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USING BLOCKCHAIN AND ARTIFICIAL INTELLIGENCE IN ENERGY MANAGEMENT AS A TOOL TO ACHIEVE ENERGY EFFICIENCY

Aleksandra Kuzior, Mariya Sira, and Paulina Brozek

Abstract. Improving energy management has received a lot of attention due to environmental issues, energy crises, and growing energy prices in today's world. Various digital technologies have been developed to enhance energy management to cover these challenges. This article investigates Blockchain and Artificial Intelligence, which have recently attracted increasing attention. The study applies the software of VOSviewer for providing bibliometric analysis. The data (pull of the scientific documents) was generated from the Scopus and Web of Science. There have been done a critical analysis of the literature for evaluating the research in the proposed area. This paper focuses on possible use cases of blockchain and artificial intelligence technologies and considers aspects of technology used to achieve energy efficiency. The findings showed that the technologies are widely applied in energy management. Besides, it is lack of documents that contain the terms 'energy efficiency and 'blockchain'. The results of analysis confirm that artificial intelligence has been rapidly integrating with energy management, helping to develop more efficient and secure energy generation techniques.

Keywords: blockchain, artificial intelligence, energy management, energy efficiency

JEL Classification: Q4, O33

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1. Introduction

Energy management is a range of activities to ensure the efficient use of energy in an organization. Energy management has turned out to be essential for organizations aiming to reduce energy costs, improve their public image, pursue a sustainable way of doing business and comply with legal requirements. Although some energy management standards and guidelines have been introduced, organisations continue to face significant challenges in implementing energy management. Companies can expand by forming working groups and committees to develop rules and a related framework for energy technology transfer would be an added benefit in delivering results in energy management. These practices include energy monitoring and measurement, establishment of the unit use standards, assignment of responsibilities, taking people on board through effective communication within the realm of society and, above all, recognising the efforts of personnel who strive and achieve energy goals (EL-Shimy, 2018). Consistent energy management helps to increase the efficient use of power in an organisation. To improve energy efficiency over the long term, an organisation needs an energy policy that extends across the organisation. Besides managerial aspects of energy management, an energy manager must have a good understanding of the technical factors as well to define a successful energy program; an energy manager must have a good understanding of both technical and managerial aspects of energy management (Awan et. al., 2014; Miśkiewicz et al., 2021). Companies constrained by external forces, such as higher energy prices and irregular energy supplies, were motivated to adopt energy-efficient technologies (Parekh et. al., 2022; Karpenko et al., 2018). Some of the key drivers to the adoption of energy-efficient methods are the long-term benefits of energy-efficient technologies. The studies on the energy efficiency gap have, to a great extent, revolved around the distribution of energy-efficient technologies. However, there is a considerable emphasis on the fact that the total efficiency potential can be achieved through investments in technology only jointly with maintenance and ongoing monitoring (Backlund et.al., 2012; Lyulyov et al., 2021; Kuzior & Staszek, 2021; Makieła et. al., 2022, Kuzior et al., 2022, Vasylieva et al., 2021; Samusevych et. al. 2021; Kuzior et. al., 2021). Particularly in the industrial sector, the compound of proven energy efficiency technology investments with continuous energy management practices in industrial installations is a cost-effective way to improve energy efficiency (Gonçalves & Mil-Homens, 2019).

Consequently, a contribution to the study has been identified. The paper focuses on blockchain and artificial intelligence as innovations adopted in energy management. Therefore, the article fulfils the objectives as follows. Firstly, there is provided an overview of the literature on the research area, and there are analysed a number of documents in which an explored keyword occurs and its place in the network. Secondly, the paper aims at examining the feasible use cases of technologies application. Furthermore, the paper addresses the existing use cases Semisexy to point out their energy efficiency.

2. Methods

This section presents the methodological approach which sustains the theoretical framework. A critical analysis of the literature on the research problem related to how disruptive technologies such as blockchain and artificial intelligence in energy management affect energy efficiency. VOSviewer provides an easy formation and visualization of bibliometric maps. This method allows the efficient collection of the literature and establishing the interrelationships between selected publications within the options. A co-occurrence map creation with all keywords as a unit is applied to achieve a network visualization.

Publications data related to the research has been collected using such terms as 'energy efficiency', 'blockchain' and 'artificial intelligence' and combinations of 'energy efficiency' and 'blockchain' as well as 'blockchain' and 'artificial intelligence' as search parameters limited to the keyword 'energy management'. The results that meet the criteria mentioned have been exported from Scopus in a CSV format and from the Web of Science (WoS) in a TXT format to be processed using VOSviewer to visualize maps. It bears noting that only publications of the type articles with final publication status in English and in open access have been selected. Thesaurus files have been used to perform data cleaning when creating a map. The files have been used to merge terms, for instance, to merge synonyms, abbreviated terms with full terms and singular and plural forms of a keyword. The minimum number of occurrences has been selected in such a way that the threshold within the range has been up to 100. The option of fractionalization has been applied to the analysis tab. This means that the fractionalization method is used for normalizing the strength of the links among items (Eck & Waltman, 2022).

3. Literature Review

Energy efficiency continues to be an area of interest for researchers, particularly due to the following two reasons but is not limited to them. Firstly, Sustainable Development Goal 7.3 target expects global progress on energy efficiency by doubling the rate of improvement in energy efficiency globally by 2030 (United Nations, n.d.). Secondly, there is the Net Zero Emissions by 2050 Scenario (NZE), released by the International Energy Agency (IEA, n.d.-b). This is a normative IEA scenario that shows a narrow but achievable pathway for the global energy sector to achieve net zero CO_2 emissions by 2050 (Sadamori & Motherway, 2021). Therefore, energy efficiency continues to attract attention as a key resource for economic and social development in all economies. The multipurpose approach of energy efficiency policy aims at broadening the perspective of energy efficiency beyond traditional measures to reduce energy demand and greenhouse gas emissions. What is more, the energy sector is changing rapidly as technologies emerge. Such questions as how artificial intelligence and blockchain can contribute to the energy industry and improve energy efficiency are still being investigated.

There are analysed a number of documents in which an explored keyword occurs and its place in the network. For the purpose of this analysis, there were exported Scopus and WoS files received through the search of such combinations as 'energy efficiency', 'artificial intelligence', 'blockchain', 'artificial intelligence' and 'blockchain', 'energy efficiency' and 'blockchain' according to queries mentioned in the section "Methods". The result of a network visualization for 'energy efficiency' obtained from VOSviewer on the base of Scopus files is shown in Figure 1.

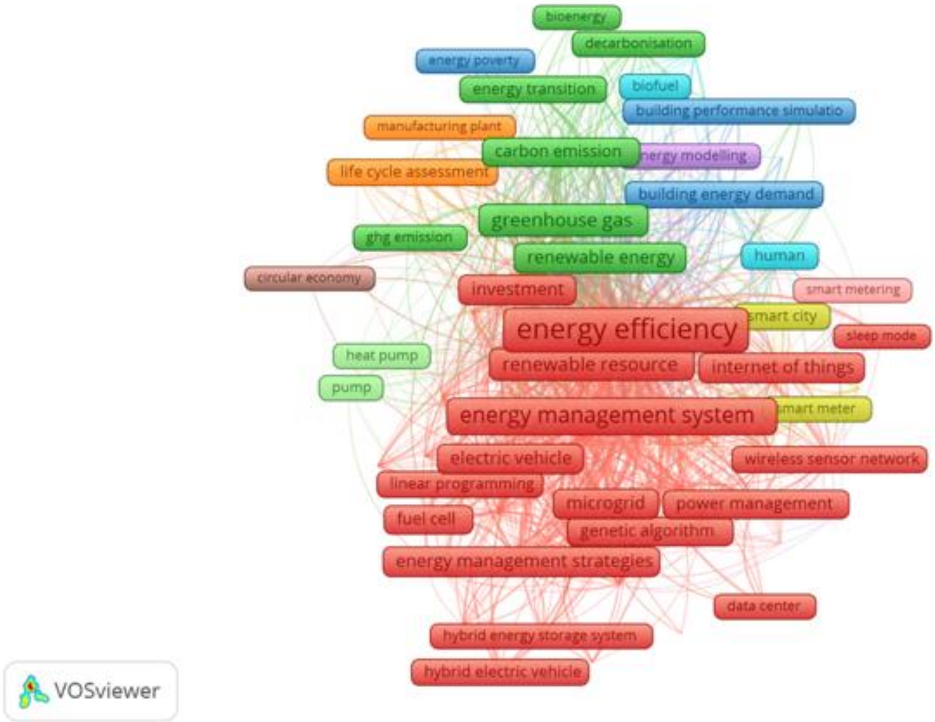

Figure 1. A network visualization of data for 'energy efficiency' query from the Scopus database

The minimum number of occurrences of a keyword is 7. Therefore, of the 13,592 keywords, 82 meet the threshold. The program selects keywords with the greatest total link strength of 82 chosen keywords. It is obvious that the 'energy efficiency' label is the biggest one. It means that its occurrence rate is the highest. It is 1,067. This phrase also has links with at least one keyword in each cluster. Its greatest total link strength is 831, being the highest one among others. This combination is followed by 'energy management system' with an occurrence rate of 380 and total link strength of 363.

Figure 2 represents a network visualization obtained from VOSviewer on the base of WoS files. The parameter for creating this map is the minimum number of occurrences of a keyword of 2. Accordingly, of the 1044 keywords 58 meet the threshold. Of 58 keywords those with the greatest total link strength are selected. A combination 'energy efficiency' occurs in 139 documents and has 296 links with other items as well as a total link strength of 554. This combination has the highest rate of occurrence and total link strength among other items from all 8 represented clusters. For instance, the second biggest item is 'optimization' with an occurrence of 55 and a total link strength of 117.

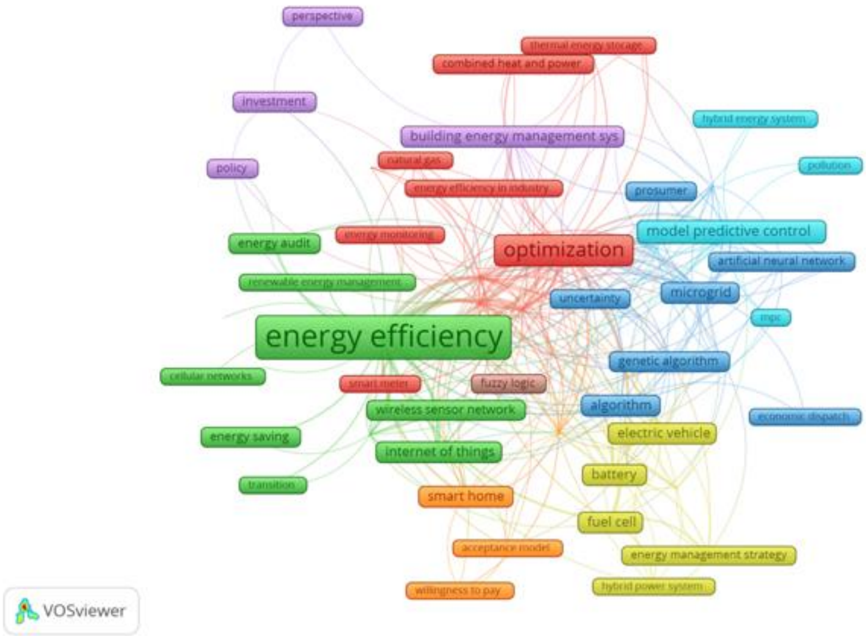

Figure 2. A network visualization of the data for 'energy efficiency' query from the WoS database

Figure 3 stands for a network visualization of the data for the 'artificial intelligence' query from the Scopus database. The criteria for creating a map on the base of exported files is the minimum number of occurrences of a keyword of 5. Accordingly, of 5,924 keywords, 30 meet the threshold.

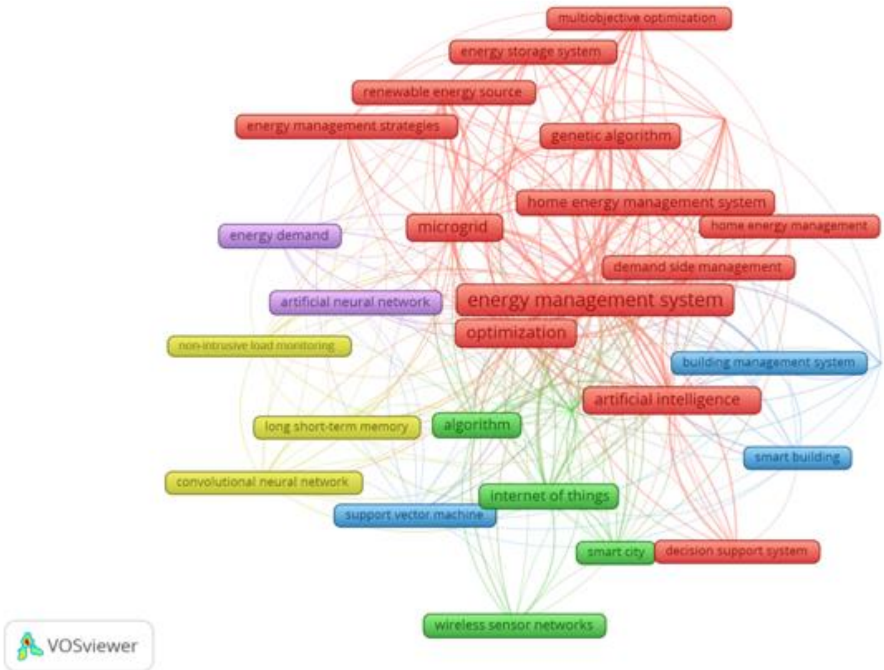

Figure 3. A network visualization of the data for 'artificial intelligence' query from the Scopus database

The result of Figure 3 leads to the following conclusions. ‘Artificial intelligence is the fifth item on the list of items with the biggest occurrence. It belongs to the first red cluster as the four keywords above on the list. It has 65 occurrences and 136 links with other items. The combinations have at least one link with another keyword in each of the 4 other clusters.

Figure 4 presents a network visualization of the data for ‘artificial intelligence’ obtained from VOSviewer on the base of Scopus files. The minimum number of occurrences of a keyword is 2. Therefore, of the 66 keywords 82 meet the threshold. ‘Artificial intelligence’ represents the biggest frame in Figure 4 with occurrences of 34 and total link strength of 97.

Figure 4. A network visualization of the data for ‘artificial intelligence’ query from the WoS database.

The result of a network visualization for ’blockchain’ obtained from VOSviewer on the base of Scopus files is shown in Figure 5. The indicator of the minimum number of occurrences of a keyword is 3. Therefore, of the 1258 keywords, 68 meet the threshold. ‘Blockchain’ stands for the fourth yellow cluster. Clusters are ranked based on the number of items included in a cluster. There are 6 items in the yellow cluster in which ‘blockchain’ represents the biggest frame. The explored item occurs in 17 documents and its total link strength with other items is 64.

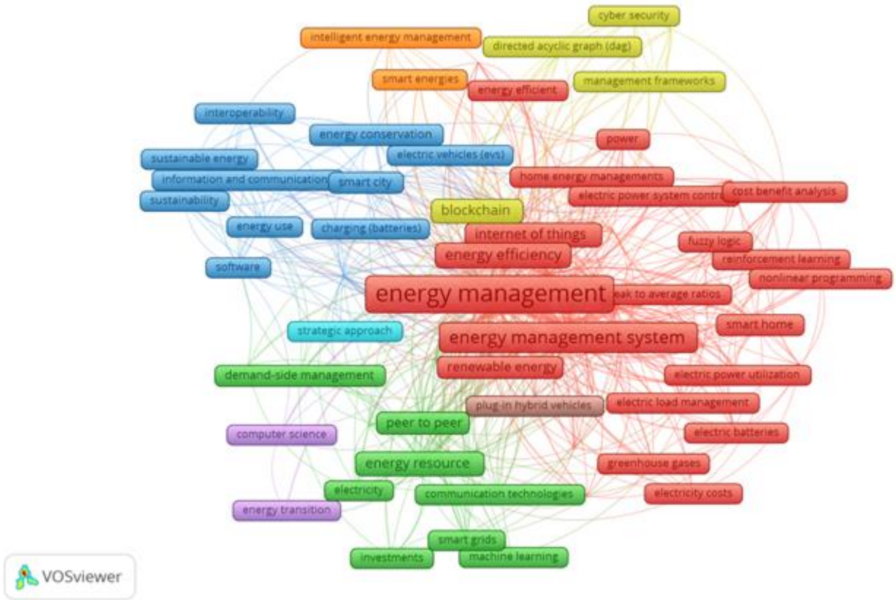

Figure 5. A network visualization of the data for a 'blockchain' query from the Scopus database.

Figure 6 represents a network visualization of the data for the 'blockchain' query from the WoS database.

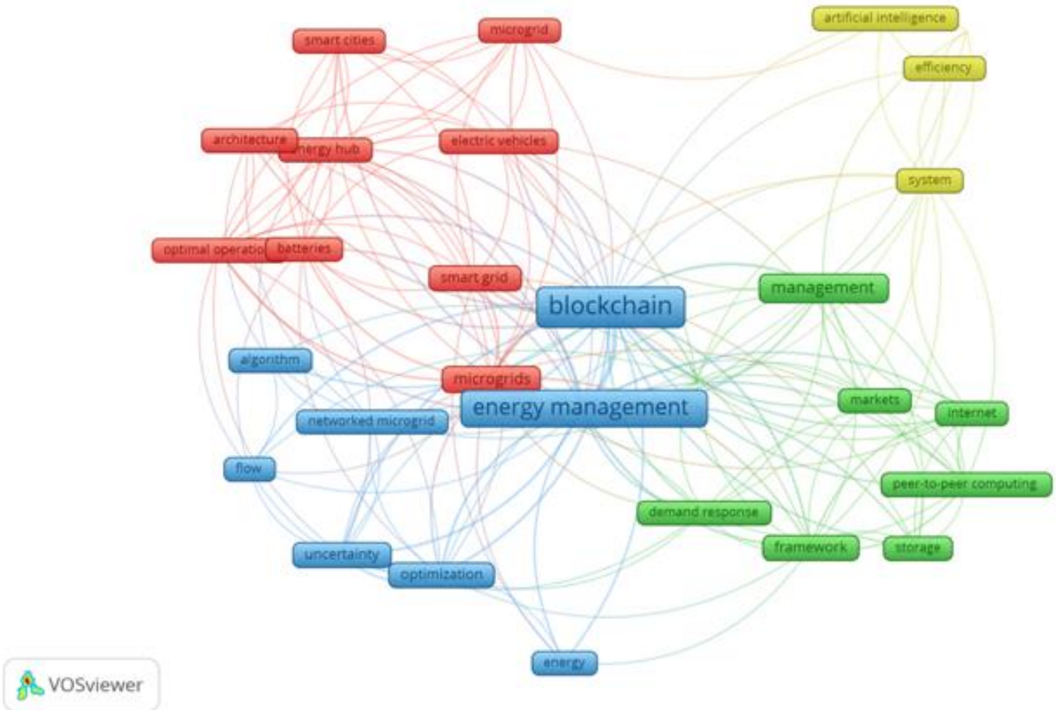

Figure 6. A network visualization of the data for a 'blockchain' query from the WoS database.

The indicator for creating a map on the base of exported files is the minimum number of occurrences of a keyword. It is 5 documents. Therefore, of the 181 keywords 29 meet the threshold. 'Blockchain' is included in a third yellow cluster being the biggest item of 8 items in this cluster as it occurs in 16 documents with a total link strength of 68.

Figure 7 represents a network visualization of the data for the 'energy efficiency' and 'blockchain' query from the Scopus database. In Figure 7 'energy efficiency' responds to the biggest frame. It has 21 occurrences and total link strength of 69. The third blue cluster includes the item. 'Energy efficiency' is the first item on the list from the ones with the highest occurrences while 'blockchain' is the fifth. 'Blockchain' is involved in the fifth violet cluster. It occurs in 6 documents and its total link strength is 17. A relative location near each other demonstrates the relatedness of the keywords in terms of occurrence.

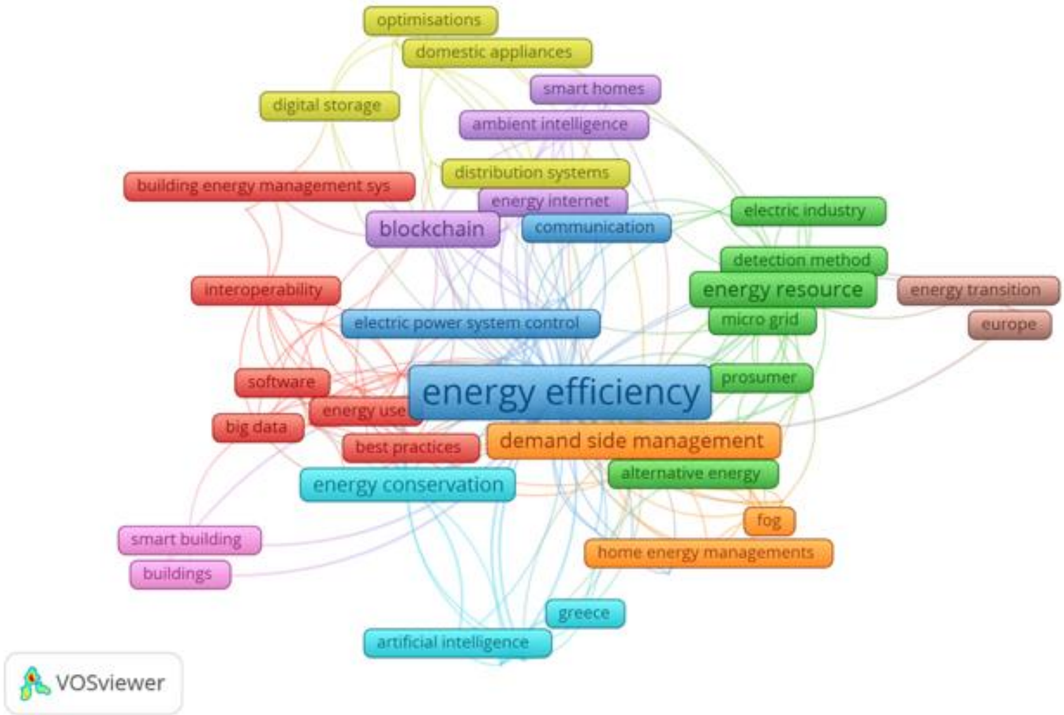

Figure 7. A network visualization of the data for 'energy efficiency' and 'blockchain' query from the Scopus database.

Figure 8 depicts a network visualization of the data for 'energy efficiency' and 'blockchain' obtained from VOSviewer on the base of WoS files. The minimum number of occurrences of a keyword is 1. The obtained results indicate that all the items have the same indicators of occurrence and the total link strength, 1 and 13 accordingly. It is important to mention that according to the VOSviewer the explored items have not been shown in Figure 8. This means that they have not occurred in the investigated documents.

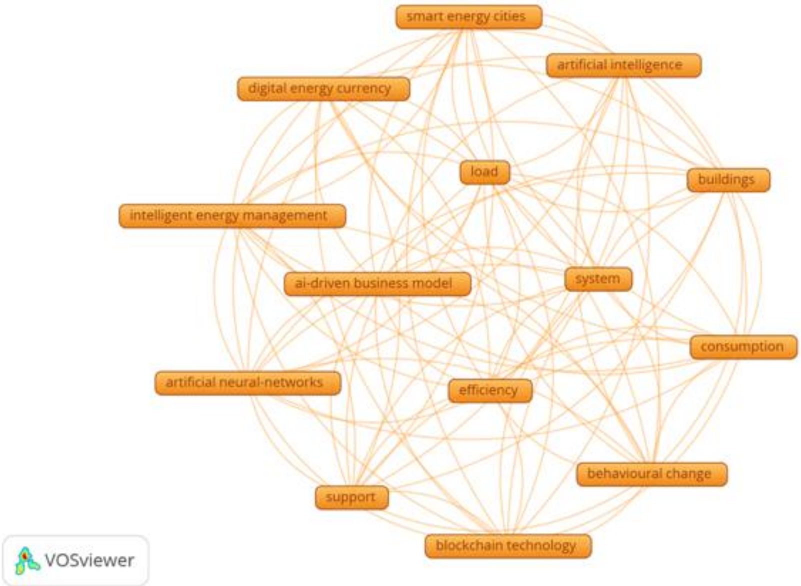

Figure 8. A network visualization of the data for ‘energy efficiency’ and ‘blockchain’ query from the WoS database.

Figure 9 represents a network visualization of the data for the ‘artificial intelligence and ‘blockchain’ query from the Scopus database. The indicator of the minimum number of occurrences of a keyword is 3. Therefore, of the 1,258 keywords 68 meet the threshold. ‘Artificial intelligence’ occurs in 201 documents while ‘blockchain’ occurs in 220 documents. The total link strength of ‘artificial intelligence’ is 484 whereas the total link strength of ‘blockchain’ is 521. As both items closely located to each other, their relatedness is strong.

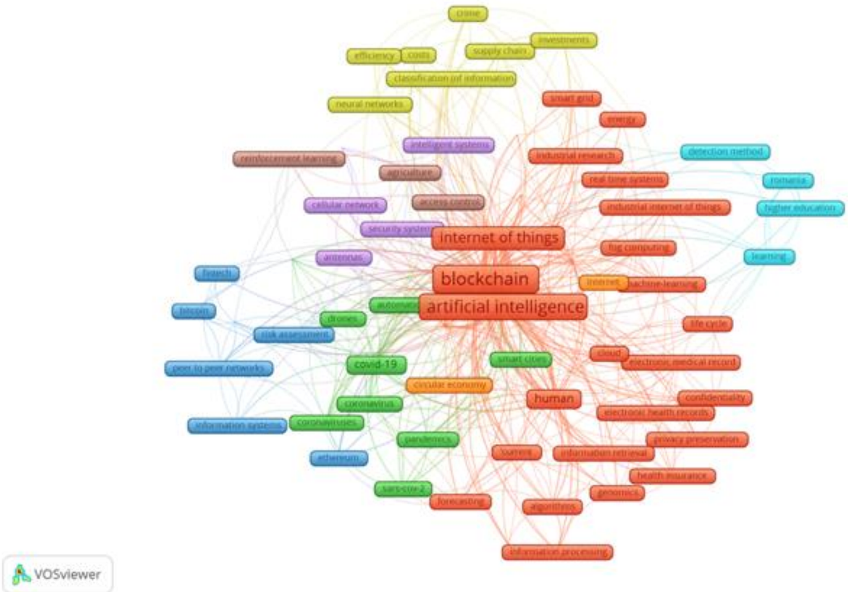

Figure 9. A network visualization of the data for ‘artificial intelligence’ and ‘blockchain’ query from the Scopus database.

Figure 10 represents a network visualization of the data for the ‘artificial intelligence and ‘blockchain’ query from the WoS database. The minimum number of occurrences of a keyword is 1. ‘Artificial intelligence’ occurs in 2 documents while ‘blockchain’ is found in no documents. The total link strength of ‘artificial intelligence’ is 21.

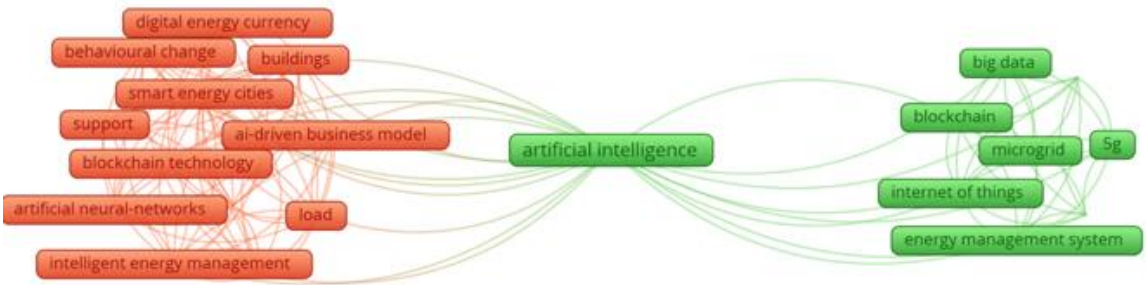

Figure 10. A network visualization of the data for ‘artificial intelligence’ and ‘blockchain’ query from the WoS database.

The summary of the achieved result is presented in Table 1. The comparison of results on base of two databases is demonstrated.

Table 1. Generalization of the conducted analysis.

<table>
<tr><th colspan="2" rowspan="2">Explored combination</th><th colspan="2">If the searched phrase occurs the most among all the keywords</th><th colspan="2">Occurrence</th><th colspan="2">Total link strength</th></tr>
<tr><th>Scopus</th><th>WoS</th><th>Scopus</th><th>WoS</th><th>Scopus</th><th>WoS</th></tr>
<tr><td colspan="2">Energy efficiency</td><td>Yes</td><td>Yes</td><td>1067</td><td>139</td><td>831</td><td>296</td></tr>
<tr><td colspan="2">Artificial intelligence</td><td>No</td><td>Yes</td><td>65</td><td>34</td><td>136</td><td>97</td></tr>
<tr><td colspan="2">Blockchain</td><td>No</td><td>No</td><td>17</td><td>16</td><td>64</td><td>68</td></tr>
<tr><td rowspan="2">Energy efficiency and blockchain</td><td>Energy efficiency</td><td>Yes</td><td>-</td><td>21</td><td>-</td><td>69</td><td>-</td></tr>
<tr><td>Blockchain</td><td>No</td><td>-</td><td>6</td><td>-</td><td>17</td><td>-</td></tr>
<tr><td rowspan="2">Artificial intelligence and blockchain</td><td>Artificial intelligence</td><td>No</td><td>No</td><td>201</td><td>2</td><td>484</td><td>21</td></tr>
<tr><td>Blockchain</td><td>Yes</td><td>-</td><td>220</td><td>-</td><td>521</td><td>-</td></tr>
</table>

Table 1 reflects the results if the searched phrase has high occurrences among other keywords, frequency how often it has occurred and its total link strength that shows its connection with other keywords due to each search query. The high occurrence of ‘energy efficiency’ reflects researchers’ considerable attention devoted to this topic. If ‘artificial intelligence’ and ‘blockchain’ are analysed separately, indicators of ‘artificial intelligence’ prevail. Though when they are both included in the query, occurrences of these keywords are almost equally weighted on the database from the Scopus. When analysing combinations ‘energy efficiency’ and ‘blockchain’ with VOSviewer on the base of files from the WoS we witness no occurrences of these keywords. Whereas their occurrences are relatively low when analysing data from the Scopus. Therefore, it could be stated that there is a gap in the research on this subject.

4. Results

The energy industry is facing a global transformation. Digital technologies stimulate profitability, provide new revenue opportunities, and change business models. Energy management has been persistently facilitated by innovations. Blockchain technology is attracting a lot of interest among scientists (Kuzior and Sira, 2022). Blockchain technology is a form of distributed ledger technology, arranged on a peer-to-peer network where all data are reproduced, shared, and simultaneously circulated across multiple peers (Butijn et al., 2020). This characteristic enables the secure accomplishment of smart contracts over peer-to-peer networks individually from a central authority such as banks, trading platforms or energy companies/utilities (T'Serclaes, 2017; Kwilinski, 2019). In the network, other participants observe transactions accomplished between a provider and a customer. These transactions are stored persistently on a digital ledger. Thus, blockchain is reproduced by every computer on the network. Blockchain promises to meet the challenge and difficulty to manage a power energy system due to its increasingly distributed structure, allowing for trusted collaboration in the absence of a trusted central authority. Therefore, promising applications of blockchain in energy systems include energy commerce, energy management and data synchronization (Chen, 2022). This means that with blockchain, participants can jointly execute and monitor these applications, ensuring that the rules are strictly applied and that data records cannot be handled.

The blockchain use cases in energy management impact different areas: 1) wholesale electricity distribution; 2) peer-to-peer energy trading; 3) electricity data management; 4) utility providers. Blockchain technologies in combination with IoT devices allow consumers to trade and purchase power directly from the grid rather than from retailers. In this way connecting end-users with the grid becomes a key reason why companies proceed to implement blockchain technology in wholesale electricity distribution. Retailers are identified as a driving source of inefficiency in the consumer electricity market as they own very little of the grid infrastructure. Instead, they only deal with the kinds of services that blockchain technology can replace, such as billing and metering usage. Supplementing retailers with a blockchain-based platform has the potential to reduce consumer bills by around 40% (ConsenSys, n.d.). By connecting users directly to the network, Ethereum allows users to buy power from the network at a price they wish. As a result, there is a fairer and more stable energy market with lower electricity costs where micro-transactions of energy can link wholesale and retail markets at a low cost through smart contracts. However, there are still important technical and economic issues as well as central, regulatory aspects to be evaluated for the final decision-making of blockchain application (Dick and Praktiknjo, 2019).

Peer-to-peer energy trading is another well-known use case for deploying blockchain technology. A peer-to-peer energy market is a shared network of individuals who trade and purchase excess energy from other participants. These energy markets are beneficial to the masses because they diminish the control of central authorities, such as wholesale entities.
An example of a blockchain application in the electricity market and trading is Enerchain/PONTON (Merz, n.d.-a; Merz, n.d.-b; Merz, 2020). It is a peer-to-peer local

community with distribution flexibility and wholesale trading. In 2019, Enerchain has been released for live trading, after a successful proof-of concept with 44 European trading companies.

Peer-to-peer energy exchange is one of the latest projects provided in the Case Studies Section in the report "Blockchain Applications in the Energy Sector" prepared by the European Union Blockchain Observatory & Forum (Vlachos, 2022). The government of Uttar Pradesh (UP) introduced blockchain technology to its rooftop solar energy segment (Powerledger, n.d.). The implemented blockchain platform fosters the use and growth of renewable energy on a large scale, without increasing congestion on the network. Blockchain is a digitised, decentralised, distributed ledger recording all energy transactions taking place on a peer-to-peer network. These features assisted the government of India with its ambitious goal of installing 40GW of solar energy on rooftops (Saur News Bureau, 2022).

To study major factors related to peer-to-peer energy exchange on the base of the case study, PESTLE analysis has been applied. It is an analytical tool to assess the impact of existing and future external factors that have the greatest influence on development projects at the macro level (CIPD, 2021). In this work, PESTLE has been used to understand the current trends affecting the environment by focusing on the main drivers for the development of the peer-to-peer energy exchange considering political, economic, social, technological, legal, and environmental aspects. Table 2 presents an overview of the perceived drivers for the case study of peer-to-peer energy exchange from the perspective of PESTLE aspects.

Table 2. Drivers for peer-to-peer energy trading under the PESTLE framework

Political	Economic	Social	Technological	Legal	Environmental
National plan	Providing prosumers more flexibility with price	Improving energy security and sustainability [3]	Blockchain technology [4, 5]	Change of regulatory framework [6]	Reduction of distribution losses
	Electricity tariff [1]	Promoting energy efficiency		Creation of a tariff order [7]	
	Improving the economic welfare of the citizens of UP				
	Energy cost reduction [2]				

Note: [1] The P2P energy market buying price was 43% lower than the retail tariff (Vlachos et al., 2022); [2] Reduced transportation costs and generation capacity costs result in reduced overall electricity supply costs; [3] Better access to affordable energy in non-electrified rural areas; [4] Head end system integrated with the blockchain platform and smart meters (Vlachos et al., 2022); [5] CC&B system developed for this project and nitration of billing system within the blockchain platform (Vlachos et al., 2022); [6] UP is the only state to have amended its regulatory framework to allow controlled trade in energy among peers (P2P) in India (Powerledger Energy Projects, n.d.); [7] Creation of a tariff order that provides a directive to all the utilities in the state of UP to implement P2P energy trading by a regulatory body (Vlachos et al., 2022).

Regarding a political driver, the government can advance peer-to-peer energy trading and influence an industry through national policies. Concerning economic drivers, they refer to the economy and its consequences. As regards social drivers, they relate to the needs of consumers and communities. In relation to a technological driver, they consider technological innovations and their influence on the industry. Legal drivers reflect certain law aspects that affect performance while an environmental driver shows the influence on the environment.

The different kinds of energy data include market prices, marginal costs, energy law compliance and fuel prices. Blockchain can provide consumers with greater efficiency and control over their energy sources. Furthermore, an immutable register provides secure, real-time updates of energy consumption data. An additional area of a potential disruption using blockchain technology is the energy trade industry. Blockchain technology application transcends existing proprietary systems as its adoption would be cheaper and more efficient and highly adaptable due to the possibility to program immutability, security, and immediacy. There are three ways in which utility providers can benefit from distributed ledger technology. Enterprise Ethereum can process and validate data from many devices at the grid edge before securing the data onto the blockchain. Secondly, energy providers can utilize blockchain to create a system for transactions of data which is critical to distribution. Lastly, distributed ledger technology can be used to develop a system for transacting energy among a diverse set of actors.

Andoni et al. (2019) specifically categorized blockchain use cases into eight larger groups according to their purpose and field of activity: 1) metering/billing and security; 2) cryptocurrencies, tokens and investment; 3) decentralised energy trading; 4) green certificates and carbon trading; 5) grid management; 6) IoT, smart devices, automation and asset management; 7) electric e-mobility; 8) and general-purpose initiatives and consortia. They set up that almost one-third of the cases are about decentralised energy trading, which includes wholesale, retail, and P2P energy trading initiatives. The second most prevalent category is cryptocurrencies, tokens and investments occupying one-fifth of the use cases. This is followed by IoT, smart devices, automation and asset management, and metering, billing, and security, estimating approximately one-tenth of total use cases, respectively.

Ogawa et al. (2021) explored the effectiveness and limitation of blockchain-based distributed optimization through the design of energy management systems (EMSs). The study suggested that blockchain-based distributed optimization can be utilizable for EMSs though blockchain-based distributed optimization cannot be applied to faster dynamical systems such as mechanical systems. The study of Ogawa et al. stated that it is important to consider utilizing distributed ledgers such as IOTA for faster dynamical systems (Merz, n.d.-b).
Yang et al. (2021) developed a blockchain system for the transactive energy management of distributed energy resources in a smart grid on which they implemented the proposed algorithm with the smart contract to guarantee the transparency and correctness of the energy management. The researchers proved the feasibility and effectiveness of their design with experimental results.

The energy management framework proposed by Wang et al. can be used in distributed energy systems, particularly if it applies to decentralised renewable energy micro-networks (Wang et al, 2021). They state that other studies will concentrate on the allowed blockchain technology and its application in the integrated energy system, in a scenario of multiple energy interactions, to show its wider applicability. Mediwaththe et al. (2016) considered a one-day decentralized energy management framework for the district grid by using a CES device to distribute the overall electricity load on the main grid throughout the day. The simulation results show that their proposed system can reduce total electricity demand on the grid throughout the day while reducing costs for energy consumers. Dzobo et al. (2021). proposed a distributed blockchain architecture model for balancing and managing microgrids in an intelligent network. The authors resulted that with architecture based on distributed blockchain, it is possible to have peer-to-peer energy trading between distributed energy prosumers' peers in a microgrid and the microgrid can be balanced in real time.

Artificial intelligence is a collection of computer systems that perform tasks that revolve primarily around human beings. AI is the simulation of human intelligence processes through machines, particularly computer systems including learning, reasoning, planning, self-correction, problem-solving, knowledge representation, perception, motion, manipulation, and creativity (Harkut & Kasat, 2019). By using Artificial Intelligence, energy management can be performed more automatically and intelligently without human intervention, while most energy systems are still operated manually or at a basic level of automation. The automation of energy systems is useful for fault diagnosis, restoration, grid safety and energy-efficient operation. Moreover, AI can cover issues connected with mitigating the uncertainties associated with energy management problems. Ahmad et al. (2022) have conducted a substantial amount of research to realize the full advantages of AI technology in terms of cost reduction through improved efficiency in electrical systems, distributed monitoring and control, electricity and investment markets, and renewable energy systems. AI can reduce machinery breakdowns, improve quality control, reduce costs, and increase productivity. The role of AI in foresight and learning is essential in energy management. AI has proven capable of predicting and learning consumer habits, values, motivations and personalities, thus contributing to a more balanced and efficient energy system and enabling more effective policies to be created (Jin et al., 2020). The role of AI in collecting and analysing data to train forecasters to manage energy better is fundamental. Artificial intelligence technologies are closely linked to the ability to deliver clean, low-cost energy that is essential for development (Makala & Bakovic, 2020). The authors state that AI has the potential to reduce energy waste, reduce energy costs, and facilitate and accelerate the use of clean renewable energy sources in electric grids around the world as well as AI can also improve how electrical systems are planned, operated, and controlled.

Lee et al. (2020) developed AI control tools to construct an AI implementation framework for energy saving for buildings. These energy savings have demonstrated feasibility of the execution framework. Investigating the promising application of AI in managing electrical systems, the researchers determined that AI facilitates the implementation of demand management (MSM).

"Flex2X", developed by the UK-based company Grid Edge, is a system that due to machine-based artificial intelligence algorithms can optimise commercial building energy use (IEA, n.d.-a). The example of this technology is important as it promises to unlock predictable new sources of flexible demand, which will help balance supply and demand, which is particularly useful when the share of intermittent renewables increases. The measured advantages of the system application include cost savings and revenue generation equivalent to >10% of annual on-site energy costs; carbon reduction through load shifting and efficiency measures (up to 40% has been evidenced) (Ahmad et al., 2022). Another example of a forecasting technique that relied on individual weather models is IBM's program for the US Department of Energy's SunShot Initiative with the result of a 30% improvement in accuracy in solar forecasting, leading to gains on multiple fronts (Mortier, 2020).

Furthermore, in his research on the example of organizations Borowski (2021) confirmed the hypothesis that blockchain and artificial intelligence increase energy efficiency. Another example is an experiment of the world's first high-frequency decentralized energy trading platform which utilizes blockchain technology and artificial intelligence. It has demonstrated a solution to the challenges of microgrid renewable electricity (S&P Global Commodity Insights, n.d.). The result that has proved its efficiency is that users have witnessed an 11% reduction in energy costs during the trial, while energy producers saw a 14% revenue improvement (Ingham, 2020).

5. Discussion

Using blockchain as a secure database is a standard practice in controlling and managing distributed energy. What is more, autonomous energy management can be obtained through the application of control rules in intelligent contracts (Wang et al., 2022). Distributed ledger networks provide important advantages over traditional banking transactions in the form of greater flexibility, security, transparency, and speed. However, in the case of customer-to-customer transactions at the distribution level, there is still no clear demonstration of the advantages of blockchain technology compared with a customer-customer bank payment system, or how this emerging technology contributes to financing a network infrastructure in the distributed power market (Serpell, 2018). Blockchain technology can achieve confidence and transparency in transactions between multiple roles, promote healthy competition and improve transport efficiency (Bao et al., 2021).

Chen et al. (2022) advised answering three questions to persuade utilities to deploy the blockchain. It is important to briefly highlight points as follows. Firstly, if strengthening confidence is important for a utility in a use case, blockchain is preferred. Secondly, in some usage cases that are not utility-focused, blockchain gives a utility a chance to get involved and not be excluded. Thirdly, in each test, a node is set to offline or tries to manipulate data records or rules. If these attempts fail, there is a proof of blockchain use. Concerns regarding the use of blockchain can be divided into two categories: 1) adherence to the law, and 2) specific technical implementations, mainly related to operation time, system scalability and data privacy (Fovino et al., 2021). Further decentralization may lead to more complex management of the energy system as a whole (Baashar et al., 2021). To maintain consistency with the law and the rights of customers, smart contracts should be incorporated into the legal code. Andoni et al. (2019) indicated another important factor that could slow down blockchain uptake is a lack of standardization and flexibility. Schletz et al. (2020) demonstrated in their research that blockchain technology can address the constraints of existing systems that currently limit intensified energy efficiency interventions, such as a lack of transparency, asymmetry of information, high transaction costs and limited access to financial support.

The Artificial Intelligence potential to change the game, particularly, for the renewable energy sector is undeniable, but its wider application throughout the sector still faces challenges. While AI has a great potential for improving energy production, transmission, distribution and consumption, the energy sector continues to face multiple challenges related to the efficiency, transparency, affordability, and integration of renewable energy sources into electric systems. Makala et al. (2020) defined possible constraints: a feasible lack of the knowledge needed to understand the specifics of power systems; dependence on cellular technologies limits the potential of Artificial Intelligence in rural and other underserved areas of many emerging markets, particularly in low-income countries; the digital transformation of the electricity network has turned it into a target for hackers; integrating different data sources or experiencing a low volume of data for machine learning models to learn from; absence of understanding of Artificial Intelligence-based models inner workings nor how they were developed, which can constitute security risk (Wang et al., 2022).

Marinakis et al. (2021) allocated access to Artificial Intelligence enablers, access to human capital, and an AI-skilled talented workforce as major challenges that may reduce the speed with which AI is adopted and thus limit the economic potential of energy stakeholders. Therefore, there is a need to democratize the data and analytics in the energy sector to allow people to be aware of the data to be able to make the right decisions. As a result, an integrated and more efficient energy value chain and more efficient business processes are facilitated. In addition, it is necessary to provide the proper framework for a reliable and legally binding data-sharing culture in the energy sector, where the value of the data is shared and exchanged among the ecosystem participants because of an equitable distribution of resources.

6. Conclusions

Rapid development of innovation and technology, and intensification of the environmental issues have led to transformations of the management paradigm in companies of the energy sector. Embedding blockchain and artificial intelligence technologies accelerate adaptation to new market trends. Higher energy costs and growing demand for businesses to reduce their carbon footprint through energy sustainability, enhancing analytics and efficiency, make the energy management sector one of the most ideal industries for applying blockchain technology. The presented research results showed that the technologies are widely applied in energy management. The need for further research has been proved based on VOSviewer analysis showing a lack of documents that contain the terms ‘energy efficiency and ‘blockchain’. Artificial intelligence has been rapidly integrating with energy management, helping to develop more efficient and secure energy generation techniques. The research results indicate use cases that prove their efficiency. There was also discussed what constraints can currently limit energy efficiency interventions scaling up.

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