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APPLICATION OF BLOCKCHAIN TECHNOLOGY IN THE ENERGY SECTOR

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Purpose: The reason for writing the paper is growing complexity of management of the electric grid. Our collective electric system faces accelerating, multi-dimensional needs that must be addressed to deliver to our communities.
Design/methodology/approach: The supply, transmission, distribution, and consumption of electricity are closely coupled, and must be actively coordinated. This requires the coordinated sensing, measurement, and control of devices and systems spread across the grid. This paper assesses the suitability of blockchain for this purpose, as a platform for transactive energy.
Findings: Blockchain technology can facilitate secure and transparent record-keeping and transactions and thus may have many potential applications in the energy sector.
Practical implications: Blockchain technology is still evolving and faces some challenges, such as scalability, interoperability, regulation, and adoption. However, blockchain has the potential to revolutionize the energy sector by transforming the way energy is produced, distributed, consumed, and traded.
Social implications: High electricity demand, aging power grids, and climate disasters are straining our current energy system. As a result, more people are looking to optimize energy usage—and transactive energy may offer an answer. A Blockchain-enabled transacted energy framework can help everyone from consumers to corporations benefit from improved energy efficiency and profit in the process.
Originality/value: Distributed energy resources, such as energy efficiency, smart demand response, smart electric vehicle charging, building-level energy storage and distributed solar photovoltaics, become more critical every year. Review of recent papers on these issues may be a valuable source of knowledge for interested parties.

Key words: Blockchain, power grid, smart grid, energy.

Category of the paper: Literature review.

1. Introduction

In 2023 the Institute of Electrical and Electronics Engineers (IEEE) - the world's largest technical professional organization, published a 'Guide to Transactive Energy: What Everyone Needs to Know' (IEEE, "Guide to transactive energy", 2023). In this Guide the concept of transactive energy was introduced since …"High electricity demand, aging power grids, and climate disasters are straining our current energy system. As a result, more people are looking to optimize energy usage—and transactive energy may offer an answer".

First, the outdated nature of legacy grid systems were described in the Guide as follows: "Over the past century, utility companies built electrical grid systems to serve as large generation hubs for certain geographies. These entities operate using a centralized model and are typically responsible for all aspects of managing and provisioning energy. Legacy grid systems are inefficient and costly. Furthermore, it's clear that our current power grid model is under a great deal of stress. Electrical grids operate using fragile, outage-prone lines that can fail when they take on too much power, or when disasters occur, such as floods and heavy storms. Due to the centralized nature of a legacy system, if one component fails, the entire infrastructure can suffer. Legacy grid operators use strict processes to ensure that plants generate the right amount of electricity at the right time to meet demand. However, intermittent renewable output disrupts this planning process, making it difficult to incorporate sustainable energy. In the past, the idea that someone could generate kilowatts of electricity using a device on their roof was unfathomable. However, these technologies are now a reality".

Finally, after defining what are transactive energy systems, the advantages and challenges of their implementation were presented as follows: "Transactive energy systems make it easier for anyone to trade and sell energy, whether they are an individual consumer, a micro-grid, or a major power company. Although this system promotes energy efficiency, it also faces significant implementation challenges. Advantages of Transactive Energy. Electrical grids distribute electricity from energy producers (large utility companies) to consumers using a traditional centralized infrastructure. Transactive energy enables decentralization, where multiple groups can produce their own energy at a local level, relying on a series of smaller devices and power grids instead of a central hub. As the legacy grid framework ages, transactive energy systems may be the future of energy. And the benefits of distributed energy resources, a variety of small, system-connected devices and virtual assets that work to provide services to the energy grid—are far reaching. A decentralized energy infrastructure can unlock several important benefits. Transactive Energy Challenges (IEEE Implementation challenges, 2023). However, there are some implementation challenges that are important to understand. Utility business models will need to evolve for transactive energy to work. Current systems rely on a centralized grid that supplies electricity to all consumers in a certain area. The utility primarily controls the excess energy and does not engage in two-way transactions. Evolving these systems will require significant effort, incentives, and consistent standards. Security issues may arise (IEEE Security, 2023). Cybercriminals can harm transactive energy systems by manipulating energy requests, siphoning excess power, and injecting false data that prevents successful transactions. Strong security protocols are necessary to prevent cybersecurity threats. Transactive energy systems require distributed energy resources. Installing these resources requires time, money, and labour investments, which can pose barriers to adoption. All devices in a transactive energy system must be able to perform autonomous computing functions and communicate with one another to exchange data. This can be difficult to accomplish in a decentralized environment. However, distributed ledger technologies, such as Blockchain, can help enable these capabilities" (Zia et al., 2020).

Benefits of Distributed Energy Resources: Shifting the Energy Landscape

Transactive energy enables everyone to participate in the energy economy. Homeowners can install small devices like rooftop solar panels to generate electricity and engage in bidirectional energy transactions. The market has many devices ready to take advantage of transactional energy, such as smart fridges or outlets that are part of the Internet of Things (IoT) ecosystem (IBM, 2023). Many IoT-connected devices can be adjusted so that they consume energy at the most cost-efficient times. Transactive energy promotes resilience (Bhattarai et al., 2019). If one part of a centralized energy system suffers damage, the whole system could fail. With a decentralized framework, only the affected infrastructure suffers an outage. The length and frequency of power outages may decrease. Transactive energy can enable a more efficient balance between supply and demand, ensuring that consumers use energy at optimal times and levels.

In this paper a concise review of the electric power system and differences between traditional power grid and smart grid is presented followed by a description of key technology trends in transactive energy applying distributed energy resources and, first of all, how the blockchain technology may be applied in energy trading.

2. Methods and Results

2.1. Electric power system

According to Edvard Csanyi from the Electric Engineering Portal (Csanyi, 2017) an electric power system is a network of electrical components that generate, transmit and distribute electricity to consumers and industries. It consists of three main parts: power generation, transmission and distribution. Power generation converts the energy stored in fuels or renewable sources into electrical energy. Transmission systems carry the electricity over long distances using high-voltage lines. Distribution systems deliver the electricity to the end-users using lower-voltage lines. Power generation is the production of electricity at power stations or generating units where a form of primary energy is converted into electricity. Power plants convert the energy stored in the fuel (mainly coal, oil, natural gas, enriched uranium) or renewable energies (water, wind, solar) into electric energy. Power from generation plants is carried first through transmission systems, which consist of transmission lines that carry electric power at various voltage levels. A transmission system corresponds to a networked, meshed topology infrastructure, connecting generation and substations together into a grid that usually is defined at 100 kV or more intermediate steps at which the voltage is converted down (transformed) to lower levels. The electricity flows over high-voltage (HV) transmission lines to a series of substations where the voltage is stepped down by transformers to levels appropriate for distribution systems. Distribution finally delivers the power to the final loads (a majority of which are supplied at low voltage) via intermediate steps at which the voltage is converted down (transformed) to lower levels. The distribution system ends up at the energy consumption points or loads where power is used for its final purpose (see Figure 1).

Edvard Csanyi considers the distribution segment of the electric power system as the most challenging part of the smart grid due to its ubiquity.

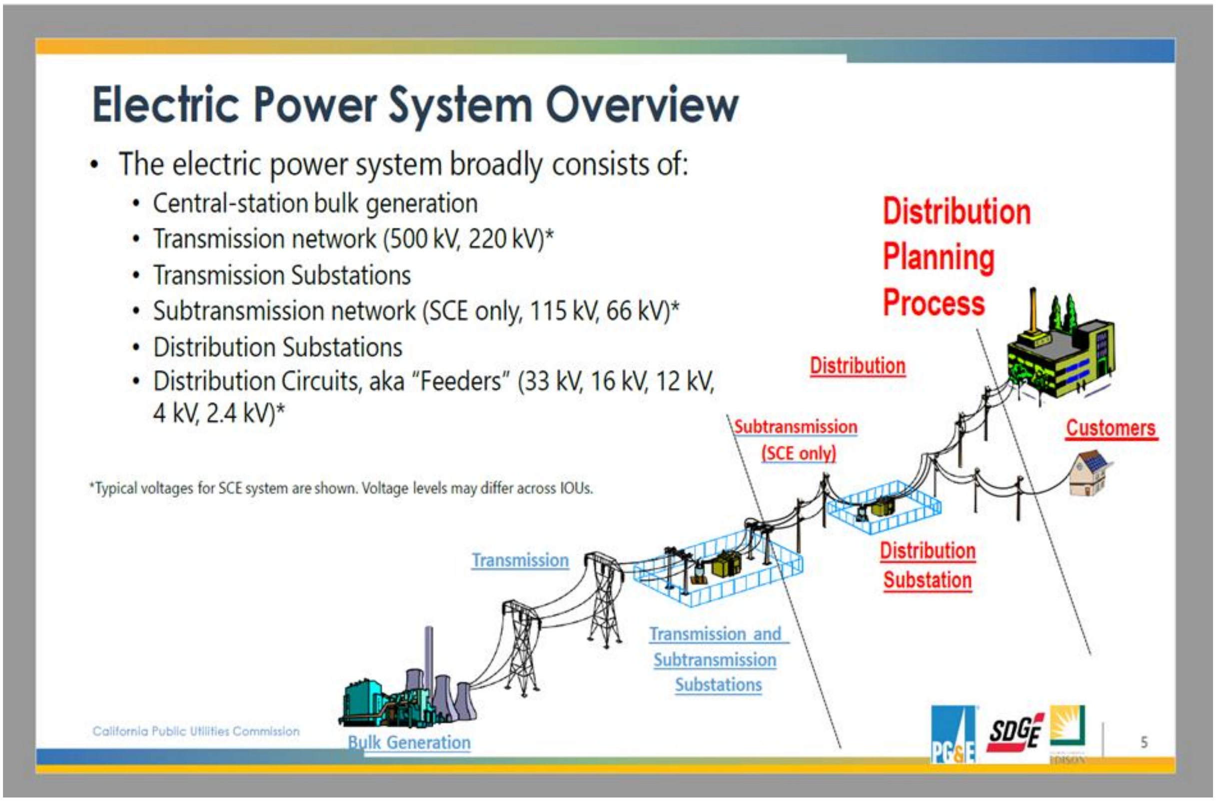

Figure 1. Structure of an electric power system.

Source: The California Public Utilities Commission. San Francisco, April, 21, 2022www.cpuc.ca.gov.directionplan.

2.2. Smart grid

Basic details of the smart grid technology and its applications as well as differences between traditional power grid and smart grid are concisely presented in papers by Ahmed F. Sheikh on the Electrical Academia Portal (Sheikh, 2016). Smart Grid is the name of the communication between the utility and the consumer. A smart grid is a powerfully manufactured plant that consists of computer programming, digitalization, automation, and control analyst that performs a two-way communication between the power provider and the consumer. If electricity system fails in a standard power grid system, the service provider will only come to know about the issue once the consumer calls and lodges a complaint. But in the smart grid system, as soon as the grid shuts down, the service provider will be notified and not just he but it will also provide data from the transmission lines, transformers, and distribution centres along with the home supplies, all will be notified at once. The smart grid is capable to monitor activities of the grid-connected system, consumer preferences of using electricity, and provides real-time information of all the events. The key components of smart grid include smart appliances, smart substations, smart meters, and advanced synchrophasor technologies, i.e. time-synchronized electrical measurements that represent both the magnitude and phase angle of the electrical sinusoids. (Application of…, 2023). Development of the smart grids has led to many changes in the current power grid structure. Application of new devices, technologies, renewable energy resources, and electric vehicles increases the need for decentralized energy management and the data transactions, i.e., the secure and economic transactions are realized through the decentralized networks (see Figure 2).

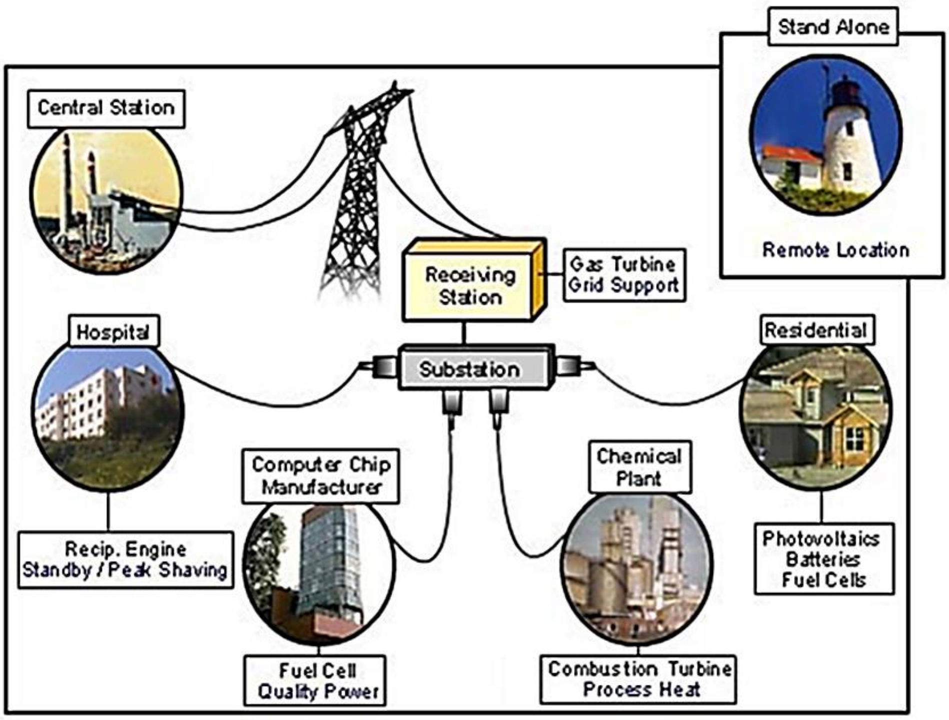

Figure 2. Types of distributed energy resources and technologies Image courtesy of the California Energy Commission.

Source: https://www.wbdg.org/resources/distributed-energy-resources-der#A.%20Der%20Taxonomy.

Authors of a recent comprehensive literature review (Hasankhani et al., 2021) observed that "the future of the smart grid considering the energy industry is very complicated, and the development of uncertain renewable resources, in addition to the rising cost of smart grid systems, has led to changes in the present networks. Therefore, Blockchain technology can be considered as an appropriate option due to these modifications. A Peer-to-peer approach for smart grids can support the renewable energies and provide economic benefits for both the consumers and the prosumers. However, the rapid development of Blockchain and the promising perspective of peer-to-peer based smart grids requires a careful study and a proper structure design".

3. Blockchain technology in the energy sector

Applying the Microsoft's Bing platform the following concise description of the application of Blockchain technology in the energy sector was received: "Blockchain technology is a form of distributed ledger technology that can facilitate secure and transparent record-keeping of transactions. Blockchain has many potential applications in the energy sector, such as energy trading, energy management and energy security. Energy trading: Blockchain can enable peer-to-peer energy trading between consumers, producers, and grid operators, without the need for intermediaries or centralized authorities. This can reduce transaction costs, increase efficiency, and empower participants to have more control over their energy usage and generation. Energy management: Blockchain can help improve the management of distributed energy resources, such as solar panels, batteries, smart meters, and electric vehicles. Blockchain can provide real-time access to energy data, transparent recording of energy transactions, and an immutable record of greenhouse gas emission savings. Energy security: Blockchain can enhance the security and reliability of the energy grid by preventing cyberattacks, fraud, and tampering. Blockchain can also enable smart contracts, which are self-executing agreements that can automate energy transactions based on predefined conditions. Blockchain technology is still evolving and faces some challenges, such as scalability, interoperability, regulation, and adoption. However, blockchain has the potential to revolutionize the energy sector by transforming the way energy is produced, distributed, consumed, and traded". Hadi Ganjineh most recently described examples of Blockchain disruption in transforming the energy industry with transparency, efficiency and decentralization (Ganjineh, 2023).

3.1. Suitability of Blockchain technology as a platform in energy sector

Ben Hertz-Shargel and David Livingston. representing the Atlantic Council, published in 2019 a comprehensive report on the suitability of blockchain applications in transactive energy (Hertz-Shargel, Livingston, 2019). This report assessed the suitability of Blockchain as a platform. It performed "a first principles analysis of Blockchain's technical attributes in order to align them with the expected needs of a transactive market, regardless of its precise design." In the opinion of the authors … "while Blockchain has many other potential energy-relevant applications for which it may be a far more logical and valuable tool, this does not currently extend to serving as the key platform for transactive energy markets. This conclusion resulted from the identification of a fundamental trade off, in which Blockchain's disintermediation of a central authority is achieved at the expense of six costs: (1) Efficiency, (2) Scalability, (3) Certainty, (4) Reversibility, (5) Privacy, and (6) Governance". Hertz-Shargel and Livingston consider that ... "the upside of this Blockchain trade-off has questionable value, and viability, in the context of transactive energy as there exist natural central authorities: public utility commissions, which have statutory authority over retail energy, and the electric utilities they oversee, which are tasked with ensuring the safe, reliable, and efficient operation of the electric distribution system".

3.2. Blockchain-enabled transacted energy (BCTE)

Within the frames of IEEE activities in the same year 2019 Muhammad F. Khan Sial, published a paper entitled: 'Blockchain Technology – Prospects, Challenges and Opportunities' (Khan Sial, 2019) in which key trends in transactive energy were discussed. In particular, the issue of how Blockchain technology may be used in energy trading was described as follows: "Blockchain-enabled transacted energy (BCTE) is a technology that has the potential to create an open, trusted, and transparent energy marketplace. This is important to society as it has the potential to lower the cost of renewable energy investments, improve our ability to combat climate change, encourage more participants into the renewables market, and increase the amount of innovation through transparent standards and access to the grid. Blockchain utilizes technologies like, distributed consensus mechanism, digital signature and cryptographic hash. The key strengths of this technology are that the records are reliable, persistent, auditable, anonymous and decentralized. To keep data secure, Blockchain systems store information using cryptography, requiring keys and signatures from users in order for them to access data. These capabilities help meet the strict regulatory requirements of various geographies, facilitating a path to transactive systems. This technology can help devices speak to each other and with the power grid while devices assess the availability and usage of energy". Later, in 2021, the IEEE has initiated a Blockchain-enabled Transactive Energy (BCTE) program. The program's Position Paper (IEEE Position & Vision Statement Paper v. 3.0, 2021) describes the basic framework and principles for using Blockchain technology in power and energy domains with the emerging participatory grid. A key goal is the development of the most promising global Transactive Energy use cases which can be advanced toward broader commercialization using Blockchain technology. This IEEE Position Paper describes potential Blockchain-Enabled Transactive Energy (BCTE) methods that can enable an economically driven, democratized, efficient energy production and market process for highly transparent yet secure distributed energy trading. While not exclusively required to implement Transactive Energy based solutions, the use of Blockchain removes some of the fragility and market domination of the traditional central generation and radial distribution grid paradigm. One can read in the Position Paper that it … "describes the IEEE initiative's goal to create a system architecture, and pursue certain real world demonstrations that will be used to inform the IEEE standardization efforts, and to advance other business model development activities. Furthermore, a set of selected use case demonstration projects and techno-political analyses covering the legislative and regulatory issues associated with these instantiations of Blockchain technology are planned to be developed within the scope of the framework. Lastly, the initiative serves to provide a cohesive structure that can align and grow worldwide local group contributions, which will be continuously refined and distributed through formal IEEE education and certification mechanisms. It is the ongoing intention of the BCTE program to catalogue the relevant initiatives that are underway worldwide to structure and deploy these energy Blockchain concepts, and to help evaluate their efficacy for energy system transformation. This paper is intended to offer a path to harmonize and unify these initiatives toward a worldwide standard. Electricity systems and markets have evolved significantly over the past forty years through five distinct yet overlapping phases: (1) Deregulation, (2) Decentralization, (3) Decarbonization, (4) Digitalization, and (5) Democratization". In the Position Paper IEEE formulates the objectives of the running project as follows (IEEE Position & Vision Statement Paper v. 3.0, 2021, pp. 8-9): "The knowledge domains for both Transactive Energy and Blockchain are intersecting and rapidly evolving. Accordingly, the underlying project (BCTE Initiative) that is launched with this paper should be intentionally pursued using a "Lean Design" methodology, where core architectural framework requirements are established and applied early to select high-value use case development and demonstration which, in turn, informs refinement and expansion of the core requirement set based on outcome data. The intention is to quickly validate and consolidate those core requirements that support all (or at least most) Blockchain applications for Transactive Energy that will lead to a formal IEEE Standards development Project (IEEE Blockchain standards, 2023)".

3.3. IEEE Standards development Project

The BCTE Initiative (IEEE Blockchain standard, 2023) … " welcomes global participation and collaboration along these lines to open bulk power and distribution system operations to include grid-edge participation through peer-to-peer and community aggregation and microgrids in these ecosystem value exchanges. Moreover, by incorporating Blockchain methodologies, the initiative seeks to reduce barriers to entry and transaction costs for these markets and to ensure open, secure access to introduce AI and automation to continually improve efficiency. There are three primary anticipated results of pursuing this project using this recursive and iterative methodology. The program is intended as a globally deployed and facilitated one, with regional clusters of organized participants each contributing to the common definition and application of Blockchain-based transactive energy solutions. The selected demonstrations and corresponding fast track architectural development, along with a highly focused Communication strategy, advanced from the framework: 1. Document existing practices for and develop improvements for the most efficient, scalable, and secure design of incremental energy systems and markets that can operate primarily through decentralized participant transactions. 2. Lower the barriers to, and improve the efficacy and security of, data access on energy demand elasticity, forward price offers, and the valuation and monetization of environmental and resilience attributes. 3. Create an effective outreach and education capability to influence the adoption of the emerging standard, to pave the way for consistent and efficient regulatory reform options where needed. 4. Ultimately leading to a formal certification path for assuring the performance and quality of compliant solutions that are built from the emerging standard. Each of the objectives is intended to reinforce the advancement of practical applications of Blockchain in energy transactions, as a foundational technology that enables more efficient, secure, and resilient market-driven value exchange processes in the production, transport, and consumption of electric power. The primary work streams of architectural framework development, rapid demonstration and expansion of user profiles, global outreach, and engagement will create an actionable roadmap to accelerate the adoption of BCTE".

4. Discussion

Results of the literature survey are the basis for formulating the following theoretical and practical implications: 1. The supply, transmission, distribution, and consumption of electricity are closely coupled, and must be actively coordinated. This requires the coordinated sensing, measurement, and control of devices and systems spread across the grid. 2. The Blockchain technology can facilitate secure and transparent record-keeping and transactions and thus may have many potential applications in the energy sector. 3. Blockchain technology is still evolving and faces some challenges, such as scalability, interoperability, regulation, and adoption. However, blockchain has the potential to revolutionize the energy sector by transforming the way energy is produced, distributed, consumed, and traded. 4. Within the power and energy sector, Blockchain technology also provides new and overwhelmingly undiscovered perspectives to enable the democratization phase of power systems and markets.

5. Summary

The electric power system is undergoing a rapid transition toward decarbonization and decentralization. The legacy model of one way power flow from large, primarily fossil-based generators to consumers on the distribution grid is being upended, driven by the plummeting costs of distributed renewables, battery storage, and smart energy technologies. Residential and commercial utility customers, once simply consumers of electricity, are deploying these distributed energy resources at scale alongside project developers, becoming producers themselves in a new, increasingly decentralized power system. These changes pose a threat not only to the business models of utilities and conventional generators, but to the stability of energy markets and the electric grid itself. At the same time, they offer an opportunity: the flexibility of these new resources and technologies, their low carbon footprint, and their proximity to consumer loads could permanently reduce electricity and infrastructure costs while enabling the power sector to meet ambitious decarbonization targets. In order for this opportunity to be realized, however, legacy retail energy markets must be reformed to allow all distributed resource owners to participate and provide value, regardless of asset size and customer classification. Conclusions and key points of the IEEE Position Paper on the Blockchain Transactive Energy A Bridge to a Democratized Energy Marketplace (IEEE Position & Vision Statement Paper v. 3.0, 2021, p. 35) read as follows: "Digitalization of power systems has evolved over the past two decades to the point where artificial intelligence and Blockchain technology has become possible to introduce to these digital ledger technologies (DLT) platforms. With more recent advances in cryptography, local compute power, and higher bandwidth network services, Blockchain technology appears to be a promising technology which opens up disruptive new paths toward cost-effective, ultra-efficient, and innovative service offers from various prosumer, commercial, and industrial domains to make, distribute, or consume electric power. This is the emerging world of Transactive Energy. It is expected to influence the development of the next-generation energy systems and the creation of new power markets for their enablement of future Transactive Energy use cases. The resulting stretch of the boundaries of existing market rules with novel forms of sharing and self-reinforcing digital economic models, all in search of ever cleaner and less wasteful energy production and consumption, will be strongly supported by Blockchain technology". Finally, based on the most recent relevant literature positions it was realized in this review paper that Blockchain technology has many potential applications in the energy sector. This technology is still evolving and faces some challenges, such as scalability, interoperability, regulation, and adoption. Within the power and energy sector, Blockchain technology also provides new and overwhelmingly undiscovered perspectives to enable the democratization phase of power systems and markets.

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