of this technology in Hype Cycle Tool: Hype Cycle for Blockchain and Web3 2022 (Gartner, 2022). As Bonsón and Bednárová (2019) reported, the technology could influence administrative practices, offering the opportunity to reshape a business and representing a step forward in the digital era.

2.1.3. Blockchain in the RE sector

As Sahebi et al. (2022) explained, 'Blockchain technology is projected to be a principal contributor to the renewable energy supply chain (RESC), offering significant changes in the degree of accountability, reliability, and traceability' (p. 2). Blockchain's potential to manage the RE sector comes from its ability to arrange the significant amount of data generated by transactions involving the parties participating in the system (Yap et al., 2023).

BT applications can improve transparency and data security and decrease transaction costs, thereby optimising processes (Nour et al., 2022). As Yamaguchi et al. (2021) suggested, the energy sector can benefit from applying the technology at various levels, enabling disintermediation in energy system operations and markets and between consumers, thereby ensuring transparency in transactions between consumers and producers of RE. As the ‘Blockchain solutions for the energy transition’ study conducted by the European Commission (Fulli et al., 2022) revealed, energy stakeholders are interested in blockchain applications within their sectors, particularly in the origin of supply or demand. According to Khezami et al. (2022), energy trading, management and storage; security; electric vehicles; and carbon emissions are the main applications for which BT can provide added value and relevance in energy sectors.

Interest in technology applications for the energy sector is growing, and numerous experiments and projects have been initiated. When the blockchain is applied, it can integrate smart devices such as smart meters by providing information about the energy produced (Yap et al., 2023). As reported by Andoni et al. (2019), most applications of this technology can be placed into the following eight groups:

1. Metering/billing and security
2. Cryptocurrencies, tokens and investment
3. Decentralised energy trading
4. Green certificates and carbon trading
5. Grid management
6. IoT, smart devices, automation and asset management
7. E-mobility
8. General-purpose initiatives and consortia

Particularly relevant for this study are groups 1, 3, 4, 5 and 6, related to metering, billing and security, decentralised energy trading, green certificates and carbon trading, grid management, IoT and smart devices.

Metering, billing and security have an important role because one of the first applications of BT in the energy sector concerns the possibility of paying energy bills through cryptocurrencies (Andoni et al., 2019).

The transition to an increasingly decentralised production system offered the opportunity to optimise the sector, with the possibility of exchanging even self-produced energy. Due to its characteristics, blockchain can support this exchange system with the recording of transactions. Recording information on electricity production and consumption by using meters plays a key role. The application of blockchain gives greater transparency by providing information to the consumer on the origin and cost of the energy consumed. The presence of meters connected to the blockchain also enables automation of payment.

For all who join the platform, it is necessary to provide high levels of security on transactions and adequate levels of privacy about the information provided.

If metering and billing were the first applications of BT in the energy sector, decentralised energy trading attracted a considerable number of projects (Onyeka Okoye et al., 2020), including those related to wholesale energy trading and platforms to facilitate consumer access to the market and P2P energy trading (Andoni et al., 2019).

Using technology, the presence of an intermediary can be eliminated, resulting in a transaction cost reduction. Consumer access to the market through platforms that offer greater choice would increase competition between operators and reduce costs. Furthermore, opening P2P platforms would allow prosumers to generate revenue. One of the first and best-known cases of a P2P community that exchanges energy through a blockchain-based platform is the Brooklyn Energy community (Brooklyn Microgrid, 2019).

There are also interesting elements regarding grid management applications. The need to provide decentralised and automated grid management and control is closely linked to the integration with suitable technology.

The coordination of transmission and distribution system operations would be facilitated by the application of BT. Moreover, it enables the balancing of energy demand and supply.

The potential of this application has led several players to explore its development through attempts aimed at solving grid congestion management in the relationship between TSOs and distribution system operators (DSOs); for example, some others are experimenting with supporting balancing and ancillary services through the use of vehicle-to-grid; still other projects aim to provide grid services through the use of residential batteries connected to BT (Andoni et al., 2019).

Blockchain integration with IoT systems and other smart devices is often suggested as a way to enhance the potential of BT. The use of IoT in the energy sector is particularly related to smart meters, referring to real-time monitoring by blockchain-based platforms with connected devices. This application opens up the possibility of optimising energy consumption through monitoring devices. The devices could integrate different functionalities such as monitoring energy prices, demand and weather forecasts. Some blockchain application projects go in this direction (Andoni et al., 2019).

The fourth group, which references green certificates, has particular relevance for this study because this application is a good representation of the traceability and transparency of blockchain-based systems. In light of European legislation that promotes the consumption of RE, RECs are representative tools of this system.

In the energy sector, RECs are essential for tracing and guaranteeing the origin of RE, the traceability of which accompanies reliable disclosure of the energy consumption of those who purchase it. The traceability of RE gives consumers a decision element referring to the origin of the energy and its price. This information can contribute to consumer empowerment, based on the resulting environmental benefits in terms of reduced GHG emissions due to RE consumption.

The traceability of energy, or electricity tracking, can account for the quantity and nature of electricity (Gkarakis & Dagoumas, 2016). Tracking energy physically is currently impossible because once it is produced, it enters the grid and mixes with energy from various sources. Thus, the composition of the mix is still being determined. A certification system enables the selection of the renewable attributes of physical energy, and ‘these certificates de-couple the green power attribute from the physical unit of energy’ (Gacitua et al., 2018, p. 348), enabling independent trade.

A REC is a useful and common tool. Known as a GO in the EU, it is used to inform consumers when their energy is from renewable sources (European Parliament, 2018). Adopting this system can provide traceability and reliability in terms of energy origin. Tracing energy flow and ensuring that it comes from an RE plant could represent a tool to assure the reliability of RE information. This information responds to the needs of stakeholders and investors for sustainability data and is an element in consumer decision-making, in additional to price. Since it is impossible to physically trace energy's origin, this system aims to offer a solution. According to Delardas and Giannos (2022), RECs can allow verification of the correspondence of the purchased energy by tracking every transaction from the moment they are issued.

In this context, blockchain can increase transparency and prevent the double-spending problem by reducing transaction costs and expanding the certification market (Zhang et al., 2020). Scholars have reported cases of BT applications for RECs (Delardas & Giannos, 2022; Yamaguchi et al., 2021; Zhang et al., 2020;). Yamaguchi et al. (2021) reported an example of an application by a Brazilian company that developed a blockchain-based platform to support REC issuance, enhancing traceability and providing higher levels of security. With an application perspective aimed at the European context, Delardas and Giannos (2022) analysed the application of BT in the case of GOs, highlighting benefits in terms of transparency and administrative simplification. Zhang et al. (2020) focused on the Chinese context, analysing the transaction process of RECs and its limitations, again proposing the use of blockchain as a tool to support its trading system.

2.2. Uses and promotion of renewable energy

2.2.1 Balancing and flexibility services

Integrating RE within a grid involves a complex system of balancing energy demand and supply. In this case, technological contributions can support the integration of RE into the system, ensuring transparent data management and energy origin. In the development of the energy system, it is important to plan the dynamics of demand and strengthen flexibility services regarding 'system stability, frequency and energy supply, local transfer, voltage and quality, scheduling and exchange' (Wu et al., 2022).

Various players are involved in the complex system of flexibility services, including transmission system operators, distributor system operators, aggregators and prosumers. The presence of the various actors involves not only the physical exchange of energy but also the production of a large amount of information. Moreover, as the integration of the RE sector into a power system increases, the need for flexibility to maintain stability in the grid by TSOs and DSOs also increases, for which cooperation is required, as underlined by the Clean Energy Package (Mladenov et al., 2022).

The coordination of various aspects, such as dispatching, supply validation, the settlement of stipulated contracts and ensuring access to the information and data produced, will be necessary among the different actors (Lucas et al., 2022). Again, BT would help support such services and processes and the exchange of information, specifically validation, data integrity, data origin and stakeholder sharing (Lucas et al., 2022).

Mladenov et al. (2020) explained how transactions among TSOs, DSOs, prosumers and flexibility service providers can be carried out securely with blockchain, improving their interaction regarding the traceability and irreversibility of agreed terms (Mladenov et al., 2020). According to Rajasekar and Sathya (2023), BT will help make energy systems more efficient, giving them accessibility, flexibility and autonomy. They also emphasised how important BT will become in maintaining the balance between electricity production and consumption amid the local energy market's need for a modern communication structure (Rajasekar & Sathya, 2023). For this reason, we will explore in the following paragraphs a real case of BT application in the European context.

2.2.2 Circular economy for renewable energy promotion

As reported by Juszczyk et al. (2022), the application of BT in the RE industry could offer advantages such as benefits for the circular economy (CE). There are many ways to define the CE. According to Morseletto (2020), the CE is a model that provides a more sustainable structure in economic and environmental terms and enables the reuse of resources. It is a complex concept, and, as reported by Ghisellini et al. (2016), three main elements have emerged: reduction, reuse and recycling—although some authors have added a fourth principle: regeneration (Morseletto, 2020). Corsini et al. (2023) listed these elements and highlighted how the transition to RE can be considered a pathway to regeneration. More generally, RE and the energy sector appear fundamental to the CE (Yildizbasi, 2021).

The adoption of RE and realisation of the CE can be fostered using BT (Corsini et al., 2023). In this sense, it is possible to identify multi-utility organisations carrying out activities compatible with the CE. In their activities and services, multi-utilities may deal with water management, waste management and energy production and distribution. They can move towards increasingly sustainable models, such as by reducing water consumption and waste, building differentiated collection and waste recycling systems and promoting the consumption of energy produced from renewable sources.

New technologies can support these activities. According to Böhmecke-Schwafert et al. (2022), BT can provide a platform for the CE ecosystem by facilitating physical and non-physical transactions and traceability. It can also foster CE processes using smart contracts for the automation of processes, costs and payments through the development of platforms such as those based on tokens.

Juszczyk et al. (2022) pointed out how adopting BT can promote new behaviours by tokenising sustainable purchases and provide advantages in various applications, including green certificates and the CE. Indeed, the push for a transition towards renewable sources can be fostered by promoting a circular system and sustainable behaviours. Interest in this transition has led to deepening the literature through the possible application for balancing the energy supply, consumption and flexibility services (Lucas et al., 2021; Mladenov et al., 2022; Wu et al., 2022). Potential benefits of applying BT in the RE sector have emerged in the literature in terms of the CE and sustainable behaviour promotion related to consumers and stakeholders.

3. METHODOLOGY AND RESEARCH DESIGN

This study is focused on BT's applications as a tool to promote the use of RE. The context selected for the study is represented by the following:

- a balancing system between energy demand and supply in the grid transmission of flexibility services, in which the integration of RE is important
- the CE as a system for promoting RE and encouraging sustainable behaviours by reducing electricity consumption and encouraging the purchase of RE.

We used a qualitative methodology through two selected cases to investigate the possible utilisation and role of BT in promoting sustainable behaviours. We examined two explorative projects in which two European companies, a multi-utility company and a balancing services organisation, applied BT in projects focused on encouraging the use of RE.

An exploratory case study was chosen because when drawing empirical evidence from literature results is difficult, it is an eligible method (Yin, 1994). Both the presented projects are exploratory cases that contribute to furthering theoretical propositions and improving the theoretical background.

The first is a joint venture between various European transmission system operators that manage high-voltage grids in their national electricity systems. The second project involved an Italian multi-utility company operating across a wide area and providing various energy, water and environmental services. The gap regarding the application of BT in the energy sector in the European context, as mentioned in the introduction of this work, derived from a non-systematic literature review.

We carried out the literature review with the Scopus database: articles were searched through the matched use of selected keywords such as: blockchain technology, renewable energy, energy sector, traceability and transparency.

The articles' selection considered a range of time from 2018 onwards.

To complement the academic literature, papers and reports referable to grey literature were also consulted.

The analysis was carried out rigorously yet aimed at providing a framework for the technology and the application context.

In May of 2022, the people responsible for the two companies’ BT application projects were contacted and semi-structured interviews were conducted. For the TSO’s joint venture, the first contact was made in May, and at the end of the month, a senior business consultant was interviewed. The same person holds the position of energy strategy analyst for one of the TSOs participating in the joint venture. The interviewee subsequently emailed a supplementary presentation to the interviewer.

In the case of the multi-utility company, contact took place at the end of May 2022, and the head of new initiative development was interviewed in early June.

Microsoft Teams was used for the interviews. The duration of each was approximately 60 minutes. They were recorded and transcribed. Institutional information on the companies promoting the projects were also collected.

The interviews were analysed to understand blockchain’s use as a tool to support the use and promotion of RE; the focus was on developmental perspectives, features and critical issues. Figure 1 illustrates our research approach.

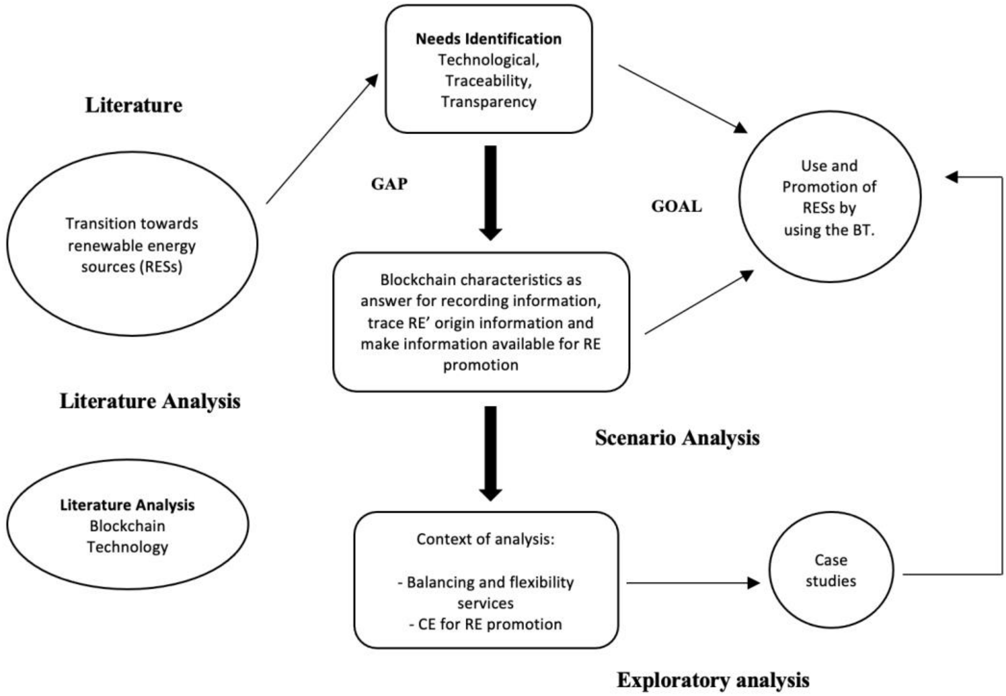

Figure 1. Research approach

4. FINDINGS

The first company analysed operates in the energy sector, providing a crowd-balancing platform for TSOs operating in Europe. The platform aims to connect the operators and to facilitate their operations in the electricity-balancing market. The complexity of this market requires operators to balance the relationship between energy supply and demand. Their operations involve the reduction or input of power into the grid. The project involves the use of small-scale flexibility sources instead of thermal power plants, as is usually the case.

The project will use a transaction-based system supported by BT and involve different system actors, including TSOs, DSOs, energy communities, power exchanges, aggregators and validation data providers (which do not yet exist). The platform has the objective of integrating RE sources for balancing services.

The increasingly distributed and decentralised energy generation system will lead to the presence of many actors (both traditional and new actors, such as prosumers), enabling smaller, flexible and distributed assets to participate in energy systems through aggregation. Aggregators can participate in electricity-balancing markets involving smaller flexibility devices, including electric vehicles and home batteries, highlighting their prosumer role. For this reason, the interviewee indicated blockchain as a technology capable of managing and recording many transactions, providing security and attributing immutability and non-modifiability. The information recorded could be considered a single, faithful version. As stated in the interview, the presence of BT could be an answer to the complex system of relationships and transactions between all the operators involved. In particular, reference was made to the management of relationships by recognising the range of intervention and responsibility that each operator has, as in the case of DSOs, who manage low voltage, and TSOs, who are responsible for high voltage. (Mladenov et al., 2022; Lucas et al., 2021)

The development of a single platform to support the operation of many actors will allow costs to be shared and synergies leveraged; moreover, it represents a way to standardise those operations.

The second real-world case is related to the multi-utility sector. The company is an Italian multi-utility that is approaching BT by developing two projects intended to increase sustainability behaviours by encouraging them through a system of incentives. The first project is applying BT to create a system in which incentives represent an element of leverage. The system has various stages, such as identifying measurable, sustainable behaviours; client self-identification by declaring the measurable behaviours they have performed; and receiving an incentive. An accumulative token represents the incentive. This token is associated with the client's digital wallet, enabling the conversion of the token into a discount voucher that can be spent at specific organisations.

The second project presents a blockchain-based system that includes the use of tokens to enable a cash-back process related to sustainable behaviours, such as a reduction in consumption and emissions. Both projects are promoted through collaboration with other actors. In the first case, this is done with organisations working in the catering and large-scale retail industries, and the second project involves collaboration with a municipality.

The possible extension of BT into the CE emerged from the interviews. Indeed, the development of such projects by a multi-utility company could be extended to matters involving waste, water and the environment. The starting idea was to connect the concept of sustainability to BT, creating an instrument that would enable the stimulation of sustainable behaviours by consumers in the first case and the broader public in the second.

The interview opened future perspectives on the multi-utility company's role. Its activities will need the support of suitable tools for managing the increasing numbers of transactions because of, for example, the diffusion of decentralised energy plants. Moreover, the future vision foresees the possibility for citizens or customers to purchase part of a local RE power plant, thereby allowing a production logic focusing on the local aspect. The interviewee also highlighted the blockchain's effects on the supply chain, attributing information on what has been bought and how it was used.

5. DISCUSSION

The theoretical background highlights the different ways blockchain can support RE adoption. The evolution of this sector towards a more decentralised model creates technological, transparency and traceability needs and calls attention to the objectives of a CE. The blockchain may be an effective tool to meet these needs, as emerged from the findings.

The reported features and strengths of BT meet the literature in many aspects. The first element noted is the respondents' awareness of the energy sector's evolution towards a decentralised energy system structure with widespreadpower plants that need to be integrated into the energy exchange system. This new condition opens scenarios in which energy is produced not far from where it is consumed.

The interviewees' interest in BT and its possible applications confirms Wang et al.'s (2022) argument regarding the predisposition of actors operating in the energy system to integrate the sector's technologies with ICT. The trend of new energy systems supported by the use of new technologies, such as blockchain which takes on the definition of energy blockchain (Teufel et al., 2019), is confirmed.

The sector's complexity is demonstrated by the growing number of involved stakeholders and the increasing amount of information managed. This is also shown by the interviewed platform, which involves not only TSOs but various operators. Organisations are driven towards the research and application of systems able to face this complexity; blockchain is included. It is possible to find evidence of this in the literature, as Lucas et al. (2021) reported the possible use of blockchain to support the development of flexibility markets. Moreover, in the perspective shown by the interviewees, operators adopt technologies to support the production, distribution and exchange of energy within the grid or to maintain stability, as reported by Rajasekar and Sathya (2023).

From the interview on the TSOs' joint venture emerged how the identification of BT as a tool to support the exchange and sharing of information between various stakeholders, which was discussed by Lucas et al. (2021). According to Mladenov et al. (2022), blockchain improves interaction regarding traceability and the irreversibility of agreed terms. This point is emphasised in the case of joint ventures between TSOs, where an instrument is needed to regulate the relationships and responsibilities between the operators involved; in particular, blockchain manages the relations between DSO and TSO or TSOs and other involved operators. The awareness of both interviewees regarding the capability of BT in traceability matches was reported by Andoni et al. (2019), who referred to energy or monetary transactions.

The adoption of tokenised systems in the multi-utility company's project reflects the contribution of BT in fostering CE processes; in fact, according to Böhmecke-Schwafert et al. (2022), the reduce, recycle and reuse principles of the CE could be realised by BT through the incentivisation of sustainable behaviours.

Some weaknesses emerged, determined by the limited adoption of technologies by organisations operating in the sector and the lack of projects in which blockchain is used with other technologies, such as IoT and AI. Moreover, on BT's role and the developments it could allow for in the RE sector, the interviewee with the Italian multi-utility speculated on a hypothetical RE traceability system to certify the origin of energy from plants located close to consumers through a smart meter system that is as yet unavailable.

The projects implementing BT applications are still at an early stage, and for this reason, many elements need to be improved before a full move toward efficient integration with RE and all players involved.

Table 1 summarises the main aspects that emerged, comparing the organisations interviewed and considering the three factors which represent the satisfied needs, including also the RE promotion.

	Balancing services organisation	*Multi-utility company*
Technological aspects	BT enables the provision of security in recording transactions, avoiding disputes and ensuring no information is changed in the balancing and flexibility service's operations. It also provides proof of delivery.	BT supports a token-based platform for creating a system of incentives to promote sustainable behaviours.
Transparency	BT facilitates a complex system of relationships and transactions between all the operators involved, such as TSOs, DSOs, prosumers and others.	The information recorded through BT can be made available and also visible to consumers and stakeholders.
Traceability	Traceability emerges through the possibility of tracing the flow of energy as an important practice; however, it requires the use of technologies that are not yet available.	Traceability is confined to providing only GO reporting to integrate the energy mix of purchased electricity.
RES promotion	The intention for the proposed platform is to integrate RES for balancing services involving smaller flexibility devices.	The promotion of renewable energy passes through a system of incentives for sustainable behaviours.

Table 1. Project's main aspects

During the interviews, considerations emerged as to the potential development of BT technology to support GHG emissions disclosure. Especially in the case of the multi-utility company, it would be possible to use BT to adapt behavioural habits towards reducing GHG emissions. Indeed, its use for regulating transactions with a tokenised system could be assumed, involving several actors and recording information useful for GHG emission measurement for Scopes 1, 2 and 3[1] related to emissions generated by the value chain.

Expressing the sensitivity of sustainability reporting, the multi-utility company mentioned an innovative idea for a project that would lead to the implementation of Scope 3 reporting by creating a carbon certificate issuing system that is able to trace certificates, although it would need regulation.

[1] Scope 1 represents the GHG emissions generated directly by the organization's activity; Scope 2 refers to the indirect GHG emissions produced by the energy consumption; Scope 3 GHG emissions refer to those produced along the value chain.

6. CONCLUSION AND FURTHER RESEARCH

We analysed how BT can support RE usage and promotion as an answer to the technological, transparency and traceability needs of a balancing services organisation and a multi-utility company in the Italian and European contexts.

The first part of this work reviewed literature on the energy sector and its movement towards RE sources and identified what BT is and what are among its features. We then analysed the interaction between blockchain and the RE segment, investigating several applications of the technology. Afterwards, we looked more deeply at applications through which blockchain can provide benefits for the use and promotion of RE.

Starting from the research aim, we adopted selection criteria to consider companies that had developed BT and were not just at the proof-of-concept stage. We delved into two practical applications of BT in the RE sector. In the first case, we observed the implementation of BT by a TSO joint venture that performs grid-balancing activities and that has established a network of multiple operators to facilitate integration with renewables. The second case was an application of BT by an Italian multi-utility company to develop a tokenised system for promoting sustainable behaviours.

This paper shows the high number of transactions and large amount of exchanged information conducted in a complex scenario, namely that of a balancing and flexibility system involving several energy sector operators. This system increases the need to move towards RE, leading to electricity consumption from renewable sources, reducing emissions levels and managing and sharing data and information securely and transparently.

The impact of energy transition in the analysed projects is highlighted in terms of new technologies, transparency and traceability because these issues must be addressed when applying technological and digital solutions promoting and using RE. The operators understood the need to integrate RE in adopting innovative technologies to enable information management, exchange and sharing. For both companies, blockchain represents a solution that will provide a safe way to record information on transactions between different operators. The traceability feature is important for the consumption of RE by consumers, who can obtain reliable information about the energy's origin. As a further application, BT's traceability can support GHG reporting and the sustainability system. Moreover, as emerged from the multi-utility blockchain-based project, when the technology involves customers, it can enrich their information on virtuous behaviours and promote them.

The main limitations of this work are related to the use of a qualitative methodology. The work is merely exploratory and does not allow the possibility of arriving at consolidated generalisations. Although the cases examined are interesting, we hope that in the future the research can be expanded to a multi-case analysis. Through additional in-depth interviews and a cross-case analysis, we can also frame, in theoretical and operational terms, the potential and limits of BT in the promotion of RE.

For future studies, it would be interesting to analyse cases in which blockchain is implemented in projects that promote sustainable behaviours and explore its application in the value chain, creating networks to enable Scope 3 reporting. As the energy sector changes, the usage of blockchain appears to be growing. Therefore, it would be interesting to deepen our understanding of this issue by monitoring the evolution of these cases and extend the exploration to others.

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