Using Blockchain to create and capture value in the Energy Sector

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Abstract

Title: Using Blockchain to create and capture value in the Energy Sector
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The undergoing digital transition of the energy sector refers to the integration of decentralized ledger technologies and data-driven solutions that have the potential to truly revolutionize its ecosystem and business practices. The aim of a decentralized, inter-connected and two-way interactive energy grid can be enabled by leveraging blockchain technologies. This research investigates how blockchain technology can create and capture value from data and the new business models applied in Web 3.0 and blockchain-based environments in the energy sector. A qualitative case study research design was conducted for primary data collection and pilot projects by the European Commission were used for secondary data collection. The analysis shows local energy communities as the main blockchain application in this sector, with adjacent applications such as P2P energy trading, smart contract & metering, carbon trading and grid management. The main benefits associated are transparency, integrity, grid automation and renewable energy sources promotion, and obstacles are mainly associated with the contrasting centralized design of the current energy systems. We conclude that value is created and captured through data provenance and transparency, data monetization and tokenization, and data sharing and collaboration in blockchain platforms. New business models include the decentralization and fusion between energy production and consumption, generating a new actor known as the prosumer. Fundamental to a successful implementation of local energy communities that allow energy and asset trading between peers.

Keywords: *Blockchain, Energy sector, Value creation, Value capture, Business model innovation*

Sumário

Título: O uso de blockchain para criar e capturar valor no sector energético
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A transição digital do sector energético baseia-se na integração de tecnologias de registo descentralizadas e de soluções de tratamento de dados que têm o potencial de revolucionar o seu ecossistema. O objetivo de uma rede de energia descentralizada e interconectada em ambos os sentidos, pode ser concretizado através do recurso a tecnologias blockchain. Esta investigação analisa a forma como esta tecnologia pode criar e reter valor a partir de dados e dos novos modelos de negócio associados à Web 3.0 e a ambientes baseados em blockchain neste sector. Para a recolha de dados primários, foi efetuado um caso de estudo qualitativo. Para dados secundários foram analisados os projetos-piloto da Comissão Europeia. A análise demonstra que as comunidades locais de energia são a principal aplicação da blockchain, com aplicações adjacentes como trocas de energia P2P, contratos e contadores inteligentes, comércio de carbono e gestão da rede. Os principais benefícios associados são a transparência, a integridade, a automatização da rede e a promoção das fontes de energia renováveis. Os obstáculos estão principalmente associados à estrutura centralizada dos atuais sistemas energéticos. Concluímos que o valor é criado e capturado através da proveniência, transparência, monetização, tokenização e integração de dados em plataformas blockchain. Os novos modelos de negócio incluem a descentralização e a fusão entre a produção e o consumo de energia, gerando um novo elemento neste sector, o *prosumer*. Fundamental para uma implementação bem sucedida de comunidades locais de energia que permitam o comércio de energia e de ativos entre pares.

Palavras-Chave: *Blockchain, Sector energético, Criação de valor, Captura de valor, Inovação do modelos de negócios*

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List of Abbreviations

BM	Business Model
BMI	Business Model Innovation
DAO	Decentralized Autonomous Organization
DLT	Distributed Ledger Technology
DR	Demand Response
DSO	Distribution System Operators
EC	European Commission
IoT	Internet of Things
LEC	Local Energy Communities
P2P	Peer-to-Peer
PoS	Proof-of-stake
PoW	Proof-of-work
TSO	Transmission System Operator

1. Introduction

A decentralised architecture for value creation and capture has been greatly facilitated by the emergence of Web 3.0 and blockchain technologies. To create and generate value and ultimately achieve a competitive edge in the Web 3.0 era, it is crucial to investigate and look into new business models made possible by blockchain technology (Zheng, Xie, Dai, Chen & Wang, 2018). Which appeals to several applications such as disintermediation, transparency and immutability. However, despite growing significance, such disruptive blockchain-based services also bring ambiguity about ownership, governance, competition and structure models (Casino, Dasaklis & Patsakis, 2019).

Blockchain technology is proving its versatility across industries. Moreover, it's showing potential to be a disruptor for the energy sector specifically. It is important to further prove how blockchain can add substantial value to the energy transition, both digitally and sustainably (Andoni, Robu, Flynn, Abram, Geach, Jenkins & Peacock, 2019). Potentially translating how proper data management can improve energy trading, management and consumption efficiency whether in local or wider markets (Hamwi & Lizarralde, 2017). In this manner, this research is aimed to shorten the gap to the actual value added these technologies can bring to the energy sector.

To answer the challenges presented previously, the first relevant research question to be answered in this paper is: "How can blockchain technology be used to create and capture value from data?". The second relevant research question, which seeks to extensively understand the managerial implications of the previous question, is: "What are the new business models applied in Web 3.0 and blockchain-based environments?". The first research question is mainly focused on better understanding the value which this type of technology can bring into this sector, whilst the second focus on the study of new business models associated with this specific environment.

The thesis structure is composed of five sections. Section one is the Introduction of the paper and an explanation of the research objectives. Section two is the Literature Review introducing concepts and components based on the existing literature. Section three is the Research Methodology focused on the type of research conducted, data collection and methods. Followed by section four, Results, to present all findings. At last, section five is the Discussion and Conclusion to answer the research questions based on the results obtained and a general overview of the research contributions and limitations.

2. Literature Review

The literature review section is an essential component of any research study. It presents a comprehensive analysis of previously published research and relevant literature regarding this thesis topic and the research questions being addressed. The purpose of this section is to introduce concepts and their constituent components, highlight key findings and impart a critical analysis of the existing literature (Webster & Watson, 2002). Moreover, it aims to identify gaps in the existing knowledge, as well as areas where further research is needed. Demonstrating where this research fits compared to past and current research on the topic.

To provide a logical literature review, the following section is thematically structured. Starting from the business-oriented analysis of the energy sector and narrowed down to the phenomenon of blockchain technology within this industry.

2.1. Energy Sector

The energy sector plays a vital role in shaping the economic, social, and environmental landscape of modern societies (Zhang, Fu, Tian & Peng, 2022). As the energy demand continues to rise and concerns about climate change intensify, there is an increasing need to understand and address the complex challenges and opportunities within this sector (Hossein Motlagh, Mohammadrezaei, Hunt & Zakeri, 2020). The shift towards sustainable energy production through renewable sources is poised to revolutionize the current energy sector, leading to a profound transformation in its operational landscape, business practices and structure (Richter, 2012).

2.1.1. Ecosystem and Value chain

To perceive this sector evolving transformation and its business implications, it is important to first understand the current sector structure. The energy sector ecosystem and value chain refer to the complex and wide interconnected network of entities, activities, and processes involved in the production, distribution, and consumption of energy resources (Zhang et al, 2022).

Figure 1 *- Energy Sector Value Chain.(Richter, 2012)*

According to Richter (2012), as represented in Figure 1, the following energy sector value chain represents the sequence of activities and value-adding processes from the extraction or generation of energy resources to its final consumption.

The process of electricity *Generation* involves converting primary energy resources into electrical power. The predominant source of industrialized electricity is derived from large-scale power plants that rely on fossil fuels and nuclear energy. However, it is anticipated that renewable energy technologies will predominantly supplant the existing generation capacity in the forthcoming decades. Despite certain obstacles such as the intermittent nature of renewable sources, renewable energy is increasingly regarded as a viable alternative to conventional power plants.

Transmission involves the high-voltage transportation of electricity across long distances through the transmission grid. The responsibility of balancing electricity supply and demand within a specific region lies with the transmission system operator (TSO). While multiple TSOs may operate in the market, the transmission grid typically operates as a natural monopoly within its designated area. Due to the growing number of renewable energy facilities the establishment of new and flexible transmission grids becomes necessary.

Distribution networks are controlled by the distribution system operators (DSO) and are specifically designed to provide electricity to end customers at the low voltage level. The DSO has responsibility for all aspects related to the grid connection of end users. The recent demand for renewable energy projects requires information and energy to flow in both directions creating the need for innovation in the distribution network grid.

Retail can be characterized as predominantly an administrative function encompassing interactions with end customers. The retail process primarily involves activities such as electricity procurement, metering, and billing. Retailers procure electricity from producers, traders, or exchanges, and subsequently distribute it to end customers.

Energy *Consumption* occurs on the customer’s end. In a traditional value chain, this represents the extremity of the energy sector demand side. However, It is anticipated that the shift towards sustainable energy will bring changes and integrations in this sector value chain, specifically on the extremities of generation and consumption.

2.1.2. Industry Transition

As mentioned, the progress and widespread adoption of decentralized power generation and storage, empowered traditional energy consumers to engage in not only energy consumption but also independent energy production (Zhou, Yang & Shao, 2016). Swift technological progressions such as solar photovoltaics, home energy management systems, smart devices and microgrids, are reshaping the landscape by empowering self-generating consumers (Sioshansi, 2015; Bryant, Straker & Wrigley, 2018). Commonly referred to as prosumers[1], energy users are no longer solely consumers but instead assume a dual role. They will possess a unique identity as both producers and consumers simultaneously (Zhou et al, 2016; Hamwi & Lizarralde, 2017). For further clarification, Appendix 1 shows a representation of the energy prosumer.

The energy sector industry transition represents a paradigm shift in the way energy is produced, distributed, consumed, and governed. The sector grows as a result of energy production technologies advancements and process development alongside innovations in market structure, business models and consumption patterns (Zhou et al, 2016). As research suggests, operations and management characteristics of the industry transition can be categorized into four main stages, starting in the second industrial revolution, as shown in Table 1 below.

Table 1 *- Evolution of Energy Systems, adapted from Zhou et al (2016)*

Decentralized Energy System	Centralized Energy System	Distributed Energy System	Smart & Connected Energy System
small-scale, isolated, self-sufficiency, low efficiency, low level of technology	industrialized production, large-scale, high efficiency, grid transmitted, high emissions	diversified, small-range, renewable, clean, flexible, low emissions	smart, inter-connected, digitized, data-rich, two-way interactive, personalized, high-efficiency

Researchers see the future of this industry as an integrated grid of renewable energy, where decentralized energy storage technology will play a critical role (Jacobsson & Bergek, 2004). Moreover, given the political nature of the sector, regulation and policy will also strongly influence the future of this sector (Sioshansi, 2016). The evolution of the energy system's purpose is to create an intelligent, effective, safe, adaptable, and environmentally-friendly network for producing and consuming energy. This system aims to supply

[1] The definition of lack of distinction between producer and consumer, first proposed by Alvin Toffler (1980).

sustainable electricity to enhance people's quality of life and drive social and economic progress (Zhou et al, 2016).

2.1.3. Importance of Data in the energy sector

As mentioned previously, the smart and connected energy system the sector is evolving into is a highly technological and data-rich environment. Diverse and complex data from multiple sources are becoming a crucial foundation for the energy system and a key business asset for energy actors. This trend is driving the development of an increasing number of innovative energy products and services that are data-focused (Zhou et al, 2016).

By processing and examining the data produced, it becomes possible to obtain a profound understanding, provide precise system responses, and enable informed decision-making regarding energy consumption within the systems. The vast quantity of structured and unstructured data created is known as Big Data. It is produced by different components like sensors, software applications, intelligent devices, and communication networks. Big data is characterized by its immense volume, high velocity, and diverse nature. Therefore, it requires efficient processing and analysis. Traditional methods are insufficient to handle big data. Advanced computing and analytical techniques are necessary to effectively manage and utilize this large-scale data (Hossein Motlagh et al, 2020). The implementation of effective management processes within systems plays a fundamental role in ensuring the optimal utilization of resources and facilitating the delivery of high-quality services to customers. (Amado, Santos & Sequeira, 2013). The table 2 below helps to visualize the energy big data-driven applications and services.

Table 2 *- Energy big data-driven applications and services. Adapted Zhou et al (2016)*

Energy Big Data	⟹	**Big Data Analytics**	⟹	**Applications and Services**
Energy Use Data		Data quality evaluation and modelling		Demand side management
Weather Data		Data clustering and classification		Distribution network management
GIS Data		Stream data processing		Remote asset management
Customer Service Data		Knowledge inference		Energy efficiency services
Social Media Data		Statistical machine learning		Real-time dynamic pricing
Electric Vehicle Data Third-Party Data		Neural networks modelling and deep learning		Optimal load distribution

The data-driven applications and services can accurately identify and cater to the ever-changing requirements of users. This not only assists energy service providers in gaining a competitive edge but also facilitates the efficient functioning of the energy sector ecosystem.

2.1.4. Local Energy Communities

As a result of such transformations and technological innovations explained above, local energy communities (LEC) are a suitable example worth exploring in this research. The idea of energy communities holds great promise since it enables tackling global challenges at a local scale (Otamendi-Irizar, Grijalba, Arias, Pennese & Hernández, 2022). These communities will offer end-users democratic open access to the energy grid, as well as the opportunity for collective self-consumption. Energy communities are extensively acknowledged as a crucial milestone in achieving a decentralized sustainable transition towards clean energy (Di Lorenzo, Martirano, Araneo, Cappello, Mingoli, & Ermellino, 2021).

In addition to their significant role in advancing renewable energy applications, energy communities are also linked to the advantages of boosting the local economy and promoting stakeholder engagement. Energy communities have garnered substantial governmental interest for their multiple benefits. The European Union, in particular, has displayed a keen interest in facilitating the broader adoption of energy communities (Kubli & Puranik, 2023). Energy communities can be regarded as a significant achievement in the progress of novel policies that promote prosumer aggregation (Di Lorenzo et al, 2021).

Integrated community grids and data-driven concepts like these, tend to generate security apprehensions for the system itself and privacy concerns for users, in this case, prosumers. However, there is a potential solution to this challenge: Blockchain (Hossein Motlagh et al, 2020).

2.2. Blockchain Technology

The first concept of blockchain technology was first introduced by Stuart Haber & W. Scott Stornetta (1991) with computational methods for time-stamping documents digitally. The method preserves the full privacy of documents without the need for any record-keeping (Haber & Stornetta, 1991). However, the technology only gained worldwide attention when the Bitcoin whitepaper was published by the pseudonymous Satoshi Nakamoto (2008). Cryptocurrency is one of the most famous blockchain-based applications. It enables online payments to be directly exchanged between parties without the involvement of intermediaries. This peer-to-peer linked-structure approach represents a decentralized electronic cash system where digital signatures have a fundamental role (Nakamoto, 2008).

2.2.1. Concepts and definition

Contracts, transactions, and their corresponding records play a crucial role in shaping our economic, legal, and political institutions. These structures safeguard assets, define organizational limits, validate documents and identities, and regulate interactions between nations, organizations, communities, and individuals (Iansiti & Lakhani, 2017). Intermediaries are responsible for conducting thorough verifications of each party involved. However, this process is not only time-consuming and expensive, but it also carries the risk of failure if an intermediary becomes unreliable (Nofer, Gomber, Hinz & Schiereck, 2017). Blockchain benefits go beyond the economic scope. The irrevocability and transparency of transactions can play a fundamental role in society's progress across several domains, such as political, social, legal and scientific to counter repressive regimes (Swan, 2015; Tapscott & Tapscott, 2016b).

Blockchain is a distributed ledger technology (DLT) that records and verifies transactions permanently (Iansiti & Lakhani, 2017). Blockchain is a decentralized, immutable data structure with appended timestamps. It facilitates the creation of a distributed peer-to-peer network where participants can interact with each other in a verifiable manner, eliminating the reliance on central authority (Casino, Dasaklis & Patsakis, 2019). Blockchain can be seen as a transparent record-keeping system where all verified transactions are stored in a sequential list of blocks. This chain expands over time as new blocks are consistently added (Zheng, Xie, Dai, Chen, & Wang, 2017). The extensive utilization of cryptography, a prominent feature of blockchain networks, ensures the legitimacy and authority of all interactions within the network. The lack of trusted middlemen results in a more efficient reconciliation between the parties involved in transactions (Christidis & Devetsikiotis, 2016). The strength of Blockchain lies in its immutability, as once data is approved by all nodes and added to the public ledger, it cannot be altered or removed. This inherent feature of Blockchain ensures its reputation for maintaining data integrity and robust security (Yli-Huumo, Ko, Choi, Park & Smolander, 2016).

The architecture of blockchain can be depicted as a series of interconnected blocks that store a comprehensive record of transaction data. Figure 2 provides a visual representation of a blockchain. Each block in the chain possesses a reference to its preceding block through the inclusion of the previous block's hash[2] in its header, resulting in a linear relationship where each block has only one parent block (Zheng et al, 2017).

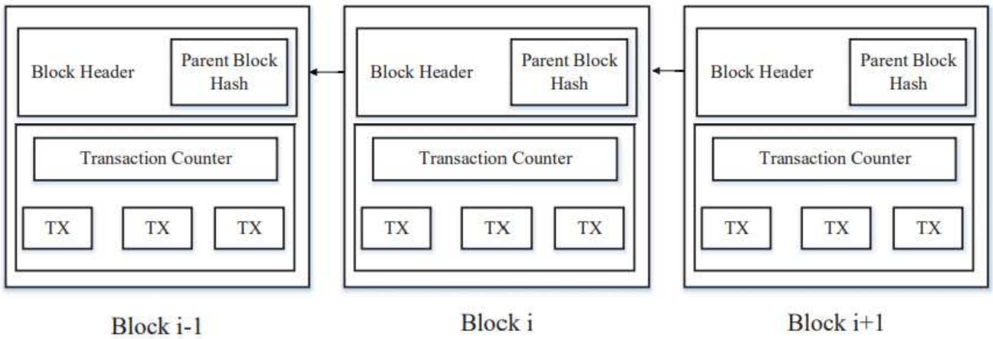


Figure 2 *- Example of Blockchain which consists of a continuous sequence of blocks, Zheng et al (2017)*

The information contained within the hash is automatically generated, which ensures that no alterations can be made (Golosova & Romanovs, 2018). The initial block of a blockchain is known as the genesis block, and it does not have any preceding parent block (Zheng, Xie, Dai, Chen, & Wang, 2018). For more detailed and technical information on the isolated block structure consult Appendix 2. And for a visualization of the signing process and verification process mentioned previously, consult Appendix 3 and 4, respectively.

2.2.2. Key Characteristics

Blockchain technology offers several key characteristics that revolutionize traditional systems. They can be presented and summarized in four main concepts:

Decentralisation – In traditional centralized transaction systems, every transaction requires validation from a central trusted authority, leading to inevitable costs and performance limitations (Zheng et al, 2017). In contrast, in a blockchain network, transactions can be performed peer-to-peer (P2P) without the need for authentication from intermediaries. This feature enables blockchain to substantially lower server costs and reduce limitations

[2] Fixed-size string of characters that is generated by applying a specific algorithm to data.

(Zheng et al, 2018). The data and information within the blockchain are not controlled by any single entity. Instead, every participant has the ability to independently verify the transaction records of their counterparts (Iansiti & Lakhani, 2017).

Persistency – Due to the requirement of confirming and recording each transaction across the entire distributed network in blocks, tampering becomes highly implausible (Zheng et al, 2018). Once transactions are included in the blockchain, deleting or rolling them back becomes extremely challenging, if not impossible. Any blocks that contain invalid transactions can be promptly identified and flagged (Zheng et al, 2017). This makes blockchain practically immutable (Bashir, 2017)

Anonymity – Every user has the ability to engage with the blockchain network using a unique generated address. Additionally, users have the option to create multiple addresses to prevent the disclosure of their identities (Zheng et al, 2018). Users have the flexibility to maintain their anonymity or furnish evidence of their identity (Iansiti & Lakhani, 2017).

Auditability - Blockchain offers enhanced traceability due to its transparent and immutable nature. The distributed ledger system allows for the easy verification and validation of timestamped transactions and records (Zheng et al, 2018).

2.2.3. Taxonomy of blockchain

Blockchain networks can be classified according to their permission model, which determines the individuals or entities authorized to maintain them (Yaga, Mell, Roby & Scarfone, 2019). A blockchain network is considered *permissionless* or public when anyone has the ability to publish a new block. Conversely, if only specific users or entities possess the right to publish blocks, the blockchain network is classified as *permissioned* or private (Wüst & Gervais, 2018; Yaga et al, 2019). Moreover, if controlled by a group of organizations/individuals in a permissioned network, is often known as a *consortium* (Yaga et al, 2019). Note that blockchain can be classified into multiple types with unique attributes that can also overlap (Bashir, 2017).

Permissionless – these types of blockchain networks are decentralized ledger platforms that allow any participant to publish blocks without requiring authorization from a central authority (Yaga et al, 2019). In a public blockchain, all records are accessible to the open public, and anyone can participate in the consensus process (Zheng et al, 2017). There are no limitations on the users who have the eligibility to create transaction blocks in this context (Golosova & Romanovs, 2018). Peers have the freedom to join or leave the network at any time, assuming roles as both readers and writers. There is no central authority responsible for managing membership or capable of prohibiting unauthorized readers or writers (Wüst & Gervais, 2018).

Permissioned – in this type of network, publishing blocks require authorization from a designated authority. Only authorized users can maintain and enforce restrictions on this type of blockchain network (Yaga et al, 2019). A private blockchain is considered a centralized network as it is under the complete control of a single organization. On the other hand, a consortium blockchain, which involves multiple organizations, is classified as partially decentralized (Zheng et al, 2017; Casino et al, 2019). Permissioned blockchain networks can either grant or limit read access exclusively to authorized individuals (Yaga et al, 2019).

The characteristics of these types of blockchain networks mentioned above can be summarized as presented in Table 3.

Table 3 - *Taxonomy of Blockchain, Zheng et al (2017)*

Property	Public blockchain	Consortium blockchain	Private blockchain
Consensus determination	All miners	Selected set of nodes	One organization
Read permission	Public	Could be public or restricted	Could be public or restricted
Immutability	Nearly impossible to tamper	Could be tampered	Could be tampered
Efficiency	Low	High	High
Centralized	No	Partial	Yes
Consensus process	Permissionless	Permissioned	Permissioned

2.2.4. Consensus Mechanisms

Consensus mechanisms are a fundamental principle of distributed technologies, it finds application in blockchain technology to establish unanimous agreement among all participants on the network regarding a single version of the truth. This agreement is essential for ensuring the integrity and reliability of the blockchain system (Bashir, 2017). These mechanisms ensure that all nodes in the network reach a consensus on the validity and ordering of transactions, as well as the state of the blockchain (Yaga et al, 2019).

One of the most widely recognized methods is the Proof-of-work (PoW) consensus algorithm. PoW involves miners to complete complex computational tasks, such as discovering hashes that match certain patterns, in order to guarantee authentication and confirmability (Casino et al, 2019). Currently used in Bitcoin and other cryptocurrencies this algorithm has proven highly efficient against cyberattacks (Bashir, 2017). However, the level of electrical power needed for processing this algorithm is concerningly high (Zheng et al, 2018). Due to this challenge, numerous blockchains are progressively transitioning to Proof-of-stake (PoS) as a result of the notable reduction in energy usage and enhanced scalability (Casino et al, 2019). The concept underlying the PoS model is that users who have invested a larger stake in the system are more inclined to ensure its success and less inclined to undermine it (Yaga et al, 2019). PoS protocols distribute stake blocks in proportion to the miners' existing wealth (Casino et al, 2019).

2.2.5. Blockchain Applications

After a detailed, extensive and technical analysis of blockchain technology, it is important to understand where the research stands on the applications it has or can bring across different areas vital to society. Such as:

Financial – Blockchain is anticipated to assume a crucial role in fostering sustainable development in the global economy. Blockchain technology finds application in diverse financial domains, encompassing financial services, financial asset settlements, prediction markets, and economic transactions (Casino et al, 2019). Applications:

- *Crypto-currencies* - Digital currency based on cryptography for secure and decentralized transactions (Nofer et al, 2017);
- *Prediction Marketplace* - Predictions trading on various events, leveraging crowd wisdom and financial incentives (Casino et al, 2019);
- *P2P financial market* - A decentralized marketplace where anonymous peer-processors can directly engage in financial activities such as borrowing, lending, investing, and trading without the involvement of third parties (Zheng et al, 2018);
- *Risk management* – Investment risk analysis increased performance with blockchain frameworks. Investment decisions and collateral assessments can be

performed faster instead of undergoing prolonged deliberations (Zheng et al, 2018);

Business and Industry – Blockchain can be a catalyst for ground-breaking innovations in business and management by enhancing, streamlining, and automating various business processes, specifically within the energy sector (Casino et al, 2019). It has the potential to improve business and logistics safety, reliability and trustworthiness (Golosova et al, 2018). Applications:

- *Supply chain management* – By leveraging blockchain, supply chain networks can enhance transparency, traceability, and accountability throughout the entire process. This technology enables real-time tracking of goods and assets, reducing fraud, counterfeiting, and unauthorized changes (Casino et al, 2019);
- *Smart Contracts – S*elf-executing agreements written in code that automatically facilitate, verify, and enforce the negotiation or performance of a contract. These contracts are stored on a blockchain, ensuring transparency, security, and immutability (Wüst & Gervais, 2018);
- *Decentralized Autonomous Organizations (DAO)* - Autonomous organizations operated by smart contracts, eliminating the need for centralized control or management found in traditional organizations or companies (Wüst & Gervais, 2018);
- *Internet of Things (IoT)* – Blockchain architecture has the potential to mitigate the limitations of IoT and unlock its maximum capabilities (Casino et al, 2019). Improving and implementing secure transactions of smart assets and sensor data that are crucial for the IoT business model (Zheng et al, 2018);

Privacy and Security – By utilizing its decentralized, transparent, and cryptographic features, blockchain provides innovative solutions to address the privacy and security challenges faced by businesses and individuals in today's digital world (Tapscott & Tapscott, 2018). Applications:

- *Security enhancement* – Blockchain as the means to improve the security aspects of big data. It ensures data integrity and reduces the risk of unauthorized access or tampering (Casino et al, 2019);
- *Privacy protection* - Blockchain holds the capability of enhancing the security of confidential data and safeguarding privacy. The decentralized system allows to

manage personal data and prioritizes user ownership and control over their information (Zheng et al, 2018);

Governance – Blockchain technology also finds extensive applications in the domains of public administration and social services (Zheng et al, 2018). It can revolutionize the operations of local and state-level governments in record-keeping processes (Casino et al, 2019). Applications:

- *Identity management* - allows individuals to have control over their personal information, authenticate their identity when needed, and selectively share their information with others while maintaining privacy and anonymity (Abou Jaoude & Saade, 2019);
- *E-voting* – Transition of traditional voting methods to a digital trusted solution. Eliminating the risk of data manipulation and human error (Abou Jaoude & Saade, 2019).
- *Healthcare management* - With the decentralized nature of blockchain technology, medical records can be consolidated on a shared ledger. This ensures the unification of medical record information across different healthcare providers (Abou Jaoude & Saade, 2019; Casino et al, 2019);

2.3. Drivers to implement blockchain technology in the Energy Sector

Blockchain technology has garnered significant attention and interest from various energy supply companies, startups, technology innovators and the academic community (Andoni, Robu, Flynn, Abram, Geach, Jenkins & Peacock, 2019). Table 4 helps to visualize the current research on the drivers that make blockchain technology so attractive and useful for the energy sector.

Table 4 *- Drivers to implement blockchain technology in the Energy Sector*

Dimension	Driver	Description	Reference
Technological	Automation	Efficient management over microgrids and decentralized energy systems. Automatic energy and economic transactions management.	Andoni et al, 2019
	Security and identity	Cryptographic techniques help improve the protection of transactions and assure data privacy and cybersecurity.	Burger et al, 2016; Ahl et al, 2022
Environmental	Resource sharing	Innovative solutions that incentivize the sharing of renewable resources among multiple users	Andoni et al, 2019
	Management optimization	Decentralized grid and network management flexibility, optimizing resource usage, increase revenues and cost reduction.	Andoni et al, 2019
Economical	Cost-competitive	Rapid mobility between energy suppliers in the market can help reduce overall electricity costs.	Andoni et al, 2019; Botticelli et al, 2020
	Trading	Optimized distributed trading platforms for commodity trading, tokenization and green certificates.	Andoni et al, 2019; Botticelli et al, 2020
	Billing solutions	Potential to revolutionize traditional billing. Through smart metering and contracts, energy micro-payments and added security.	Andoni et al, 2019
Social	Tailored service	Innovative services to achieve end-user loyalty. Individual consumer profiling for improved sales and marketing strategies.	Botticelli et al, 2020; Ahl et al, 2022
Institutional	Data transfer	Communication and data transmission between smart grid devices. Such as sensors, meters and monitoring equipment.	Burger et al, 2016
	Transparency and traceability	Improved compliance with the law and regulatory processes. Transparent data-sharing with end-user.	Dal Canto, 2017
	BM diversification	Engaging in disruptive and new business models associated with the digital and sustainable transition.	Botticelli et al, 2020

2.4. Barriers to implement blockchain technology in the Energy Sector

Even though blockchain technology shows great promise in the energy sector, it is important to note that it is not a one-size-fits-all solution for all energy system challenges. Blockchain has its inherent limitations and it should be followed by targeted improvements that align with the specific needs and practical requirements of energy systems (Wang, Hua, Wei & Cao, 2022). Table 5 provides an overview of the challenges to implementing this technology in the energy sector.

Table 5 *- Barriers to implement blockchain technology in the Energy Sector*

Dimension	Barrier	Description	Reference
Technological	Scalability	Transactions and participants increase in a blockchain network, compromises the system's capacity to handle and process transactions promptly.	Ahl et al, 2022 Wang et al, 2022
	Centralized energy systems	Conventional large-scale energy systems technology still operates in a centralized and unilateral manner towards the end consumer.	Ahl et al, 2022
	Smart meter infrastructure	Deficit of smart meters presents a technical obstacle for digital advancements in this industry since it has a crucial role in blockchain applications.	Ahl et al, 2022
Environmental	Energy-intensity	Validation and verification data mechanisms require significant computational power leading to high energy consumption and costs.	Andoni et al, 2019
	Grid balancing	Physical infrastructure interventions might be needed in the grid to support innovations in the energy system.	Ahl et al, 2022
Economical	Cost of change	High implementation and development costs for infrastructure and user expansion in comparison to the existing and established market.	Andoni et al, 2019 Ahl et al, 2022
	Risk aversion	High financial risk aversion and lack of funding. Uncertainty on use cases, financial returns and user adoption.	Ahl et al, 2022
Social	Cultural shift	Lack of technical knowledge could represent a real-world trust issue since smart contracts are performed virtually instead of the conventional method.	Wang et al, 2022
Institutional	Regulatory complexity	New legal framework is required to support most use cases of blockchain in this sector. Inflexible energy market policies and regulations.	Ahl et al, 2022 Botticelli et al, 2020
	Incumbent interests	The energy transition is considered to be highly influenced by political interests. Political risk aversion has a strong influence on this sector.	Ahl et al, 2022

2.5. Blockchain use cases in the Energy Sector

The energy industry has just started to explore the potential of blockchain technology, evident through the growing presence of startups, trial initiatives, and research projects dedicated to exploring its use cases (Andoni et al, 2019). The following table represents current and potential use cases according to the literature.

Table 6 *- Blockchain use cases in the Energy sector*

Use Case	Description	Reference
P2P energy trading	Direct exchange of energy between individual producers and consumers without the involvement of centralized authority in local communities through physical power connections.	Wang et al, 2022 Andoni et al, 2019
Microgrid energy market	Energy trading can extend beyond local communities and involve multiple microgrids managed by various groups that are not physically connected. Creating a virtual community where participants can engage in energy transactions	Wang et al, 2022
Energy cryptocurrency, tokens & investment	Cryptocurrencies are employed as a mechanism to tokenize assets or services. For example, rewards can be given to producers based on clean energy production quantity.	Wang et al, 2022 Andoni et al, 2019
Smart Metering, Billing & Security	Production and consumption of energy can be traced at individual endpoints with blockchain integration. Providing consumers with valuable information about the source and cost of their energy supply.	Andoni et al, 2019
Green certificate & Carbon trading	Green certificates authenticate clean energy producers. Carbon credits can be bought, sold, or traded between producers and customers, encouraging the use of renewable energy sources.	Imbault et al, 2017
Energy control & management	Monitoring and control of energy transactions, grid balancing, and asset management. Efficient coordination among participants, and automation of grid management processes.	Andoni et al, 2019
Internet of Things	Efficient approach for IoT current challenges of data privacy, integration and management.	Wang et al, 2022
Electric e-mobility	The organic decentralized nature of e-mobility transportation, such as charging stations, mobility services, and vehicles, makes it a suitable environment for blockchain applications.	Andoni et al, 2019

2.6. Business models

As mentioned previously, emerging technologies like blockchain, Web 3.0, and IoT have the potential to reshape industries and create entirely new business models (Tapscott & Tapscott, 2016a). Innovation in business models involves rethinking traditional approaches, exploring new revenue streams, and adapting to changing market and social dynamics (Nosratabadi, Mosavi, Shamshirband, Zavadskas, Rakotonirainy & Chau, 2019). Thus, it is important to understand where research stands on this topic alongside technological innovation.

2.6.1. Concept, Definition & Elements

A business model serves as a conceptual framework that encompasses various elements, ideas, and interconnections that form the operational principles of an organization (Osterwalder, Pigneur & Tucci, 2005). It is essential to analyse the concepts and relationships that facilitate a clear and concise depiction of the value created and delivered to customers, the methods employed to achieve it, and the resulting financial implications (Teece, 2018). When considering the objectives of a business model, its components should aim to fulfil service commitments, meet customer needs, and ensure profitability, all of which contribute to establishing a sustainable competitive advantage in the long run (Wirtz, Pistoia, Ullrich, & Göttel, 2016).

The notion of a business model encompasses an abstract interpretation of how value is exchanged and the interactions among different value components within an organizational entity. The fundamental components of value within organizations revolve around the proposition, creation, delivery, and capture of value (Nosratabadi et al, 2019).

Throughout the years researchers have proposed different ways of categorizing business models proposing different elements belonging to each concept as presented in Table 7. These elements can be categorized into three core integrative dimensions (Teece 2010). *Value offering* for the strategic and competitive positioning proposition. *Value network* refers to core competencies, resources and structure, and the *Revenue & cost* dimension for the firm earnings and cost approach (Spieth & Schneider, 2016).

***Table** 7 - Business Model Elements, adapted from Spieth & Schneider (2016)*

Publication	No. of elements	Value offering	Value network	Revenue & Cost
Amit & Zott, 2001	3	Transaction content	Transaction structure Transaction governance	_
Morris et al, 2005	6	Offering Market Competitive strategy	Internal capability Personal factors	Economics
Shafer, Smith & Linder, 2005	4	Strategic choices	Value creation Value network	Value capture
Chesbrough, 2007	6	Value proposition Market segment Competitive strategy	Value chain structure Positioning in the value network	Revenue generation mechanisms
Osterwalder & Pigneur, 2010	9	Customer segments Value proposition	Channels Customer relationships Key resources Key activities Key partnerships	Revenue streams Cost structure
Teece, 2010	4	Value proposition	Mechanisms to deliver value Mechanisms to capture value	Architecture of revenues and costs

2.6.2. Value Creation & Value Capture

Zott, Amit and Massa (2011) suggested that business models essentially seek to understand how value is created and captured. The concept of value creation and value capture encompasses two essential functions that are vital for the long-term viability of any organization. Successful companies can generate significant value by adopting unique approaches that set them apart from their competitors (Shafer et al, 2005).

Value creation refers to the process of generating or adding value to products, services, or business activities to enhance the perceived worth or usefulness in the eyes of the consumer (Chesbrough, Lettl & Ritter, 2018). For organizations, the process of value creation is directly influenced by innovation and invention. When companies explore novel techniques, technologies, or materials, they have the potential to generate new value (Lepak, Smith & Taylor, 2007).

Value capture can be defined as the mechanism through which organizations extract and retain profits resulting from the value they have created. It involves the distribution of these values among various stakeholders, including providers, customers, and partners (Sjödin, Parida, Jovanovic & Visnjic, 2020). At an organisational level, value capture is how firms utilize support mechanisms to maximize advantage over competitors (Lepak et al, 2007).

In many cases, executives tend to prioritize and emphasize the value creation aspect of the business model while neglecting or underestimating the importance of value capture. As a result, organizations may struggle to realize the economic returns that align with the value they have created (Shafer et al, 2005).

2.6.3. BM use of blockchain technology in the energy sector

The selection of a business model impacts the methods by which technology is monetized and profitable for the involved companies. This implies that the relationship between business model selection and technology is mutually influential and intricate. Additionally, it is acknowledged that technology itself can shape the range of possibilities for business models (Baden-Fuller & Haefliger, 2013).

According to Niesten and Alkemade (2016), there are two main dimensions for value creation with the implementation of decentralized technology in the energy sector as a whole. The first one is demand response and demand-side management services. Generates value for response by reducing peak demand, enhancing system reliability, and ensuring stability. For demand by decreasing energy consumption and expenses, and increased control over energy usage. The second dimension is services for renewable energy integration. To ascertain the feasibility and assess the financial and environmental value for both the consumers and producers.

As a result of the innovative dimensions, Hamwi and Lizarralde (2017) associated three major business model innovations for the energy transition. Customer-owned product-centred business models, where the ownership of the electricity generation or management lies with the customer. Third-party service-centred business models, in cases where a third party provides energy services to the client. And lastly, Energy community business models, in situations where community members pool and share resources.

Focusing on local energy communities as presented in 2.1.4, the different design options of the business model, members, key functions, network effects and value associated with this type of concept can be visualized in Table 8.

Table 8 *- Energy community design options, adapted from Kubli & Puranik (2023)*

BM dimension	**LEC design options**				
Community value proposition	Renewable energy generation	Increasing self-consumption	Increasing self-reliability	Energy consumption reduction	Energy costs reduction
Energy community members	Residential prosumers	Large-scale prosumers	Local energy producer	Energy service company	Community platform operator
Energy value capture	Energy services revenue	Energy cost savings	External services revenue	Community service fee	Data valorisation
Key functions	P2P trading	Aggregating energy and flexibility	Storage systems management	Co-optimizing energies	Coordinating partners
Network impact	Peer effects	Community feeling	Economies of scale	Learning effects	Benefits and amortization of investments

3. Methodology

The methodology section is a crucial part of the research process, providing a detailed description of the methods used to collect and analyse data. This section serves as a roadmap for the research project on how to answer research questions and achieve the research objectives (Saunders, Lewis & Thornhill, 2009). A well-designed methodology ensures that the research is conducted rigorously and systematically, enhancing the validity and reliability of the results.

3.1. Research Approach

To gain a deeper understanding of this complex and rising topic, qualitative research was chosen. This type of research allows data collection in a legitimate context sensitive to the area, people and location under study (Creswell, 2016). It accounts for real-world conditions and acknowledges the relevance of several sources of evidence (Yin, 2015). It is an interpretive philosophy (Denzin & Lincoln, 2005). The main challenge of qualitative research is to develop a greater theoretical perspective compared to the existing literature with an inductive approach (Saunders et al, 2009).

The strategy chosen for the qualitative research design was multi-case study research. The research design strategy is the proposition of how the research questions will be answered. (Saunders et al, 2009). Fundamentally being able to answer "what", "how" and "why" the phenomenon at study works. A case study examines a research topic within its setting, or in this case, multiple real-life settings. The multiple cases approach focuses on the capacity to demonstrate the replicability of findings across cases. (Yin, 2018). Case selection plays a vital role in qualitative research in order to solve the challenge of representativeness (Seawright & Gerring, 2008). A diverse method was prioritized to have categorical values within the use cases of blockchain in the energy sector. This way is possible to achieve larger variance within relevant dimensions (Seawright & Gerring, 2008) and enrich the analysis.

3.2. Sample

Within business research, especially case study research, non-random sampling techniques are most common due to the element of subjective judgement (Saunders et al, 2009). From the existing different sampling techniques, the chosen was the Snowball sampling also named Chain sampling for the primary data. This technique is commonly used when it is difficult to identify members within the population (Saunders et al, 2009). This is the case due to the novelty of the technology and its applications. This technique involves seeking information-rich cases from key informants in the field. As it is "particularly useful for capitalising on expert wisdom, identifying studies that are highly valued by different stakeholders and identifying studies outside the academic mainstream" (Suri, 2011). However, there is a risk associated with this technique. The similarity between the identified respondents can result in a homogeneous sample (Lee 1993).

The description of the sample used in this research for primary and secondary data is presented in the table below. The sample represents organizations using disruptive technologies, such as blockchain, in their business models focused distinctively on the energy sector.

Table 9 *– Data Profile*

Interview

Interviewee	Type of Organization	Use Case	Annual revenue 2022	Size	Country
CEO 1	Start-up	Local energy communities	200K €	Small	Portugal

Project Reports

Project	Theme	Website	Number of pages
Bright	Boosting demand response (DR) through increased community-level consumer engagement by combining data-driven and blockchain technology tools with social science approaches and multi-value service design.	brightproject.eu	176
Cinea	European Climate, Infrastructure and Environment Executive Agency of the European Commission report on digitalization in urban energy systems.	cinea.ec.europa.eu	97
eDream	Enabling new demand response advanced, market-oriented and secure technologies, solutions and business models.	edream-h2020.eu	298
Enerchain	Blockchain-based distributed trading infrastructure that enables energy trading in power and gas products such as standardised spot and forward contracts.	enerchain.ponton.de	14
F-Pi	Financing energy efficiency using private investments is a project, funded by the European Commission, whose aim is to promote and speed up the development of private investments in energy efficiency, sustainable mobility and self-consumption.	fpih2020.eu	11

JRC	European Commission's Joint Research Centre. Results of the experimental tests and the results carried out to implement: Blockchain solutions for the energy transition; Blockchain in the Energy Sector;	joint-research-centre.ec.europa.eu	129
Parity	Prosumer-aware, transactive markets for the valorisation of distributed flexibility enabled by Smart Energy Contracts.	parity-h2020.eu	190

Given the limitation in conducting additional interviews, the reports of the projects funded by the European Commission were used as secondary data. These reports from credible sources provided valuable insights enabling a more comprehensive exploration of the role of blockchain in the energy sector.

3.3. Data collection and methods

These multiple case studies were taken in the form of semi-structured interviews. This method is one of the most valuable sources of case study evidence and allows targeted and insightful views and perceptions (Yin, 2018). Semi-structured guidance allows dynamic and fluid inquiry leading to more valuable information (Rubin & Rubin, 2011). It is crucial to balance the needs of the research line of inquiry and the open-end questions (Yin, 2018). The recorded interviews were conducted with full support and consent from the participants. The purpose of the study was shared and the anonymity of participants was preserved so no ethical issues were faced in this qualitative research.

In terms of sample size, the concept of 'data saturation' or 'thematic saturation' was applied. This concept was presented by Glaser and Strauss (1967) and refers to the point in data collection when all significant concerns or insights have been mostly explored by the data. It is an indicator of an adequate sample. Translating in diversity and depth of the issues of the phenomenon at study (Hennink & Kaiser, 2022).

3.4. Data Analysis Technique

The data analysis technique used in this research is the Gioia coding method. This approach allows inductive concept development whilst maintaining the rigour that qualitative research requires (Gioia, Corley & Hamilton, 2013). In qualitative research, coding is a method to essence-capture and summarize language-based data (Saldaña, 2021). The method consists of organizing the data in order of categories. The first order analysis is ‘concepts’. A comprehensive examination of the raw data. Through the identification and categorization of frequently used words, phrases, terms, and labels provided by the participants and reports, it is possible to establish primary code categories. These categories accurately capture the perspectives of the respondents and reports related to the research questions. The second order ‘Themes’ is already more of a theoretical realm. It is an iterative process, identifying second-order themes, which are conceptual frameworks that emerged from the combination of first-order categories. These themes represent distinct theoretical concepts that further enhance our understanding of the data. Until we reach the ‘aggregate dimension’ completing the basis for the data structure. It represents a high level of abstraction in the coding based on the first and second-order themes to present practical and theoretical categorization. It is then possible to begin “cycling between emergent data, themes, concepts, and dimensions and the relevant literature” (Gioia et al, 2013).

4. Results

The results are presented in this section according to the research areas approached in the literature and both primary and secondary data collection. These findings were produced from our qualitative examination of the data, during which we identified and categorized responses that provided practical and applicable information regarding the dynamics at hand.

Applications:

The interviewee and pilot project reports revealed specific actions and most commonly used applications of this technology in the energy sector based on their entrepreneurial experience. We will be looking at the first dimension of concepts in applications. First, the most referenced application in the data: 'Creation and management of local energy communities of organized prosumers and consumers for P2P trading' (CEO 1). The peer-to-peer energy community exemplifies a scenario where a collective of individuals engage in an autonomous exchange of electricity among themselves (JRC WP4, 2021). Prosumers can trade energy in a P2P fashion directly or through an energy aggregator (eDream, 2018). Blockchain and smart contracts are the enablers for this P2P trading mechanism (BRIGHT, 2022). This application arises due to a progressive change in the traditional electric market operated as a unified network where a sole monopolistic operator manages the energy cycle (JRC WP3, 2021). Technological advances in small-scale energy generation have contributed to market liberalisation and disruption in centralized energy production (JRC 2022). 'Not only blockchain technology allows for efficient peer-to-peer energy transactions between members, but also with energy operators' (CEO 1). Thus, blockchain technology integration allows for a 'unique local flexibility market platform' (Parity, 2019).

Other applications are interconnected with the previous one, since they co-exist and enable one another. For example, smart metering plays a vital role in enabling a smart grid in energy communities (JRC 2022). It allows to record and transmit real-time electricity consumption and generation data crucial for monitoring and billing purposes. It is the main tool to create interaction between the energy provider and the end user (JRC WP3, 2021). 'It allows to record the transaction, which is very important' (CEO 1). It is considered a core service for any application supported by blockchain technologies since it offers traceability of the energy produced and consumed at each endpoint informing consumers about costs and origins (JRC 2022). 'Certifications of origin are beneficial to the members involved' (CEO 1). It allows for renewable energy traceability and brings transparency to the consumer about the energy origin (JRC WP3, 2021). Not only does DLT provides certifications, but it also provides authentication and verification processes of energy assets such as ownership, green certificates and carbon credits trading (JRC 2022). For a visual representation of European investments in digital infrastructures in the energy sector consult Appendix 5.

Additionally to these representative quotations, the aggregate dimension corresponding to the applications based on the data is presented in Figure 3 to support the data structure.

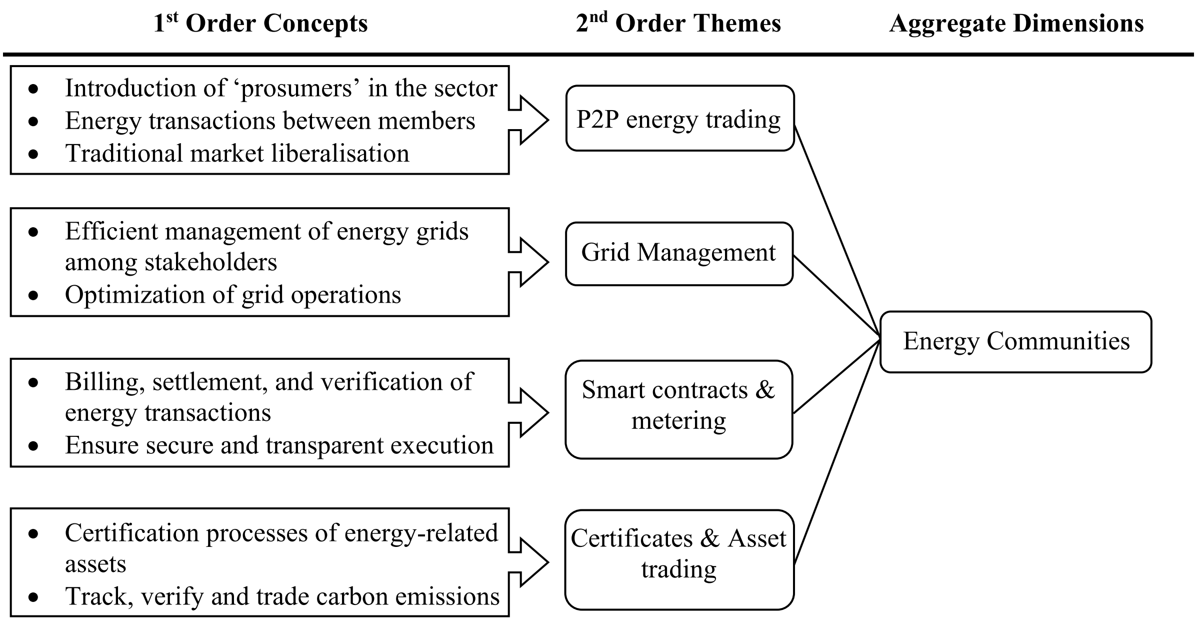


Figure 3 *- Applications data structure*

Benefits:

The benefits and drivers present in the data for the application of decentralized ledger technology in the energy sector can be categorized into four main dimensions. The concepts for the first dimension, the technological benefits, are the following: In the energy sector, digitalization encompasses the utilization of computerized information and the processing of vast volumes of data that are generated at various stages of the energy supply chain. This is crucial to solving issues related to privacy, security, safety and ethical issues in data management (JRC, 2021, Fulli et al). Moreover, it provides opportunities to enhance energy efficiency through the utilization of technologies that collect and analyse data, enabling the implementation of changes in the physical environment. These advancements are heavily associated with blockchain technology (JRC WP3, 2021, Nai Fovino et al). 'Not only it brings benefits for energy trading, but also in asset management through data integration of monitoring devices' (CEO 1). It also helps with the distribution of power generation, interconnection of various sectors, market liberalization and restructuring, and flexibility in both supply and demand (Bright Project, 2020). Advanced grid management technologies also provide optimal grid monitoring, automation and regulation. Aiming to improve the resilience and security of the electricity grid while ensuring reliable system operation (Parity Project, 2019). By introducing unprecedented trust in data, blockchain has the capacity to fundamentally transform the sharing of information and the execution of transactions without the need for a third party. (JRC, 2021, Fulli et al). In this case, it mitigates the dangers of price volatility and supply shortages while enhancing the reliability and effectiveness of electricity provision (Bright Project, 2020). Maintaining system stability within specified thresholds and ensuring uninterrupted and secure energy provision with a real-time balance of supply and demand in a decentralized environment (eDream Project, 2018).

The second dimension is environmental benefits, the concepts found in the data underlines that climate-neutrality targets heavily rely on digital transformation, which is already influencing the design and operation of the energy system (JRC, 2021, Fulli et al). For example, engaging in energy communities increases environmental consciousness (Bright Project, 2020). Digitalization and decentralization have the potential to streamline the integration of intermittent renewable energy sources, aiding in the optimization and synchronization of energy demand with weather predictions (JRC WP3, 2021, Nai Fovino et al). DLT in this sector will help reduce greenhouse gas emissions, promote the deployment of renewable energy (eDream Project, 2018) and ‘maximize local self-consumption’ (CEO 1).

The third dimension analysed is the socio-economic benefits and drivers. The utilization of blockchain technology, which incorporates distributed transaction verification, has the potential to empower individual consumers to engage in seamless power trading and payment transactions (JRC, 2021, Fulli et al). ‘The economic cost-benefit for users is ground-breaking’ (CEO 1). It offers the opportunity to lower energy expenses and explore supplementary income sources. Moreover, it increases awareness among prosumers due to the possibility to monitor ecological and monetary returns (Bright Project, 2020). The flexible pricing structures and innovative approaches help to minimize the financial burdens associated with the shift towards sustainable energy sources (Parity Project, 2019). Ultimately, the applications provide grid independence to individual end-users and encourage customer engagement, fostering community participation in the electricity supply process (eDream Project, 2018).

The last dimension of the data analysis is the institutional benefits. Blockchain possesses characteristics that hold the potential to revolutionize the energy industry by introducing novel grid management techniques and business models that capitalize on decentralization, transparency, integrity, and the removal of intermediaries (JRC, 2021, Fulli et al). It fosters a collaborative and distributed model of governance in the emerging transition that actively engages a network of actors and a range of institutions (Bright Project, 2020). It allows system participants to share information efficiently, reliably and securely (Parity Project, 2019). By implementing blockchain technology in the energy sector, there is an opportunity for significant transformation, leading to decreased operational and transaction expenses. Additionally, it can enhance trust among stakeholders by providing a unified and reliable source of information (JRC, 2021, Fulli et al). The transformative potential lies in its 'capacity to eliminate barriers between energy sectors, enhancing flexibility and enabling seamless integration across the entire system' (CEO 1).

Additionally to these representative quotations, to support the data structure, the four aggregate dimensions corresponding to the benefits and drivers based on the data are presented in Figure 4.

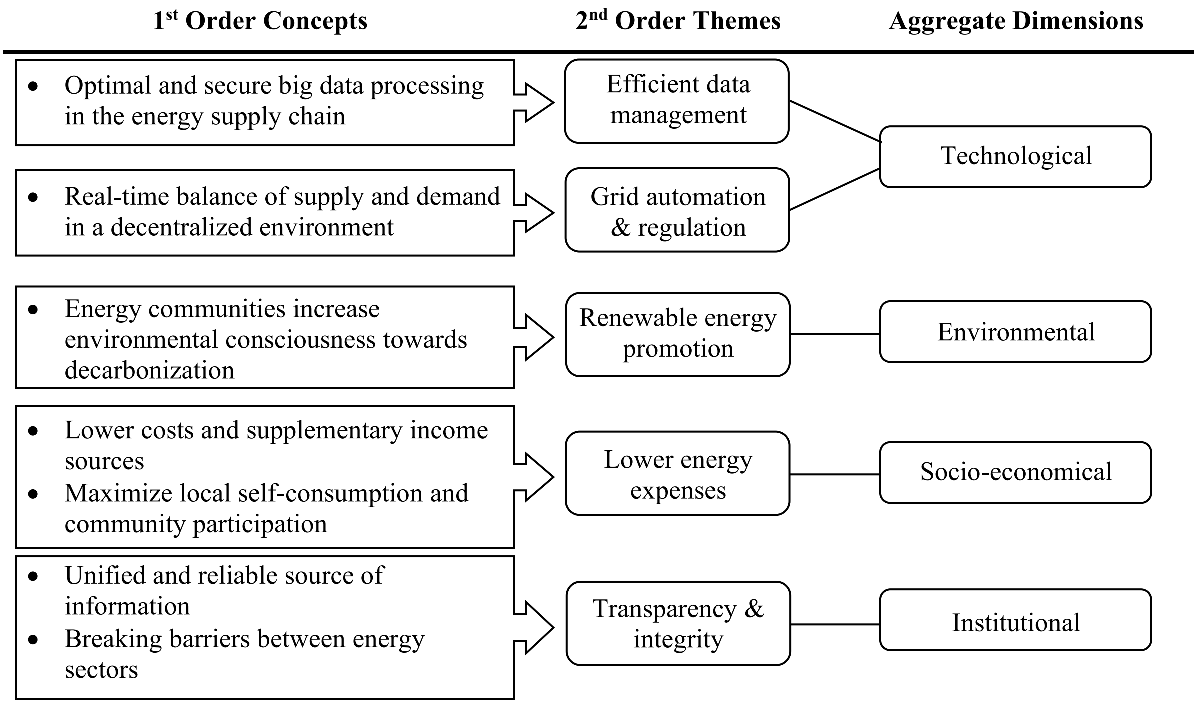


***Figure 4** - Benefits data structure*

Challenges:

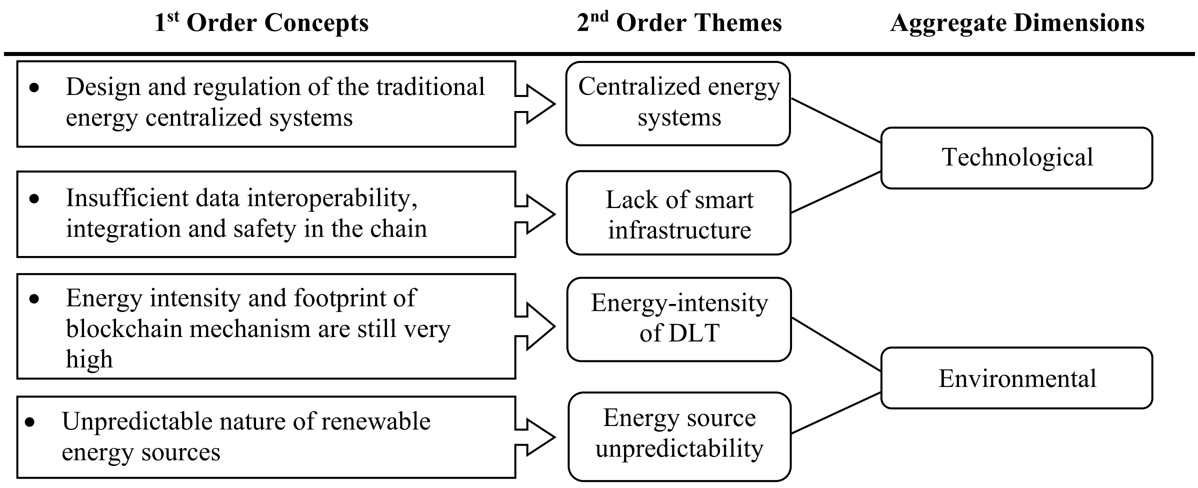
The challenges and barriers present in the data for the application of decentralized ledger technology in the energy sector are also categorized into four main dimensions to provide a cohesive presentation of the results. On the technological barriers and challenges, the data indicate that novel energy management solutions are still maturing both technically and commercially due to the centralized design and regulation of traditional energy systems. Specifically regarding the complexity of data security and cybersecurity (Bright Project, 2020). The evolution of smart grids in recent years highlights the necessity for innovative concepts, particularly for key stakeholders such as aggregators and utilities. For instance, local distribution networks cannot accommodate reverse flows. Thus, stakeholders need to reassess and reimagine their current operational tools and mechanisms (eDream Project, 2018). Optimising these key aspects, such as decentralisation, security and scalability, still poses a big challenge before moving to large-scale applications. The primary reason behind this is the insufficient assurance concerning safety, certification, and standardization, which are the essential prerequisites for operating critical infrastructures (JRC, 2021, Fulli et al). There is a clear insufficient data interoperability, resulting in a lack of data integration in the chain and unclear data ownership (CINEA, 2022, Alpagut et al). ‘ The lack of know-how on the blockchain technology presents a great challenge both internally and externally’ (CEO 1). Many users perceive the use of intelligent systems as a technological barrier, resulting in a lack of trust in the energy community concept. Hence, it is essential to emphasize the tangible advantages of implementing cutting-edge technologies in the energy sector, specifically targeting energy communities (JRC WP3, 2021).

The environmental dimension data showcases that consumers are still not yet fully engaged with digital energy initiatives such as decentralized energy production (JRC, 2021, Fulli et al). Also described as general ‘energy illiteracy’ (CEO 1). For a successful implementation and usage of this technology, there is a need for advanced metering physical infrastructure implementation to foster consumer engagement and technical feasibility (Bright Project, 2020). Moreover, the energy intensity and footprint of blockchain use are not significantly different compared to current methods. (JRC, 2021, Fulli et al). Lastly, the most challenging to deal with is the unpredictable nature of renewable energy sources. That represents significant difficulties in managing the grid across various levels, including distribution, transmission, and generation (Parity Project, 2019).

In the socio-economic dimension, consumer-related issues such as trust, acceptance and reliability of applications, may compromise their participation in energy communities and energy trading. The potential monetary incentives might not outweigh the effort, time and risk perceived by the consumer (Bright Project, 2020). Furthermore, the financial cost associated with acquiring and installing the necessary equipment to become a prosumer might be considered too high when weighed against the promised advantages, creating a significant obstacle for most individuals (JRC WP3, 2021). The users can have a lack of trust in the energy community infrastructure and actors in general, usually paired with hesitations towards the technology due to its complexity (JRC, 2021, Fulli et al). There is also a 'high level of end-user dependency on traditional energy operators' (CEO 1).

The institutional dimension data revealed that one of the key dilemmas faced by policy decision-makers is finding the right equilibrium between fostering innovation, safeguarding consumer interests, and maintaining market integrity (JRC, 2021, Fulli et al). 'There is resistance to consumer independence on energy production from current energy providers because it ultimately translates in losing market share' (CEO 1). In addition, blockchain-based applications in this sector are still in their infancy (eDream Project, 2018). The real benefits of energy communities are mostly assumptions as they are not extensively validated in practice yet (Bright project, 2020). 'It is important to look over the buzz of blockchain technology to truly understand its challenges' (CEO 1) because there is a lack of knowledge on potential revenue streams and business models applied to this technology (Bright Project, 2020).

Additionally to these representative quotations, to support the data structure, the four aggregate dimensions corresponding to the challenges and barriers are presented in Figure 5.



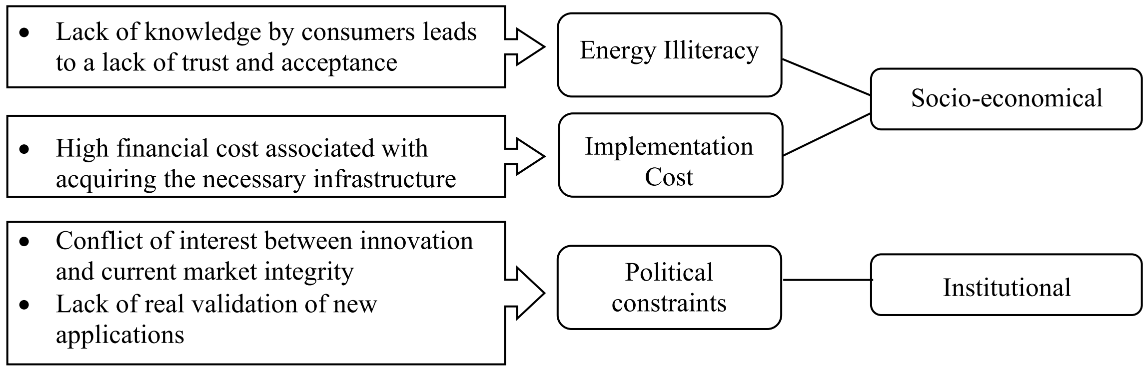


Figure 5 *- Challenges data structure*

Value Creation and Value Capture for BMI:

In this dimension, the results of the data collected represent how business models change and innovate regarding blockchain technology applications in the energy sector. Two main dimensions were considered to explain these changes, how value is created and subsequently how value is captured.

For the value creation dimension results, blockchain has been proven to be a versatile tool that can facilitate data-driven decision-making in the fields of climate neutrality and energy. For instance, blockchain technology can be utilized to support carbon credit, as well as empower citizens to participate in the production and sale of clean energy within markets (JRC, 2021, Fulli et al). To 'provide access to renewable energy locally produced to all' (CEO 1). In this environment, for value creation, key issues need to be addressed related to business development. Such as the level of privacy, decentralization and security of applications (JRC WP4, 2021). The technology provides a multi-objective framework to enable the cross-sector value-stacking of various services. This approach aims to enhance system stability and promote the seamless integration of renewable energy sources (Bright Project, 2020). By transcending conventional grid management practices, it is possible to revolutionize the energy landscape with a distinctive local flexibility market platform. This type of platform seamlessly integrates IoT and blockchain technologies to enable automated transaction exchange. Resulting in lower energy costs and reduced energy consumption and carbon footprint (Parity Project, 2019). In addition to 'long-term stability of energy provision' (CEO 1). Innovative decentralized and community-driven energy systems that fully utilize local capabilities need to present cutting-edge and user-centric solutions to foster engagement (eDream Project, 2018). This approach not only alleviates congestion within power grids but also strengthens the resilience of local communities. By eliminating obstacles for new independent producers, and enabling participants to directly access market data generated by themselves (Enerchain, 2019). Ultimately the goal is the ‘democratization of local renewable energy production and consumption’ (CEO 1) and deploying blockchain as the distributed driving brain of energy communities (JRC, 2021, Fulli et al).

In the value capture dimension, for a successful business model innovation and implementation of strategies and instruments within energy services, peer-to-peer trading, and energy communities, it is essential to identify their specific requirements and devise tailored design and evaluation approaches. This process involves considering the needs and behaviours of community members, going beyond mere economic incentives. By actively engaging with these communities, we can develop comprehensive methods that address their unique dynamics and foster their participation in shaping the energy landscape (Bright Project, 2020). A business model that has decentralized control and empowers consumers presents difficulties in managing disputes and control strategies (JRC WP4, 2021). There is a clear need for the definition, elaboration and validation of innovative business models to facilitate the exchange and capture of value among local market actors (Parity Project, 2019). This is facilitated by decentralized intelligence and autonomous learning capabilities, guided by the cost-responsive signals from the blockchain-based market platform (Enerchain, 2019). A competitive marketplace for digital energy services that safeguard data privacy and sovereignty, while fostering investments in digital energy infrastructure (JRC, 2021, Fulli et al). With this ‘prosumers can benefit from the assets’ financial return, create an additional source of passive income, reduce their own energy cost by 30-40% and take part in the upcoming energy transition’ (CEO 1).

Additionally to these representative quotations, to support the data structure, the two aggregate dimensions corresponding to the value creation and value capture based on the data are presented in Figure 6.

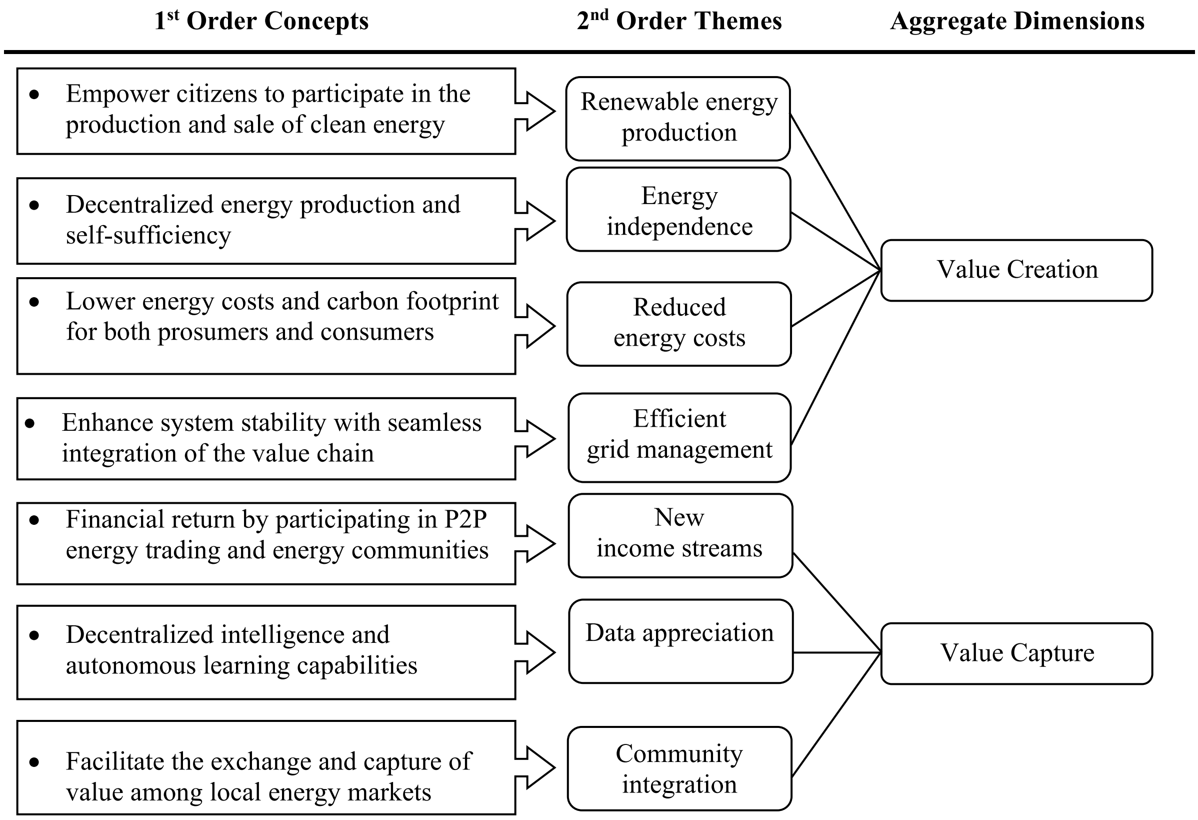


Figure 6 *- Value Creation and Value Capture Data structure*

5. Discussion and Conclusion

5.1. General overview of the findings of data analysis

The findings from both primary and secondary data collection, which include the case study and pilot project reports respectively, present that the recent implementation of blockchain technology in the energy sector essentially translates into energy communities and sub-applications associated with it. Such as P2P energy trading, grid management, smart contracts and asset trading. Moreover, the benefits associated with this implementation are due to efficient, secure, transparent and automated data processing and generation. Such innovative implementations bring challenges of implementation and compatibility to existing systems and users. A decentralized approach like this one brings new and transformative business model opportunities. Where value creation and capture are assured by an active and fundamental role of the end-user in the business cycle.

5.2. Discussion of the results

Blockchain-based applications in the energy sector have gained significant attention due to their potential to revolutionize the way energy is generated, distributed, and traded. This is due to the vast digitalization process this sector is undergoing with the integration of digital technologies and innovative solutions to transform and optimize various aspects of the energy industry. The theoretical discussion and ongoing research present multiple opportunities and applications for decentralized ledger technologies in this area as presented by Wang et al (2022) and Andoni et al (2019). Which are in line with the results obtained in this thesis. However, some of the applications presented in the literature are still on a high conceptual and theoretical level, due to the novelty of this technology, they are not implemented yet in real-life scenarios at considerable scales. The current and most common application of blockchain in the energy sector is in local energy communities and all sub-applications adjacent to it. Such as energy and asset trading, grid management and smart contracts that allow for local energy communities to be successfully implemented as also mentioned by Zheng et al (2018). The growing phenomenon of decentralized and autonomous energy production in microgrids requires complex big data management and integration where blockchain acts as a viable solution. Blockchain technology is well-suited for energy communities due to its decentralized nature, transparency, and ability to enable peer-to-peer energy trading. It provides trust and immutability to energy transactions, ensuring the integrity of data. With blockchain, community members can directly trade energy with each other, eliminating the need for intermediaries. Local energy communities are thriving and growing mostly due to increasing environmental concerns and a shift towards decentralized and independent renewable energy production. Results show and underline high institutional and governmental influence and involvement in this transition in comparison to the literature since a lot of public and private financial resources are being allocated towards the energy transition. A disruptive change was imminent in this sector whether on an institutional or individual (prosumer) level since traditional energy markets are centralized, monopolistic and highly inflexible. In summary, blockchain applications and implementation are heavily influenced by market interests and needs, political initiatives, funding and investments, start-ups and trial initiatives. In this case, blockchain is vital for the shift this sector is experiencing since it empowers local energy communities by facilitating self-governance, efficient data management and accelerating the transition to sustainable energy systems.

From all the dimensions approached in this research, the drivers for blockchain integration in this sector are the most theoretically explored concepts in the literature that are closely demonstrated in the results obtained. This dimension allows us to understand why blockchain technology is showcasing such potential and versatility across different applications. The digitalization of this sector implies communication and data transmission between smart grids and monitoring devices for efficient management over decentralized energy systems as mentioned by Burger et al (2016). DLT provides a secure and transparent platform for recording and verifying these energy transactions. The decentralized nature of blockchain eliminates the need for intermediaries, reducing costs and increasing efficiency. It improves the reliability and security of energy systems. Additionally, blockchain's transparent and immutable ledger ensures the integrity of energy data and transactions, enhancing trust and accountability in the energy sector. In sum, blockchain technical characteristics answer a lot of the concerns faced in the energy transition. Hence it is so associated. These benefits have the potential to transform the industry and drive the transition towards a more sustainable, efficient and decentralized energy future.

Regarding the challenges of implementation, the literature has a strong technical component in comparison with the results collection. There is a high theoretical focus on technological barriers. For example, scalability issues regarding the systems' capability of handling and processing transactions in a timely manner as the number of transactions and participants increases as described by Ahl et al (2022). On the other hand, challenges related to regulatory, institutional and complexity as presented by Botticelli et al (2020) are not sufficiently contextualized and perceptive of real implications. The results obtained emphasise the difficulty of change regarding the energy transition on a more socio-economical and institutional dimension. The already established energy supply market usually linked to governmental entities presents the major obstacle to this transition. There are incumbent interests regarding the current market structure opposing innovation. Data privacy, policy complexity and ambiguity are also commonly mentioned challenges. And the lack of real validation of new applications does not play in favour. Moreover, infrastructures are not ready for this type of innovation and digitalization implying high financial costs. On the social spectrum, the lack of consumer and institutional knowledge of blockchain, is a concern for organizations, since it increases risk aversion. In essence, even though blockchain is not a universal solution for this energy transition, most of the challenges found in the results are external to the technical capacity. In overcoming these challenges, collaboration among stakeholders, including industry players, regulators, and technology providers, is essential.

This brings us to the last dimension of results that ultimately answer the research questions proposed for this thesis. Recalling the first research question, that seeks to answer how blockchain technology can be used to create and capture value from data. This can be achieved by: (1) Data provenance and transparency: Blockchain can be utilized to track and verify the origin and characteristics of energy sources throughout the supply chain. By recording information related to energy generation, distribution, and consumption on the blockchain, stakeholders can ensure transparency, traceability, and accountability. Via recording energy transactions, blockchain allows for secure and verifiable peer-to-peer energy trading. This creates value by facilitating the efficient utilization of distributed energy resources, promoting renewable energy integration, and enabling prosumers to monetize their excess energy production. (2) Data monetization and tokenization: Blockchain allows for the creation of digital tokens that represent ownership or access rights to data. Tokenization allows energy-related assets, such as renewable energy generation capacity, green certificates, or carbon credits, to be represented as digital tokens on a blockchain. These tokens can be bought, sold, or traded among participants in the energy ecosystem. (3) Data Sharing and collaboration: Blockchain technology can enhance grid management and system operations by providing real-time data visibility, traceability, and automation. By securely recording and sharing grid data, such as meter readings, energy flows, and system status, blockchain enables better coordination and optimization of grid operations. This improves the reliability, efficiency, and resilience of the energy system, creating value by reducing costs, minimizing downtime, and facilitating the integration of renewable energy sources.

Recalling the second research question, that seeks to understand the new BM's applied in Web 3.0 and blockchain-based environments. New business models in this sector are directly associated with the previous value creation and capture this technology can generate from data. A pivotal point in this sector specifically is the appearance of the prosumer which brings significant changes to the industry environment. Consumers are now also energy producers changing the dynamics of the business itself and generating new business models associated with this phenomenon. These new models leverage the decentralized nature of blockchain to create innovative solutions unprecedented to this sector. As literature supports the observed results, Hamwi and Lizarralde (2017), new business models are in place. Ownership of electricity generation can now lie with the customer, third parties can provide services to clients, or community members can share resources both physically and digitally in energy communities. This empowers new value propositions for new business models. Such as (1) P2P energy trading: energy trading platforms where individuals and businesses can directly buy and sell energy without intermediaries. Producers can sell excess energy to consumers in real time, fostering a decentralized energy market and promoting renewable energy generation. (2) Tokenized Energy Assets: Blockchain enables the creation and trading of carbon credits and emission allowances in a transparent and auditable manner. Incentivizing emission reductions and promoting sustainability. (3) Grid Management and Optimization: Blockchain-based solutions can optimize grid management by facilitating real-time energy balancing, demand response, and grid stability. Smart contracts on the blockchain can automate energy transactions and grid operations. (4) Energy Traceability and Certification: Blockchain can be used to track the origin and certification of renewable energy generation. It provides a tamper-proof record of energy production, ensuring transparency and trust in renewable energy claims.

5.3. Theoretical contributions

This research's main theoretical contribution is the real-life insights provided by the conducted case study and pilot project analysis on blockchain technology implementation in local energy communities. These contributions were based on a thorough review and analysis of existing literature to advance the knowledge and understanding of the mentioned topic.

Also, the development of several conceptual frameworks that synthesizes and organizes existing research and concepts in a novel way. These frameworks can provide a comprehensive and structured understanding of existing literature on blockchain implementation in the energy sector. The same was done for the empirical research performed.

These contributions help advance the theoretical understanding of decentralized ledger technologies in the energy transition by providing empirical evidence and insights that can inform future research and practices.

5.4.Managerial implications

As a consequence of the energy transition transfiguration on the traditional value chain and ecosystem of the energy sector, several managerial implications are worth underlining.

The conventional vertical value chain of the energy sector as presented in section 2.1.1., presents consumers and producers as independent actors on extreme and opposite points. Managing supply and demand in this scenario implies different approaches, meaning upscale and downscale interactions. With the creation of the prosumer, as mentioned before, this value chain now represents a decentralized close cycle where production and consumption may be coincidental. Communication and management approaches may no longer work on a vertical system, since now the ecosystem presents itself as an integrated and decentralized sector. Managers need to follow closely the lack of knowledge and possible risk aversion to this new business model for both producers, consumers and prosumers.

5.5. Research limitations

The theoretical research limitations in this study include the novelty of the topic. Blockchain is a fairly recent topic, and its application to the energy sector is even more. Meaning that this topic still doesn't have much theoretical foundation, especially regarding case studies and literature with compelling real-world implications. Blockchain technology is still emerging and has not yet gained widespread acceptance. Due to the limited number of adopters, there is a scarcity of conclusive evidence regarding the profitability potential of these platforms and their contribution to the ongoing expansion of the sector.

In terms of empirical research limitations, there are still very few companies and start-ups in the world implementing blockchain technology in the energy sector. Since is a very specific, recent and emerging topic. And lastly, the lack of response and availability of these companies for interviews concerning this research.

5.6.Future directions

Recommendations on future direction aim to cover the research gaps and limitations presented. There is still a need for further theoretical development in this area. Especially in regulatory and legal implications, integration of blockchain with other emerging technologies (e.g. artificial intelligence), user acceptance and adoption of blockchain in the energy sector, and cost-effectiveness of blockchain in the energy sector. Furthermore, it would be useful to focus on qualitative and quantitative data to try to obtain empirical evidence to test concept theories.

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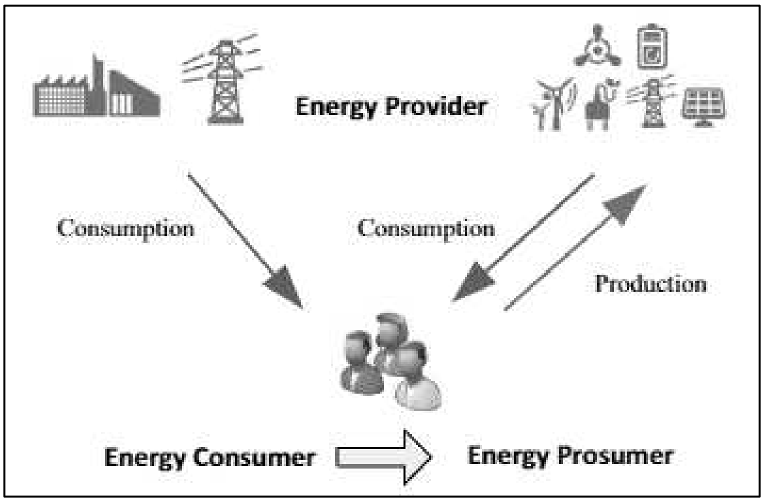
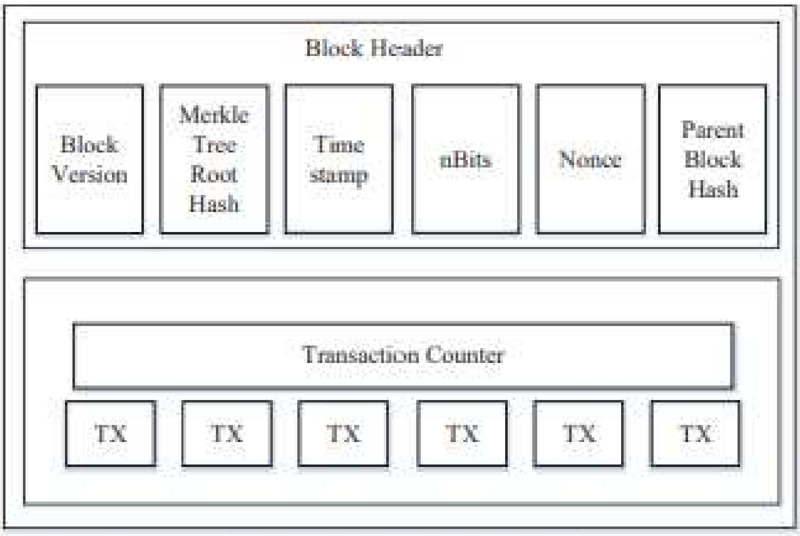
Appendix

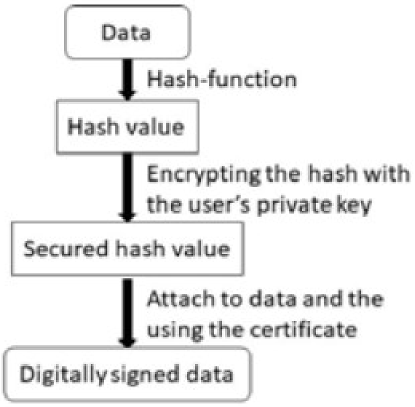
Appendix 1 – Energy Prosumer (Zhou, Yang & Shao, 2016)



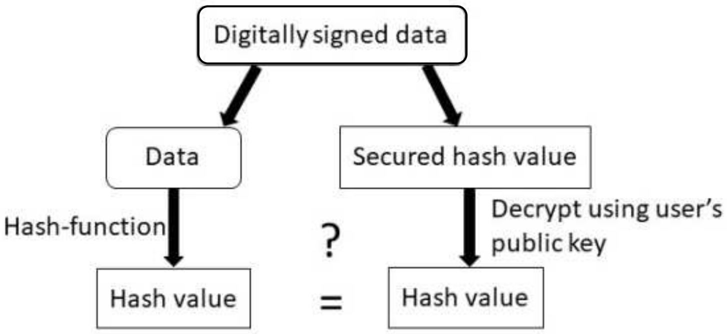
Appendix 2 – Block Structure (Zheng, Xie, Dai, Chen, & Wang, 2017)



Appendix 3 – The signing process in the Blockchain. (Golosova & Romanovs, 2018)



Appendix 4 – The verification process in the Blockchain. (Golosova & Romanovs, 2018)



Appendix 5 – Investments in digital electricity infrastructure and software, source: EC