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THE RELATIONSHIP BETWEEN RENEWABLE ENERGY AND BLOCKCHAIN AS A SUSTAINABLE TECHNOLOGY TOOL

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Abstract

The European Union is accelerating its transition to energy independence by 2030 in response to new geopolitical realities. This study aims to demonstrate the advantages of blockchain technology for the energy sector and how renewable sources themselves may lower costs and generate significant amounts of electricity. These networks encourage the use of renewable energy sources in place of conventional ones and enable sustainable consumption reduction at the same time.

The paper demonstrates how blockchain may connect to renewable energy sources, most often solar and wind, to grow this industry in a sustainable way. New technologies like blockchain have sparked the emergence of contemporary forms of trade and consumption. The collaborative and circular economies represent a nexus of economic, technological, and socio-cultural phenomena brought about by technological advancements and economic disruption. Blockchain technology offers a wide range of non-financial applications, and its use is acknowledged as a brand-new opportunity for sustainability and energy.

The goal of this study is to clarify the relationship between the two and determine whether blockchain technology can be sustainable for the development of the energy market. The paper is addressed to all parties involved in the energy, blockchain, and sustainability industries.

Keywords: renewable energy, blockchain, sustainability

JEL Classification: D16, O44, Q20, Q40, Q55

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Introduction

This paper looks at the relationships and connections that may be drawn between some of the most hotly debated ideas in recent literature, including energy sustainability, the market as a whole, and renewable energy. The report also examines how blockchain might improve sustainability by utilising renewable energy sources such as solar and wind. In essence, this contrast between a sizable market that uses blockchain as a next-generation technology while forgoing electricity consumption and powering the grid exclusively with renewable sources makes it easier for blockchain to eventually become a sustainable technology tool.

Energy prices rose for EU homes in the winter of 2022-2023, with the impact on impoverished households being the most noticeable (Blake and Bulman, 2022). Many households with low incomes find it difficult to maintain a comfortable temperature, and some are forced to choose between energy and other necessities such as food and health. European governments are already implementing adaptation strategies that address both energy supply and demand. From a research point of view, the 2022-2023 energy crisis and the constraints facing many consumers and markets present opportunities to change consumption patterns and use renewable energy.

Given that renewable energy consumption has received less attention in terms of sustainable consumption and production pattern versus environmental performance, the time has come to put more focus on the sustainability of natural resources.

Considering the importance of environmental health and well-being, it is imperative to invest in renewable energy instead of fossil fuels and to improve efficient energy production and generation capacities.

Blockchain technology represents a significant advancement in system transparency, security, and traceability. It offers creative solutions to deal with system inefficiencies and focuses on data immutability, information flow, data quality, and availability for all stakeholders. Numerous industries and fields have found use for blockchain technology, including supply chains and logistics, healthcare, energy systems, insurance, food safety, and digital certifications. Many academics have noted that blockchain technology is evolving into a general-purpose technology because of its very diverse applications. Decentralised digital currency served as an inspiration for the blockchain technology. Some notable characteristics of the blockchain technology are its decentralisation, dependability in distributed systems, safe data storage method, and cost-free exchange transactions. In essence, a blockchain is a network of distributed ledgers where nodes connect with one another to exchange data and conduct transactions. Decentralisation and immutability are two of a blockchain's fundamental features (Hannan, Hussain and Tab, 2023). The energy business could be made more environmentally friendly by using blockchain technology to improve processes, markets, and users. The greenhouse effect and carbon dioxide (CO₂) emissions caused by current consumption can be reduced with the use of green energy. Blockchain technology provides a new framework for sustainable innovation that lowers the risks associated with centralised server design. Without the need for conventional centralised cloud servers, it allows safe design and low energy consumption for remote monitoring of physical activity. The final result is a greener Internet of Things (IoT) ecosystem, commonly referred to as green innovation. Sustainable innovation is increasingly utilising blockchain technology. Most notably, it has been shown that a sustainable orientation can benefit businesses' primary

concerns and the world's natural resources thanks to the focus on understanding strategic environmental and sustainability activities.

In such a context, the present paper aims to clarify the relationship between renewable energy and blockchain and to determine whether blockchain technology can be sustainable for the development of the energy market. Thus, the paper has two main parts, besides this introductory section and conclusions. The theoretical framework and current state of knowledge are included in the first section, while a review of databases and publications from both domestic and foreign countries is included in the second section.

1. Blockchain technology perspective

Renewable energy sources, which have a lower environmental impact than fossil fuels, have recently emerged as an essential consideration for blockchain technology adoption. Renewable energy sources that can be used to generate electricity include wind, geothermal heat, sunlight, and rain. The use of these resources generates clean, renewable energy. The advances in renewable energy technology enable people to generate their own electricity without relying on expensive fossil fuels. This is where a smart grid, a modernised electricity system that uses information technology and analogue or digital communications, comes in. Furthermore, smart grids must address the issues of security, interoperability, and data transfer. Because renewable energy sources fluctuate and are unpredictable, complex technology must be integrated into the current grid. A blockchain-based smart grid design can be used to increase the use of renewable resources and create a more sustainable environment.

1.1. History of the first energy blockchain

Through a peer-to-peer network, users of the distributed data structure known as blockchain technology can exchange data. This technology fundamentally integrates different elements to create a network that is safe, transparent, and visible. These aspects include a decentralised structure, smart contracts, a consensus method, a storage mechanism, distributed notes, and asymmetric encryption. All transactions and data are connected, secure, and readily available. Figure no. 1 shows the differences between a centralised and a decentralised system. Records that are added to the blockchain cannot be changed without also changing earlier records, which requires consent from all or most of the persons involved. This method gives this technology a high level of operational security. This technology is crucial to creating long-term environmental sustainability, which could have a good impact on mitigating climate change. However, the use of blockchain to address environmental sustainability challenges is still in its infancy. The complexity of production systems and a lack of optimisation have caused the performance of installed production systems to perform far worse than intended, which causes carbon emissions. Blockchain technology uses a decentralised peer-to-peer communication mode to process information between machines in an efficient manner, which can considerably increase process flexibility and societal sustainability (Su et al., 2023).

According to Kouhizadeh et al. (2019), blockchain technology can act as a decentralised platform for energy trading, enabling profit growth, facilitating connections between businesses and other stakeholders, and promoting direct energy exchange between parties.

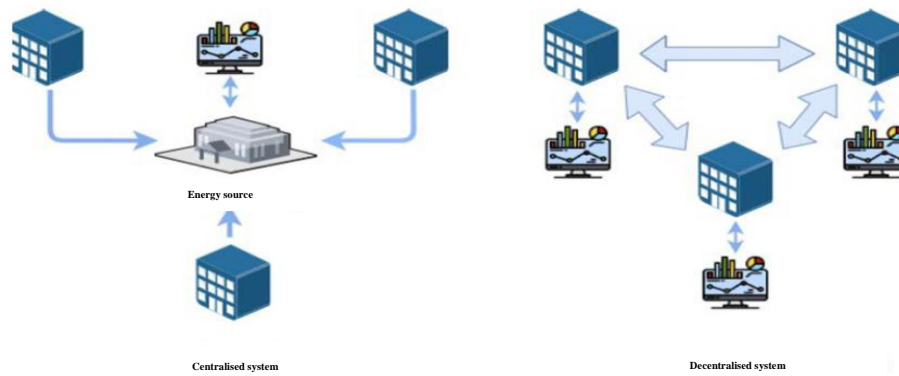


Figure no. 1. Comparison of the centralised and decentralised systems

Source: Cantillo-Luna et al., 2022

In Brooklyn, New York, the first energy blockchain was created. Five homes' worth of solar energy were sold directly to five other neighbouring homes over the blockchain network. More and more scientists are becoming interested in blockchain-based energy management, as it is consistent with the distributed information interaction mode of the blockchain. For instance, a bilateral trading mechanism has been implemented on an integrated blockchain-based energy management platform that optimises energy flows in a microgrid. A dataset from a genuine prosumer community in Amsterdam was used to test this platform, which showed certain technological advantages. The full utilisation of renewable energy through free and counter-cost real-time trading was assisted by a number of novel bidding mechanisms for multi-energy trading based on a blockchain network that was developed. A keyless approach with safe authentication was created for energy systems in terms of security. With the help of blockchain technology, this plan can increase the validity of certification and non-repudiation. A general structure for a blockchain platform that enables peer-to-peer energy trading in the retail power market has been developed to increase the applicability of trading platforms. This study further illustrates the technological benefits of blockchain for distributed energy management. Many scientists from all over the world have devoted the last five years to studying and using energy blockchains. However, there is no evidence that blockchain-based energy management will be widely adopted in the existing energy industry. The primary cause, which is embodied in the following three features, is that the present blockchain-based energy management mode cannot be adapted to the system with a large penetration of renewable energy sources. (1) Through the use of an electronic exchange, the current energy blockchain technology primarily ensures the atomicity of asset interaction. The traditional blockchain architecture cannot be immediately applied to complex energy management scenarios, since the current energy system comprises enormous computing burdens, such as frequency, voltage, and power. (2) Financial transactions and currency circulation are intended uses for the primary blockchain consensus processes. Energy management, unlike the financial trading platform, must take into account energy balance, consumption of renewable energy, reduction of carbon and other pollutants, etc. Energy blockchains require the establishment of a consensus mechanism that is in line with the properties of energy interaction. (3) As renewable energy sources become more prevalent, managing energy in a timely manner is essential to address the unpredictability of energy

production. Existing blockchain encryption algorithms prioritise data security over operational efficiency almost exclusively. However, system dependability and the use of renewable energy sources may be impacted by network delay (Wang et al., 2023).

1.2. General presentation of renewable energy and IoT

As a non-renewable natural resource, fossil fuels have propelled our economy by supplying electricity to businesses and residences. As society becomes increasingly technologically advanced and digitally aware, so does our need for power. In contrast, renewable energy harnesses the power of flowing, dynamically renewing resources such as water to create hydropower (Afzaletal., 2020). These materials can be created indefinitely and have a nearly limitless supply. Fossil fuels, also known as non-renewable energy, have a limited supply and will run out by the early 22nd century at current usage rates. A greater emphasis has been placed on alternative energy sources, notably renewables like wind and solar power, as a result of this scarcity as well as the acknowledged environmental challenges related to carbon emissions, which are an inevitable result of burning coal to provide heat. As a result, society has used IoT to alter the energy sector in several ways during the past ten years. The IoT promises to reduce energy waste by first developing a smart energy infrastructure for information processing and use. Second, the IoT has improved the performance, generation, and distribution infrastructure of electricity while revolutionising the generation, distribution, and transmission system by combining sensors, the web, smart grid, renewable energy sources, and autonomous techniques that have decreased costs and raised system efficiency. Third, power producers have introduced paradigm shifts to the electricity market, assisting distribution operators to adapt to the concept of local energy markets to reward and dispatch efficiently in the face of the emergence of distributed generation units along with issues like energy volatility, demand-supply mismatch, and so forth. While the random nature of power generation necessitates innovative techniques to manage demand and supply across suppliers, the gradual transition to distributed renewable resources has made power generation more weather sensitive (Alladi et al., 2019).

Peer-to-peer energy trading is a crucial component of the IoT, but it still raises significant privacy and security issues. While the current energy infrastructure relies on a sizable centralised grid that generates energy and delivers it over long distances via transmission lines, microgrids connect smart households and smart streets. In transmission and distribution networks, electric utilities, suppliers, and market organisations collaborate (Chitchyan and Murkin, 2018). Peer-to-peer electricity market prospects for the IoT include trade between smart buildings, homes with wind and solar power systems, electric cars and electric grids for peak load control, hybrid and electric vehicles, and renewable energy to grids.

Renewable energy sources complicate grid load balancing and resource scheduling, since charging an electric car takes a lot of energy. Demand management becomes significantly more difficult as network nodes grow because more transactional data is generated. For the successful implementation of IoT technology, load management must be controlled. By balancing energy-consuming activities, it seeks to produce the optimal load (Ghosh et al., 2018). Increased asset usage efficiency, improved green energy supply consistency, bill savings, capacity expansion, decreased inventory volatility, decreased administrative costs, and peak load control are just a few advantages of load management control. Predictive control management is often referred to as energy consumption management, supply side

management, and economic responsiveness to change. Another justification for developing a load management control system is the absence of an energy storage system. Direct load control and price optimisation are two popular demand response strategies in this situation. A few examples where the blockchain system can be used in the energy sector can be seen in figure no. 2, as well as the societal problems it hopes to handle.

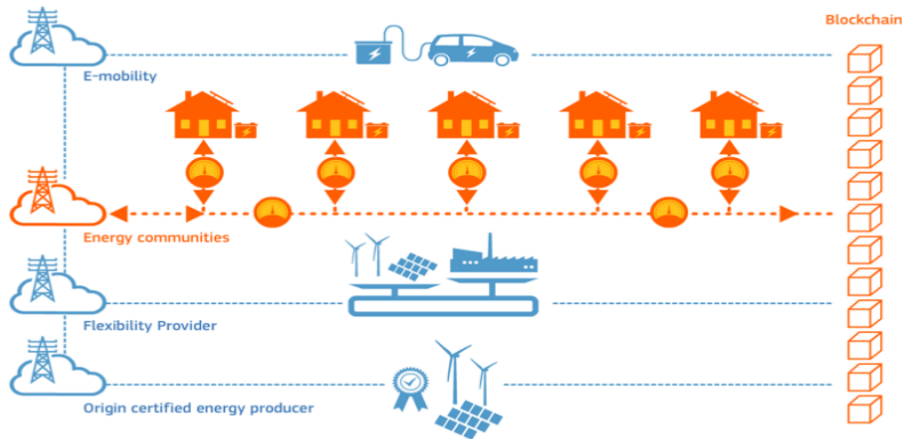


Figure no. 2. Blockchain technology in Smart energy integration example

Source: European Commission, 2022

A method for controlling consumers’ real-time responses to market demand-supply dynamics is the introduction of dynamic pricing, where power rates fluctuate dynamically over time. Dynamic pricing is used to adjust the price of electricity according to market demand. The modern energy grid’s supply will alter as a result of this constantly changing price structure as the supply adjusts to blockchain-based technologies.

Prices are thus low when consumption is low and production is high, while they are high when demand is high and production is constrained. Customers may be compensated for reducing their electricity use during peak hours if they adjust their energy consumption. Due to the high prices in peak periods, customers are compelled to modify their energy use. Smart meters can be useful by identifying the user’s patterns of energy consumption and delivering notifications about price hikes when usage has to be reduced and price reductions when usage can be changed. Dynamic pricing schemes include true prices, peak power reductions, and peak power prices, for instance.

1.3. The energy sector towards sustainability through renewable and transactive energy

The production process of today is built from a linear viewpoint (Muranko et al., 2018). This is irresponsible, and the natural pattern of economic expansion does not promote the long term sustainability of natural resources. As a result, the circular economy (CE) alternative concept has received a lot of attention in recent academic studies (Babbitt et al., 2018). An industrial system that is “restorative and regenerative by design and objectives” is referred to as CE (Ellen MacArthur Foundation, 2015, p.2). By prolonging material productivity and

product life cycles in closed systems, where resources are kept in a loop of re-evaluation and usage through reuse, repair, refurbishment, and recycling operations, researchers believe that CE promotes cleaner production and consumption (Merli et al., 2018). Individual users or consumers in CE can make a significant difference by altering their patterns of frequent material consumption (He et al., 2021). Experts agree that cutting-edge technologies like blockchain can be crucial to the adoption of CE (Bockel et al., 2021). However, despite the apparent potential advantages, the adoption of blockchain for the CE implementation by businesses is modest (Kouhizadeh et al., 2019). Researchers admit that there is a lack of vision about blockchain technology applications that could help businesses in establishing CE business models (Bockel et al., 2021), even though this may be partially due to technological maturity issues (Upadhyay et al., 2021). Reducing energy usage appears to be the only way to lower energy expenses, which have risen because of the conflict in Ukraine, rising prices, rising interest rates, and the expansion of the COVID-19. Most people must cut back on their spending and save money because they can no longer afford such costs. These worldwide concerns will have a substantial positive impact on collaborative consumption, sustainable consumption, and behavioural change. Utilising natural resources in a way that ensures their survival for future generations is the goal of sustainable development. The collaborative economy offers businesses and people the opportunity to make financial profit from shared resources. Shah et al. (2021) discussion of confidence, risk, and privacy in the evolution of value creation in the collaborative economy is relevant in this context. Many state and federal properties are underutilised and can be rented out for profit. Consumers might benefit from services that are not privately owned, but are, instead, made accessible to everyone. People at every stage profit from categorising services as being accessible to everyone, whether they are services or goods. Due to a lack of widely applicable technology, the production of renewable energy has increased considerably over the past few decades, filling many gaps. The production of renewable energy promotes sustainable growth in Europe and many other nations. Global industry's growth and sustainability depend on the generation of energy. The connection between sustainable growth, non-renewable energy, and renewable energy in the economy's production sectors is covered by Guney (2019). The creation of renewable energy is most frequently related to natural processes and resources. (Chang and Fang, 2023). For various governments, energy efficiency and sustainable development are the top priorities, particularly considering the dramatic rise in the exploitation of natural resources that has resulted in severe environmental issues (Dabous and Tarhini, 2021). Energy economy refers to using less energy to produce the same amount of goods and services, and it has many advantages. Making transactions traceable and open would eliminate any risk of fraud, and using blockchain in collaborative economy processes could address other ethical and managerial issues as well. (Ran et al., 2023).

According to economic and market-based energy standards, "transactive energy refers to the economic and management approaches used to govern the flow or exchange of energy inside an existing electricity system. It is a theory that is applied to generation systems to increase their effectiveness and dependability, pointing to a smarter and more interactive future for the energy sector." (Borojeni et al., 2016). Traditionally, centralised power plants produce electricity using non-renewable fossil fuels like oil, natural gas, and coal. Energy is distributed and transferred in centralised grid power generation, where all energy sources (renewable or not) are connected to a single system. By expanding the use of decentralised energy generation (from renewable energy sources) in the current energy mix, several energy issues can be resolved. Renewable energy sources, such as solar and wind power, are used in

decentralised energy production. Due to the reduced physical distance between the source of the energy and the location where it will be used, the greater share of distributed energy will help to minimise environmental issues and reduce transmission losses. It converts the consumer-focused market into one that is prosumer-focused. The peer-to-peer energy market is a new distributed energy market that has emerged in place of the traditional energy industry (Afzal et al., 2020). Communication technologies and automated sensors, including IoT, play a crucial role in scheduling consumer electrical appliances to reduce human involvement and increase peer-to-peer energy markets' autonomy (Afzal et al., 2020). A distributed ledger technology, such as blockchain, is an emerging platform for information technology that presents new opportunities for the energy system, in accordance with the distributive nature of peer-to-peer energy markets (Wu et al., 2021). Power generation, a sector of the energy market made possible by blockchain, is shifting from being centralised and dependent on fossil fuels to being distributed, small-scale, and dependent on renewable energy. It offers a fresh method of promoting the green economy among market players without the need for a centralised authority. As a distributed method for secure transaction recording and settlement, blockchain technology is being deployed. Users can use it to exchange energy and maintain the track of transactions without running the danger of changing them. The energy market is restructured by blockchain, going from a monopoly situation to one that is more competitive and distributed (Afzal et al., 2022).

2. Connections and correlations between the energy market and the new blockchain technology

One of the initial steps in conducting this research was documentation. This is based on bibliographical materials from the literature on the energy industry that discuss the blockchain idea. The paper also contains a qualitative analysis based on potential correlations and links between the emerging blockchain technology and the energy sector. By analysing the afferent databases and the national and international publications, the operationalisation of independent variables tries to identify some particular indices.

Blockchain technology, which may be used to increase the effectiveness, transparency, and security of transactions in the energy industry, can be seen as closely related to the energy market. First, energy production and consumption can be tracked and monitored using the blockchain technology model, allowing for more effective management and better distribution of energy resources. For instance, owners of solar panels or wind turbines can sell their excess energy at a better price in a decentralised market by employing smart devices that use blockchain, resulting in the creation of new business models in the energy industry. Second, blockchain can increase the security and transparency of energy transactional processes. Now, intermediaries that charge high fees and commissions handle energy transactions. By eliminating middlemen and lowering costs, the blockchain enables transactions to be carried out directly between buyers and sellers. Blockchain technology can also be used to register and authenticate renewable energy sources, guaranteeing that the energy produced from renewable sources is consumed and exchanged ethically. Consumer confidence may increase as a result, and renewable energy consumption may be encouraged. In summary, blockchain technology can help make energy markets substantially more transparent and efficient, leading to a more effective and sustainable use of energy resources.

According to a survey of the literature, 82% of individuals who wrote on the application of blockchain in the energy sector mentioned solar energy, with wind energy coming in at roughly 12% (Figure no. 3). Hydropower, biomass, and geothermal energy make up the remaining 6.71% of renewable energy sources. These three types of energy are relatively new, have received less attention, and require further research to fully weigh their benefits and drawbacks.

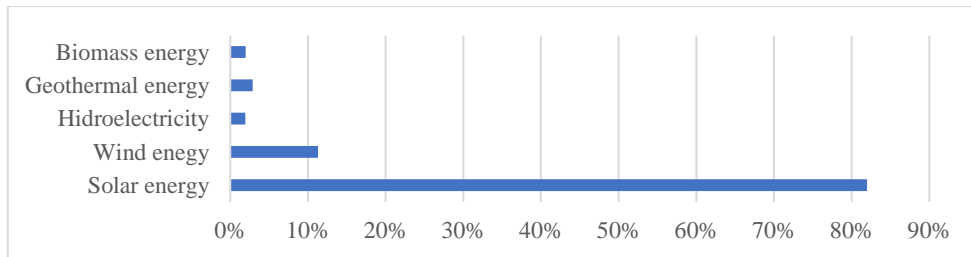


Figure no. 3. Renewable energy sources used for blockchain technology

Source: Nadhira Khezami et al., 2022, p.26

There are various ways to power blockchain technology with green energy. The blockchain network’s servers can run on solar and wind energy. Businesses think that employing renewable energy to power their operations is a sustainable choice and can lessen the negative environmental effects of blockchain technology. In general, blockchain technology powered by renewable energy can help reduce the carbon footprint of the system and encourage a more sustainable use of energy resources. The adoption of blockchain varies by geographic location in the worldwide energy business, as shown in figure no. 4. The Asia-Pacific energy market blockchain is anticipated to experience the highest compound annual growth rate (CAGR) in the global energy market between 2019 and 2024, at 60.01%. Overall, energy use and environmental impact are significant considerations in the creation and application of blockchain technology, and research in this field is ongoing to identify more long-lasting and enduring solutions.

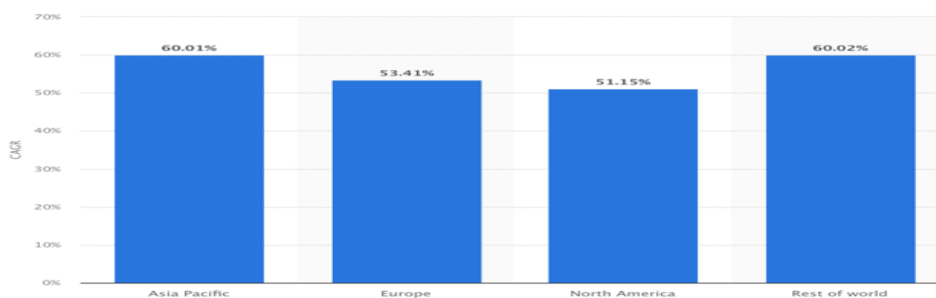


Figure no. 4. The annual growth rate of the blockchain on the global energy market from 2019 to 2024, by region

Source: Statista, 2023a

In a similar vein, it has been discovered that researcher interest is growing in IoT and artificial intelligence in correlation with the energy sector and blockchain, as can be seen in figure no. 5. Energy and blockchain have been associated with some of the emerging technology areas.

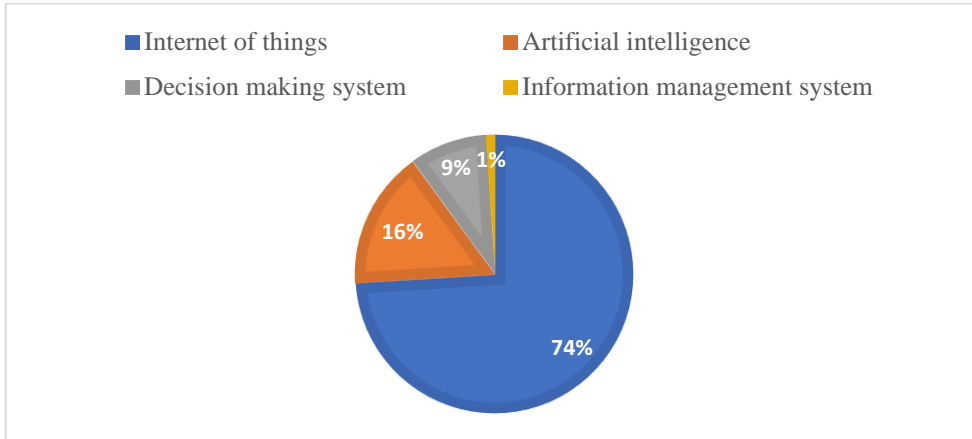


Figure no. 5. Emerging technology fields in correlation with the concept of blockchain and energy

Source: Nadhira Khezami et al., 2022, p.33

IoT and blockchain can collaborate to open new possibilities for energy efficiency, security, and sustainability. IoT devices, for instance, can be used to track and manage energy usage in homes and businesses, and blockchain technology can guarantee that data is maintained securely and without alteration. Blockchain technology can also be used to enable peer-to-peer energy trading, which allows people to buy and sell the extra energy produced by their renewable energy installations. Making a system more transparent and effective is one of the main advantages of combining blockchain with IoT for energy management. Energy suppliers, for instance, might automatically execute energy transactions based on predetermined parameters, such as the availability of renewable energy sources, using blockchain-based smart contracts. Overall, there is significant interest in the development of IoT and blockchain technology integration in the energy industry, since it has the potential to open up new prospects for sustainability, security, and efficiency.

Figure no. 6 illustrates how 36% of direct energy trade between consumers and prosumers (consumers who also create energy) is made possible without the use of middlemen by peer-to-peer energy transactions powered by blockchain technology. Individuals can buy and sell extra energy on peer-to-peer energy trading systems, establishing a decentralised market. By offering a transparent and secure platform for managing network assets, recording energy transactions, and integrating distributed energy resources, blockchain network management and optimisation can ease the improvement and management of energy networks. With an 11% sustainable component, the blockchain also offers a transparent and auditable mechanism to track energy generation, ownership, and transfer. As a result, the veracity and integrity of energy consumption declarations are enhanced. Blockchain can be used to create a decentralised platform for managing electric vehicle charging stations, tracking charging sessions, and managing payments, so in 2017-2018, global initiatives in this regard were 11%. Microgrids are localised power systems that can run independently or in cooperation

with the main grid. Blockchain technology can make it possible to administer and coordinate microgrids effectively. Such an initiative was supported at the global level by 24% of people worldwide.

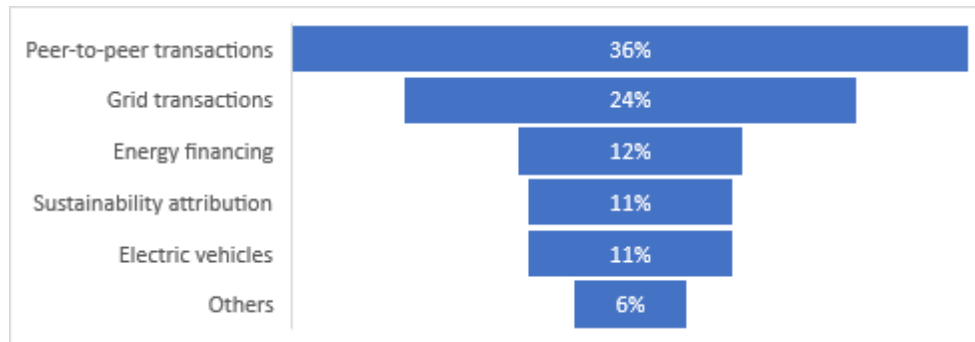


Figure no. 6. Distribution of blockchain initiatives in the electric power sector worldwide between March 2017 and March 2018, by application

Source: Statista, 2023b

It is crucial to remember that the distribution of blockchain projects in the energy sector during a given time period depends on a number of variables, including geographical location, market conditions, the regulatory environment, and the degree of blockchain acceptance in the sector.

Conclusions

There is a significant relationship between energy use, blockchain, renewable energy, and sustainability. The application of blockchain in the energy transition demonstrates its tremendous potential for usage as the “distributed leadership brain” of an energy community, a concept that has the capacity to fundamentally alter the energy industry.

Companies, producers, and governments can collaborate to monitor the flow of energy if blockchain technology is used in the energy sector, as it enables transactions. Inflation can be reduced with renewable energy. As long as inflation is kept under control, the poverty rate can decrease.

New methods of utilising energy, the development of infrastructure, government assistance, and sustainable technology are all effective approaches to implement more sustainable concepts and practices for developing nations. More industrialised nations can help less developed or developing nations set up infrastructure and educate their citizens about sustainable consumption.

Blockchain technology, which can be used to increase the effectiveness, transparency, and security of transactions in the energy industry, is intimately related to the energy market. First, energy production and consumption can be tracked and monitored using the blockchain technology model, enabling more effective management and better distribution of energy resources. Because it is a transparent and secure system with transactions being maintained in all participating nodes rather than in a central database, blockchain technology can be a

sustainable tool for the energy industry. It ensures that information can be traced. The secure trade of public electricity is the main benefit of blockchain technology. Using smart contracts, the blockchain will modernise the established energy trade contract. However, putting blockchain into use on a wide scale comes with a lot of difficulties. Therefore, it is suggested that further research on the application of blockchain technology in numerous fields is needed. The blockchain best suited for electricity trading is not known yet. To find the kind of blockchain system that is most appropriate for the trading of energy, several criteria (such as scalability, cost, computing efficiency, transaction size and duration, security, and irreversibility) need to be explored and investigated.

The impact of digital and energy technology on people, businesses, and the economy has been heightened by the COVID-19-related crisis. In order to work remotely, heat homes, operate hospitals, and run enterprises, society increasingly depends on digital and energy solutions.

To promote and hasten the European Union's transition to a greener and more sustainable future, it is crucial to track the development of digital technologies like blockchain and identify those that are most disruptive and promising. Blockchain technologies show that they have a lot to offer when it comes to assisting and facilitating reasoned decision-making in the fields of climate and sustainable energy.

In summary, blockchain technology has many advantages in the energy sector, including reliable transactions, emissions reduction, demand response, and system contributions from energy consumers that are dynamically described as the value of energy contributions.

Sustainability is related to renewable energy and blockchain; both create a sustainable society and can cooperate. If used effectively, any digital system can lower expenses and the use of energy.

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